DWLBC REPORT

A regional climate change decision framework for natural resource management

2008/21

Government of South Australia
Department of Water, Land and Biodiversity Conservation

A regional climate change decision framework for natural resource management

Douglas K Bardsley[1,2,3] and Susan Sweeney[1]

With input from Geoff Rogers, Chris Raymond and Jan Rowland (DWLBC); Peter Houston (PIRSA); Craig Liddicoat, Andy Cole and Tim Herrmann (Rural Solutions SA); Neville D Crossman and Brett A Bryan (CSIRO); Julian James (City of Onkaparinga) and Vic Waclawik (REM).

[1] Land and Biodiversity Services
Department of Water, Land and Biodiversity Conservation
[2] School of Geography, Planning and Architecture,
The University of Queensland,
[3].Geography and Environmental Studies, School of Social Sciences, University of Adelaide

June 2008

Report DWLBC 2008/21

Government of South Australia
Department of Water, Land and Biodiversity Conservation

Land and Biodiversity Services
Department of Water, Land and Biodiversity Conservation
25 Grenfell Street, Adelaide
GPO Box 2834, Adelaide SA 5001

Telephone	National	(08) 8463 6946
	International	+61 8 8463 6946
Fax	National	(08) 8463 6999
	International	+61 8 8463 6999
Website	www.dwlbc.sa.gov.au	

Disclaimer

ISBN 978-1-921528-12-5

Preferred way to cite this publication

Bardsley DK & Sweeney S, 2008, *A regional climate change decision framework for natural resource management,* DWLBC Report 2008/21, Government of South Australia, through Department of Water, Land and Biodiversity Conservation, Adelaide

Download this document at: http://www.dwlbc.sa.gov.au/publications/reports/html

FOREWORD

South Australia's unique and precious natural resources are fundamental to the economic and social wellbeing of the state. It is critical that these resources are managed in a sustainable manner to safeguard them for both current users and future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are managed so that they are available for all users, including the environment.

In order for us to best manage these natural resources it is imperative that we have a sound knowledge of their condition and how they are likely to respond to management changes. DWLBC scientific and technical staff continue to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

Climate change adds another layer of complexity to the management of these natural resources. In this project, DWLBC has collaborated with the Adelaide and Mount Lofty Ranges Natural Resources Management Board to help identify climate change risk and develop adaptation strategies. Lessons learnt from this project should assist all natural resources managers in responding to the enormous challenges imposed by climate change.

Scott Ashby
CHIEF EXECUTIVE
DEPARTMENT OF WATER, LAND AND BIODIVERSITY CONSERVATION

ACKNOWLEDGEMENTS

The authors wish to thank the many people within the Adelaide-Mount Lofty region and the natural resources management community more specifically, who assisted them during the development of the Adelaide and Mount Lofty Ranges Natural Resources Management (AMLR NRM) climate change project. This project extended widely throughout the AMLR NRM community and many hundreds of people have given their time and input into this work, from attending workshops and presentations through to in-depth involvement in research and case studies. It is impossible to thank all of these people individually in this document, but their ongoing interest in and concern for the sustainable management of the AMLR environment and associated resource assets is fundamental to the successful adaptation of the region to future climate change.

Some particular support received by the authors needs to be acknowledged beyond that of the extended authorship. The support of the AMLR NRM Board and the regional employees was fundamental to the success of this project, with Stephen Smith and Kym Good in particular providing excellent support throughout the duration of the work. Many thanks also to Andrew Fisher and Peter Butler, Department of Water, Land and Biodiversity Conservation, for their support and guidance throughout the project.

The authors also wish to thank Rohan Hamden, Department of Water, Land and Biodiversity Conservation, Dr Rachael Dempsey, Department of Climate Change and Chris Raymond Department of Water, Land and Biodiversity Conservation for reviewing this report.

This work has been financially supported by the Department of Water, Land and Biodiversity Conservation, the Australian Government through the Department of Climate Change, (formerly the Australian Greenhouse Office in the Department of the Environment and Water Resources), and by the AMLR NRM Board.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

PURPOSE OF THE STUDY

This report describes a regional approach to adapt to climate change that focuses on engaging the natural resources management community. The approach was developed between the Adelaide and Mount Lofty Ranges Natural Resources Management (AMLR NRM) Board and the Government of South Australia. Although future climate change is uncertain, the magnitude of the warming-drying trend projected for the region which experiences a Mediterranean climate is challenging the sustainability of management goals. Natural resources practitioners are looking to policy makers and planners for approaches to respond to climate risk, and yet the tools to guide the decision making processes are limited. The partnership approach described here successfully engaged regional stakeholders through a combination of direct relationship building and the application of a comprehensive communication strategy. An increased awareness of the vulnerability of the region's natural resources to projected change was used to engender ownership of climate change risk and to influence adaptation planning. A series of case studies were undertaken to provide more detailed analyses of the participatory processes that would be required in different sectors and in different subregions to support the type of transformative change required to restore resilience into NRM systems. The different approaches undertaken were: scenario modelling; applied participatory Geographic Information Systems (GIS) modelling; participatory action learning; and a formal environmental risk analysis. The relative merits of the different approaches are discussed in relation to their involvement by local stakeholders and their likely impact to support effective adaptation options.

MAJOR FINDINGS

The potential risks to Mediterranean climate regions from projected climate change create an immediate need to ensure that regional NRM systems in South Australia are managed sustainably. Projections of climate change impacts for the AMLR region are quite strongly negative for many stakeholders: farmers would need to manage pastures and crops that are experiencing less rainfall and greater evapotransporation; water managers must consider both less groundwater recharge and annual runoff, and the increased risks of extreme rainfall events; biodiversity managers must consider the complex implications of rapidly changing climate drivers to ecosystems; and increased risks of bushfires and coastal flooding must also be managed (McInnes et al. 2003; Suppiah et al. 2006).

Recognising that new levels of risk are apparent, which cannot be properly assessed by current management and planning tools, the South Australian Government and AMLR Board worked in partnership to implement a broad framework to assist decision making within and across AMLR NRM sectors. The approach recognised that climate change adaptation responses could no longer be considered separately from other NRM activities.

The proposed framework to engage the community and support decision making processes was:

1. Awareness raising and ownership of climate change
2. Vulnerability analyses
3. Development of adaptation responses
4. Appropriate integration of adaptation responses into management and planning activities across different timeframes:
    a. Incorporation of climate change into risk management approaches in the short-term
    b. Application of adaptive management techniques which can be adjusted over time
    c. Application of decisions based on the precautionary principle that allow for increased long-term risk
5. Ongoing revision, reassessment and alteration of the approaches above.

The partnership between the South Australian government and the AMLR NRM Board to develop awareness and ownership of climate change risk was seen as a vital early step in developing and implementing the regional decision making framework, and supporting understanding more broadly in relation to climate change risk for the region.

An initial integrated assessment of the vulnerabilities of NRM to climate change was generated, both to support regional stakeholders' capacities to imagine future climate change risks and opportunities, and to provide a baseline review of information on impacts and ideas for adaptation. There are specific characteristics of the AMLR that suggest significant capacity for climate change adaptation to 2030. In broad terms, the most vulnerable systems were initially assessed to be those that are not managed intensively, or those that are managed intensively but have long management response timeframes (namely coastal and bushfire management), and biodiversity conservation and perennial horticultural systems. Other systems will require significant human intervention to reduce their vulnerability, most importantly for water management within both local catchments and the associated Murray-Darling Basin. The fact that the findings from the initial review have at times been challenged by stakeholders, and will need to be reviewed regularly in the future, is considered a very good outcome for the project as stakeholders have sought to develop a deeper understanding of the analysis.

Research to understand how key stakeholders perceive climate risk was recognised as important to ensure that methods are employed to best engage the NRM community, to identify requirements for skills and knowledge development, and to help engender community ownership of management responses to change. Due to the concerning projections for climate change in South Australia, it is deemed particularly important to recognise stakeholders' knowledge as both valid and locally appropriate in the context of the participatory research undertaken for this project. Guided processes of investigation into the implications of climate change can provide stakeholders with the opportunity to examine impacts and adaptation options within the context of their own lives.

A significant barrier to the evolution of adaptation responses seems to lie between goals and action. With a growing community awareness of the need to design and implement directions for NRM in South Australia, it should be less problematic to enact policy and programs to support sustainable adaptation options. A major part of the AMLR NRM climate change project involved supporting stakeholders to overcome the gap between understanding the need to respond to future climate risk and the application of climate change knowledge to guide future strategic and action planning.

It was recognised by stakeholders that considerably more integrated research was needed in the region to guide specific short- and long-term planning goals. During the second phase of the AMLR NRM climate change project, six case studies were developed with key sectoral stakeholders, in part based on specific vulnerabilities and adaptation options. The case studies, which cover aspects of water, soil, biodiversity, coastal, and land use management and planning were designed to avoid replicating other work that is underway in the region.

The six case studies addressed the development of detailed adaptation responses within the sectors. They used four key approaches that are increasingly being used to guide decision making across NRM sectors, namely: scenario modelling; applied and participatory GIS modelling; participatory action learning; and, environmental risk analysis. The major conclusions of the case studies are outlined in this report and full case study reports are available separately. In addition to this final report, a number of other publications have been produced, which support much of the discussion. These include: an integrated analysis of vulnerability of AMLR NRM to climate change (Bardsley 2006); an information brochure (AMLR NRM Board 2007b); a report summarising community perceptions of climate change impacts in the AMLR NRM (Bardsley & Liddicoat 2007) as well as the series of detailed case study reports on sectoral issues of climate change risk. These case studies and the approach they used are defined in Table 1.

Table 1. Climate change adaptation case studies undertaken for this project

Case study	Title	Approach used
Land capability	Climate Change and the potential for wind erosion - a model for the Adelaide and Mt Lofty Ranges NRM region (DWLBC 2008)	Scenario modelling
Groundwater	Discussion paper on the potential impact of climate change on the groundwater resources of the McLaren Vale Prescribed Wells Area (Waclawik 2007)	Scenario modelling
Biodiversity	Modelling native and exotic flora distributions under climate change (Crossman, Bryan & Bardsley 2008)	Applied and participatory GIS modelling
Land use planning	Room to move: towards a strategy to assist the Adelaide Hills apple industry adapt to climate change in a contested peri-urban environment (Houston & Rowland 2008)	Applied and participatory GIS modelling
City of Onkaparinga	Developing industry climate change adaptation strategies: A case study for the McLaren Vale viticulture and Fleurieu Peninsula oliveculture industries (James & Liddicoat 2008)	Environmental risk analysis
Coastal	Mapping landscape values and perceived climate change risks for natural resources management: A study of the Southern Fleurieu Peninsula region, SA (Raymond 2008)	Participatory action learning

The different approaches to guiding decision making, outlined in Table 1, represent a spectrum of approaches, from those that rely strongly on science-led analyses and scenario modelling through to stakeholder-led participatory research.

Key findings suggest that:

- Scenario modelling successfully reinforced or improved knowledge of climate change impacts and potential adaptation responses. In particular, the work effectively reinforced the point that where resource use is currently marginal it is likely to become more marginal with climate change.
- Scenario modelling can be used to test whether management systems that have been put in place in the past can significantly reduce the vulnerability of systems.
- Scenario modelling outputs are limited by the range of factors included in the model, incomplete knowledge of current systems and their lack of immediate application.
- Better integration between scientific researchers, planners, the managers of natural resources and the local community, expands available knowledge of current and historic resource condition and enhances the legitimacy of strong planning conclusions. Data on resource condition and processes needs to be collated and made available for other researchers to maximise the opportunities for knowledge development to respond to climate risk.
- The environmental risk assessment process identified immediate and valid concerns for the grape and olive growers, but the risk assessment framework appears to struggle to guide the required broader examination of industry needs and associated natural resources management issues over the longer term. Risk assessments should not be seen as a supplement for long-term engagement and resilience building within any NRM system.
- Due to the significant uncertainties related to climate change risk, appropriate adaptation responses will need to be framed more broadly than the specific responses to specific other perceived climate risks.
- Climate change is likely to undermine important landscape values unless environmental planning is able to become more explicit about what is at risk within our landscapes, and as a consequence, what needs to be a focus of early attention for adaptation responses.
- Community knowledge may well be as important for guiding decision making as the scientific information emerging from the down-scaling of global circulation models or the more detailed studies of climate impacts on future resource condition.
- The importance of good scientific evaluations and monitoring of resource condition to inform analyses of possible futures cannot be overestimated. Of particular concern was the lack of detailed base-line information on subregional micro-climates within particular areas of the AMLR.
- Different approaches to support NRM decision making will be applicable in different contexts (Table 2). All may have a role depending on the complexity of the region under investigation.

Even with significant goodwill and ownership of climate change risk, the implementation of explicit, long-term planning responses to climate change remains a very challenging task, particularly as significant investments or regulations could be seen to be unwarranted if the uncertain change does not eventuate as envisaged. It should not be expected that any region will establish comprehensive, effective adaptation response plans in the first instance – that is simply asking too much of NRM planning and policy, given the level of uncertainty.

Table 2. Possible application of different climate change adaptation approaches

	Adaptation approach			
	Scenario modelling	**Applied and participatory GIS modelling**	**Environmental risk analysis**	**Participatory action learning**
Case studies and the approach they used	Land capability (section 4.1) Groundwater (section 4.2)	Biodiversity (section 4.3) Land use planning (section 4.4)	City of Onkaparinga (section 4.5)	Coastal (section 4.6)
Possible application	Adjusting resource condition assessments according to potential climate change scenarios to raise awareness of potential sectoral impacts and develop appropriate adaptation responses	Maximise engagement with stakeholders in different NRM sectors as modelling is developed, so that key vulnerabilities can be further highlighted and responses articulated.	A formal risk assessment with impact and likelihood components, to guide stakeholders through an analysis of the impact of climate change on their systems	Where stakeholders need to identify and analyse their local vulnerabilities to climate change without significant information from external sources.
When approach might be most applicable	When seeking specific guidance to better understand vulnerability of a natural resource. Also when good background data is available concerning the NRM issue, and yet specific climate change implications are uncertain.	When seeking specific guidance to better understand the vulnerability of a natural resource. Also when the development of good background data concerning the NRM issue will require stakeholder input.	When trying to formally involve stakeholders in a process of analysing risk. Ideally supported with empirical data to best inform planning outcomes. Likelihoods and consequences are well understood.	When the community support needs to be generated and/or articulated to support difficult decision making. Particularly when seeking to generate greater awareness of climate risks.

It cannot be emphasised enough that participation in the research process makes it more likely that key decision makers will understand the validity of providing broad suggestions for many adaptation responses, rather than suggesting that we can always have specific understandings of uncertain futures.

FUTURE DIRECTIONS

As the community becomes increasingly aware of the implications of climate change, there will be great opportunities to generate the will to support specific NRM planning responses.

Many detailed recommendations have been provided under the individual summaries from the case studies and the project more generally. It is not the intention to repeat those comments here as most are relevant to particular sectors or places within the AMLR. Some major issues that are repeated across the case studies can be identified, suggesting a vision for future work.

Particular recommendations that emerge include:

- Local communities should seek further knowledge of changing climate conditions on local scales, particularly when such research and monitoring can provide detailed evidence of change over time, to guide managers who aim to learn about better approaches to adaptation.

- Monitoring of the implications of resource condition needs to become more detailed and widespread across different sectors and locations and linked to regional, state and national monitoring, evaluation and reporting frameworks. Over time, improved information will provide a great resource for modelling that aims to articulate possible NRM futures. The AMLR NRM community may wish to draw more strongly from oral traditions and non-scientific historical sources to strengthen and lengthen the period of knowledge on environmental issues.
- Information on likely impacts of climate change must include adequate reference to the level of uncertainty.
- Where detailed local information on resource or climate conditions is unavailable or of limited quality, stakeholders should be involved to develop guidelines that prioritise adaptation strategies.
- Research to understand how stakeholders perceive climate risk helps: to ensure that methods are employed to best engage the NRM community; to identify requirements for skills and knowledge development; and to help engender community ownership of management responses to change.
- Methodologies developed during the case studies need to be expanded on to better understand complicating factors, including the social and ecological complexities of local situations that could support holistic decision making over time.
- Significant momentum has been developed within the region in relation to climate change adaptation. Future work could build on the established professional/stakeholder networks, methodologies developed, and sectoral knowledge to examine how a regional response to climate change planning alters the vulnerability of NRM systems over time.
- While cost-benefit analyses of such decisions were not undertaken in this work, more detailed future studies should incorporate the financial benefits of early action or costs from a lack of or inappropriateness of responses.
- Where it is appropriate for governments to invest in NRM activities, the way in which costs are shared between landholders, local communities and governments will be influenced by policy, technology and institutional arrangements.

At a more general level, important themes emerge to provide guidance on how to move forward, to help put natural systems, biodiversity, production processes and society in general on track towards sustainability in an era of rapid climate change. NRM respondents have suggested broadly that a mix of the following will be required:

- research, knowledge and technological development to better understand the complex impacts on and associated interactions between our natural and social systems, and to create opportunities for changes in planning management over time
- education to raise awareness of the impacts, to better understand options for change and to create the support for change
- policy mechanisms to encourage better management of scarce resources, particularly water, as the resource conditions change with climate change
- acknowledgement of significant barriers to, or challenges for effective adaptation
- resourcing of activities in a manner which evaluates and responds to a detailed examination of the costs and benefits of research and adaptation options
- restrictions on activities that are seen to be highly detrimental to the sustainability of NRM
- policy and planning guidelines to incorporate the implications of climate change and support the community to change.

Although many of these points are fundamental to good NRM anyway, it is clear that sustainable management of landscapes in the future is only going to become more important.

Positive, action based leadership at all levels of NRM and societal governance is necessary to bring about the changes required. Recognising that many negative environmental impacts will happen without public attention, the NRM sector may wish to increasingly articulate strongly, clearly and in greater detail the observed and potential risks to their activities, and the interests of the wider AMLR community, from future climate change.

1. INTRODUCTION

This project aimed to work within the AMLR NRM region in South Australia, to undertake an assessment of key NRM sectors that are vulnerable to climate change. Subsequently, it aimed to develop and demonstrate participatory methodologies with NRM stakeholders for creating a regional framework for wider application in managing climate change risk and developing adaptation responses.

Anthropogenic, or human-induced, climate change has the potential to undermine the sustainable management of natural resources (AGO 2003; IPCC 2007). Due to the rapidity of change, it is likely that the world will need to begin to manage the significant and dangerous climate risks more quickly and comprehensively than was originally anticipated. Moreover, changes to climate are projected to continue throughout this century in association with the high growth rates in the world economy and the continuing reliance on high carbon dioxide emission fossil fuels, as sources of energy to power the processes of industrialisation and consumption (Garnaut Climate Change Review 2008). Although the magnitude and implications of impacts arising from anthropogenic climate change are uncertain, there is increasing acceptance that communities will need to respond by adapting to the changes to their regional environments if they wish to maintain or improve their quality of life (Adger, Arnell & Tompkins 2005; Zahran et al. 2006; Kok & de Coninck 2007).

In many cases, market forces are unlikely to lead to efficient adaptation and governments have long recognised their public good role in forward planning. The State and Commonwealth governments are continuing to work on policy frameworks that avoid or reduce the negative impacts of climate change. This was recognised in the Stern review in their discussion of regional climate change responses (Stern 2006). Although the need for societal transformations to achieve both mitigation and adaptation to climate change have been highlighted, there are relatively few attempts to support communities to develop institutions, planning processes and investment strategies to guide the transition in NRM activities in the face of climate change (Orr 2002; Adger 2003; Pelling & High 2005; Bardsley & Edwards-Jones 2007; Etkin & Ho 2007). For example, the South Australian Government has developed plans to adapt to future climate change (see for examples DWLBC 2006; Sustainability and Climate Change Division 2007), but as will be discussed further below, it remains a difficult challenge to integrate the uncertain projections for future climate into the NRM planning process to maximise opportunities for effective adaptation.

The AMLR NRM region is entering a time when the frontiers of viable natural resources exploitation are reaching limits of expansion, and the availability of some resources, particularly water for dryland and irrigated agriculture, is projected to decline (Suppiah et al. 2006). To initiate adaptation to climate change, risks associated with projected climate change need to be factored into regional NRM planning (Zahran et al. 2006; Blackmore 2007). However, deciding when and how projected impacts of climate change should be incorporated into management programs and policies is both complex and difficult. To achieve sustainable NRM during a period of rapid climate change will require the ongoing development of understanding about effective adaptation, and the broad scale application of both new and old ideas and regular monitoring and review.

To support AMLR NRM stakeholders to coordinate and implement appropriate local and regional climate change adaptation strategies, the project prioritised engagement between government and regional bodies. This partnership approach was applicable primarily because the climate science is of such an uncertain nature that a regional adaptation approach will need to empower stakeholders to increase the resilience of NRM systems (Adger, Arnell & Tompkins 2005; Pelling & High 2005; Lebel et al. 2006; IPCC 2007). In fact, due to its very nature, the future projections of climate change are likely to remain highly uncertain, requiring constant adjustment and revision (Schneider 2004; Kerr 2006). The people who manage responses to climate change, including the regional NRM board, state and local government, their associated bureaucracies, non-government organisations and industry bodies, will all need to make complex planning decisions to increase the resilience of systems to cope with uncertain change. Many of these decisions are likely to be unpopular in the short-term when they involve restrictions on resource exploitation or place limits on development in areas of high risk. At the same time, the people making decisions will not want to make poor business decisions by:

- not responding enough and failing to adapt
- being too cautious in relation to risk and over adapting
- making incorrect decisions and mal-adapting.

The approaches outlined in this report supported a regional NRM planning process to account for climate change, by working in partnerships across governance structures and sectors to develop effective methodologies to guide adaptation decision making. The project presented here (referred to in this report as the AMLR NRM climate change project) tested participatory methods to improve capacities to understand and undertake regional adaptation responses within the context of the urban, peri-urban and rural areas of the AMLR region. The work was undertaken as a partnership between the AMLR NRM Board and the Government of South Australia.

This final report for the AMLR NRM climate change project critiques work that has been undertaken over a four year period (2005–08), including the period prior to the formal project period itself (which was July 2006–June 2008). An analysis of the role of initial research and community engagement was seen as justified because it led directly to the research established within the federally funded project and was seen as fundamental to developing a regional response to climate change risk. It is important to embed the project into the broader context of regional climate change adaptation processes because the spatial and temporal aspects of the work are directly relevant to the approach undertaken. In particular, there is a sense that the world has woken up to the risk of climate change over the last four years. Therefore, the context of the research and discussions outlined below occurred within a period of rapidly rising community interest in climate change. Apart from local actions by the South Australian Government and others in the NRM community, the one in 1000 year drought across much of south-eastern Australia, the film *An Inconvenient Truth*, tours from environmental speakers including Al Gore and David Suzuki, and reports on the economic implications of climate change from the United Kingdom (UK) Government (Stern 2006), the Intergovernmental Panel on Climate Change (IPCC) (2007), and the Australian Government (Garnaut Climate Change Review 2008), have all significantly increased awareness of the implications of an enhanced greenhouse effect in South Australia.

INTRODUCTION

The initial section of this final report outlines the broader context of the AMLR NRM region, and subsequently outlines the process of engagement between the South Australian Government, the AMLR NRM Board and a broad range of NRM stakeholders. The evolution in decision making processes led to some important changes in the regional response to climate change at the regional, sectoral and local levels, most importantly in relation to the AMLR NRM planning process. The discussion describes and critiques six case studies which were undertaken in the AMLR NRM region during 2006–07, which applied different approaches to working with decision makers, including planners and practitioners, to develop adaptation methodologies. While there were some clear, successful components of the AMLR NRM climate change project, there are limitations and problems with the specific methodologies tested to assist decision making that also need to be critiqued to determine how these could be better applied in the future. The conclusion presents a summary of major findings and recommendations from the AMLR NRM climate change project.

2. THE ADELAIDE AND MOUNT LOFTY RANGES NATURAL RESOURCES MANAGEMENT REGION AND FUTURE ADAPTATION

The AMLR NRM Region is one of eight NRM regions in South Australia that were defined under the *Natural Resources Management Act (SA) 2004* (the Act) (Government of South Australia 2004; AMLR NRM Board 2007a). The regional integration of previously separate issues of water, land, biodiversity and invasive species management at the regional scale, has created the opportunity to establish integrated governance frameworks for sustainable NRM. During the period that these governance structures for NRM have been reorganised, there has been an increasing demand from natural resources researchers, planners and practitioners for tools to assist them to prepare for climate change. In particular, the prolonged drought across south-eastern Australia has accentuated concerns about the capacity of NRM to respond effectively to climate variability and extremes in the short-term, and to climate trends at the regional level in the long-term. The South Australian Government has prepared a policy framework to guide sectoral responses to climate change (see Sustainability and Climate Change Division 2007). Goal 1 of the South Australian state NRM plan 2006 (DWLBC 2006, p. 33) relates directly to the issue by targeting 'landscape scale management that maintains healthy natural systems and is adaptive to climate change'. In addition, all South Australian NRM regions mention the need for building the capacity to respond to climate change in their NRM investment strategies and/or regional NRM plans (DWLBC 2007).

The AMLR region (Fig. 1) covers a land area of about 535,000 hectares and a similar area of marine and estuarine environments (AMLR NRM Board 2007c). It contains the state capital, Adelaide, a city of approximately 1.1 million people, which aims to position itself in relation to other like cities in a rapidly globalising economic and social environment (Forster 2006; Planning SA 2006). A recent review of the socio-economic characteristics of the AMLR region reported that in 2005–06, the top five contributors to gross regional product were: property and business services (10.3%); ownership of dwellings (9.5%); health and community services (8.6%); finance and insurance (7.7%); and public administration and defence (6.3%) (Urban & Regional Planning Solutions 2007a, p. 66). Adelaide remains highly reliant on its immediate hinterland, with its primary industries contributing an estimated A$1 billion per annum to the state's economy (AMLR NRM Board 2007a). In most years, 60% of Adelaide's water comes from local catchments, with the remainder coming from the River Murray (AMLR NRM Board 2006). Although only 13% of its original terrestrial native vegetation remains, the AMLR contains 50% of South Australia's native plant species and 75% of the native bird species (Paton, Rogers & Harris 2004).

The climate of the AMLR region and much of South Australia is Mediterranean. The AMLR region is of special significance for climate change planning because it is relatively humid in contrast to surrounding areas. The Mount Lofty Ranges are in effect a terrestrial 'island' of cool, moist environmental conditions in a 'sea' of relative aridity (Suppiah et al. 2006). Climate projections from the IPCC and others indicate that Mediterranean climate types are more likely than other climate systems to experience a future drying trend (Dünkeloh &

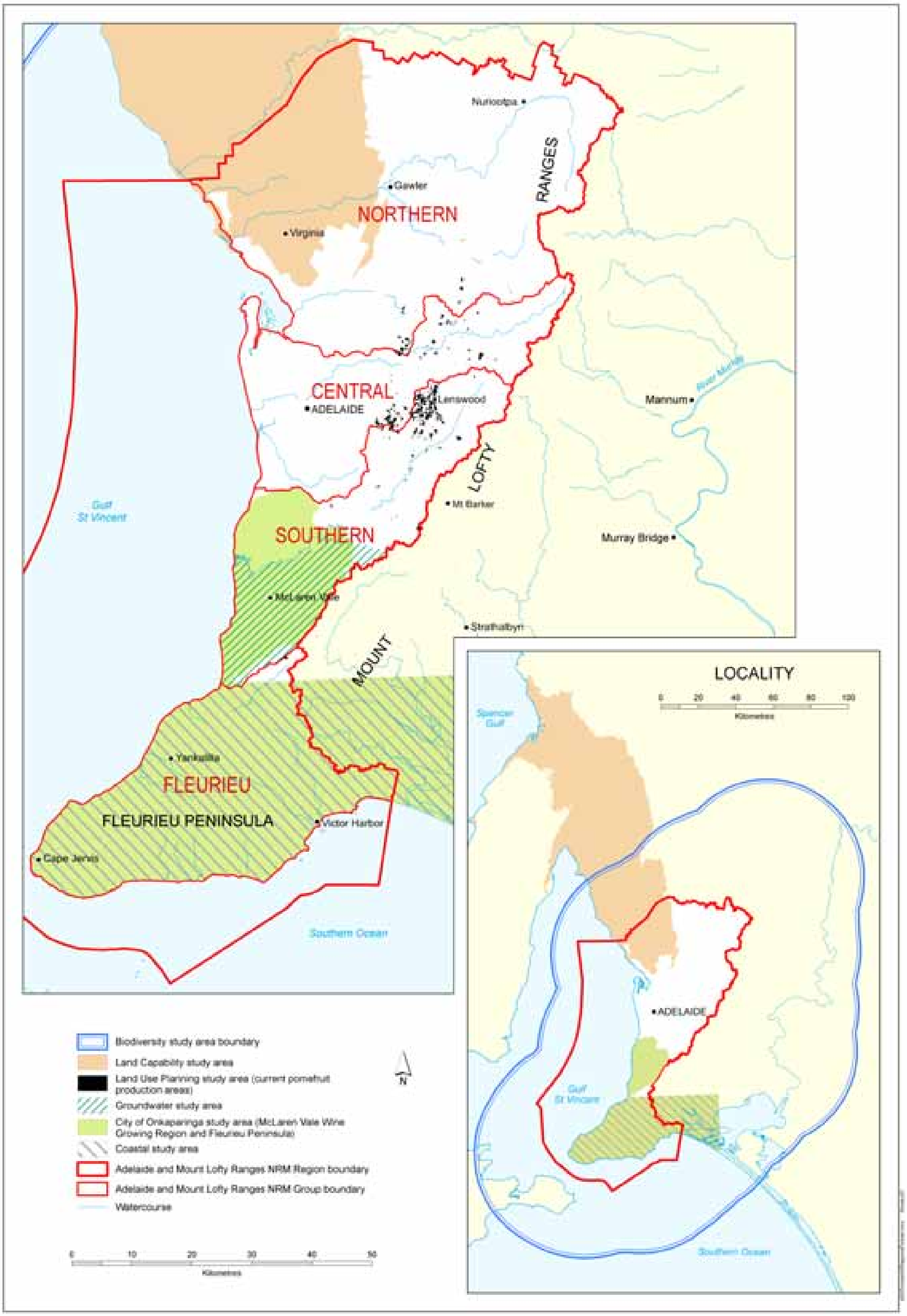


Figure 1. Map of AMLR NRM region showing the four subregions and case study areas

Jacobeit 2003; Bengtsson, Hodges & Roeckner 2006; Fu et al. 2006; IPCC 2007). As summarised in Bardsley & Edwards-Jones (2007), it is already clear that most Mediterranean systems globally have shown substantial warming and drying trends since the 1970s. In contrast, current rainfall trends in South Australia are unclear, with only a minor drying trend apparent (Suppiah et al. 2006). Although the specific implications of future climate change are uncertain for the AMLR, if realised projections of warming, as well as reductions in average annual rainfall of up to 15% by 2030, less reliable rainfall, shorter growing seasons, more extreme weather events and hotter and longer hot spells have the potential to undermine the region's management systems (McInnes et al. 2003; Suppiah et al. 2006).

The potential risks to Mediterranean climate regions from projected climate change create an immediate need to ensure that regional NRM systems in South Australia are managed sustainably.

Global climate change is likely to involve broader average trends including a net global warming and a rise in sea levels. However, there are specific projections for Mediterranean climate systems associated with the increasing intensity in the circulation of the Hadley Cell and the associated jet streams, which could lead to fundamental synoptic change within the mid-latitudinal regions of the globe (Bengtsson, Hodges & Roeckner 2006; Fu et al. 2006; Hope 2006). Other regions are likely to experience changing resource conditions, but it could be argued that if the autumn-winter-spring rainfall of Mediterranean climate systems becomes significantly more variable, or there is a trend towards drying over time, there could be a fundamental shift in Mediterranean climate regions associated with the repositioning of the subtropical high pressure belt. In just one example from outside of the AMLR, Gertner (2007) notes for south-west United States of America (USA) that 'the combination of limited Colorado River water supplies, increasing demands, warmer temperatures and the prospect of recurrent droughts point to a future in which the potential for conflict among those who use the river will be ever present'. Declining rainfall and increasing evapotranspiration rates associated with warming, could lead not only to changed resource conditions in the AMLR, but a shift to non-linear declines in runoff and plant productivity, and eventually the evolution of climate scenarios that more closely resemble semi-arid conditions on the margins of what we now consider Mediterranean climate areas.

'Dangerous climate change' (as outlined by Schneider 2001) for such regions, as for other more vulnerable parts of the globe including small island states and low-lying coastal cities, may already be occurring in Mediterranean regions and changes are projected to become more significant in the future.

At the same time as the AMLR climate change project was underway, there were a number of extreme weather events, which are of interest because they are projected to become more common in the future (Suppiah 2006). For example, during February–March 2008, Adelaide endured the longest heat wave recorded for any Australian capital city. While the Bureau of Meteorology (BoM) stated that the heat wave of 15 consecutive days was a one in 3000 year event, the likelihood of similar events occurring is projected to increase with climate change (ABC News 2008a). In another example, record high temperatures and strong winds in August and September 2007, that followed several months of unseasonably dry weather, led to significant reductions in crop yields across South Australia (Jenkin & Austin 2007).

There are specific characteristics of the AMLR that indicate significant capacity for climate change adaptation to 2030, which was the timeframe of this study. Already the relatively wealthy, well-educated population of the AMLR have considerable environmental management capacities (AMLR NRM Board 2007a). Irrespective of climate change, however, the management of the AMLR region is reaching a fundamental impasse due to both the ongoing expansion of urban areas into rural areas and the declining availability of water resources, both from the immediate hinterland and the Murray-Darling Basin (Planning SA 2006; Urban & Regional Planning Solutions 2007a; Van Dijk et al. 2006). The process of defining and regulating to sustainable environmental limits is progressing in the AMLR, with biodiversity protected through controls on vegetation clearance; limitations on residential development, including very effective restrictions on development along the Hills Face Zone of the Mount Lofty Ranges; greater prescription of water resources; and the reduction of more polluting agricultural activities (AMLR NRM Board 2007a; Bunker & Houston 2003; DWLBC 2007). As the regional natural resources base, and water resources availability in particular, is likely to decline with climate change, the importance of redefining limits of sustainable use according to future climate, or at least allowing for the uncertainty of future resource availability, has become paramount (Rosenzweig et al. 2004; Suppiah et al. 2006).

There is an increasing acknowledgement that those who manage climate change well and early, within a competitive global environment, are likely to experience the least negative impacts of rapid climate change, and may experience some benefits (Brooks, Adger & Kelly 2005; Preston & Jones 2006; Thomas & Twyman 2005). Moreover, early lessons learnt from both successful and failing adaptation approaches, applied by a wealthy, politically-stable region such as the AMLR NRM region, could assist to guide responses globally. There is a moral responsibility for wealthy societies to test adaptation approaches in this way, because many other societies will not be able to afford to err significantly in their responses to climate change even in the short-term (Bardsley & Thomas 2006; Barnett 2006; Parks & Roberts 2006). Recognising the urgency to plan for climate change, the AMLR NRM Board, in association with the South Australian Government, has worked to better understand the implications of projected change in relation to the unique characteristics of the region. The AMLR NRM climate change project has developed a framework for integrating climate change into the region’s NRM planning processes.

2.1 DEVELOPING OWNERSHIP TO CLIMATE CHANGE RISK IN THE ADELAIDE AND MOUNT LOFTY RANGES

Guiding decision making to adapt to a changing climate necessitates an acceptance and ownership of the concept of change itself by NRM planners and practitioners (Adger, Arnell & Tompkins 2005; Parks & Roberts 2006). Ownership, in the NRM context, will involve planning processes, developing locally applicable adaptation responses to clearly identified vulnerabilities, and supporting local communities to organise to build capacity to incorporate these responses into all activities. The initial work of the AMLR NRM climate change project helped to create widespread acceptance that while uncertainty remains about a future under climate change, change itself is a reality and information that is already available regarding new levels of climate risk must be integrated into NRM decision making processes (Bardsley & Rogers 2008).

In order to initiate a partnership approach with the assistance of the AMLR NRM Board and other state government agencies, strong associations were developed with gatekeepers of stakeholder organisations. As the initial integrated NRM plan for the AMLR (Mount Lofty Ranges Interim Natural Resource Management Group 2003) made little reference to climate change, interest needed to be raised amongst key stakeholders in the AMLR NRM Board planning process. To generate broader support, presentations were made to all South Australian regional NRM liaison officers, and a partnership developed to integrate climate change issues into the AMLR NRM Board's agenda and activities. Time was available for employees to begin to examine the key vulnerabilities of regional NRM to climate change, to foster greater interest in the issue and begin to establish key alliances with regional stakeholders and the board itself. The strong professional relationships developed also provided a basis for obtaining additional resources and formulating a broad approach to support change management.

Recognising that new levels of risk are apparent, which cannot be bounded by current assessment, management and planning tools, the South Australian Government and AMLR Board worked in partnership to implement a broad framework to assist decision making within and across AMLR NRM sectors. The approach recognised that climate change adaptation responses could no longer be considered separately from other NRM activities. The proposed framework to engage the community and support decision making processes was:

1. Awareness raising and ownership of climate change
2. Vulnerability analyses
3. Development of adaptation responses
4. Appropriate integration of adaptation responses into management and planning activities across different timeframes:
    a. Incorporation of climate change into risk management approaches in the short-term
    b. Application of adaptive management techniques which can be adjusted over time
    c. Application of decisions based on the precautionary principle that allow for increased long-term risk
5. Ongoing revision, reassessment and alteration of the approaches above.

The partnership between the South Australian Government and the AMLR NRM Board to develop awareness and ownership of climate change risk was seen as a vital early step in developing and implementing the regional decision making framework, and supporting understanding more broadly in relation to climate change risk for the region.

Raising awareness of the new levels of climate vulnerability involved providing valid, up-to-date information on projections for future change and assisting stakeholders to analyse the implications of those projections for sustainable NRM. The educational process was aided by an increasing global awareness of climate change issues during the period of this work from 2005–08 (Cameron 2005; Stern 2006). Numerous criticisms of common methods of communicating knowledge to NRM stakeholders have focused on information provision that does not allow for the specific complexity of local experiences (Daines, Daines & Graham 2002; Pannell et al. 2006). Projections of climate change impacts for the AMLR region are quite strongly negative for many stakeholders: farmers would need to manage pastures and crops that are experiencing less rainfall and greater evapotransporation; water managers must consider both less groundwater recharge and annual runoff, and the increased risks of extreme rainfall events; biodiversity managers must consider the complex implications of rapidly changing climate to ecosystems; and increased risks of bushfires and coastal flooding must also be managed (Bardsley 2006; McInnes et al. 2003; Suppiah et al. 2006). Due to such concerning projections, it was deemed particularly important to recognise stakeholders' knowledge as both valid and locally appropriate, for if there was any sense that an 'educator' did not recognise the importance of local contextual issues, over- or under-emphasised future risk, or did not present the uncertainty of future change, practitioners were unlikely to alter their plans and actions (Mayo 1999).

To engender ownership of climate change by stakeholders, the ideas for adaptation were developed through participatory research techniques, which educate and utilise local knowledge to better inform guidance of integrated regional planning and management responses (Blackmore 2007; Walker, Cowell & Johnson 2001; Wals 2007). Climate modelling results for South Australia are often presented in a manner that reflects the uncertainty, and are difficult to decipher, occasionally inconsistent, or suggest such high levels of ambiguity that they do not engender great faith in their accuracy (McInnes et al. 2003; Suppiah et al. 2006). A workshop tool, *The Adaptation Challenge*, was developed and applied to guide people through an interrogation of their own management systems in relation to the projected change (Bardsley & Bardsley 2007). The method provides relevant climate change information to assist NRM stakeholders to develop the capacities and confidence to educate themselves on climate change risks relevant to their NRM sector or area.

The AMLR NRM climate change project attempted to support the development of a broad base of knowledge about climate change impacts on the AMLR NRM systems. This work was not occurring in a vacuum however, with considerable simultaneous activity in the AMLR by other government and research agencies. There has also been enormous international and national media interest in the topic during the period of the project from 2006–08. In reviewing the outcomes of the awareness raising process, it is virtually impossible to disassociate the broader rapid increase in awareness of climate change issues from the specific impacts of the AMLR NRM climate change project, except where the work has been cited or referenced.

As detailed below in various sections, the AMLR NRM climate change project has directly influenced decision makers to incorporate climate change adaptation concerns into their planning and management activities. An integrated assessment of the vulnerabilities of NRM to climate change was also generated, both to support regional stakeholders' capacities to imagine future climate change risks and opportunities, and to provide a baseline review of information on impacts and ideas for adaptation.

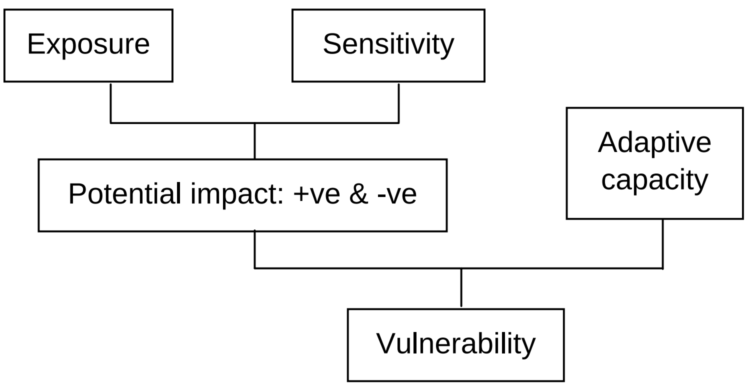
3. ASSESSING REGIONAL NATURAL RESOURCES MANAGEMENT VULNERABILITY TO CLIMATE CHANGE

The vulnerability of NRM systems in the AMLR was analysed using a methodology outlined by The Allen Consulting Group (2005), which involves an examination of exposure and sensitivity to climate change and associated environmental changes, and an analysis of capacity for the systems to adapt successfully to those changes. According to The Allen Consulting Group (2005):

Exposure — relates to the important weather events and patterns that affect the system and to broader influences such as the background climate conditions against which a system operates and any changes in those conditions. Exposure is influenced by a combination of the probability and magnitude of climate change.

Sensitivity — reflects the responsiveness of systems to climatic influences and the degree to which changes in climate might affect it in its current form: the threshold points at which effects will be exhibited, whether change will occur in trends or steps, and whether they will be reversible.

Adaptive capacity — reflects the capacity of a system to change in a way that makes it better equipped to deal with external influences via either autonomous or planned adaptation.



(Source: The Allen Consulting Group 2005)

The NRM sectors in the initial vulnerability analysis were chosen in negotiation with staff from the AMLR Board and the Department of Water, Land and Biodiversity Conservation (DWLBC). The AMLR Board suggested a marine study was also warranted, but this was considered outside the scope of the review. It was considered that South Australian marine issues required their own review to parallel the examination of terrestrial and coastal issues.

At the time that the integrated vulnerability assessment was initiated in 2005, there had been very little empirical or modelling research for the AMLR examining specific risks for NRM that might eventuate from climate change. However, it was recognised that current decisions were being made in the absence of regional advice on climate change impacts, and a comprehensive analysis of the available information would provide important guidance within the caveats of the lack of detailed information (Brooks, Adger & Kelly 2005; Dessai, Xianfu & Risbey 2005; Morgan & Dowlatabadi 1996). Another critical factor is that as the climate change science is so uncertain and the scientific understanding changing so rapidly, all modelling projections or references to past trends and responses to climate extremes will only ever be partially valid for guiding planning (see for examples McInnes et al. 2003; Suppiah et al. 2006). For these reasons, it was considered necessary to create a baseline of current knowledge on impacts and ideas for NRM adaptation in a form that could be readily critiqued by regional stakeholders, to create what Blackmore (2007, p. 516) refers to as a 'convergence of goals, criteria and knowledge', which could subsequently be disseminated and debated.

The vulnerability assessment methodology involved triangulating the available scientific evidence of climate change risks to NRM systems, with the application of the upper-end of projections from McInnes et al. (2003) and input from key stakeholders (Bardsley 2006). Vulnerability levels for the region were only vaguely defined, but that is often the case in summary tables of this type, which are based on rational analyses of key issues. Regional stakeholders also expressed concern about the vagueness of the vulnerability assessment. Nevertheless, the vulnerability assessment has been part of a process that has led to excellent examples of developing understanding of what exactly the vulnerability of different systems in the region does mean in the AMLR. The fact that the findings from the initial review have at times been challenged by stakeholders, and will need to be reviewed regularly in the future, is considered a very good outcome as stakeholders have sought to develop a deeper understanding of the analysis.

In one example from the integrated analysis, a review was undertaken of current knowledge of vulnerabilities and adaptation opportunities for horticultural production (Table 3). The establishment of horticultural plantings in the region may be affected by more hot, dry spells as may other key points in the production cycle such as flowering, pollination and fruit development (Bureau of Rural Sciences 2004; Jones et al. 2005; Preston & Jones 2006). Fewer chilling periods may affect vernalisation requirements and fruit set of some crops, especially cherries and apples. Vegetable and wine production could also suffer from extreme weather conditions such as flooding or extended hot spells, or increasing pest and disease impacts which lead to crop losses or quality downgrades. Horticulture is a major water user in the AMLR and, in turn, horticulture management can have significant impacts on water quality. The development of water allocation plans that secure water rights within prescribed water resource zones under the Act, could be a significant issue for producers if reduced rainfall, increasing evaporation and greater local demand for water result from climate change (AMLR NRM Board 2006; AMLR NRM Board 2007a; DWR 2000; DWLBC 2006). This sectoral review led directly to the detailed Land use planning case study outlined in detail below (Houston & Rowland 2008) and the City of Onkaparinga project (James & Liddicoat 2008).

Specific input was drawn from a consulting group made up of South Australian Government and AMLR NRM Board staff, and other interested parties including local natural resources practitioners, public servants and academics, through meetings, telephone discussions and the examination of published and unpublished data. The synthesis of information was used to critically examine key issues influencing vulnerability across NRM sectors, with occasional differences of opinion presented as unresolved positions on risks and opportunities (Table 4).

Table 3. Key components of the vulnerability assessment of Adelaide and Mount Lofty Ranges horticultural production to climate change (source: Bardsley 2006)

Assessment component	Exposure	Sensitivity	Impact	Adaptive capacity	Vulner-ability
Level identified	Medium	High	Medium-High	Medium	Medium-High
Key issues in analysis	• Horticultural systems buffered by significant external inputs, especially irrigation water. • Temperature and rainfall extremes may be of greater importance	• Some systems including apple, grape, cherry and vegetable production sensitive to temperature range and extremes • Flooding impacts cause significant losses • Longer-term impacts of regulatory restrictions on water use		• Adjust systems to change, including use of different species, varieties and water management systems • Perennial horticultural systems require significant time to change and adjust • Water resources already limited	

Table 4. Summary of vulnerability analyses for NRM in the AMLR (source: Bardsley 2006)

NRM sector/issue	Exposure	Sensitivity	Potential impact	Adaptive capacity	Vulnerability
Riparian flood management	Medium	Medium	Medium	Limited	Medium–High
Surface water	High	Medium	Medium–High	Significant	Medium
Groundwater	High	Medium	Medium–High	Significant	Medium
Coasts: flooding	High	High	High	Medium	High
Coasts: beaches	High	High	High	Medium	Medium–High
Biodiversity: terrestrial	High	Medium	Medium–High	Medium	Medium–High
Biodiversity: freshwater	High	High	High	Limited	High
Invasive species	Medium	Medium	Medium	Medium	Medium
Parks and gardens	Medium	Low	Low–Medium	Significant	Low
Revegetation	High	Medium	Medium	Significant	Medium
Agriculture: annual cropping	High	Medium	Medium–High	Significant	Medium
Agriculture: horticulture	Medium	High	Medium–High	Medium	Medium–High
Agriculture: livestock	Medium	High	Medium–High	Significant	Medium
Land management	Medium	Medium	Medium	Significant	Low–Medium
Bushfires	High	High	High	Medium	Medium–High
Air quality	High	Low	Low–Medium	Significant	Low–Medium

Colour key for exposure, sensitivity, potential impact and vulnerability (not adaptive capacity):

Low	Low–Medium	Medium	Medium–High	High
(dark green)	(light green)	(yellow)	(red)	(dark red)

Key for adaptive capacity:

Significant	Medium	Limited
(green)	(yellow)	(dark red)

In broad terms, the most vulnerable systems were judged by stakeholders to be those that are not managed intensively, or those that are managed intensively but have long management response timeframes, namely coastal management, bushfire protection, biodiversity conservation and perennial horticultural systems. Other systems, particularly water and land management, will require significant human intervention to reduce their vulnerability through adaptation, particularly within important local catchments and the associated Murray-Darling Basin.

Ideas for adaptation to climate change and important gaps in knowledge were also detailed under the different sections (Bardsley 2006). All levels of vulnerability are highly dependent upon the capacity of human action to support adaptation in the long-term. For example, it is suggested that the adaptive capacity for annual crop production in the region is considerable, because people are able to make flexible management decisions to increase the resilience of their systems (Turner 2004). Such an assumption is based on the current wealth of our society and the historical adaptive capacity of agriculture, not in regard to uncertain future risk associated with policy changes, global economic interdependency, production costs or local urban encroachment (Bardsley 2003; Beck 2000; Tait & Morris 2000). In contrast, adaptation options for the perennial horticultural industries, with their longer timeframes for returns on investment at establishment, are likely to require greater strategic planning to ensure that the production system is resilient enough to deal with potential changes.

The results were presented broadly across the AMLR and elsewhere, while also gathering information on NRM stakeholders' perceptions of climate risk. With the projects' assistance, the AMLR Board presented the vulnerability analysis as their own work and published a brochure outlining this information (see AMLR NRM Board 2007b). The integrated analysis was also used quite specifically in targeted workshops throughout the region aimed at analysing regional perception of long-term climate risk.

3.1 ANALYSIS OF KEY ADELAIDE AND MOUNT LOFTY REGION NATURAL RESOURCES MANAGEMENT STAKEHOLDER PERCEPTIONS

The presumption that the awareness of climate change issues needed to be raised amongst the AMLR NRM community was tested by a study of key stakeholder perceptions of climate change (Bardsley & Liddicoat 2007). Such research to understand how key stakeholders perceive climate risk was recognised as important to ensure that methods are employed to best engage the NRM community, to identify requirements for skills and knowledge development, and to help engender community ownership of management responses to change. The results suggest that key stakeholders in the NRM community recognise the need, and are generally willing, to make significant sacrifices to prepare for climate change: to mitigate greenhouse gas emissions and to increase the resilience of NRM systems in the face of change. Respondents indicated that a full understanding of the future implications of climate change was not required to begin to implement a significantly increased response to climate change risk.

This stakeholder perception analysis examined the perceptions of climate change and associated impacts on NRM amongst key stakeholders in the AMLR NRM region during 2006. Stakeholders' perceptions were collated from responses to a survey questionnaire, as well as through group workshop discussions and targeted key stakeholder interviews. The work followed on from the earlier integrated analysis of climate change impacts, by supporting and strengthening available knowledge of regionally applicable adaptation and mitigation options. Subsequent to informing stakeholders of the potential implications of projected climate change on the NRM sector, people were asked to provide their opinions of current climate change and how their particular NRM activities may be affected in the future. Respondents were also asked to provide their opinions of potential adaptation options to respond to projected climate change and support sustainable development of local resources.

A particular focus of this stage of the project was a series of workshops with each of the regional NRM groups associated with the four AMLR NRM subregions: Northern, Central, Southern and Fleurieu (see Fig. 1). These four regional groups have been established within the AMLR to advise the regional board on local issues, to raise awareness of NRM and to work with local NRM communities and stakeholders to implement the comprehensive regional NRM plan. During the workshops, five major climate change issues for each AMLR NRM group were determined through a process of presenting the climate change information from McInnes et al. (2003) and Bardsley (2006) and then asking the NRM group members to complete the questionnaire. Subsequent to this group brain-storming, free-ranging discussions then allowed for grouping issues and prioritising to reduce the number to five key climate change issues for each sub-region.

The major findings of the stakeholder perception study indicate that climate change is now regarded as a potentially significant environmental management issue for NRM stakeholders throughout the AMLR, for example:

- On average, respondents rated climate change, drought and bushfire risk as the most important environmental issues likely to be faced in the region by 2030.
- Many respondents provided examples of observed changes in their local landscapes and production systems that could be associated with a changing climate.
- Many respondents already perceive warming of day temperatures, a drying trend in rainfall, and/or increased rainfall variability.
- Where changes in climate conditions were perceived, as a general rule respondents did not consider that these trends were an indication of ‘climate change’.
- Respondents were more likely to attribute warming temperatures to climate change, than they were to link perceived changes in rainfall amounts and variability to climate change.
- NRM stakeholders’ responses suggest that while people accept the primary impact of climate change will be warming, the broader impacts on climate processes and patterns are less clear.

Climate change will not impact on all areas of NRM evenly and it was perceived by respondents that the key impact areas are likely to be water and biodiversity management, with primary production and coastal issues also ranking highly. These issues were also identified as important vulnerabilities in the integrated assessment undertaken for the region (Bardsley 2006), although it was noted in that earlier review that those systems which are managed more intensively, such as water and intensive agriculture, are more likely to have substantial adaptive capacities. The relative importance of different climate change impacts on NRM was rated fairly consistently across the AMLR subregions, and subregional group responses paralleled responses from the wider NRM community.

Respondents provided a broad range of possible practical examples for effective adaptive responses to climate change at regional, local and sectoral levels. Many of these are detailed by Bardsley and Liddicoat (2008), but in one important example, respondents placed less emphasis on developing new sources of water, such as via desalination of seawater, and far greater emphasis on managing existing water supplies sustainably through increased stormwater harvesting, improved water use efficiencies, recycling and reducing consumption. Even though the work focused specifically on opportunities to better adapt to future climate change, a large number of suggestions were also provided for greenhouse gas mitigation responses, which respondents saw as part of a broader societal adaptation response. Education, policy, planning and a greater scrutiny of consumer lifestyles were all suggested as a means to change behaviour and motivate more sustainable practices. In other words, it was rarely perceived by respondents that it would simply be enough to adapt to projected changes at the local or regional NRM level for ongoing sustainable development in the AMLR.

Bardsley and Liddicoat (2008) note that the community was calling for more local information relating to both the impacts and timeframes of climate change across all sectors, and realistic options for climate change adaptation and mitigation. A need for more knowledge on climate change issues was identified, as was the need for greater community debate before ‘best practices’ for management can be identified. Even then, adaptive management approaches will be required, with outcomes and plans reviewed on a continual basis in light of changing climate conditions, changes to natural resource condition, and updated modelling of future impacts. Many respondents called for leadership to implement change now, so that future generations would not need to deal with the projected extremes of climate change if mitigation of greenhouse gas emissions were absent.

The review of key stakeholder perceptions by Bardsley and Liddicoat (2008) suggested that at least amongst the major stakeholders undertaking NRM decisions within the region, there is little need to change people’s attitudes to bring about changes in planning and action. There is significant agreement that decision making will need to become more detailed and constraining of exploitative practices for sustainable development in the region.

In fact, the great barrier to the evolution of adaptation responses seems to lie between goals and action. With a growing community awareness of the need to design and implement directions for NRM in South Australia, it will be less problematic to enact policy and programs to support sustainable adaptation options.

The AMLR NRM climate change project supported stakeholders to overcome the gap between understanding the need to respond to future climate risk and the application of climate change knowledge to guide future strategic and action planning. It was recognised that considerably more integrated research was needed in the region to guide specific short- and long-term planning goals. During the second phase of the AMLR NRM climate change project, six case studies of the interactions between climate and different aspects of NRM have been developed with key sectoral stakeholders, in part based on specific vulnerabilities and adaptation options identified in Bardsley (2006). The case studies, which cover aspects of water, soil, biodiversity, coastal and land-use management and planning were designed to avoid replicating other work that is underway in the region. For example, there has already been considerable research and planning work to examine the potential impacts of sea level rise on metropolitan coastlines in the region (Caton et al. 2007; Jacobi & Syme 2005; South Australian Coast Protection Board 1992). There is also considerable work underway on surface water resources and management (Heneker & Cresswell 2008, SEACI 2008). By integrating climate change into subregional or sectoral NRM work and following lines of enquiry, specific participatory methodologies were examined for different NRM contexts.

4. CASE STUDIES FOR DEVELOPING DETAILED DECISIONS ON CLIMATE CHANGE ADAPTATION

The initial vulnerability analysis presented in Bardsley (2006) was conceived as a starting point for analysing the vulnerability of NRM systems and proposing adaptation options. A general lack of immediate empirical evidence for drawing conclusions led to more detailed assessments of vulnerability to be undertaken. Six case studies were completed to better understand the specific implications of projected climate change for each sector. The case studies and the approach they used are outlined in Table 5.

Table 5. Climate change adaptation case studies undertaken for this project

Case study	Title	Approach used
Land capability (section 4.1)	Climate Change and the potential for wind erosion - a model for the Adelaide and Mt Lofty Ranges NRM region (DWLBC 2008)	Scenario modelling
Groundwater (section 4.2)	Discussion paper on the potential impact of climate change on the groundwater resources of the McLaren Vale Prescribed Wells Area (Waclawik 2007)	Scenario modelling
Biodiversity (section 4.3)	Modelling native and exotic flora distributions under climate change. (Crossman, Bryan & Bardsley 2008)	Applied and participatory GIS modelling
Land use planning (section 4.4)	Room to move: towards a strategy to assist the Adelaide Hills apple industry adapt to climate change in a contested peri-urban environment (Houston & Rowland 2008)	Applied and participatory GIS modelling
City of Onkaparinga (section 4.5)	Developing industry climate change adaptation strategies: A case study for the McLaren Vale viticulture and Fleurieu Peninsula oliveculture industries, (James & Liddicoat 2008)	Environmental risk analysis
Coastal (section 4.6)	Mapping landscape values and perceived climate change risks for natural resources management: a study of the Southern Fleurieu Peninsula region, SA (Raymond 2008)	Participatory action learning

These case studies are described in greater detail in the following sections and full case study reports are referenced and available separately to this report. The discussion following these case study summaries presents some conclusions about which approach might be most appropriate for guiding decision making in different NRM contexts.

4.1 CASE STUDY: CLIMATE CHANGE AND THE POTENTIAL FOR WIND EROSION - A MODEL FOR THE ADELAIDE AND MOUNT LOFTY RANGES NATURAL RESOURCES MANAGEMENT REGION

Reference: DWLBC 2008

Introduction

There is significant agreement that there will be a reduction in rainfall as a consequence of climate change. One implication is that more areas of agricultural land will potentially be susceptible to wind erosion, because reduced rainfall will likely see soil surface cover decline.

Purpose

The aim of this project was to develop and test a methodology to determine and analyse the possible impacts of projected climate change on the potential for soil erosion and land degradation. The results would identify areas of land likely to change in class, and locate the most vulnerable areas of land susceptible to wind erosion, enabling appropriate land management practices to be implemented to avoid any increases in erosion.

Methodology

Land capability, e.g. the potential for wind erosion, relies on assessing agricultural land for its potential to degrade under particular land uses (Table 6).

Table 6. Land classes and potential wind erosion

Land class	Description	Potential wind erosion
1	Arable	Low
2	Arable	Low/moderate
3	Arable	Moderate
4	Semi arable	Moderate/high
5	Non arable	High
7	Non arable	Extreme

Land capability maps showing wind erosion potential for soils in the agricultural areas of South Australia are available using current average annual rainfall figures. This mapping relies upon an assessment of soil characteristics within individual soil landscape units (typically 0.5–50 km^2). These characteristics include: textural class, depth of sand, topography and average annual rainfall (mm).

Utilising a new database system—the CSIRO Australian Soil Resource Information System (ASRIS)—it was possible to assess more accurately each soil type within the soil landscape unit. The underlying rules for determining wind erosion potential were then modified to ascertain changes in land capability resulting from decreasing rainfall. As the precise effects of climate change on rainfall are unknown, assessments were conducted on current annual average rainfall (benchmark), and 10%, 20% and 30% reductions in current values.

Results

The study area extended north of the AMLR NRM region border to examine a larger region that might be more prone to wind erosion. Maps were produced for the study area depicting the potential for wind erosion (Fig. 3), where the potential for wind erosion ranges from low (green) to high/extreme (red). Changes to land capability were also mapped for the different rainfall scenarios (see full report p. 10).

Discussion

The wind erosion potential maps (Fig. 3) highlight the most erosion prone areas of the region being investigated. As rainfall declines (i.e. 20% and 30%), the areas with the highest risk of wind erosion increase significantly. In most cases this occurs in exposed deep sandy dune systems.

There is a substantial increase in land classified as 'non arable' (Fig. 2) from 892–30 569 ha, when rainfall is reduced by 30% (see full report p. 9). This is a significant area which will provide land managers with challenges when determining future management techniques to avoid land degradation. The importance of no-till farming and the use of perennial plant based grazing systems are key adaptive management responses to consider.

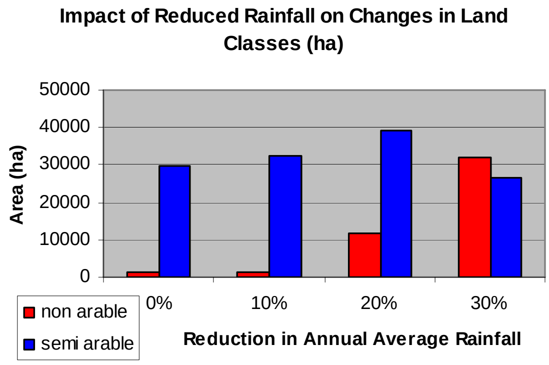


Figure 2. Potential changes in land classes as a consequence of climate change

Conclusions

This case study only investigated wind erosion potential. Determining future water erosion potential is more difficult as rainfall is not a parameter in determining current water erosion potential. However, the lessons learnt from examining wind erosion will be used to help guide the process for a study on water erosion. This methodology has the potential to be developed further to examine land capability and the impacts of other climate change variables such as seasonal rainfall, and increases in temperature and frost on the potential for wind and water erosion, provided the underlying rules for determining land capability can adequately describe the interactions.

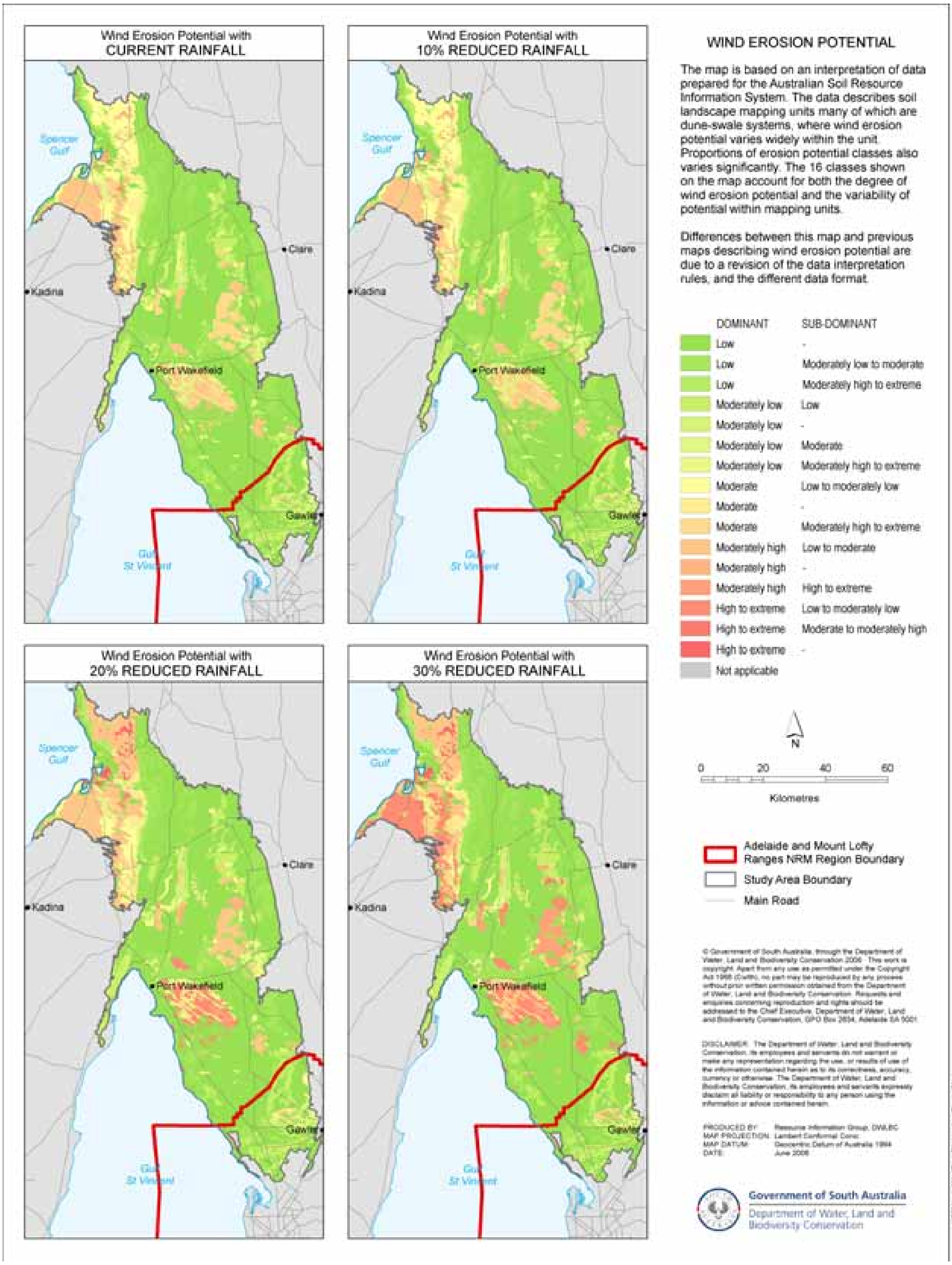


Figure 3. Wind erosion potential. The study area extends beyond the AMLR NRM region border to examine a larger region that might be more prone to wind erosion.

4.2 CASE STUDY: POTENTIAL IMPACT OF CLIMATE CHANGE ON THE GROUNDWATER RESOURCES OF THE McLAREN VALE PRESCRIBED WELLS AREA

Reference: Waclawik, 2007

Introduction

The groundwater resources of the McLaren Vale Prescribed Wells Area (PWA) provide up to 6600 ML/y of water for irrigation, commercial and industrial uses. The technical investigations that underpin the water allocation policy are partly based on estimates of rainfall recharge. This estimate is likely to alter under future climate change scenarios.

This case study presents an overview of the potential implications of climate change for the groundwater resources of the McLaren Vale region. It does not consider social or economic impacts.

Overview of the groundwater system

There are four main aquifers within the McLaren Vale PWA (Fig. 4). Of these, the Port Willunga Formation and Maslin Sands aquifers are the most important groundwater resources for the region.

Groundwater extraction and groundwater levels

Groundwater extraction exceeded the estimate of sustainable yield prior to the implementation of the water allocation plan. Since groundwater allocations were introduced in 2000–01, groundwater use in the McLaren Vale PWA has decreased.

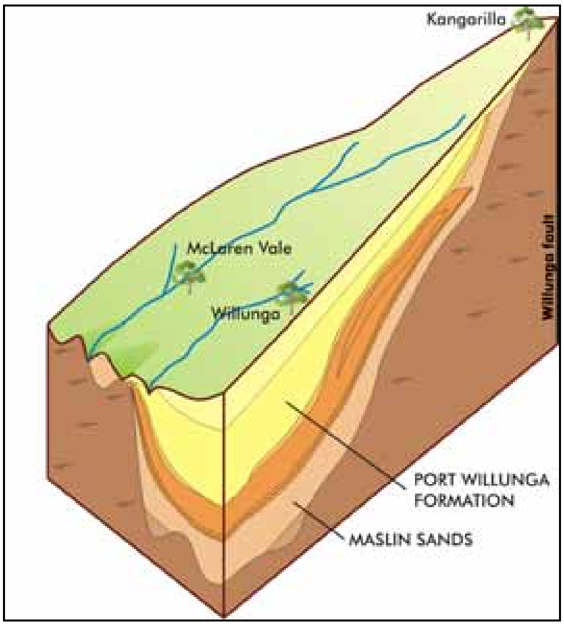


Figure 4. McLaren Vale PWA groundwater system

Modelled changes due to reduced recharge associated with climate change

A numerical groundwater flow model has been developed for the McLaren Vale PWA. The numerical groundwater flow model is a tool that can allow the impacts associated with groundwater extraction to be examined and to test the effect of different rates of rainfall recharge on the groundwater resource. The model encompasses the surface water catchment of the Willunga Basin and incorporates the most up-to-date information on hydrogeological conceptualisation and design, and is calibrated to time series groundwater levels.

Estimated impact of climate change on groundwater resources

Predictive scenarios were examined with the model based on a 25-year simulation. Scenarios examined included the current rainfall recharge, and 10%, 20% and 30% reductions in rainfall recharge.

For all simulations, groundwater extraction was held constant at the metered 2003–04 rate of 4400 ML/y.

Predicted groundwater levels in the Port Willunga Formation aquifer are up to 0.2 m lower (after 25 years) with a 10% reduction from assumed current average rates of recharge. This predicted drop in groundwater levels increases to 0.6 and 0.8 m when recharge is reduced by 20% and 30% respectively.

The Maslin Sands Aquifer response to reduced recharge is similar to that of the Port Willunga Formation aquifer, and a decrease in groundwater level is also predicted around Kangarilla where the Port Willunga Formation is absent.

Figure 5 presents model water budgets calculated as the difference between the base case water budget and the reduced recharge scenario budgets. The plots show that a 10% reduction in modelled rainfall recharge equates to a volumetric reduction of 570 ML/y over the McLaren Vale PWA. This reduction is partially accounted for by a reduction in modelled groundwater discharge to the ocean, a reduction in net discharge to streams, and a slight reduction in modelled evapotranspiration (due to lower water tables). The remaining shortfall in the water budget is made up by an increase in the amount of water released from storage (resulting in decreased water levels).

These plots also show that the groundwater system does not reach a steady state with the new recharge regime within the 25-year model time frame.

The reduction in groundwater levels over the 25 years due to reduced recharge is not considered significant relative to the thickness of the aquifer, however the impacts on groundwater dependent ecosystems (GDEs), for example baseflow to streams, is potentially more significant and requires further investigation.

These results apply for the 25 year modelled period but are likely to be greater when the model is run for a longer period. At equilibrium the full impact from climate change will be realised.

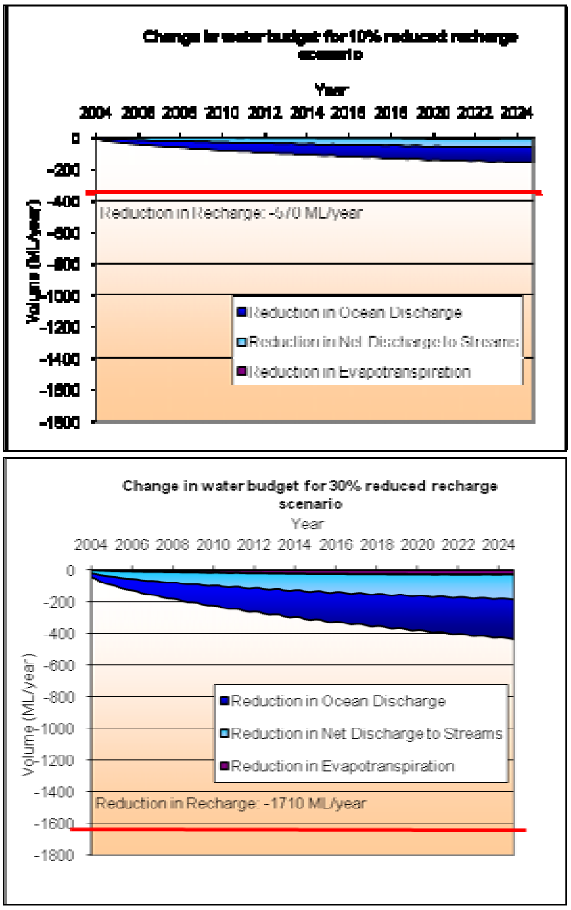


Figure 5. Changes in water budget for 10% and 30% reduced recharge model scenarios

Implications for GDEs

The modelling suggests that the reduced rainfall recharge may impact GDEs through reduced discharge and the lowering of groundwater levels more significantly than consumptive users. The reduction in groundwater levels are a consequence of a reduction in aquifer storage. This leads to a reduction in groundwater discharge to the ocean and reduced net discharge to streams, both important sources of supply for GDEs, potentially affecting baseflow ecosystems and the marine environment.

A fall in groundwater levels may also mean that terrestrial vegetation has less access to soil moisture within the capillary fringe.

The role of groundwater in supporting ecological outcomes is not sufficiently understood to fully comprehend the impacts of reduced groundwater levels. Policies that broadly maintain the existing range of groundwater depth and salinity in the water table aquifers are likely to protect the water requirements of ecosystems. However, each ecosystem will have its own characteristics and its own water requirements. Ongoing monitoring and research will help to clarify the particular needs of specific ecosystems.

Impacts of climate change not explicitly modelled

The change to climate will also alter the rate of evapotranspiration and flow of surface water along creeks. Changes to these two factors can also affect the groundwater balance. An increase in the rate of evapotranspiration will potentially increase the rate of groundwater losses where vegetation takes water from the capillary fringe and reduced streamflow may result in less water leakage from creeks to the shallow aquifers from creeks.

Saltwater intrusion

Given the decreases evident in groundwater outflows to the ocean it is possible that intrusion of highly saline groundwater will become a greater problem. However, it is noted that most estuarine, small lagoonal or discharge areas along the coastline are formed on perched systems and a significant change in groundwater gradient would be required to prevent localised flow to these systems. The groundwater associated with deeper aquifers along the coast is somewhat more saline and hence there are no large irrigation areas along the coastal strip. The groundwater gradient would need to be reduced along the coastal strip (through large scale groundwater extraction) to cause saltwater intrusions into the Port Willunga Formation and Maslin Sands aquifers.

Conclusions

A numerical groundwater model of the McLaren Vale PWA has shown that as a result of climate change:

- there will be a decrease in groundwater levels of less than a metre which will have minor implications for consumptive water users
- the impact of climate change on GDEs is unquantified and requires further research.

4.3 CASE STUDY: MODELLING NATIVE AND EXOTIC FLORA DISTRIBUTIONS UNDER CLIMATE CHANGE

Reference: Crossman, Bryan & Bardsley 2008

Introduction

This case study aimed to estimate habitat shifts under climate change by native and exotic flora present within the AMLR NRM Region, and synthesise the outputs, to contribute to:

- understanding the implications for flora in the AMLR of anthropogenically induced climate change
- the science to inform biodiversity planning for NRM in the AMLR.

This case study directly addresses both the methodological questions surrounding species habitat modelling and a lack of confidence in the practitioner community, and builds on the burgeoning science of species habitat prediction in the face of climate change by:

- using systematic selection methods to identify which native and exotic flora species to model for improved decision making
- developing ensemble forecasts that remove bias inherent in any single modelling approach
- developing multi-species management indices to simplify the complexity of native and exotic species responses to climate change and thereby better inform biodiversity planning and management under climate change
- ascertaining practitioners' perceptions of such modelling work in an attempt to better understand the drivers of doubt. The results can be used to improve the modelling and increase the likelihood of uptake by decision makers.

Methods

Ensemble forecasts of species habitat were developed for the AMLR by combining outputs from three different models: logistic regression, a generalised additive model (GRASP) and maximum entropy (Maxent). Native flora species within the region were extracted from the Biological Survey of South Australia database. The resulting native flora species database was queried to identify those species whose range is sensitive to three scenarios of climate change for the year 2030:

- mild, 0.8 ˚C warming and 5% reduction in rainfall
- medium, 1.2 ˚C warming and 10% reduction in rainfall
- severe, 1.6 ˚C warming and 15% reduction in rainfall.

Predictions of habitat suitability under current climate and the three climate change scenarios were made for each of the climate-sensitive native flora species. A multi-species index was developed that synthesises the magnitude and location of change in species habitat suitability between current and future climates for all species. The index also accounts for dispersal through a simple dispersal function.

Ensemble forecasts were also made for exotic flora species in the region. Predictions of habitat suitability under current climate and the severe 2030 climate change scenario were made for each exotic flora species. A multi-species index was also developed for exotic flora predictions.

Regional ecologists and biodiversity project managers were surveyed in an attempt to understand:

i. the level of decision making responsiveness to climate change impacts on biodiversity
ii. the value held by potential end-users of the habitat suitability modelling outputs.

Results

The number of climate sensitive native flora species modelled for each scenario was: i) 9 species in the mild scenario; ii) 17 species in the medium, and; iii) 42 species in the severe scenario. Fourteen (33%) climate-sensitive species have populations considered to be of concern from a conservation perspective at a state level and four (10%) have a national-level conservation rating.

The proportion of climate-sensitive native flora species whose suitable habitat was predicted to shrink was 100% (9/9), 94% (16/17) and 83% (35/42) across the mild, medium and severe scenarios, respectively. Native flora species of greatest concern are *Acacia triquetra, Allocasuarina robusta* (Fig. 6), *Prostanthera eurybioides, Pultenaea kraehenbuehlii,* and *Stackhousia aspericocca.* The area of suitable habitat for these species may be reduced by more than 20% by 2030 if the severe climate change scenario becomes a reality.

Locations of high priority for adaptation strategies for biodiversity (e.g. strategically located ecological restoration), as identified by the multi-species index of native flora, shift in response to increasing severity of climate change.

The number of exotic flora species modelled was 62. The proportion of exotic flora species whose suitable habitat was predicted to reduce under a severe climate change scenario was 80% (n = 49). Nine exotic flora species are of special concern because the extent of their suitable habitat may increase under climate change. Species of most concern are *Oncosiphon suffruticosum* (Calomba Daisy, Fig. 7), *Ulex europaeus* (Gorse) and *Vicia sativa* (Common Vetch). *Olea europaea* (European Olive) is predicted to see a reduction in suitable habitat under a warming climate (Fig. 7).

Locations of high priority identified by the multi-species index of exotic flora should be the focus of attention for weed control and surveillance strategies because it is these locations that provide increasingly suitable habitat for the majority of exotic flora and are near existing distributions.

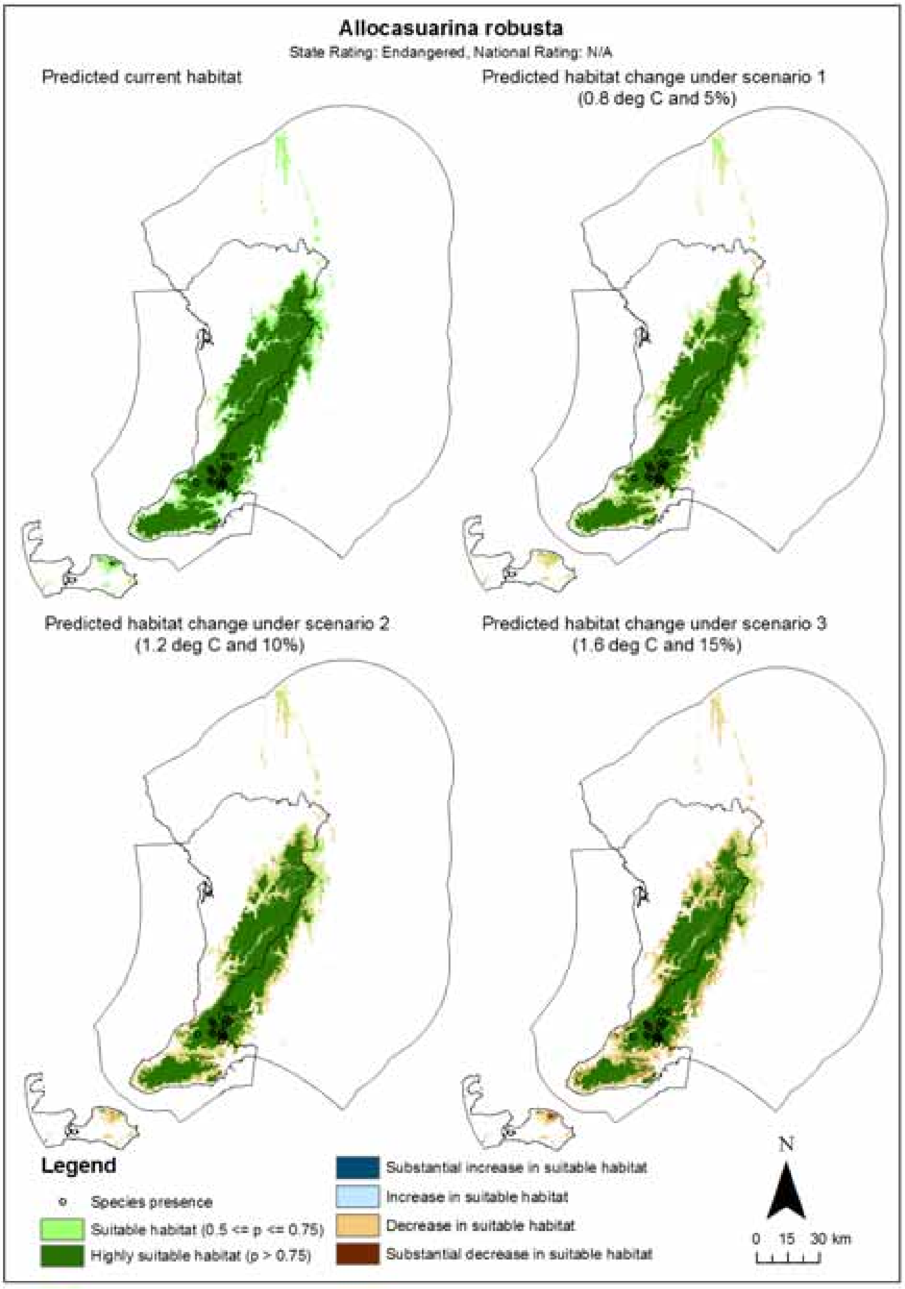


Figure 6. **Change in predicted *Allocasuarina robusta* habitat suitability from current climate to future climate change scenarios**

Surveys of regional ecologists and managers revealed that they considered the most important climate change impacts on biodiversity management and planning were: increasing external pressure on land and water use, changing ecological disturbance regimes, and increasing seasonal rainfall variability.

The factors that most prohibit regional ecologists' and managers' decision making in response to climate change were: uncertainty of impacts of climate change on ecosystems and not knowing what changes to make.

Discussion

Investment in NRM and climate change adaptation efforts for biodiversity can be targeted directly at the short-list of climate-sensitive species and associated predictive habitat models by designing protection and restoration strategies in high priority areas such as those identified by the multi-species index of native flora. For example, locations in the high priority areas that adjoin existing areas protected for conservation could be targeted for ecological restoration. In addition, disturbance regimes within high priority existing habitat could be monitored and managed more intensively. Doing so may provide the best opportunity for climate-sensitive species to disperse in response to shifting climate envelopes or be retained as long as possible in relatively intact systems.

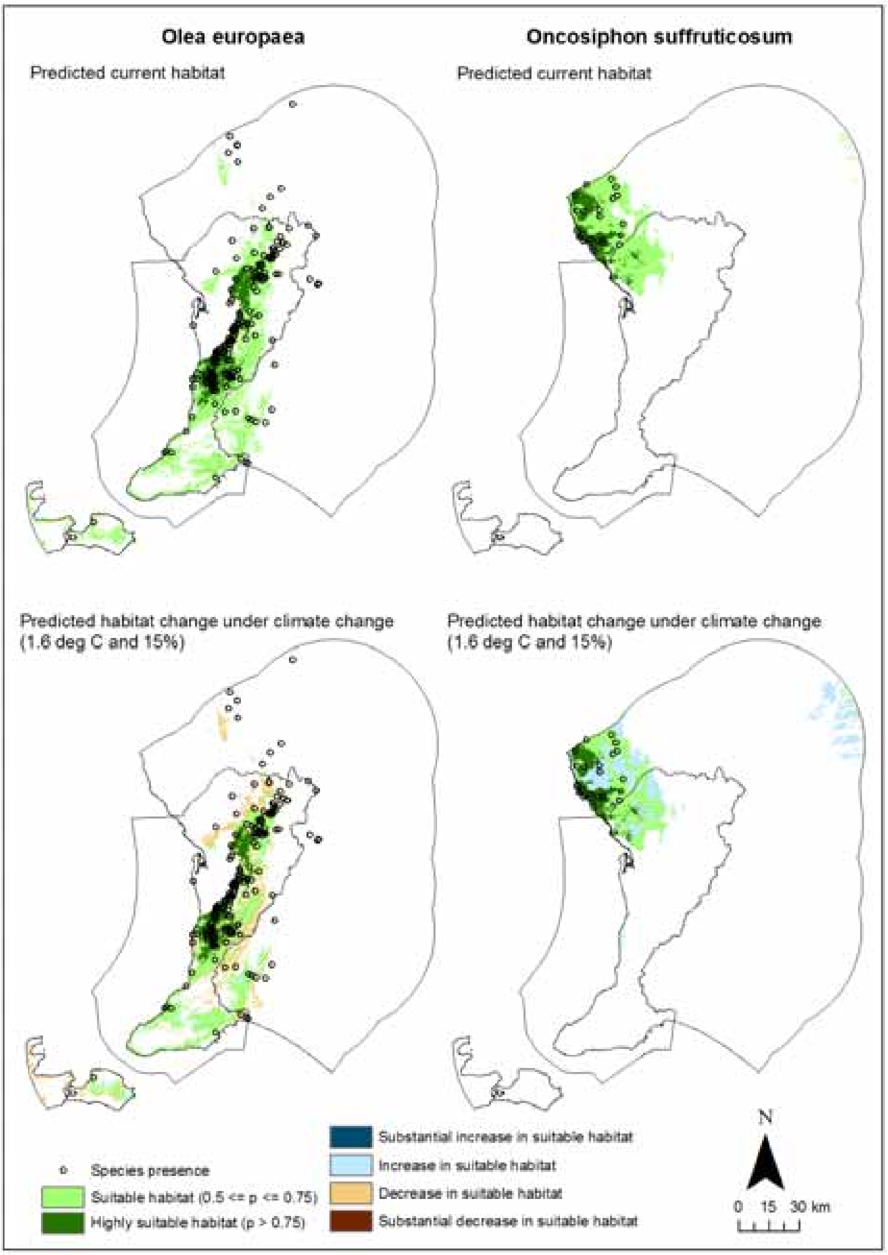


Figure 7. **Change in predicted habitat suitability from current climate to future warming and drying climate for two exotic plants, *Olea europaea* and *Oncosiphon suffruticosum***

Conversely, weed management and surveillance efforts could be concentrated in the locations of high priority identified by the multi-species index of exotic flora. Emergence of exotic populations in locations of increasing habitat suitability could be controlled before they are established and fill the niches vacated by native flora that move in response to their shifting habitat.

Regardless, all exotic species modelled in this study are of concern because they may exhibit invasive traits and rapidly shift in response to climate change, thereby filling niches vacated by climate-sensitive species unable to respond to shifting climates with sufficient rapidity. Existing state and national weed risk assessment protocols and methodologies should be updated to give due consideration to exotic species responses to climate change.

The multi-species indices raise an important point about the highly variable responses of species at fine regional scales. At fine scales, over which there is considerable spatial variation in topography and climate, the geographic distribution of management priorities shifts according to the extremity of climate change. In this study, the highest priorities for management of native flora under a mild climate change scenario are located in flat, low elevation topography to the east of the AMLR. As climate change becomes more severe, the location of highest priorities shifts to the high elevation and highly variable topography along the southern Mount Lofty Ranges.

Conclusions

- More than three quarters of climate-sensitive native flora species in the AMLR NRM Region, many of which have a conservation rating, are predicted to see their habitat decline by 2030 under current estimates of climate change.
- Native flora species of greatest concern are *Acacia triquetra, Allocasuarina robusta, Prostanthera eurybioides, Pultenaea kraehenbuehlii,* and *Stackhousia aspericocca.* The area of suitable habitat for these species may be reduced by more than 20% by 2030. *A. robusta, P. eurybioides* and *P. kraehenbuehlii* are conservation-rated.
- Many exotic species are already widely distributed and may experience a decline in suitable habitat by 2030 under a severe climate change scenario.
- Habitat suitability of exotic species *Oncosiphon suffruticosum* (Calomba Daisy), *Ulex europaeus (*Gorse) and *Vicia sativa* (Common Vetch) is likely to increase in a warmer and drier climate.
- State and national weed risk assessment protocols and methodologies should be updated to give due consideration to exotic species responses to climate change.

Future Work

- Determine the longer-term impacts of more severe climate change on species habitat suitability to, for example, the year 2070.
- The distribution of species may be controlled by limiting factors extraneous to climate and environment, such as predation, ecological interdependencies and competition. Further research is needed to understand these dynamics for climate-sensitive native flora and exotic flora species.
- Significant investment into empirical data collection is needed to better understand the impacts of climate change on native species interactions (mutualisms and dependencies) and exotic species population responses (fecundity, dispersal and germination).
- The multi-species indices identify priority locations for protection and restoration for improved management of species threatened by climate change. Further investigation is needed into the policy instruments and mechanisms available for adopting and implementing the multi-species indices developed in this study.
- The lack of confidence within the practitioner community may be overcome through revision of the methodologies and further research into species dynamics, as well as increased awareness of the potential benefits for decision making from species habitat suitability modelling.

4.4 CASE STUDY: ROOM TO MOVE: TOWARDS A STRATEGY TO ASSIST THE ADELAIDE HILLS APPLE INDUSTRY ADAPT TO CLIMATE CHANGE IN A CONTESTED PERI-URBAN ENVIRONMENT

Reference: Houston & Rowland 2008

Introduction

Located on the eastern edge of the AMLR NRM region, the Adelaide Hills are an ‘island’ of high rainfall, cool-climate conditions in an otherwise dry state. For South Australia’s apple industry, the Hills are its key asset. The region generates on average 85% of the state’s total pome (apple and pear) fruit production—worth $25.5m in 2005–06—and most of its premium quality fruit. Other production districts are comparatively minor elements of the industry in South Australia and could not fully replicate the role of the Hills.

There appears to be a sound prima facie argument for employing land use policy to secure strategic land resources for the apple industry. Figure 8 shows the level of competing urban development in the Adelaide Hills (the number of rural dwellings constructed between 1985–2005).

However, the credibility of any policy prescription will depend on a robust understanding of both the sensitivity of Adelaide Hills apple production to climatic variables and climate change, and the resources available to the industry in future. To investigate those matters this project used GIS to develop an interactive model identifying land that might be suitable for high quality apple production in the AMLR region.

Methodology

1. A project team was formed to collate and evaluate data sets, including spatial climatic data, as well as existing industry distribution, elevation and areas excluded from future industry development, including remnant vegetation, urban development and rural dwellings.
2. A technical reference group—including industry experts, experts in climate science and applications, soils and water resources—was established and consulted to identify key climatic parameters and other important considerations.
3. The suggested climatic parameters were compared with the existing industry distribution to determine the criteria to be used in the modelling.
4. The current climatic envelope for the industry and a likely future climatic envelope under a climate change scenario were modelled, using the chosen criteria.
5. Mapping results were presented to the technical reference group and reviewed by technical experts in the apple industry and climate science.
6. The maps and a report were produced.

Key climatic risks and requirements identified included:

- heat stress (temperatures above 33 °C are undesirable)—linked with the requirement for an adequate water supply to manage heat stress
- chilling requirements for fruit set (temperatures of sufficient duration below 7 °C)
- frost susceptibility during spring.

In addition, there is a need for relatively deep soils with good drainage and appropriate magnesium levels, and slopes generally below 30%, roughly correlating with land capability Classes 1 and 2 in the South Australian Department for Water, Land and Biodiversity Conservation Soil Landscapes database.

As a result, the following criteria were applied to identify land suitable for apple production:

- class 1 or 2 land capability for apples according to the South Australian Department for Water, Land and Biodiversity Conservation Soil Landscapes database
- April to October rainfall over 600 mm
- average autumn, winter and spring minimum temperatures below 8, 6 and 7 °C respectively.
- average autumn, spring and summer maximum temperatures below 26, 24 and 29 °C respectively.
- groundwater salinity below 1500 ppm, anticipating increased demand for watering, as well as for water resources generally.

When the model was run a second time, the possible climate change scenario used was that both minimum and maximum temperatures effectively increased by 1 °C and April to October rainfall was decreased by 50 mm. An additional criterion for groundwater yield was set at above or equal to 5 L/s.

Modelled changes

Anticipated climate change seems likely to shrink the already limited opportunities for high quality apple production in the AMLR region. This will restrict the industry’s ability to adapt by relocating or reconfiguring itself. Peri-urban pressures, especially rural residential development, will further narrow those options and amplify the effect of climate change.

Using the abovementioned criteria, the modelling suggests that there is currently an area of approximately 20 300 ha in the AMLR region with bio-climatic conditions broadly similar to those of the current significant industry locations. Based on temperature increases of 1 °C for minima and

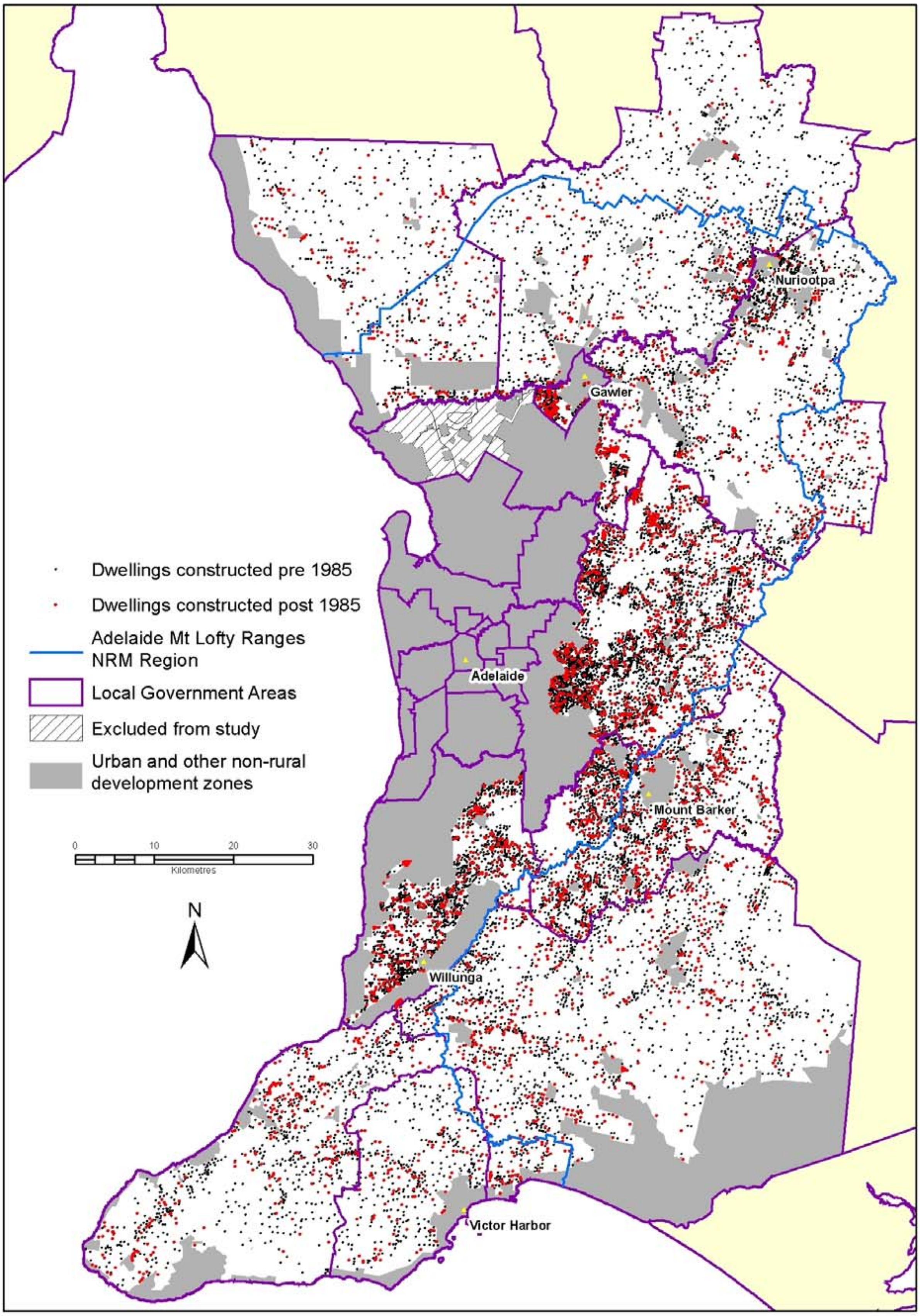


Figure 8. Rural dwelling construction in Adelaide's peri-urban region, 1985–2005

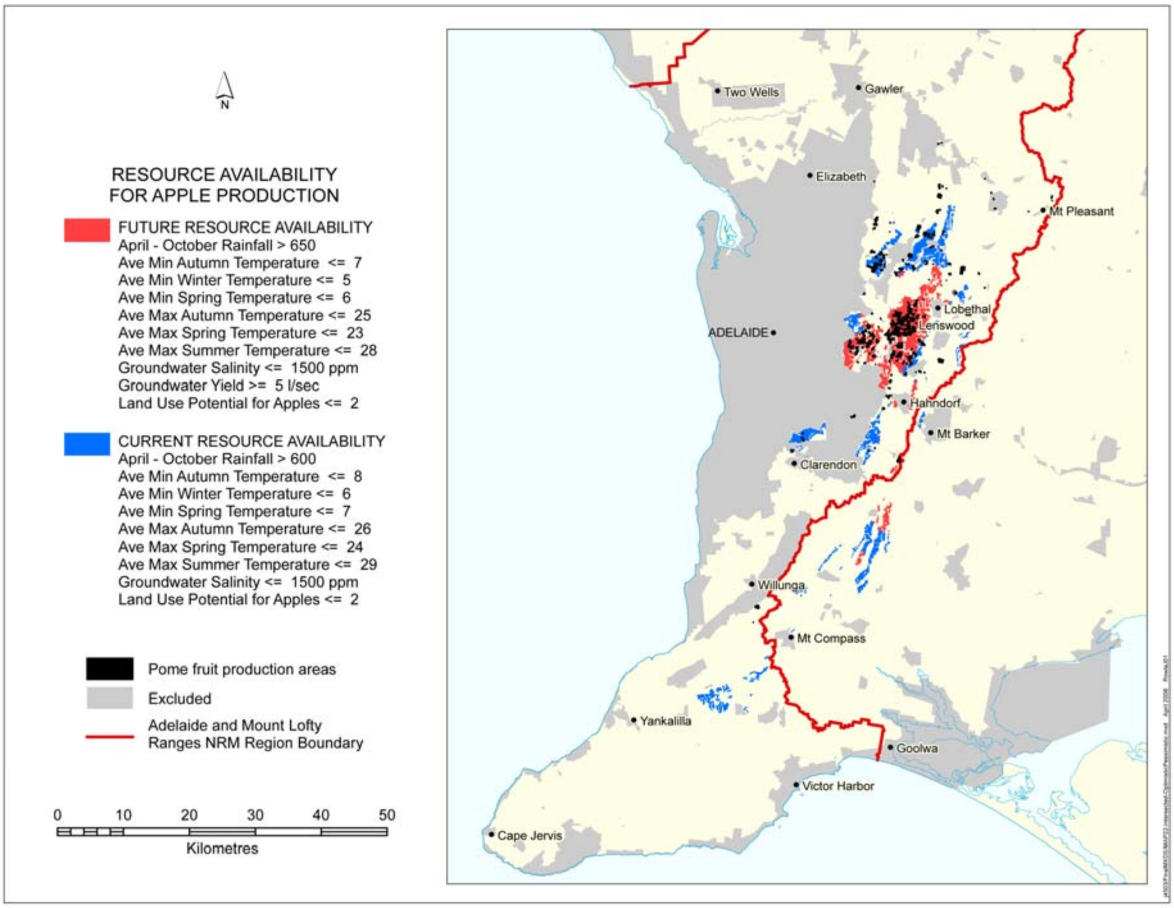


Figure 9. **Current and future resource availability modified by excluded areas and existing orchards**

maxima and a 50 mm decrease in April to October rainfall, the model predicts future land resource availability will shrink to around 8550 ha. After accounting for urban areas, public land, major infrastructure, rural land for non-farm purposes (e.g. landscape zones, special purpose zones), native vegetation and ad hoc rural residential development, the figures for current and possible future resource availability fall to approximately 11 400 and 5500 ha respectively. The blue and red areas together in Figure 9 indicate the model's estimated area for current apple production. The red area alone indicates the model's available land for apple production under the climate change scenario.

All of these figures include the 1750 ha of current production areas (shown in black on Fig. 9), making the area of potential new production sites correspondingly smaller again.

These assessments are most likely conservative (i.e. overestimates). They do not yet account for future water quality protection policies or the indirect effects of ad hoc rural residential development such as 'right to farm' issues. Neither do they attempt to calculate the likely consequences of future rural residential development across the region. In these circumstances the case for utilising land use policy to reserve strategic resources for the apple industry in the AMLR region seems compelling. However, the analysis behind this conclusion would benefit from further development.

Limitations

Three principal types of limitations have been identified: limitations in the data used, limitations as a result of the binary choices used in the model, and limitations in the climatic projections.

As a result of time and budgetary constraints, monthly climatic data were used, instead of daily data (which would facilitate better measurement of extremes). This was a pivotal limitation of the project. Daily data are particularly important for assessing the level of heat stress, frost vulnerability and adequacy of chilling conditions. Hail risk was not included.

Timing can be crucial. For example, vulnerability to sunburn depends upon the growth stage. The duration of temperatures meeting chilling requirements is of vital importance. Climatic variables may influence the time of flowering and harvest, as well as yield and quality. The use of strict binary (yes/no) choices in the modelling limited the exploration of such responses to climatic changes.

The binary choices used in the model were based on limited information on the effects of different climatic conditions on different apple varieties.

In addition to temporal data limitations, spatial data limitations were also a factor. Figures 10 and 11 show the location of monitoring sites for temperature and rainfall. The GIS model must interpolate between these sites. Micro-climatic variation may affect conditions at a finer scale.

Rainfall, groundwater salinity and groundwater yield were included as separate criteria. It has been suggested that these could be combined to make a more sophisticated ‘adequate water resources’ criterion, taking into account the fact that groundwater and surface water can be used somewhat interchangeably in some circumstances.

Not all rainfall is necessarily equal in terms of its ‘usefulness’. It has been emphasised that water allocation planning may be a key limiting factor in the future, with few viable new dam sites remaining and possible significant limitations on permits and/or licences to use water. The majority of the areas currently used and identified as suitable for apple production are located within the Mount Lofty Ranges watershed protection zone. This may result in further constraints limiting the area of land suitable for apple production.

As part of the review process, it was pointed out that the Boolean aggregation method used—along with binary choices—is not flexible enough to take into account measurement error or ambiguities.

Increasing minimum and maximum temperatures by 1 °C and decreasing the April to October rainfall by 50 mm is a rough projection of possible climatic conditions in the future. More refined projections could be applied. However, the use of binary choices would likely be a limiting factor here too.

Finally, the ‘critical mass’ required to sustain the apple industry in South Australia is unknown. Significant reductions in area and/or yield will test how much the industry can shrink before becoming non-viable, and this is likely to be strongly linked with economic conditions.

Conclusions

This process produced useful information on the likely magnitude of effects of climatic changes on the apple industry, particularly given the limited time and budget involved. When minimum and maximum temperatures were modelled to increase by 1 °C, and April to October rainfall was decreased by 50 mm, then—according to the criteria set—the area suitable for high quality apple production was estimated to fall to less than 50% of the current suitable area.

Such a process is likely to be useful in other situations where climate is a major driver of the distribution of an activity or industry.

It would be of great benefit for future projects of this nature to have access to daily climatic data at a reasonable cost.

Continuous improvement or ‘ground truthing’ of the climate data is recommended, along with the production and utilisation of further information on correlations between climatic variables and factors affecting the feasibility of apple production (and other agricultural industries). This could perhaps be better incorporated into the methodology of this type of project. Inclusion of well-informed farmers in the technical reference group was suggested by industry reviewers.

It is also recommended that a more comprehensive literature review be undertaken (at Step 1) at the start of a process such as this one (see references in the full case study report).

Fuzzy sets or the analytic hierarchy process (AHP) have been suggested as preferable methodologies, overcoming some of the limitations of the Boolean approach.

Given the limitations of the project and uncertainties involved, great caution has been urged in the communication and interpretation of the modelling results and mapping—particularly the estimated areas suitable for apple production (in hectares).

The findings from this project (and similar projects) are likely to be useful for strategic planning undertaken by state agencies and regional NRM boards, as well as industry bodies. This is particularly appropriate given that, in a case such as the apple industry, the decreasing area of land available for production may be approaching (or threatening to fall below) a critical mass for maintaining production in the Adelaide Hills.

Further investment in the development of the data sets required and the methodologies used could facilitate better analysis across a range of industries and regions.

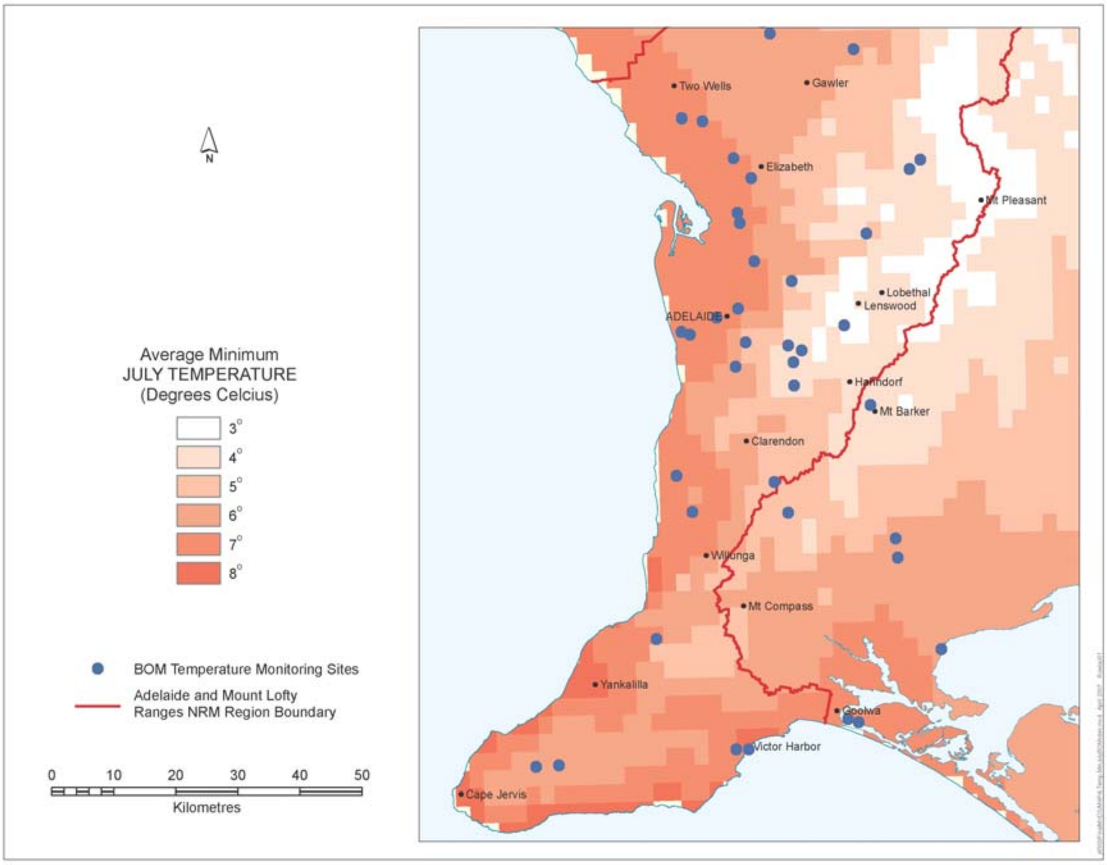


Figure 10. **Bureau of Meteorology temperature monitoring sites**

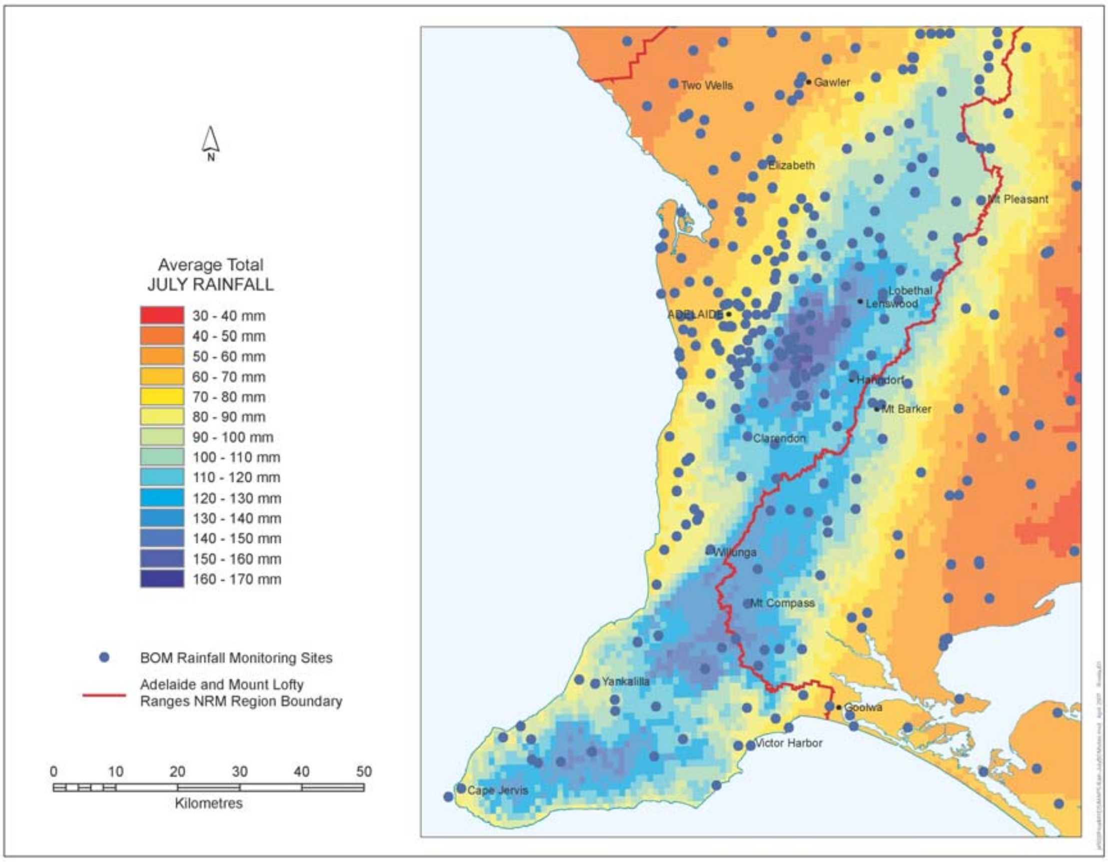


Figure 11. **Bureau of Meteorology rainfall monitoring sites**

4.5 CASE STUDY: DEVELOPING INDUSTRY CLIMATE CHANGE ADAPTATION STRATEGIES: THE McLAREN VALE VITICULTURE AND FLEURIEU PENINSULA OLIVECULTURE INDUSTRIES

Reference: James and Liddicoat 2008

Introduction

This case study presents work aimed at developing climate change adaptation strategies for two key horticultural industry groups in the AMLR region: the McLaren Vale grape growers and Fleurieu Peninsula olive growers. This work follows on from an initial assessment of projected climate change impacts in the region which indicated perennial horticulture was among key sectors vulnerable to projected climate change broadly characterised by a warming and drying trend.

The City of Onkaparinga (the Council) took the lead role in implementing the case study, engaging with key stakeholders and facilitating the adaptation planning process. This work involved a participatory approach, engaging and educating key stakeholders, and encouraged a two-way flow of information between growers, researchers, policy and planning organisations.

Objectives

Objectives of the work included:

- engagement, education and ownership of the climate change issue for stakeholders
- identification of priority climate risks, and development of potential adaptation response strategies, with a focus at the industry level
- identification of future work, roles and responsibilities for business, industry associations and other stakeholders
- generation of feedback on the engagement process and project methodology to assist future adaptation planning work
- informing local industry strategic planning, including: the AMLR NRM Board, the Southern Adelaide Economic Development Plan, the City of Onkaparinga Water Management Strategy, the South Australian Wine Industry Association (SAWIA) climate change response and other natural resources managers in the region
- demonstrating a climate change response model for local government interaction with industry.

Key industry questions of climate change impacts to water security in McLaren Vale and possible increased weed risk from olives were also investigated.

Methodology

Adaptation response strategies were developed through a participatory process, facilitated by the Council. Industry focus groups were formed to oversee the planning process. Grower workshops were undertaken to present available information on climate change projections, regional water issues and an overview of potential climate implications for the respective industries. Group discussions during these grower workshops also generated an initial scan of climate risks and potential adaptation options.

Issues raised during the grower workshops, along with available information on potential climate implications, formed the basis of a risk assessment survey. To aid decision making and limit uncertainty, a common set of climate assumptions and management considerations were provided with the risk assessment survey. This assumed climate scenario was within the range of projected climate change data available at the time.

Results from the risk assessment survey were reviewed by Council and the industry focus groups. The focus groups then identified priority climate risks and suggested a range of adaptation strategies and potential organisations to foster their implementation.

Expert comments were then sought to provide a more objective view of the climate risks and adaptation strategies, and hence a more solid foundation for action. Feedback on the overall process was also sought to improve future adaptation planning activities. Specific areas reviewed included the application of climate projection information, potential gaps in business or agronomic aspects of the risk assessment, and impacts to the respective industries under the climate scenarios presented.

Key findings

Priority climate risk areas and potential industry adaptation strategies identified through this case study are outlined below. Water supply, soil salinity, summer impacts and business profitability emerged as key risk areas for both industries. Following the expert review a wider range of risk areas were also suggested for consideration.

Implementation of these strategies will require involvement and leadership from a range of science, research, policy and planning organisations, along with the industry groups themselves.

Key climate risks and suggested industry adaptation strategies [V=Viticulture, O=Oliveculture]

Risk area	Adaptation strategies
Irrigation	• Maximise water use efficiency [V, O] • Research low water use varieties [V] • Encourage at-risk growers to seek greater water security [V, O] • Establish links with weather forecasters specific to industry needs [V, O]

Risk area	Adaptation strategies
	• Provide early warnings of reduced water allocations [V, O] • Develop business strategies for coping with drought [V, O] • Advocate for industry access to drought relief [V, O]
Salinity	• Targeted research on salinity avoidance [V, O] • Develop practices and inform growers to avoid salinity build-up [V, O] • Shift to least saline water supplies [V] • Identify areas at high risk of salinity accumulation [V] • Monitor salinity build up in high risk areas [V, O] • Review long-term salinity and natural resources impact risk with key stakeholders [V, O] • Promote salinity management as a key pillar of industry environmental management [V, O]
Impacts of changing summer climate	• Research heat resistant varieties and heat management techniques [V] • Inform growers on managing hot weather impacts on vines [V] • Establish links with researchers investigating climate change impacts on wine grape varieties [V] • Establish links with weather forecasters specific to the needs of the industry [V] • Research into olive industry pest and disease management [O] • Investigate effective management of increased pest and disease pressure [O] • Increase grower capacity to manage pest and disease pressures [O] • Increase plant resilience to pest and heat pressure [O]
Business	• Review sustainability of current grape/ olive product pricing practices [V, O] • Winery/grower collaboration in grape pricing and wine marketing [V] • Identify ongoing need (quality, cost, timing) for salinity flushing irrigation applications [V, O] • Targeted research to reduce costs of grape production [V] • Improve margins per kg of fruit [O] • Identify and monitor high risk commercial olive groves [O]

Expert review

The approach adopted in this case study was generally viewed as an excellent first step towards developing industry adaptation strategies in the context of the challenging and complex issue of climate change.

Suggestions to improve adaptation planning include:

- Greater technical/scientific input during the early project planning and delivery phases—to ensure that growers are provided with the best available information on projected climate change and potential impacts.
- Do not narrow the focus of potential climate risks too early. Water security and salinity issues will be a priority but there is potential to overlook other important climate risks. This is also a factor of the experience of participants involved in the risk assessment process.
- Allow greater thinking ‘outside the square’ to encourage development of a range of adaptation options.
- Keep abreast of the latest climate projections and tools for engaging and informing stakeholders. Climate change is the subject of active research and information is continually being updated
- Care must be taken when presenting information on the parameters, range and uncertainty associated with climate change projections, to ensure responses are in balance with available information.

Conclusions

This work has successfully engaged industry stakeholders to promote greater awareness and ownership of the climate change issue. This case study has demonstrated the application of the widely accepted generic risk assessment framework to the context of climate change. The expert review process suggests that the adaptation planning process has been successful in generating initial industry directions for climate change adaptation. It also suggests that outputs from future risk assessment and planning processes can benefit from a wider range of experience and expertise during the input phase. This project has contributed to the City of Onkaparinga being a leading council in responding to climate change.

Future work

Adaptation to climate change will require an iterative planning process as better modelling and climate information become available, and implications for natural resources management become more apparent.

As a first step, this work has generated an initial scan of the climate risks facing the two industry groups and given direction to future adaptation planning activities. To implement future adaptation planning activity there is a need to establish a roles and responsibilities framework, to encourage progress and avoid duplication of efforts.

Understanding of climate change is progressing rapidly and the regional to local scale information required by growers may become increasingly available in the future. Future work, particularly in reviewing industry adaptation plans, will benefit greatly through the maintenance of links with key research and scientific organisations, local government (with regional economic development perspectives) and state government policy and planning agencies.

4.6 CASE STUDY: MAPPING LANDSCAPE VALUES AND PERCEIVED CLIMATE CHANGE RISKS FOR NATURAL RESOURCES MANAGEMENT

A study of the Southern Fleurieu Peninsula region, South Australia

Reference: Raymond 2008

Introduction

While the science community has an important role in identifying climate change risks, current scientific knowledge of adaptation is insufficient for rigorous evaluation of planned adaptation options[1]. At the same time, policy makers are being urged to develop new strategies for encouraging adaptation to climate change risks at the local level. How do planning authorities use the collective knowledge and wisdom available in local and scientific communities to prioritise adaptation strategies?

This case study compares public perception and expert assessment of conservation value and threat in the Southern Fleurieu Peninsula region, South Australia, with the goal of informing local climate change adaptation responses.

Methods

A public survey technique known as the landscape values methodology (LVM)[2] was further developed to systematically identify landscape values (i.e. aesthetic, economic, recreation, learning, biodiversity, intrinsic, heritage and future), and perceived climate change risks (i.e. biodiversity loss, land erosion, bushfire, riparian flooding, sea-level rise and storm surges). Using workshop (n=245) and postal (n=130) surveys, secondary school students and adult property owners in the region were asked to map their landscape values and perceived climate change risks by placing sticker dots on a 1:125 000 scale map of the Southern Fleurieu (Fig. 12). The mapped dots were digitised into a GIS and then overlaid with the spatially referenced conservation values and threats assessed by ecologists[3]. To enable comparison, the conservation value and threat layers shown in this case study were clipped to within 3 km of the shoreline.

Figure 12. Volunteers from Friends of Newland Head Conservation Park (Victor Harbor, SA) mapping their landscape values and perceived climate change risks

In addition to the mapping component, survey participants were asked about threats to their quality of life, their knowledge of climate change and level of concern, and their preferences for climate change adaptation. Attitudinal responses were examined across school student and adult sub-groups considering the paucity of information on young people's views toward climate change. A 61% survey response rate was achieved for the postal survey.

Spatial overlap between public perception and expert assessment of conservation value

This section compares and contrasts public perception and expert assessment of conservation value for the Southern Fleurieu region. In the survey, 'places that provide for a variety of plants, wildlife, marine life, or other living organisms' was used as a proxy for perceived conservation value. The layer representing expert assessment of conservation value (Fig. 13) was generated using the total sum of means from a number of themes: the condition of remnant vegetation communities (14 themes), significant or a diversity of flora and fauna (eight themes), sites of heritage significance (three themes), and sites of geological and geomorphic significance (three themes).

There is moderate alignment between the conservation values of survey participants and experts for the Southern Fleurieu, with some important differences. Both respondents and experts identified Deep Creek Conservation Park as a high priority for conservation (Fig. 13). Survey participants assigned higher conservation value to the coastal townships of Victor Harbor (high priority vs. medium-low priority) and Middleton (medium priority vs. low priority). The conservation assessment recommended the planting of corridors from Newland Head Conservation Park to Deep Creek Conservation Park and from Deep Creek to Morgan Beach; however, respondents assigned low conservation value to these places.

Spatial overlap between public perception and expert assessment of conservation threat

In the survey, 'areas vulnerable to loss of native plants or animals as a result of projected climate change by 2030' was used as a proxy for perceived conservation threat. The following layers formed part of the conservation threat assessment undertaken by experts: council provision for urban development, the level of visual amenity, the proximity of dump sites to sensitive areas, environmental weeds affecting the area, the stability of cliffs and dune areas, the presence of coastal acid sulfate soil, and projected climate change.

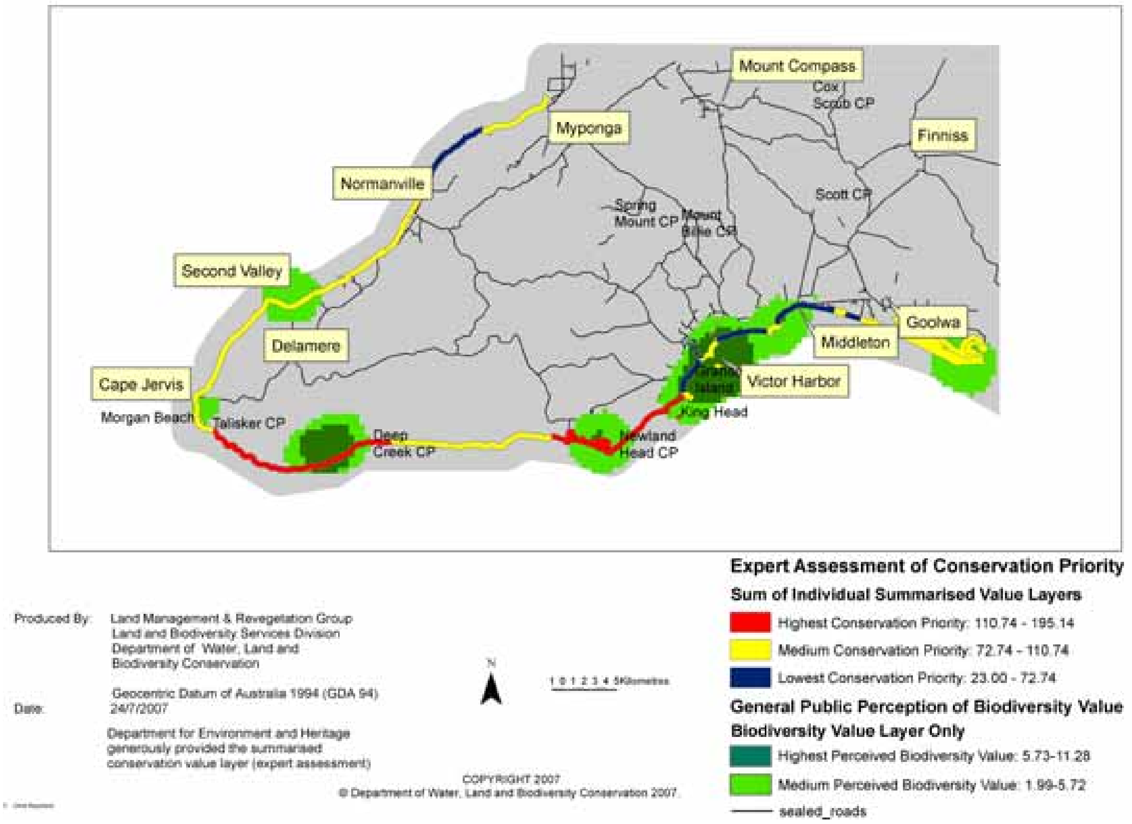


Figure 13. **Comparison of expert assessment and public perception of conservation value within 3 km of the Southern Fleurieu coastline**

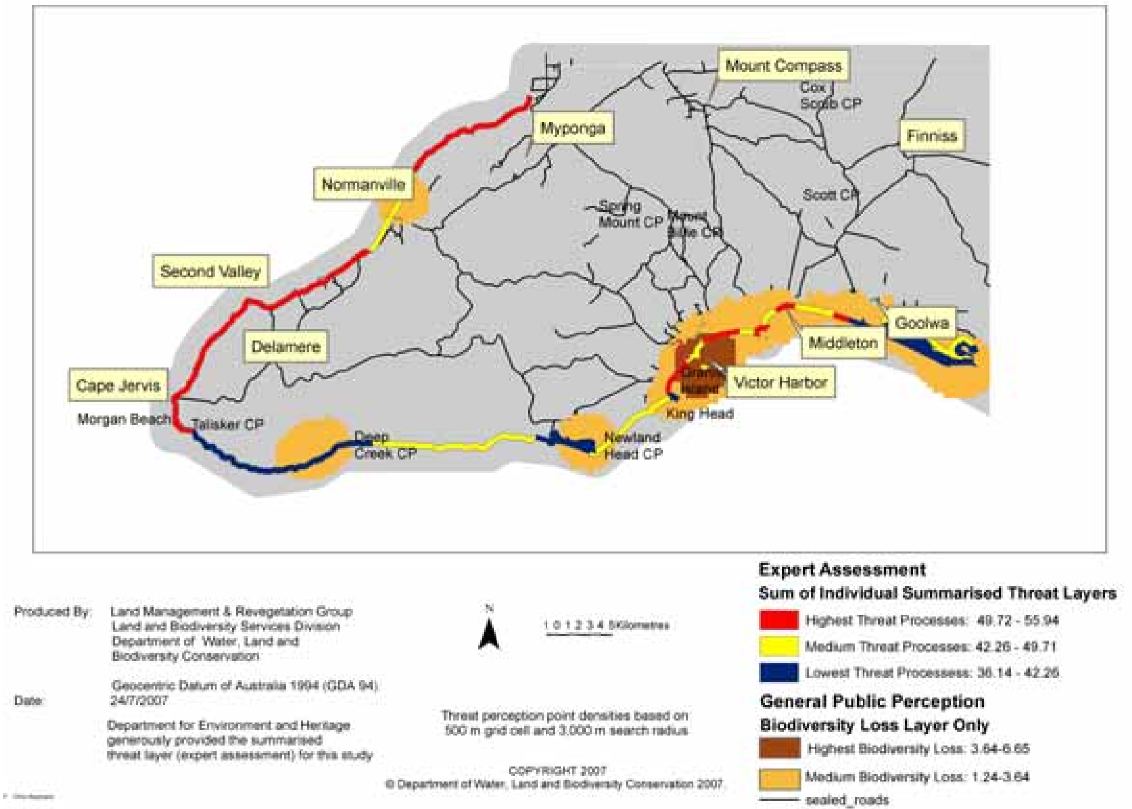


Figure 14. **Comparison of expert assessment and public perception of conservation threat within 3 km of the Southern Fleurieu coastline**

There is moderate alignment between the conservation threats identified by survey participants and experts, with some notable exceptions (Fig. 14). Survey participants and experts identified the region between Victor Harbor and Goolwa to be medium or high conservation threat in the light of climate change. Respondents assigned higher conservation threat to Deep Creek (medium conservation threat vs. low conservation threat) and Newland Head Conservation Parks (medium conservation threat vs. low conservation threat). Conversely, experts assigned higher conservation threat to the area from Cape Jervis to Second Valley (high conservation threat vs. low conservation threat). Respondents did not assign high conservation threat to two areas proposed by experts for protective buffering by zoning: the area from Deep Creek Conservation Park to Morgan Beach, and the area including King Head to Newland Head Conservation Park.

Conclusions

This study has shown that authorities responsible for NRM and climate change planning should consider and act upon public perceptions of landscape value and climate change risk. Public perceived values and risks, as presented in this summary, provide an important additional layer in climate change adaptation assessments. Soliciting these values early in the planning process may increase trust in decision making and community support for and involvement in climate change adaptation responses. The values of quiet voices in society can also be recognised as part of this engagement process.

Further, when collected using systematic sampling and survey techniques, both local and expert knowledge systems have an important role in climate change and NRM planning. Overlaying both forms of knowledge enables more integrated assessment of climate change adaptation strategies and provides a means for NRM agencies to move from just ‘listening and providing feedback’ to looking for direct input and innovation from local groups in formulating solutions to NRM problems.

Specific recommendations from this case study include:

- NRM planning authorities responsible for climate change adaptation strategies use systematic social survey techniques, such as the LVM, to take into account public perceptions of climate change when designing NRM programs.
- Park authorities note the need to promote the conservation value of the area from King Head to Newland Head Conservation Parks and Deep Creek Conservation Park to Morgan Beach in order to enjoy public support for protective buffering by zoning.
- Coastal planning authorities develop strategies to better understand why the conservation threats posed to the area between Cape Jervis and Normanville were not recognised by survey participants.
- NRM planning authorities responsible for climate change adaptation strategies note the high conservation and climate change threat assigned by ecologists and survey respondents to the area between Victor Harbor and Goolwa.
- NRM agencies consider the application of the LVM presented in this report to different land-use contexts and across different NRM issues, including the possibility of using a web-based approach to increase cost effectiveness.
- Researchers to develop new tools for understanding the connections between people and place at different geographic scales, and the relationships between place values and place meanings.

1. Yohe GW, Lasco RD, Ahmad QKArnell NW, Cohen SJ, Hope C, Janetos AC & Perez RT, 2007, ‘Perspectives on climate change and sustainability’, in Parry ML, Canziani OF, Palutikof JP, van der Linden PJ & Hanson CE (eds), *Climate change 2007: impacts, adaptation and vulnerability*, contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK, pp. 811–841

2. Brown G, 2005, ‘Mapping spatial attributes in survey research for natural resources management: Methods and applications’, in *Society and Natural Resources*, 18(1), pp. 1–23

3. Caton B, Fotheringham D, Lock C, Royal M, Sandercock R & Taylor R 2007, *Southern Fleurieu coastal action plan and conservation priority study*, prepared for Adelaide and Mount Lofty NRM Board, Alexandrina Council, City of Victor Harbor, District Council of Yankalilla, Goolwa to Wellington Local Action Plan and Department for Environment and Heritage

5. KEY ISSUES RELATING TO DECISION SUPPORT APPROACHES

The six case studies develop more detailed NRM responses using four key approaches to guide decision making across NRM sectors, namely: scenario modelling; applied and participatory GIS modelling; participatory action learning; and environmental risk analysis. A scenario modelling approach was applied to the land capability and groundwater studies. These aimed to adjust previous resource condition assessments according to potential scenarios to raise awareness of the types of sectoral impacts that might be expected from climate change. Applied and participatory GIS modelling approaches were applied for the land use planning and biodiversity case studies. These aimed to maximise engagement with the stakeholders in the different sectors as modelling was developed, so that key vulnerabilities could be further highlighted and responses articulated. The third approach, which was applied in detail by the coastal study aimed to provide mechanisms through a participatory action learning approach, by which stakeholders are able to analyse their local vulnerabilities in some greater depth without significant information from external sources such as scientific or other public materials. Finally, the City of Onkaparinga case study utilised a formal environmental risk analysis approach to guide stakeholders through an analysis of their NRM systems. This final method applies a formal risk assessment approach matrix with impact and likelihood components included, in contrast to the vulnerability assessment process which does not have a likelihood component. At the same time as the case studies were underway, parallel work examining perceptions of climate change throughout the AMLR also focused on maximising engagement with stakeholders.

It is worth contrasting the six case study approaches to get a better idea of the opportunities and limitations that the different methodologies provide to guide decision making and advise which is the most appropriate for different NRM scenarios. A summary of these case studies and an analysis of how they fit the proposed framework is presented in Table 7.

5.1 SCENARIO MODELLING

The scenario modelling approaches, namely in relation to the groundwater, land capability and to a certain extent the biodiversity study, provided opportunities but also faced limitations of methodology. Particularly in relation to the groundwater and biodiversity assets, the current scientific knowledge was insufficient to effectively apply scenario modelling to examine potential futures. Both Waclawik (2007) and Crossman, Bryan & Bardsley (2008) acknowledge that significant gaps are still present in understanding the natural resources systems themselves, so that the outcomes of the groundwater and biodiversity modelling are only partially valid. Similarly, the complexity of applying a climate change layer in the analysis of soil erosion potential limited the land capability work to an examination of wind erosion only (DWLBC 2008).

The land capability and groundwater modelling projects reinforced the point that where resource use is currently marginal in the AMLR NRM region, it is likely to become more so with climate change.

Table 7. Case study benefits and limitations and how they fit the proposed climate change framework

Case study	Land capability	Groundwater	Biodiversity	Land use planning	City of Onkaparinga	Coastal
Approach	Scenario modelling	Scenario modelling	Applied and participatory GIS modelling	Applied and participatory GIS modelling	Environmental risk analysis	Participatory action learning
Awareness raising and ownership of climate change	Seminars for NRM board members and staff.	Seminars for stakeholders and in-depth interviews with resources managers.	Stakeholder surveys and feedback workshops, involving interactive discussion and revision of modelling.	Participatory research featuring a series of stakeholder workshops and a growers forum.	Participatory research between state and local government, seminars and workshops for stakeholders	Participatory research featuring seminars and workshops for stakeholders.
Vulnerability analyses	GIS scenario modelling and potential wind erosion maps based on projected annual rainfall reductions.	Numerical groundwater flow model developed to assess subregional groundwater extraction impacts and to test the affect of different rates of rainfall recharge.	Combined output of three models identified species vulnerable to climate change and high priority areas for adaptation strategies.	GIS modelling using likely future climatic production envelope, and stakeholder input into development of key criteria for premium apple production.	Risk assessment developed with stakeholders applying a scenario that reflected CSIRO climate change projections.	LVM applied to systematically identify perceived climate change impacts.
Proposed key adaptation responses for management and planning activities across different timeframes (for more detail, see case study summaries)						
Incorporation of climate change into risk management approaches in the short-term	Identify high risk areas and develop adaptation actions for these areas. Develop recommended changes in land management practices for risk prone soils e.g. no till farming, increase stubble retention, introduce perennial based grazing systems to replace cropping, fence and revegetate.	Set annual allocations based on trends in groundwater levels. Upgrade irrigation technologies, utilise other water sources.	Design protection and restoration strategies in high priority areas. Focus weed and pest management efforts in high priority locations.	A significant number of existing orchards will in future lie outside the predicted future bio-climatic envelope. Therefore need to implement short-term prioritisation of property-level adaptation actions across the region.	Need to establish a roles and responsibilities framework, to encourage progress with adaptation strategies. Obtain better climate information.	Promote the conservation of important vulnerable conservation areas which are currently not recognised by the community.

Proposed key adaptation responses for management and planning activities across different timeframes (for more detail, see case study summaries)						
The application of adaptive management techniques which can be adjusted over time	Access appropriate climate data to more accurately predict seasonal rainfall. Reassess model as more accurate rainfall projections (particularly seasonal) become available.	Policies need to be adopted to achieve maintenance of the existing range of groundwater depth and salinity in the water table aquifers.	Disturbance regimes within high priority existing habitat monitored and managed more intensively. With improved data collection and modelling, continually reassess high priority areas where adaptation responses should be focused.	Planners to maintain the integrity of existing areas so that orchards can use different parts of the adjacent landscape.	Research and implement effective horticultural practices in relation to declining resource condition. Develop business strategies to cope with reduced water availability. Adaptation strategies could be incorporated directly into strategic planning for both industries, although many assumptions were made and gaps identified which need to be addressed.	Ongoing analysis of changing community perceptions over time to inform updates in management responses.
The application of decisions based on the precautionary principle that is allowing for increased long-term risk	Develop new industries and opportunities in high risk cropping areas e.g. livestock, carbon offsets, biofuels.	There is a need to evaluate the drivers for current patterns of groundwater extraction and to use this knowledge to develop a range of future demand scenarios that can then be used to evaluate the capacity of the aquifers to meet future demand with a changed climate.	Determine the longer-term impacts of more severe climate change on species habitat suitability, e.g. to the year 2070. Target areas adjacent to high priority areas for ecological restoration. Include identified high risk areas in comprehensive conservation programs e.g. NatureLinks.	Case for developing land-use policy to reserve key resources in relation to climate change.	More detailed risk analysis required. Apply controls on further exploitation of water resource. Identify alternative water sources e.g. stormwater reuse.	Stricter controls on potentially damaging activities in high value coastal areas.

Ongoing revision, reassessment and alteration of those approaches.	Further develop and refine the model to assess other land capability issues identified from climate change projections. Ground-truth modelled results over time.	Continually monitor groundwater trends. Analysis of responses of resource condition to changing climate or management activities.	Improve data collection and modelling techniques. Integrate stakeholder knowledge into scientific biodiversity data. Ground-truth modelled results over time.	Continuous improvement of the climate data is recommended, along with the production and utilisation of further information on correlations between climatic variables and factors affecting the feasibility of apple production (and other agricultural industries).	Need to better understand the implications of projected climate change on local resources management systems. Review growers adaptation responses and their effectiveness.	Further develop web based survey to reduce cost.
Benefits	Risk maps will be useful to identify and target projects into areas of highest need. The development of a methodology that can be transferred to other land management issues.	Contributes to the understanding of the potential implications of consumptive use Confirmation that previous management responses have improved the resilience of the groundwater system	Contributes to the understanding of the potential responses of native and exotic plants to climate change. Identifies high priority locations to focus adaptation responses.	The identification of options to enable the apple industry to adapt to a changing climate.	Provided an understanding of the impacts of climate change on the wine grape and olive industries and how this might lead to adaptation planning. A limited focus helped industry to start thinking about climate impacts, while not becoming overwhelmed by all the possible outcomes.	Help NRM planners to identify differences in community and expert opinion and target promotion of important areas not valued by the community. Identifies areas valued by the community. Potential to engage ‘quiet’ voices in the community who may be overlooked.
Limitations	Could only properly assess wind erosion at this stage, other land capability criteria more complex (e.g. water erosion, soil acidity) Only looks at changes in annual rainfall. Seasonal changes in rainfall and extreme rainfall events difficult to assess due to the uncertainty and irregularity of these events.	Evapotranspiration and flow of surface water not modelled. The impact of climate change on GDEs is unquantified. Limited stakeholder involvement	Current scientific knowledge insufficient. Did not include the complexity of species interactions and dependencies.	Data validity and availability. Suggested adaptation responses lacking sufficient detail for immediate planning outcomes.	Limited focus narrowed people’s thinking. Greater technical input required earlier in the process to help inform participants of the range and complexity of possible impacts to production systems from climate change. Struggled to incorporate the uncertainty and complexity of climate change because levels of future risk are difficult to quantify.	Can be expensive and time consuming to conduct. Possible lack of direct application to inform decision making as participants are potentially not knowledgeable on technical issues.

The resource management risk information emerging from the scenario modelling provides some important insights. For example, in relation to land capability, it is evident that the area of non-arable land is likely to increase with the projected increase in wind erosion risk resulting from a drying, warming trend (DWLBC 2008). One of the contributors stated that, ‘This study has highlighted vulnerable areas where the potential for wind erosion would most likely increase as a result of decreasing rainfall, and produced data and maps to identify changes in land capability’ and goes on to conclude that ‘quantitative data showing the amount of land likely to become “non arable” gives a good indication of the magnitude of the challenge for land managers’ (pers. comm., April 2008). An AMLR Board staff member noted when commenting on the land capability modelling outcomes that the ‘Production of risk maps will be useful for identifying and targeting projects into areas of highest need’ (pers. comm., April 2008). The level of the scientific challenges to undertake such scenario modelling are summarised neatly by Andy Cole, Rural Solutions, as he states:

> Due to the complex nature of the methodology required to produce meaningful results, this case study only investigated wind erosion potential. At this stage, water erosion potential is seen as more difficult. However, the lessons learnt from examining wind erosion will be used to help guide the process for a study on water erosion. Predicting the extent and frequency of extreme climatic events presents even greater challenges for this model, due to the uncertainty and irregularity of these situations.
>
> (pers. comm., April 2008)

Modelling by Waclawik (2007) of groundwater in the McLaren Vale area suggests that climate change of the order of magnitude until 2030 will not undermine the sustainability of current irrigation management practices.

The McLaren Vale area is an excellent example of where a broadening of the resilience of the groundwater management system in the past, through the reduction in water use by grape growers and the increased reliance on other sources, particularly recycled sewage water, has significantly reduced the vulnerability of the system irrespective of the change that eventuates.

The groundwater modelling suggested however, that groundwater dependent and coastal ecosystems might be more susceptible to a warming, drying trend because there is little capacity for anthropogenic improvements in management systems.

The scenario modelling successfully reinforced or improved knowledge of climate change impacts and potential adaptation responses. However, such modelling approaches can be criticised in that they focus on a subset of the range of possible implications of change, the modelled outputs are limited by incomplete knowledge of current systems and the immediate application of outcomes could be limited.

In the land capability and groundwater studies, the stakeholder involvement was restricted to technical officers and researchers, rather than people who manage local resources. The development of better knowledge of the likely implications of climate change through modelling is clearly required, but simultaneously, methods to link the modelling to decision making processes are required to assist in the development of directly applicable ideas. As one land capability study author stated, ‘The key to the success of this methodology will ultimately rely upon how well the main messages are relayed to land managers and the extent of relevant research and development to provide alternative land management practices in the face of global warming' (pers. comm., April 2008). Some of those mechanisms are established and include formalised government and NRM communication and planning processes, where information is provided to government advisors or the AMLR Board itself to assist with decision processes. Beyond such formal mechanisms, it may be necessary for modelling to be directly accompanied by a process of supporting stakeholder understanding of the complex effects of likely management outcomes for better adaptation. Such participatory studies were attempted in conjunction with GIS modelling activities for both the land use planning (see Houston & Rowland 2008) and biodiversity studies (Crossman, Bryan & Bardsley 2008) described below.

5.2 APPLIED AND PARTICIPATORY GEOGRAPHIC INFORMATION SYSTEM MODELLING

The applied and participatory modelling approaches aimed to develop new information about climate change impacts on resource condition through the use of previous modelling and local stakeholder knowledge. For example, the biodiversity modelling utilised current resource information and examined the implications of climate change scenarios in a more sophisticated manner than the work undertaken on land capability and groundwater studies which followed the scenario modelling approach. The significant broadening of the scope of the biodiversity case study was to involve key planners and practitioners in the process of developing the modelling outcomes. In this manner a learning approach was applied to the concept of future biodiversity conservation in the AMLR, rather than expecting that modelled outcomes would represent, in an accurate manner, the uncertain future of regional species distributions. In fact, the biodiversity modelling as it stands, was perceived by regional and sectoral stakeholders as having only limited immediate practical application. Crossman, Bryan & Bardsley (2008, p. 39) conclude that, 'The surveyed practitioner community demonstrated scepticism and a lack of confidence in the modelling that potentially confounds the use of these results in NRM planning'.

A major limitation to the biodiversity study was associated with the initial data on biodiversity densities and distributions, which were deemed by stakeholders to be of only limited quality.

It is clear that the lack of knowledge about existing resources, let alone the long-term monitoring of the condition of resources over time, will limit the application of futuring science in relation to potential climate change risks.

In this case study, biodiversity managers heavily criticised the dataset used in modelling, yet it was the best dataset available to scientists for modelling. For example, comments from practitioners suggested that much better knowledge on species presence or absence was held by individuals and organisations who were undertaking the groundwork. In such a case, the ongoing participation of local experts in presenting that knowledge could be essential to developing better conceptualisations of future resource condition.

Better integration between scientific researchers, planners and managers of natural resources would assist in the development of more comprehensive knowledge sets of current and historic resource condition. Data on resource condition and processes needs to be collated and made available for other researchers to maximise the opportunities for knowledge development to respond to climate risk.

All climate change adaptation will require improved knowledge and action over time. It is wrong to assume that any of the modelling will be 'correct' in the first instance, and that includes modelling from very local scales through to modelling of the future atmosphere. This important point is emphasised by Crossman, Bryan & Bardsley (2008, p. 39) in relation to biodiversity:

> The present case study provides a baseline and stimulates thinking, but there are many gaps in knowledge, particularly relating to native species interactions (mutualisms and dependencies) and exotic species population responses (fecundity, dispersal and germination) that will require significant empirical data collection.

The land use planning study to assist the apple production industry to adapt to climate change developed the GIS modelling in a step-wise participatory manner through a series of workshops and technical development sessions (Houston & Rowland 2008). The case study focused its examination on the planning implications along the peri-urban fringe for high-value agriculture, such as apple production, in relation to climate change projections. By working closely with the Apple and Pear Growers Association of South Australia, SARDI and BoM, priority areas for growing apples in the Mount Lofty Ranges were identified to guide more detailed land use planning.

In many ways, the land use planning study was successful in balancing the use of technical knowledge and skills with local knowledge. As one of the authors stated, 'In the first instance I think it will provoke discussion and improve understanding of the dimensions of the issue, such as resource availability threats and adaptation options for Adelaide Hills apple growers. The project doesn't provide any immediate answers but does establish a mechanism for stakeholders to: i) improve their understanding of the issues likely to affect resource availability, and ii) prepare, justify and present a case for a regional scale policy response' (pers. comm., April 2008). An AMLR Board staff member states in relation to the approach that it 'Provides a clear pathway for industry in its long-term planning for a sustainable and viable industry. It also communicates clearly the steps required at a strategic policy level if a viable and sustainable apple and pear industry is considered to be an important activity in the Adelaide Hills' (pers. comm., April 2008).

The large range of stakeholder input reinforces the legitimacy of a strong conclusion from the participatory GIS work in the land use planning study.

Houston and Rowland (2008) note that, 'The case for utilising land use policy to reserve key resources for the apple industry in the AMLR region seems compelling'. Such a conclusion suggests that development planning within the peri-urban fringe will need to begin to more formally respond to climate change risk, not only in relation to agricultural production but for all NRM sectors. In fact, an AMLR NRM Board staff member notes that a success of the approach was that it, 'Identified how critical state development planning policy is to the future viability of the apple and pear industry' and suggested that similar studies should be undertaken for other industries (pers. comm., April 2008).

The use of modelling processes that are repeatable, justifiable and have involved critical input from regional stakeholders supports the development of convincing arguments for better protection of key spaces in the landscape. In both the land use planning and biodiversity modelling case studies the suggested adaptation responses are largely not immediately applicable and will require decision makers external to the project to assess the information independently of the case studies. As one author from the biodiversity case study stated, when asked if the approach was a success, ‘That depends on the response of ecologists and NRM planners in the region, and further investment in the modelling. The research has the potential to raise awareness and be used to directly inform biodiversity and climate change adaptation planning strategies. Adoption will require a trust of the science and logic behind prediction of species distribution’ (pers. comm., April 2008). In contrast, formal environmental risk analysis integrates the stakeholders’ decisions directly with the development of climate change adaptation information.

5.3 FORMAL ENVIRONMENTAL RISK ANALYSIS

James and Liddicoat (2008) undertook a process of participatory research in relation to climate change risk for wine grape and olive production in the City of Onkaparinga that utilises the formal structure of the risk analysis framework. The key points raised during the workshops with industry stakeholders in the McLaren Vale area raised immediate and valid concerns for them as they manage their seasonal activities. In one recent example, the extended hot spell in summer–autumn 2008 raised important issues with the timeliness of wine grape harvesting. As one stakeholder noted, the process ‘Gives growers a better understanding of how climate change will affect them directly; hence they can start thinking about how they are going to manage their vineyards in the future’ (pers. comm., April 2008).

There are, however, further significant longer term implications for the wine and olive industries that will need to be examined in significantly greater depth (see for examples Jones et al. 2005, Rosenzweig & Tubiello 1997).

The risk assessment framework appears at times to struggle with providing the guidance required for the examination of broad industry needs over the longer term.

There is a danger in using numbers to guide risk assessments, especially as people may interpret those numbers emerging from subjective risk analyses literally and act on them. As well, the risk assessment does not replace the need for critical analysis at the individual business level. Rather the values derived from climate risk assessments should be used to guide improvements in NRM resilience more broadly, especially because only comparatively minor impacts of climate change are being seen at the moment. For example, the multiple criteria associated with the ‘consequence descriptors’ for risk assessment, would make it difficult for stakeholders to perceive or articulate the level of future risk. The case study could also be criticised as the chosen focus group did not necessarily represent all the views of stakeholders or examine all of the complex risks to the McLaren Vale systems. As one stakeholder stated, the major drawback of the approach was that there was ‘only limited engagement with growers’ (pers. comm., May 2008). The important risks associated with water resource availability focused the discussion, but other complex issues such as those linked to direct heat impacts were not considered in-depth. However, one case study author notes: ‘By having a limited focus this work helped the industry to start thinking about climate impacts, while not becoming overwhelmed or losing interest because of all the possible outcomes’ (pers. comm., April 2008).

During the City of Onkaparinga case study, assumptions were made about the information presented to stakeholders to guide their decisions in relation to climate change risk. However, the climate change implications for the McLaren Vale region to 2030 remain uncertain. It is exactly because of the imprecise nature of future climate change that the work has justifiably focused on the importance of engagement and the development of future participatory research through strengthening partnerships. As a key stakeholder from the McLaren Vale region notes, ‘The case study has provided the McLaren Vale Grape, Wine and Tourism Association with a framework with which to begin addressing climate change risks and implementing adaptation strategies. The McLaren Vale Grape, Wine and Tourism Association will now initiate projects and form linkages to address key issues outlined in the study’ (pers. comm., April 2008). Similarly, one of the City of Onkaparinga study authors notes that ‘Adaptation planning is still at an early stage, however, this initial activity has raised awareness, encouraged industry thinking about addressing climate change risks and helped to establish links with the partner organisations (research, policy, industry, etc.) that will be needed to implement successful responses to climate change’ (pers. comm., April 2008).

Such general risk assessments could be seen as an important early step in a longer process of re-organising industries to allow for both short-term and longer-term impacts of climate change (AGO 2006; Standards Australia/Standards New Zealand 2004). More detailed risk analysis is one path to take to further learning about climate change implications, and could possibly extend the general framework presented in section 2.1. However, effective risk analyses will require considerable additional information that may not be available. One City of Onkaparinga case study author noted that:

> Greater scientific/technical input early in the process would have helped inform participants of the range and complexity of possible impacts to production systems from climate change. For example, experts in plant growth/plant physiology would have been able to discuss possible impacts to growth cycles from a range of different climate parameters. However, to some extent this type of detailed knowledge may be lacking and still subject to ongoing research.
>
> (pers. comm., April 2008)

Many issues relevant to climate change adaptation for NRM will be managed effectively in a manner reactive to explicitly perceived risks, or by applying ‘no regrets’ actions that generate socio-economic and environmental benefits irrespective of the extent of climate change (AGO 2006). On the other hand, there remains a concern that risk assessments will be used as the singular approach to guide climate change adaptation, when it is only one of several routes to expand knowledge and inform action. Historical evidence would suggest that there is a danger that formal risk analyses can be used as token processes that are subsequently ignored by decision makers. In fact, traditional risk management frameworks are likely to struggle to incorporate the uncertainty and complexity of climate change because the levels of future risk are inherently difficult to quantify (Beck 2000; Bruckner et al. 1999; Lempert et al. 2004). Rare historical events are readily discounted in the risk assessment process, and yet such events may rapidly become less rare as climate changes. For example, the South Australian Murray-Darling Basin, which provides about 80% of urban Adelaide’s water supplies in a dry year (Government of South Australia, 2005), is currently experiencing such a water resource management crisis, which in turn is placing significant pressure on the AMLR (MDBC 2008; Van Dijk et al. 2006). Relying on risk assessments alone will lead to a constant chasing of systemic failures, while a broader understanding of vulnerabilities and a building of resilience into systems will limit and prevent failures in the first place.

There is the particular concern that even regions with significant capacity to adapt will continue to rely upon short-term responses to risk and will fail to ensure that transformative processes are put in place to accommodate long term climate change (Etkin & Ho 2007). If governance decisions are solely reactive or minimalist in nature, there is a significant risk of systems lurching from one crisis to another. As uncertainty is a key feature of climate change, it can be argued that risk analysis will fail to support the fundamental societal changes required, because it will base assessments of likelihood on past precedents, support insufficient, short-term responses, or only trigger action where the need for a response is very clear.

It could be argued that due to the significant uncertainties related to climate change risk, appropriate adaptation responses will need to be framed more broadly than the specific responses to specific perceived risks.

Long-term adaptation responses will need to be embedded in a broader precautionary approach: which are flexible and adaptive to change over time, or which lead to such significant improvements in resilience that most change will be manageable within the planning time frame. As awareness of the implications of climate change is improving, there are great opportunities to generate the will to support long-term NRM planning to building resilience and flexibility into sustainable systems.

5.4 PARTICIPATORY ACTION LEARNING

Along the spectrum from a science-led, scenario modelling approach to a participatory learning approach for developing adaptation responses, a number of methods can be applied that empower stakeholders to analyse and use information, in combination with their own knowledge, to better understand the implications of climate change on their own systems. The coastal study (Raymond 2008) provides the best example from the case studies of a participatory action learning approach, but this approach is also exemplified by the entire AMLR NRM climate change project, which aimed to engage strongly with NRM stakeholders throughout the region. By undertaking a stakeholder perceptions analysis (detailed above in section 3.1, Bardsley & Liddicoat 2007) and developing *The Adaptation Challenge* (Bardsley & Bardsley 2007), the AMLR NRM community was broadly engaged to imagine possible futures for their places or systems under different climate change scenarios. In all of these cases, community workshops focused and guided stakeholders through analyses of their own systems, by supporting them in following lines of enquiry to address abstract and complex climate risks. This provided stakeholders with the opportunity to examine impacts and adaptation options within the context of their own lives.

The coastal study mapped landscape values and perceived climate change impacts for NRM in the Southern Fleurieu Peninsula and raised a wealth of issues concerning the way people perceive environmental value and risk. The work of mapping values and perceived risks simultaneously engaged, developed and informed understanding amongst stakeholders. Raymond (2008) reveals that it is possible through participatory mapping to develop understanding within a community that can also inform climate change NRM decision making.

Climate change is likely to undermine important landscape values unless environmental planning is able to become more explicit about what is good and at risk within our landscapes, and as a consequence, what needs to be a focus of early attention for adaptation responses.

The case study author has stated that, ‘The major success of the approach is the uncovering of gaps: in knowledge of biodiversity values; in knowledge between different age groups; in perception between different age groups; and in values between scientific assessment and public perception' (pers. comm., April 2008). An AMLR NRM Board staff member stated that the approach 'May help to identify community perceptions and, therefore, gaps in knowledge. This will help guide education programs. It may help guide policy development, but is of limited use in guiding on-ground action' (pers. comm., April 2008).

Community knowledge may be as important to decision making for future resource management as the scientific information about climate projections.

Participatory action learning approaches have been criticised because a direct application to inform decision making can be difficult, particularly as solutions to technical issues are required for which participants have little experience. Also, the research approach may require considerable resources. However, a counter argument would note that adaptation to climate change will require a social transformation through a series of social adjustments supported by an action learning approach. With this approach, Australian regional stakeholders can describe what particular areas and systems are most valuable to them, so that planning for climate change will ensure that those spaces are not neglected. Also, environmentally valuable areas that are not immediately valued by the community can be identified and subsequently promoted as important by natural resources managers.

5.5 CRITIQUING THE CASE STUDIES TO SUPPORT BROADER DECISION MAKING

The case studies have examined key AMLR NRM sectors identified as being vulnerable to climate change impacts, to develop tools to assist decision makers to adapt their systems to projected change. The work has generated significant interest both across the region and more widely, and in each case has led to important research outcomes. However, each methodology that was employed could be seen to have strengths and weaknesses for different management contexts. This section attempts to identify the major criticisms of the methods with the aim of learning from their limitations in order to guide appropriate application of the different approaches in the future.

One of the limitations of the work is that many of the adaptation strategies co-developed with stakeholders will not have direct application or lead to immediate action. While such initial aims of better understanding resource vulnerability to climate change were achieved and immediate decisions were better informed, generally the larger scale or more complex decision making goals have not yet been met. For example, while the land use planning case study's objectives to develop better understanding of resource needs and development pressures were met, the decision making regarding changes to any subsequent land-use planning rules lies exterior to the project itself. The division between knowledge creation and governance within NRM is highly established and formalised, so a project of this nature was unlikely to overcome that division in a couple of years. However, the devolution of more decision making to regional and local levels could provide significant opportunities for the immediate application of appropriate adaptation ideas.

The issue of governance was often raised by the case studies, generally without specific reference to particular roles and responsibilities of different decision making bodies. Where such roles were specified, in relation to the City of Onkaparinga study for example, it was not clear how potential partner organisations would be determined. For example, stakeholders do not perceive a role for different government departments or organisations even if they may have statutory authority for those activities. As an example, DWLBC was not understood by stakeholders to have a major role in developing water resource management strategies in the McLaren Vale area even though this department has responsibility for water management under the Act (James & Liddicoat 2008).

Apart from guiding decision making within their respective sectors, a specific aim of the case studies involved the deconstruction of the important adaptation responses into their short- or long-term components, although this was not always effective. The outcomes from the land use planning study perhaps provides the best example of how responses could be broken down into the three levels of adaptation response based on the immediacy of needs, from short-term responses to immediate risks such as choosing a range of varieties to best buffer against the uncertainty of future climate, through to land use planning to help maintain a viable apple industry in the Adelaide Hills.

A purpose of the AMLR NRM climate change project was that the approaches developed while working with the NRM board would become exemplars for other regions. To assist that process, the importance of replicability of the approaches needs to be addressed. While several of the case studies claim to be representative of the sector, much of the analysis is either quite specific to the place or regional industry, or too general such that broader sectoral issues are not necessarily recognised. In fact, with a few exceptions, the case studies as currently described are not specifically embedded into the broader framework of adaptation that is occurring in the AMLR, South Australia or more widely in Australia or universally. Further referencing to other work external to the sector or region, or more detailed information relevant to a better understanding of the local sectors/industries, would allow for comparisons with other industries or the same sectors in different regions. Referencing the approaches used to the broader NRM literature would also assist future comparisons with methodologies applied in comparative regions, or the same sectors in different regions.

Often the outcomes of the case studies are presented as key technical management recommendations and they generally fail to mention the significant role of initial engagement with different stakeholders, interviews, informal discussion and negotiation to establish the case studies. There are also clear indications from the majority of the case study authors that some of the more significant outcomes were associated with engaging closely with stakeholders to develop partnerships. While there are important outcomes associated with improved guidelines for management, ownership of the need to adapt to climate change by stakeholders remains a fundamental and important step along the path to developing methodologies for guiding good decision making. In a couple of examples, namely the biodiversity and groundwater studies, where ownership of the research techniques were not present within the practitioner communities, there was generally less confidence in the outcomes of case studies informing effective adaptation.

There were significant impacts of the project on regional adaptation decision making, often through more subtle and implicit mechanisms (Rebbeck et al. 2007, Campbell 2008). The development of trust between stakeholders were an important component of this project. Even though the management changed during the duration of the project, it was clear that the development of trust meant building good relationships between the project actors and the decision makers at all levels. There were key points of interaction with the local council and the industry bodies leading up to these case studies that are generally not mentioned as significant in the case study methodologies and yet the case studies would not have been possible without them. Many of the less formal steps involve the development of professional relationships and levels of trust that enable decision makers to feel confident to critique the modelling work that is being developed and to make judgements on the veracity of the outcomes. An explanation of the less formal processes of engagement would also help to embed the approaches tested during the AMLR NRM climate change project, into what is a broader process of integration of NRM across South Australia.

In probably the best example of this informal engagement, work with the City of Onkaparinga not only led to the wine and olive grower risk assessments and the groundwater studies but also played a role in supporting the local council to become a leading organisation in climate change responses. This has included the development of a climate change strategy by the council, undertaking a detailed study of coastal risks and also supporting greenhouse gas mitigation through carbon dioxide emission reduction and sequestration (City of Onkaparinga 2007). Although most of the council's activities cannot be attributed directly to the project, involvement in workshops, one-on-one discussions and the initial vulnerability analysis for the AMLR provided a basis for further activities at the local level.

5.6 GUIDING ADAPTATION DECISION MAKING THROUGH REGIONALLY BASED RESEARCH

A wealth of knowledge has been developed through the AMLR NRM climate change project to inform decision making, separate from the specific case studies. Scenarios of future resource conditions were developed that provide examples of how scientific modelling can assist in imagining possible futures. At the same time, participatory approaches were applied that simultaneously developed knowledge on the potential implications for climate change, while also guiding stakeholders to make informed adaptation decisions. A review of feedback from stakeholders suggests that different approaches have varying application in different contexts (Table 8).

Many of the outcomes of the AMLR NRM climate change project for NRM decision making in the future will not be quantifiable, and yet the number of stakeholders at all levels of decision making who were engaged and supported to make their own decision regarding their own systems was substantial—running into the thousands. The approach sought to engage with a region to initiate and support a process of sustainable adaptation to climate change and is therefore considered to have been a great success. That said, these are early days in explicit responses to the implications of a change in climate that we are only beginning to understand.

There are key lessons from the AMLR NRM climate change project that could be applicable for regional planning bodies and government agencies aiming to establish partnerships for climate change adaptation. The baseline of the current situation including key vulnerabilities, ideas for adaptation and gaps in information was presented and broadly acknowledged by stakeholders—as indicated by many invitations to presentations or workshops on climate change issues in 2006–08, which over 2000 people in total have attended (Bardsley & Liddicoat 2007). Many of these workshops guided regional attendees through a self-examination of their NRM systems' vulnerabilities and adaptation options. The vulnerability analysis approach is now being emulated in various forms to influence planning within different subregions and by different sectors (for examples see AMLR NRM Board 2007b; City of Onkaparinga 2007; Rebbeck et al. 2007; Urban & Regional Planning Solutions 2007b).

Table 8. Possible application of different climate change adaptation approaches

	Adaptation approach			
	Scenario modelling	**Applied and participatory GIS modelling**	**Environmental risk analysis**	**Participatory action learning**
Possible application	Adjusting resource condition assessments according to potential climate change scenarios to raise awareness of potential sectoral impacts and develop appropriate adaptation responses.	Maximise engagement with stakeholders in different NRM sectors as modelling is developed, so that key vulnerabilities can be further highlighted and responses articulated.	A formal risk assessment with impact and likelihood components, to guide stakeholders through an analysis of the impact of climate change on their systems.	Where stakeholders need to identify and analyse their local vulnerabilities to climate change without significant information from external sources.
When approach might be most applicable	When seeking specific guidance to better understand vulnerability of a natural resource. Also when good background data is available concerning the NRM issue, however specific climate change implications are uncertain.	When seeking specific guidance to better understand the vulnerability of a natural resource. Also when the development of good background data concerning the NRM issue will require stakeholder input.	When trying to formally involve stakeholders in a process of analysing risk. Ideally supported with empirical data to best inform planning outcomes. Likelihoods and consequences are well understood.	When the community support needs to be generated and/or articulated to support difficult decision making. Particularly when seeking to generate greater awareness of climate risks.

The Australian Government has recently supported a tender to compile existing climate change information at the regional level, to encourage a nationally consistent approach of how NRM regions implement appropriate and effective adaptation actions and strategies. This will in part be guided by the AMLR NRM climate change project approach (Department of the Environment and Water Resources 2007).

The AMLR Board NRM planning team has been examining ways to integrate climate change into the NRM planning process, and the ten-year regional NRM plan in particular (AMLR NRM Board 2007a). Currently, planning targets are based on historical levels of resource availability and natural hazard events—many of which are likely to alter with climate change. The major climate change planning goal for the board is to ‘Understand the potential impacts of climate change and integrate into the adaptive management of natural resources’ (AMLR NRM Board 2007c, p. 17). In discussions with board staff, it was suggested that anything more prescriptive would undermine the aim to incorporate climate change into all activities. Highlighting the level of awareness at Board level, the Presiding Member for the AMLR NRM Board stated in her foreword for the plan:

> New and significant future challenges also exist with changes to our climate. While uncertainty still exists we know that we must prepare now for more intense storm events, changes in the timing of flowering and breeding cycles, more variable breaks in the winter growing season, sea-level rise, high coastal storm surges, more frequent and intense bushfires, more frequent erosive events, changes in the impacts of weeds and animal pests, reductions in groundwater recharge, and reductions in average stream flows.
>
> (AMLR NRM Board 2007a, p. 1)

AMLR land use planning may need to become more prescriptive to support adaptation, including stronger prescriptions on land use to allow for climate hazard mitigation and support for anticipatory adaptation outcomes, including improving the interconnectedness of key biodiversity assets and protecting areas of high-value horticultural production (Cullen 2004; Houston 2005; Kueppers et al. 2004). A good example of a planning response to the need to improve interconnectedness for landscape scale biodiversity conservation is underway in the form of the NatureLinks strategy in South Australia (DEH 2006). In another example of planning to respond to climate change in the region, the South Australian Coast Protection Board has already applied the precautionary principle to inform coastal development along the Adelaide metropolitan foreshore by detailing planning guidelines which allow for greater sea-level rise than is currently projected over the next century (Harvey et al, 1997; South Australian Coast Protection Board 1992). However, constraining planning regulations of this type needs broad community support to be acceptable. Attempts at strengthening planning provisions to better manage riparian and coastal flood risk have been seen by some in Australia as potentially deleterious for future property prices (Blong 2004; Faulkner 2008). Many good ideas are available for building the resilience of systems, but these ideas face barriers of community acceptance. An argument could be made that regional decision makers will increasingly need to be held accountable for their decisions to govern the emerging risks to NRM systems, but the difficulty remains that information to guide those decisions lacks detail and is highly uncertain (Lebel et al. 2006).

The AMLR NRM Board is investing in a range of projects with climate change adaptation components in relation to biodiversity conservation, coastal management and other targeted research and development over the next three years (AMLR NRM Board 2007d). Specific climate change threats to NRM processes are listed under each sector in the board's State of the Region report (AMLR NRM Board 2007a). The regulatory and policy framework for the AMLR NRM Board makes clear that regional development planning policies for the region currently do not consider climate change risk in detail, and it is a priority issue for the board to ensure that NRM and development plans interact in relation to climate change (AMLR NRM Board 2007e). The NRM plan states that 'the Board will adopt objectives that reflect the likely risks of climate change and allow for adaptive land use change' (AMLR NRM Board 2007e, p. 22).

It is apparent, however, that even with significant goodwill and ownership of climate change risk, the explicit, detailed recognition of long-term planning responses to climate change remains a very challenging task, particularly as significant investments or regulations could be seen to be unwarranted if the uncertain change does not eventuate.

In a highly uncertain climate change and global economic environment, with associated resource pressures such as rising oil and food prices, the complexity of the decisions required places decision makers in unenviable positions. That said, the pressure should not be applied to decision makers to be absolutely correct in the first instance, rather to adopt an adaptive management approach. The acknowledgement that there will be a process of developing understanding through the application of adaptation ideas is the essence of a decision making framework that allows for associated readjustments of responses over time. It could be argued that the best decisions will be framed in a manner that better allows for learning and improvements over time. That is partly why the development of detailed research that imagines the implications of specific aspects of climate change is important to further guide detailed planning.

6. CONCLUSION

The significant challenges posed by climate change are clearly evident within the AMLR region and yet regional stakeholders are, quite understandably, unwilling to make fundamental transformations in their NRM systems while little evidence of the likely scope of climate change impacts is available. Appropriate long-term strategic planning responses aim to anticipate change and allow for sustainable management of trends in resource condition and climate-induced hazards. However, these responses will only be applicable at a local level if approaches for participatory research are applied to allow for exploration of effective paths to adaptation within specific biophysical and social contexts. The risks associated with future climate in the AMLR suggest a new era of risk management is required for NRM which may be as fundamental as a shift from traditional to industrial production methods in the 20th century.

There have been several major policy developments relevant to AMLR climate change adaptation process over the last year. These key policy developments are external to the AMLR NRM climate change project but are indicative of the growing level of concern and opportunities for response to climate change risk. Australia ratified the Kyoto Protocol in late 2007 as one of the initial acts of the new Australian Government. This signing challenges the Australian community to continue to work to reduce emissions. The most important of the policy changes for NRM adaptation in the AMLR is perhaps the Council of Australian Governments' $10 billion national water agreement. A key component of the initiative will see the Commonwealth Government purchase permanent water licences back from Murray-Darling Basin irrigators who wish to sell, and invest in water infrastructure improvements (ABC News 2008b; MDBC 2008; Warren 2008).

In another very interesting development for South Australian climate change adaptation that is suggestive of the new order of thinking in relation to climate change risk, there was a very strong legal decision concerning a coastal development on southern Yorke Peninsula. Lower (2008) noted in the media that, 'An 80-lot subdivision at popular holiday destination Marion Bay has been knocked back due to rising sea levels and environmental impact', and continued, 'the Supreme Court decision to reject the developer's appeal for the subdivision to be allowed is believed to be the first to consider the impact of rising sea levels on coastal development'. Lower (2008) also quoted Chris Russell from the Local Government Association of South Australia who stated that developers would need to read the provisions of council development plans 'much more carefully' in relation to coastal development in the future. This type of decision is indicative of a broader awareness of the emerging implications of climate change risk.

Given the level of uncertainty, it should not be expected that any region will establish comprehensive, effective adaptation response plans in the first instance—that is simply asking too much of NRM planning and policy, which will rather aim to learn from the experiences of managing the consequences of climate change over time

In fact, adaptation responses to climate change will be a great global experiment, with the requirement for ongoing understanding and improvements in actions as more evidence becomes available (Adger, Arnell & Tompkins 2005; Fankhauser, Smith & Tol 1999; IPCC 2007; Wals 2007). That said, the adaptation required for sustainable futures in the AMLR will involve a deep-rooted transformation in levels and forms of sustainable production and consumption in the region. Overcoming the inertia to incorporate the challenge of a new era of risk is the primary challenge of an effective regional response strategy. That transition may well involve a change in understanding of the AMLR NRM region from a place of known facts, stability and abundance to a place of relative uncertainty, variability, change and limited resources.

There are clear gaps in the capacity of researchers to develop the knowledge from scientific sources to guide decision making. Much previous research on risk within natural resources systems has been reductionist in nature—attempting to better understand sectoral impacts or components of systems by analysing their respective parts (Meinke et al. 2006). While such research has been valuable in building the empirical knowledge of the managed systems, there are clear barriers to the application of outcomes associated with a lack of integration of the research with local interpretations and values of NRM. There are also clear gaps in relation to insufficient knowledge of current NRM systems, particularly within the context of historical change, and significant uncertainty about environmental change in the future. Some feedback from stakeholders has suggested that the lack of precise guidelines from case studies may frustrate planners and policy makers as they seek to use empirical and modelling studies to directly inform their decisions. However, while the future remains highly uncertain in relation to climate and the associated condition of natural resources, precise guidance is very difficult to provide. In response to this, as one case study project leader suggested, there may need to be funded scenario modelling development programs, with reference groups comprising key decision makers, industry and other stakeholders/co-funders for all NRM sectors where key vulnerabilities have been identified. To assist this process, work with the decision makers at all levels can aid to effectively explore current knowledge and identify gaps in that knowledge.

Where detailed local information on resource or climate conditions was unavailable or of limited quality, the case study projects that worked closely with stakeholders acted effectively to develop guidelines for prioritisation of adaptation effort. The project itself has directly led to a range of spin-off activities associated with climate change adaptation research and education both in the AMLR and elsewhere (see for example Partington 2007; Bardsley 2007; Bardsley & Bardsley 2007; River Murray Urban Users Committee 2008; Research Institute for Climate Change and Sustainability 2008).

Participation in the research process makes it more likely that key decision makers will understand the validity of providing broad suggestions for adaptation, rather than suggesting that we can have specific understandings of uncertain futures.

While there is growing information on the adaptation response strategies that will become more applicable in different contexts and at different rates of change, the uncertainty of future resource condition suggests that a broad application of the precautionary principle would be applicable to plan for long-term change. Such an approach will ensure that adaptation options will be outlined in a manner that is more highly formalised and strategic than simply reacting to crisis situations. The decision making framework presented and tested here provides some guidance on how such a strategic response could be arranged.

As individuals and organisations apply adaptation strategies there will be both successes and failures. Modest acceptance that we are unlikely to implement the ideal solution in the first instance will in turn enable improvements in management over time. An important base-line target for regional responses to climate change is the ownership of the issue by stakeholders, which leads to an acceptance that actions to adapt and mitigate are both possible and important. The premise of the AMLR NRM climate change project has been that to guide transformative action in relation to climate change, research would need to examine local perceptions of systems, as well as to develop critical knowledge of the rules, institutions and systems of management that prevail in the region. Such knowledge would subsequently be utilised to support ongoing transitions in thought and action to contemplate and alter future NRM.

The AMLR NRM climate change project successfully engaged regional NRM stakeholders, raised awareness of the vulnerability of NRM systems to climate change, and influenced regional adaptation planning. There is genuine goodwill amongst the NRM community to become partners in a new approach to management that emphasises values of resilience and longevity in an era of risk. Further work in the AMLR and elsewhere will need to test explicit detailed planning and management responses to new knowledge, with the aim of implementing complex, long-term adaptation to climate change over time.

Effective NRM is all about individuals, groups or organisations making good decisions based on the best information. Where the information about the future is uncertain, as in relation to climate change, those decision makers need to be confident that they are well informed and responding appropriately. While cost-benefit analyses of such decisions were not undertaken in this work, more detailed future studies should incorporate the financial benefits of early action or costs from a lack of or inappropriateness of responses. In the meanwhile, the deep engagement involved with this project has brought people forward in their thinking and has supported them to make difficult decisions that are leading examples of effective NRM in an era of rapid climate change.

UNITS OF MEASUREMENT

Units of measurement commonly used (SI and non-SI Australian legal)

Name of unit	Symbol	Definition in terms of other metric units	Quantity
day	d	24 h	time interval
gigalitre	GL	10^{6} m^{3}	volume
gram	g	10^{-3} kg	mass
hectare	ha	10^{4} m^{2}	area
hour	h	60 min	time interval
kilogram	kg	base unit	mass
kilolitre	kL	1 m^{3}	volume
kilometre	km	10^{3} m	length
litre	L	10^{-3} m^{3}	volume
megalitre	ML	10^{3} m^{3}	volume
metre	m	base unit	length
microgram	µg	10^{-6} g	mass
microlitre	µL	10^{-9} m^{3}	volume
milligram	mg	10^{-3} g	mass
millilitre	mL	10^{-6} m^{3}	volume
millimetre	mm	10^{-3} m	length
minute	min	60 s	time interval
second	s	base unit	time interval
tonne	t	1000 kg	mass
year	y	365 or 366 days	time interval

GLOSSARY

Act (the) — In this document, refers to the *Natural Resources Management (SA) Act 2004,* which supercedes the *Water Resources (SA) Act 1997*

Adaptation — Action in response to, or anticipation of, climate change to reduce or avoid adverse consequences or to take advantage of beneficial changes. Adaptation is usually distinct from actions to reduce greenhouse gas emissions.

Adaptive capacity — Reflects the capacity of a system to change in a way that makes it better equipped to deal with external influences via either autonomous or planned adaptation

Adaptive management — A management approach often used in natural resources management where there is little information and/or a lot of complexity, and there is a need to implement some management changes sooner rather than later. The approach is to use the best available information for the first actions, implement the changes, monitor the outcomes, investigate the assumptions, and regularly evaluate and review the actions required. Consideration must be given to the temporal and spatial scale of monitoring and the evaluation processes appropriate to the ecosystem being managed.

AGO — Australian Greenhouse Office

AMLR — Adelaide and Mount Lofty Ranges

Biodiversity — (1) The number and variety of organisms found within a specified geographic region. (2) The variability among living organisms on the earth, including the variability within and between species and within and between ecosystems

Biological diversity — See 'biodiversity'

BoM — Bureau of Meteorology, Australia

Carbon offsets — Carbon offsets represent reductions in greenhouse gases relative to a business-as-usual baseline. Carbon offsets are tradeable and often used to negate (or offset) all or part of another entities emissions.

Catchment — That area of land determined by topographic features within which rainfall will contribute to run-off at a particular point

Climate change — A change in climate, which is attributed directly or indirectly to human activity, which alters the composition of the global atmosphere, and is in addition to natural climate variability observed over comparable time periods.

Climate projection — A projection of the response of the climate system to emission or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions by the more substantial degree of uncertainty in the underlying assumptions e.g. regarding how future technological and economic trends may affect emissions.

CSIRO — Commonwealth Scientific and Industrial Research Organisation

DEH — Department for Environment and Heritage (Government of South Australia)

DWLBC — Department of Water, Land and Biodiversity Conservation (Government of South Australia)

Ecosystem — Any system in which there is an interdependence upon, and interaction between, living organisms and their immediate physical, chemical and biological environment

Enhanced greenhouse effect — The greenhouse effect is the process where gases in the lower atmosphere such as carbon dioxide, methane and water vapour are warmed by radiation released by the Earth's surface after it has been warmed by solar energy. These gases then radiate heat back towards the ground - adding to the heat the ground receives from the Sun. The effect of naturally occurring greenhouse gases keeps the Earth 33°C warmer than it would otherwise be. The enhanced greenhouse effect refers to increases in the Earth's atmospheric temperatures as a result of increases in atmospheric concentrations of greenhouse gases due to human activities.

EPA — Environment Protection Authority (Government of South Australia)

Erosion — Natural breakdown and movement of soil and rock by water, wind or ice; the process may be accelerated by human activities

Exposure — Relates to the important weather events and patterns that affect the system and broader influences such as the background climate conditions against which a system operates and any changes in those conditions. Exposure is influenced by a combination of the probability and magnitude of climate change.

Extreme event — Weather conditions that are rare for a particular place and/or time such as an intense storm or heat wave.

GIS — Geographic Information System; computer software linking geographic data (for example land parcels) to textual data (soil type, land value, ownership). It allows for a range of features, from simple map production to complex data analysis

Greenhouse effect — The balance of incoming and outgoing solar radiation which regulates our climate. Changes to the composition of the atmosphere, such as the addition of carbon dioxide through human activities, have the potential to alter the radiation balance and to effect changes to the climate. Scientists suggest that changes would include global warming, a rise in sea level and shifts in rainfall patterns.

Greenhouse gas emissions — The release of greenhouse gases into the atmosphere. A greenhouse gas is an atmospheric gas that absorbs and emits infrared or heat radiation, giving rise to the greenhouse effect (e.g. carbon dioxide, methane, nitrous oxide, etc.).

Ground truthing — The act of physically going to a field to determine the cause of variability detected in an image or model.

Groundwater — Water occurring naturally below ground level or water pumped, diverted and released into a well for storage underground; see also ‘underground water’

GDEs — Groundwater dependent ecosystems

Habitat — The natural place or type of site in which an animal or plant, or communities of plants and animals, live

Hazard — A situation or condition with potential for loss or harm to the community or environment.

Indigenous species — A species that occurs naturally in a region

Invasive species — An animal, plant or pathogen that is a risk to indigenous species, ecosystems and/or agricultural ecosystems and/or human health and safety.

IPCC — Intergovernmental Panel on Climate Change

Irrigation — Watering land by any means for the purpose of growing plants

Landscape — A heterogeneous area of local ecosystems and land uses that is of sufficient size to achieve long-term outcomes in the maintenance and recovery of species or ecological communities, or in the protection and enhancement of ecological and evolutionary processes.

Long-term — No strict definition, although in this study normally refers to a period of 10-100 years (see also short-term).

LVM — Landscape values methodology

Landscape values — The values people hold or assign to places for different reasons, ranging from instrumental value (places that provide tangible benefits) to symbolic value (places that represent ideas). This study refers to eight landscape values: aesthetic, economic, recreation, learning, biodiversity, intrinsic, heritage and future.

MDBC — Murray–Darling Basin Commission

Modelling — Use of mathematical equations to simulate and predict real events and processes.

Natural resources — Soil, water resources, geological features and landscapes, native vegetation, native animals and other native organisms, ecosystems

NRM — Natural resources management; all activities that involve the use or development of natural resources and/or that impact on the state and condition of natural resources, whether positively or negatively

NatureLinks — A vision and framework for an ecologically sustainable future for South Australia, through planning and the development of partnerships to integrate landscape scale biodiversity management with regional development and NRM (DWLBC 2006).

'No regrets' — A measure that has other net benefits (or at least no net costs) besides limiting greenhouse gas emissions or conserving or enhancing greenhouse gas sinks.

Participatory Research — A range of collaborative approaches to conducting research where stakeholders participate in the research process by working with professional researchers to form the research question, design methods, and/or undertake data collection, analysis and evaluation.

Pasture — Grassland used for the production of grazing animals such as sheep and cattle

Peri-urban — Areas around the edge or fringe of urban areas.

PIRSA — Primary Industries and Resources South Australia (Government of South Australia)

Precautionary principle — Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation

Prescribed water resource — A water resource declared by the Governor to be prescribed under the Act, and includes underground water to which access is obtained by prescribed wells. Prescription of a water resource requires that future management of the resource be regulated via a licensing system.

PWA — Prescribed Wells Area

Projection — See 'Climate projection'

Regional NRM board — A body established under Chapter 3 Part 3 and includes a body appointed under that Part to be a regional NRM board under the *Natural Resources Management Act (SA) 2004*.

Resilience — The ability of a system to withstand and recover from stresses and disturbances.

Riparian— That part of the landscape adjacent to a water body that influences and is influenced by watercourse processes. This can include landform, hydrological or vegetation definitions. It is commonly used to include the in-stream habitats, bed, banks and sometimes floodplains of watercourses

Risk — A probalistic measure of the consequence of a threat acting on an asset, typically expressed as a product of likelihood and consequence. Risk can also be a measure of the probability of management actions not delivering the desired outputs and outcomes.

SA — South Australia

SARDI — South Australian Research and Development Institute, a division within PIRSA

Sensitivity — Reflects the responsiveness of systems to climatic influences and the degree to which changes in climate might affect it in its current form; the threshold points at which affects will be exhibited, whether change will occur in trends or steps and whether they will be reversible.

Short-term — No strict definition, although in this study normally refers to a period of 0-10 years (see also long-term).

Stormwater — Run-off in an urban area

Surface water — (a) water flowing over land (except in a watercourse), (i) after having fallen as rain or hail or having precipitated in any another manner, (ii) or after rising to the surface naturally from underground; (b) water of the kind referred to in paragraph (a) that has been collected in a dam or reservoir

Sustainability — The ability of an ecosystem to maintain ecological processes and functions, biological diversity, and productivity over time

UK — United Kingdom

USA — United States of America

Vulnerability — The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes

Water allocation — (1) In respect of a water licence means the quantity of water that the licensee is entitled to take and use pursuant to the licence. (2) In respect of water taken pursuant to an authorisation under s.11 means the maximum quantity of water that can be taken and used pursuant to the authorisation

WAP — Water allocation plan: a plan prepared by a CWMB or water resources planning committee and adopted by the Minister in accordance with the Act

REFERENCES

ABC News, 2008a, 'Adelaide heatwave "one in 3000 yrs" ', ABC News, viewed 1 April 2008, http://www.abc.net.au/news/stories/2008/03/18/2192987.htm?section=justin

ABC News, 2008b, 'Water buyback details outlined', ABC News, viewed 3 March 2008, http://www.abc.net.au/news/stories/2008/02/26/2173120.htm

Adger WN, 2003, 'Social capital, collective action, and adaptation to climate change', in *Economic Geography*, 79(4), pp. 387–404

Adger WN, Arnell NW & Tompkins EL, 2005, 'Successful adaptation to climate change across scales', in *Global Environmental Change*, 15(2005), pp. 77–86

AGO, 2003, *Climate change: an Australian guide to the science and potential impacts*, Pittock B (ed), Australian Greenhouse Office, Department of Climate Change, Canberra

AGO, 2006, *Climate change impacts and risk management: a guide for business and government*, Australian Greenhouse Office, Department of the Environment and Heritage, Canberra

AMLR NRM Board, 2006, *Initial natural resources management plan for the Adelaide and Mount Lofty Ranges natural resources management region 2006–2008*, Adelaide and Mount Lofty Ranges Natural Resources Management Board, Adelaide

AMLR NRM Board, 2007a, 'Creating a sustainable future: a natural resources management plan for the Adelaide and Mount Lofty Ranges Region. Volume A—State of the region report', Draft Consultation Document 2007, Adelaide and Mount Lofty Ranges Natural Resources Management Board, Adelaide, viewed December 2007, http://www.amlrnrm.sa.gov.au/Portals/1/Our_Plans/Docs/VOLA_finaldraft_oct07-LR.pdf

AMLR NRM Board, 2007b, 'Climate change in the Adelaide and Mt Lofty Ranges region', Adelaide and Mount Lofty Ranges Natural Resources Management Board, Government of South Australia, Adelaide, viewed September 2007, http://www.amlrnrm.sa.gov.au/Portals/1/Issues&Problems/Docs/cc_brochure_web.pdf

AMLR NRM Board, 2007c, 'Creating a sustainable future: a natural resources management plan for the Adelaide and Mount Lofty Ranges Region. Volume B—Ten year plan for the region', Draft Consultation Document 2007, Adelaide and Mount Lofty Ranges Natural Resources Management Board, Adelaide, viewed December 2007, http://www.amlrnrm.sa.gov.au/Portals/1/Our_Plans/Docs/VOLB_finaldraft_oct07_w.pdf

AMLR NRM Board, 2007d, 'Creating a sustainable future: a natural resources management plan for the Adelaide and Mount Lofty Ranges Region. Volume C—The board's investment plan', Draft Consultation Document 2007, Adelaide and Mount Lofty Ranges Natural Resources Management Board, Adelaide, viewed December 2007, http://www.amlrnrm.sa.gov.au/Portals/1/Our_Plans/Docs/VOLC_finaldraft_oct07_w.pdf

AMLR NRM Board, 2007e, 'Creating a sustainable future: a natural resources management plan for the Adelaide and Mount Lofty Ranges Region. Volume D—Regulatory and policy framework', Draft Consultation Document 2007, Adelaide and Mount Lofty Ranges Natural Resources Management Board, Adelaide, viewed December 2007, http://www.amlrnrm.sa.gov.au/Portals/1/Our_Plans/Docs/VOLD_finaldraft_oct07_w.pdf

Bardsley D, 2003, ‘Risk alleviation via in situ agrobiodiversity conservation: drawing from experiences in Switzerland, Turkey and Nepal’, in *Agriculture, Ecosystems & Environment*, 99(1-3), pp. 149–157

Bardsley D, 2006, *There's a change on the way: an initial integrated assessment of projected climate change impacts and adaptation options for natural resource management in the Adelaide and Mt Lofty Ranges region*, DWLBC Technical Report 2006/06, Department of Water, Land and Biodiversity Conservation, Adelaide

Bardsley DK, 2007, ‘Education for all in a global era? The social justice of Australian secondary school education in a risk society’, in *Journal of Education Policy* 22(5), pp. 493–508

Bardsley D & Thomas I, 2006, ‘In situ agrobiodiversity conservation: examples from Nepal, Turkey and Switzerland in the first decade of the Convention on Biological Diversity’, in *Journal of Environmental Planning and Management*, 49(5), pp. 653–674

Bardsley DK & Bardsley A, 2007, ‘A constructivist approach to climate change teaching and learning’, in *Geographical Research*, 45(4), pp. 329–339

Bardsley DK & Edwards-Jones G, 2007, ‘Invasive species policy and climate change: social perceptions of environmental change in the Mediterranean’, in *Environmental Science & Policy*, 10(3), pp. 230–242

Bardsley DK & Liddicoat C, 2008, *Community perceptions of climate change impacts on natural resource management in the Adelaide and Mount Lofty Ranges,* DWLBC Report 2008/14, Department of Water, Land and Biodiversity Conservation, Adelaide

Bardsley DK & Rogers G, 2008, *Prioritising engagement for sustainable adaptation to climate change: an example from natural resource management in South Australia, Society and Natural Resources*, in press

Barnett J, 2006, ‘Climate change, insecurity and justice’, in Adger W, Paavola J, Mace M & Huq S (eds), *Fairness in Adaptation to Climate Change*, MIT Press, Cambridge MA, pp. 115–129

Beck U, 2000, *What is globalization?*, trans. P Camiller, Polity Press, Cambridge UK

Bengtsson L, Hodges KI & Roeckner E, 2006, ‘Storm tracks and climate change’, in *Journal of Climate*, 19, pp. 3518–3543

Blackmore C, 2007, ‘What kinds of knowledge, knowing and learning are required for addressing resource dilemmas?: a theoretical overview’, in *Environmental Science & Policy*, 10(6), pp. 512–525

Blong R, 2004, ‘Residential building damage and natural perils: Australian examples and issues’, in *Building Research and Information*, 32(5), pp. 379–390

Brooks N, Adger WN & Kelly PM, 2005, ‘The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation’, in *Global Environmental Change,* 15(2), pp. 151–163

Bruckner T, Petschel-Held G, Tóth FL, Füssel H-M, Helm C, Leimbach M & Schellnhuber H-J, 1999, ‘Climate change decision-support and the tolerable windows approach’, in *Environmental Modelling and Assessment,* 4(4), pp. 217–234

Bunker R, & Houston P, 2003, ‘Prospects for the rural-urban fringe in Australia: observations from a brief history of the landscapes around Sydney and Adelaide’, in *Australian Geographical Studies*, 41(3), pp. 303–323.

Bureau of Rural Sciences, 2004, *Climate change: adaptation in agriculture*, Science for Decision Makers December 2004, Department of Agriculture, Fisheries and Forestry, Canberra

Cameron TA, 2005, 'Updating subjective risks in the presence of conflicting information: an application to climate change', in *The Journal of Risk and Uncertainty,* 30(1), pp. 63–97

Campbell, A. 2008. Managing Australian Landscapes in a Changing Climate: A climate change primer for regional Natural Resource Management bodies. Report to the Department of Climate Change, Canberra, Australia.

Caton B, Fotheringham D, Lock C, Royal M, Sandercock R & Taylor R, 2007, *Southern Fleurieu coastal conservation assessment and action plan*, AMLR NRM Board, Adelaide

City of Onkaparinga, 2007, 'Addressing climate change', Strategic Directions 2020 discussion paper 2, June 2007, viewed September 2007 http://www.onkaparingacity.com/web/binaries?img =9442&stypen=html

Crossman N, Bryan B & Bardsley D, 2008, *Modelling native and exotic flora distributions under climate change*, CSIRO Land and Water Science Report 01/08, CSIRO, Adelaide

Cullen P, 2004, 'Making waves: water challenges for Adelaide in the 21st century', Public address, Adelaide Town hall Tuesday 25 May 2004, Land & Water Australia, Canberra, viewed February 2006, http://www.lwa.gov.au/downloads/general_doc/ Making_Waves-Peter_Cullen.pdf

Daines J, Daines C & Graham B, 2002, *Adult learning, adult teaching*. Welsh Academic Press, Cardiff

DEH, 2006, *NatureLinks. East meets west corridor plan draft. Implementing South Australia's strategic plan,* Department for Environment and Heritage, Adelaide

Department of the Environment and Water Resources, 2007, *National scoping study of climate change impacts on natural resource management regions*, Department of the Environment and Water Resources request for tender 0708-648, AusTender, Department of Finance and Deregulation, Canberra, viewed January 2008, https://www.tenders.gov.au/?event=public.atm.show&ATMUUID =FB10BC3E-E09A-6320-56F92E7101748F8E

Dessai S, Xianfu L & Risbey JS, 2005, 'On the role of climate scenarios for adaptation planning', in *Global Environmental Change*, 15(2), pp. 87–97

Dünkeloh A & Jacobeit J, 2003, 'Circulation dynamics of Mediterranean precipitation variability 1948–1998', in *International Journal of Climatology,* 23(15), pp. 1843–1866

DWLBC, 2006, *State natural resources plan*, Department of Water, Land and Biodiversity Conservation, Adelaide

DWLBC, 2007, 'Regional natural resources management in SA', Department of Water, Land and Biodiversity Conservation, Adelaide, viewed March 2007, http://www.dwlbc.sa.gov.au/nrm/delivery/ index.html

DWLBC, 2008, 'Climate Change and the potential for wind erosion - a model for the Adelaide and Mt Lofty Ranges NRM region', Department of Water, Land and Biodiversity Conservation, Adelaide

DWR, 2000, *State Water Plan 2000: Volume 2 South Australia's water resources*, Department for Water Resources, Department of Water, Land and Biodiversity Conservation, Adelaide

Etkin D & Ho E, 2007, 'Climate change: perceptions and discourses of risk', in *Journal of Risk Research*, 10(5), pp. 623–641

Fankhauser S, Smith JB & Tol RSJ, 1999, 'Weathering climate change: some simple rules to guide adaptation decisions', in *Ecological Economics*, 30(1), pp. 67–78

Faulkner A, 2008, 'Rising seas stop beachfront homes', *The Australian*, 12 March 2008, viewed March 2008, http://www.news.com.au/business/story/0,23636,23360880-31037,00.html

Forster CA, 2006, ‘The challenge of change: Australian cities and urban planning in the new millennium’, in *Geographical Research*, 44 (2), pp. 174–183

Fu Q, Johanson CM, Wallace JM & Reichler T, 2006, ‘Enhanced mid-latitude tropospheric warming in satellite measurements’, in *Science* 312(5777), p. 1179

Garnaut Climate Change Review, 2008, ‘Garnaut climate change review. Interim report to the commonwealth, state and territory governments of Australia’, Garnaut Climate Change Review, viewed 11 April 2008, http://www.garnautreview.org.au/CA25734E0016A131/pages/reports-and-papers

Gertner J, 2007, ‘The future is drying up’, New York Times, viewed 23 October 2007, http://query.nytimes.com/gst/fullpage.html?res=9C0CEFDA103CF932A15753C1A9619C8B63&sec=&spon=&pagewanted=10

Government of South Australia, 2004, *Natural Resources Management Act (SA) 2004*

Government of South Australia, 2005, *Water Proofing Adelaide Strategy, A thirst for change*, viewed July 31 2008, http://www.waterproofingadelaide.sa.gov.au/NR/rdonlyres/C79D0A6F-0788-4545-806A-5773BF61F3CD/0/wpa_Strategy.pdf

Harvey N., Carvalho P. & Clouston B. (1997) *Coastal Vulnerability Assessment: South Australian Coast Protection Board*, Report 31, http://www.environment.sa.gov.au/coasts/pdfs/no31.pdf, accessed 11/5/06

Heneker TM & Cresswell D, 2008, ‘Potential impact on water resource availability in the Mount Lofty Ranges due to climate change’, DRAFT DWLBC Report, Department of Water, Land and Biodiversity Conservation, Government of South Australia

Hope PK, 2006, ‘Projected future changes in synoptic systems influencing southwest Western Australia’, in *Climate Dynamics*, 26(7–8), pp. 765–780

Houston P, 2005, ‘Re-valuing the fringe: some findings on the value of agricultural production in Australia’s peri-urban regions’, in *Geographical Research*, 43(2), pp. 209–223

Houston P & Rowland J, 2008, *Room to move: towards a strategy to assist the Adelaide Hills apple industry adapt to climate change in a contested peri-urban environment,* DWLBC Report 2008/20, Department of Water, Land and Biodiversity Conservation, Adelaide

IPCC, 2007, *Climate change 2007: The physical science basis*, Intergovernmental Panel on Climate Change, Geneva, Switzerland

Jacobi D & Syme B, 2005, *Port Adelaide seawater stormwater flooding study*, City of Port Adelaide Enfield Volume 1—Final Report, Tonkin Engineering, Adelaide and WBM Oceanics Australia

James J & Liddicoat C, 2008, *Developing industry climate change adaptation strategies: A case study for the McLaren Vale viticulture and Fleurieu Peninsula oliveculture industries*, DWLBC Report 2008/11, Department of Water, Land and Biodiversity Conservation, Adelaide

Jenkin C & Austin N, 2007, ‘Wind, heat turn crop hopes to dust’, *The Advertiser*, 31 August 2007, viewed 31 August 2007, http:www.news.com.au/adelaidenow/story/0,22606,22336525-5006301,00.html

Jones GV, White MA, Cooper OR & Storchmann K, 2005, ‘Climate change and global wine quality’, in *Climatic Change*, 73(33), pp. 319–343

Kerr RA, 2006, ‘A worrying trend of less ice, higher seas’, in *Science* 311(5768), pp. 1698–1701

Kok MTJ & de Coninck HC, 2007, ‘Widening the scope of policies to address climate change: directions for mainstreaming’, in *Environmental Science & Policy*, 10(7–8), pp. 587–599

Kueppers LM, Baer P, Harte J, Haya B, Koteen LE & Smith ME, 2004, ‘A decision matrix approach to evaluating the impacts of land-use activities undertaken to mitigate climate change’, in *Climatic Change*, 63(3), pp. 247–257

Lebel L, Anderies JM, Campbell B, Folke C, Hatfield-Dodds S, Hughes TP & Wilson J, 2006, ‘Governance and the capacity to manage resilience in regional socio-ecological systems’, in Walker BH, Anderies JM, Kinzig AP & Ryan P (eds), *Exploring resilience in social-ecological systems: comparative studies and theory development*, CSIRO Publishing, Canberra pp. 119–138

Lempert R, Nakicenovic N, Sarewitz D & Schlesinger M, 2004, ‘Characterizing climate-change uncertainties for decision-makers’, in *Climatic Change,* 65(1–2), pp. 1–9

Lower G, 2008, ‘Supreme Court rejects development due to rising sea’, *The Advertiser*, 11 March 2008, viewed 11 March 2008, http://www.news.com.au/adelaidenow/story/0,22606,23353161-5006301,00.html

Mayo P, 1999, *Gramsci, Freire and adult education: possibilities for transformative action*, Zed Books, New York

McInnes KL, Suppiah R, Whetton PH, Hennessy KJ & Jones RN, 2003, *Climate change in South Australia*, CSIRO Atmospheric Research, Melbourne

MDBC, 2008, *Murray-Darling Basin risks strategy: a strategy for addressing the activities, events and processes that pose a risk to the shared water resources of the Murray-Darling Basin*, MDBC Publication No. 01/08, Murray-Darling Basin Commission, Canberra

Meinke H, Nelson R, Kokic P, Stone R, Selvaraju R & Baethgen W, 2006, ‘Actionable climate knowledge: from analysis to synthesis’, in *Climate Research*, 33(1), pp. 101–110

Morgan MG & Dowlatabadi H, 1996, ‘Learning from integrated assessment of climate change’, in *Climatic Change,* 34(3–4), pp. 337–368

Mount Lofty Ranges Interim Natural Resource Management Group, 2003, *Integrated natural resource management plan for the Mount Lofty Ranges and greater Adelaide region*, Mount Lofty Ranges Interim Integrated Natural Resource Management Group, Adelaide

Orr DW, 2002, *The nature of design: ecology, culture, and human intention*, Oxford University Press, New York

Pannell DJ, Marshall GR, Barr N, Curtis A, Vanclay F & Wilkinson R, 2006, ‘Understanding and promoting adoption of conservation practices by rural landholders’, in *Australian Journal of Experimental Agriculture*, 46(11), pp. 1407–1424

Parks BC & Roberts JT, 2006, ‘Globalization, vulnerability to climate change, and perceived injustice’, in *Society and Natural Resources*, 19(4), pp. 337–355

Partington F, 2007, ‘The vulnerability of the Riverland irrigation industry to climate change: identifying the perceptions of risk of irrigators’, Masters thesis, Flinders University

Paton DC, Rogers DJ & Harris W, 2004, ‘Birdscaping the environment: restoring the woodland systems of the Mt Lofty Region, South Australia’, in Lunney D (ed), *Conservation of Australia’s forest fauna* (2nd edition), The Royal Zoological Society of New South Wales, Sydney, pp. 331–358

Pelling M & High C, 2005, ‘Understanding adaptation: what can social capital offer assessments of adaptive capacity?’, in *Global Environmental Change*, 15(4), 308–319

Planning SA, 2006, *Planning strategy for metropolitan Adelaide*, Planning SA, Adelaide

Preston BL & Jones RN, 2006, *Climate change impacts on Australia and the benefits of early action to reduce global greenhouse gas emissions*, A consultancy report for the Australian business roundtable on climate change, CSIRO, Canberra

Raymond C, 2008, *Mapping landscape values and perceived climate change risks for natural resources management: a study of the Southern Fleurieu Peninsula region, SA*, DWLBC Report 2008/07, Department of Water, Land and Biodiversity Conservation, Adelaide

Rebbeck M, Dwyer E, Bartetzko M & Williams A, 2007, *A guide to climate change and adaption in agriculture in South Australia*, SARDI, PIRSA and Rural Solutions SA, Adelaide

Research Institute for Climate Change and Sustainability, 2008, 'Climate change impacts on Adelaide gardens', Research Institute for Climate Change and Sustainability, The University of Adelaide, viewed 14 May 2008, http://www.adelaide.edu.au/climatechange/research/risccsagricprogram.html

River Murray Urban Users Committee, 2008, 'MurrayCare: a partnership working to care for the Murray', MurrayCare, River Murray Urban Users LAP Commiittee Inc., viewed 14 May 2008, http://www.murrayusers.sa.gov.au

Rosenzweig C, Strzepek KM, Major DC, Iglesias A, Yates DN, McCluskey A & Hillel D, 2004, 'Water resources for agriculture in a changing climate: international case studies', in *Global Environmental Change Part A*, 14(4), pp. 345–360

Rosenzweig C & Tubiello FN, 1997, 'Impacts of global climate change on Mediterranean agriculture: current methodologies and future directions', in *Mitigation and Adaptation Strategies for Global Change*, 1(3): 219–232

Schneider SH, 2001, 'What is "dangerous" climate change?', in *Nature*, 411(6833), pp. 17–19

Schneider SH, 2004, 'Abrupt non-linear climate change, irreversibility and surprise', in *Global Environmental Change Part A*, 14 (3): 245–258

SEACI, 2008, 'South Eastern Australian Climate Initiative', South Eastern Australian Climate Initiative, viewed May 2008, http://www.mdbc.gov.au/subs/seaci/

South Australian Coast Protection Board, 1992, *Coastline: coastal erosion, flooding and sea level rise, standards and protection policy*, Report no. 26. Department for Environment and Heritage, Adelaide.

Standards Australia/Standards New Zealand, 2004, *Risk management guidelines companion to AS/NZS 4360:2004*, HB 436:2004, Standards Australia International Ltd, Sydney and Standards New Zealand, Wellington

Stern N, 2006, *The economics of climate change: the Stern review*, Cambridge University Press, UK

Suppiah R, Preston B, Whetton PH, McInnes KL, Jones RN, Macadam I, Bathols J & Kirono D, 2006, *Climate change under enhanced greenhouse conditions in South Australia*, CSIRO, Australia

Sustainability and Climate Change Division, 2007, *Tackling climate change: South Australia's greenhouse strategy 2007–2020*, Sustainability and Climate Change Division, Department of the Premier and Cabinet, Adelaide

Tait J & Morris D, 2000, 'Sustainable development of agricultural systems: competing objectives and critical limits', in *Futures,* 32(3), pp. 247–260

The Allen Consulting Group, 2005, *Climate change risk and vulnerability: promoting an efficient adaptation response in Australia*, Australian Greenhouse Office, Department of the Environment and Heritage, Canberra

Thomas DSG & Twyman C, 2005, 'Equity and justice in climate change adaptation amongst natural-resource-dependent societies, in *Global Environmental Change*, 15(2005), pp. 115–124

Turner NC, 2004, 'Sustainable production of crops and pastures under drought in a Mediterranean environment' in *Annals of Applied Biology*, 144(2), pp. 139–147

Urban & Regional Planning Solutions, 2007a, *Adelaide & Mt Lofty Ranges Natural Resources Management Board: Social and economic study*, final report, Adelaide and Mount Lofty Ranges Natural Resources Management Board, Adelaide

Urban & Regional Planning Solutions, 2007b, 'Fleurieu peninsula region integrated strategic tourism plan 2007–2012', South Australian Tourism Commission, viewed December 2007, http://www.tourism.sa.gov.au/tourism/plan/Fleurieu-Peninsula/FP_Plan_Jan_07.pdf

Van Dijk A, Evans R, Hairsine P, Khan S, Nathan R, Paydar Z, Viney N & Zhang L, 2006, *Risks to the shared water resources of the Murray-Darling Basin*, Murray-Darling Basin Commission, Canberra

Waclawik V, 2007, 'Discussion paper on the potential impact of climate change on the groundwater resources of the McLaren Vale Prescribed Wells Area',

Walker DH, Cowell SG & Johnson AKL, 2001, 'Integrating research results into decision making about natural resource management at a catchment scale', in *Agricultural Systems*, 69(1-2), pp. 85–98

Wals AEJ, 2007, *Social learning. towards a sustainable world: principles, perspectives, and praxis*.Wageningen Academic Publishers

Warren M, 2008, 'Cash tap turned on for water in Murray-Darling', *The Australian*, 14 May 2008, p. 10

Zahran S, Brody SD, Grover H & Vedlitz A, 2006, 'Climate change vulnerability and policy support', in *Society and Natural Resources,* 19(9), pp. 771–789