DWLBC REPORT

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

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

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

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FOREWORD

South Australia's 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 both for current users and for future generations.

The Department of Water, Land and Biodiversity Conservation (DWLBC) strives to ensure that our natural resources are developed and managed in a way that advances economic, social and environmental outcomes.

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 intended actions and other manmade changes. DWLBC scientific and technical staff continue to improve this knowledge through undertaking investigations, technical reviews and resource modelling.

Climate change is one of the most important issues we are facing and this has been clearly identified in the State Natural Resource Management Plan. The Government has committed to effective water resource planning to manage the expected impact of climate change. This report is an important step forward in responding to climate change impacts and will help inform the development of our regional Natural Resource Management plans and water allocation plans. The work was undertaken by the Department in partnership with the Adelaide and Mount Lofty Ranges Natural Resource Management Board and provides a good example of what can be achieved when we adopt a collaborative approach to natural resource management.

Rob Freeman
CHIEF EXECUTIVE
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1.1 PURPOSE OF THE STUDY

Climate change is a reality. Around the world, climate change is impacting on Mediterranean systems similar to ours in South Australia (SA), in a manner more severe than for most other climate types. An enhanced Greenhouse Effect is likely to become a significant issue for Natural Resource Management (NRM) within the Adelaide and Mt Lofty Ranges (AMLR) region, as changes to climate are projected to be substantial. A warming/drying trend is projected for the AMLR, as well as less reliable rainfall, later breaks in the winter growing season, more extreme weather events and hotter, longer hot spells. The AMLR Region is in effect an 'island' of cool, moist environmental conditions in a 'sea' of relatively arid conditions. Such 'islands' are shown to be highly vulnerable to rapid environmental change.

The vulnerability of different aspects of NRM in the AMLR are reviewed based on current knowledge using a methodology from a recent report undertaken by The Allen Consulting Group (2005) for the Australian Greenhouse Office (AGO), which involves an examination of exposure and sensitivity to climate change and opportunities for adaptation. There are potentially significant effects of climate change on all aspects of NRM reviewed including flood management; surface and groundwater resources; coastal management; biodiversity; invasive species; gardens; revegetation; agricultural production; land management; bushfires; and air quality.

1.2 KEY VULNERABILITIES

There are significant NRM vulnerabilities to projected climate change in the AMLR region. The integrated assessments of these vulnerabilities are outlined in Table 1. In general the management of water, land, biodiversity and air across the region is highly exposed to changes in climate. Due to the different sensitivities of NRM to such change, the potential impacts have been assessed to be most severe in relation to coastal management, bushfires and biodiversity, with water issues and agriculture management also significant considerations. This does not mean that other NRM issues are not important, rather that the issues mentioned could be considered priority areas for investigation in the short-term.

All levels of vulnerabilities are highly dependent upon the capacity of human action to support adaptation of the NRM systems in the long-term. For example, it is suggested that the adaptive capacity for agriculture in the region is considerable and as a result, agriculture and land management would not necessarily be highly vulnerable to climate change. Yet, such an assumption is based on the current wealth of our society and the historical adaptive capacity of agro-ecosystems, not with regard to uncertain future risk associated with policy changes, globalisation, fuel costs and urban encroachment. For that reason, specific vulnerability assessments need to be built into risk assessment for different NRM contexts.

Table 1. Summary of vulnerability analyses for NRM in the AMLR

	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 crops	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

Colour Key for Adaptive capacity

Significant Medium Limited

1.3 IMPORTANT ADAPTATION OPTIONS

Specific ideas for adaptation to climate change are detailed under the different sections that follow. More broadly, there are opportunities to mitigate emissions, build resilience, create options for adaptation, and benefit from opportunities if effective actions can be undertaken to respond to projections of future change. It is important to recognise that responses to climate change will be a great global experiment. Early effective responses, that are balanced and reflective of the intensity and scope of change will help minimise negative impacts and maximise potential benefits. Such responses can no longer be considered as an issue separate to other NRM activities.

The temptation to provide prescriptive answers to respond to change has largely been resisted here due to the desire to engage each sector in researching particular climate change impacts and developing their own responses.

That said, a base-line target for regional NRM 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. Beyond that baseline, some actions can be undertaken in the short-term. 'No regrets' actions are those that would create socio-economic and environmental benefit irrespective of whether climate change eventuates. They could be particularly important climate adaptation measures in the shorter term. It is clear from the review that where there is a significant social component to the response to climate change risk, there are likely to be greater opportunities for adaptation in the short-term. Note that:

- Many good adaptation ideas are already available and needing wider application to support the resilience of systems.
- While it is important that biodiversity conservation aims to preserve target species within particular habitat locations, resting or breeding areas, the focus of conservation must necessarily broaden in an era of climate change, ensuring both high levels of ecological integrity and connectedness across the landscape, including the role of conservation on private land. Goal 1 of the State NRM Plan 2006 relates directly to this issue by targeting 'Landscape scale management that maintains healthy natural systems and is adaptive to climate change' (DWLBC 2006, p. 33).
- Sustainable agricultural practices, such as increasing the efficiency and diversification of farming systems and supply chains are valuable for many reasons, including reducing the social, economic and environmental vulnerabilities to climate risk.

Climate change is likely to have major impacts on NRM, but the specific impacts are uncertain. Due to the uncertainty of an enhanced Greenhouse Effect, responses need to be embedded in a broader risk management approach based on the Precautionary Principle. As the form and extent of climate change become clearer, policy that recognises and responds to the need for trade-offs between short and long-term goals for NRM could become more applicable. Land use planning and policies may need to become more prescriptive to ensure the sustainable use of vulnerable resources and the on-going sustainable management of key agro-ecological and environmental assets in the future (Kueppers et al. 2004). Controls on the spread of urban land uses in key natural resource areas of the AMLR may need to be examined in greater detail (see for examples Cullen 2004, Houston 2005).

1.4 GAP ANALYSIS AND RECOMMENDATIONS FOR FUTURE WORK

There are significant themes that emerge from this review that are in need for further detailed investigation:

- Apart from a few exceptions mentioned in the text, there has been very little scientific research and modelling to date examining the specific impacts of climate change on NRM in the AMLR, including the potential for different impacts according to the different rates and extents of climate change.
- Detailed case studies are required of complex interactions between climate and different aspects of NRM, such as the work undertaken examining flood risk and stormwater management in the City of Port Adelaide-Enfield. For example, managers of water and

biodiversity increasingly will need to incorporate the projections of climate change into their modelling and planning.

- While there is work underway to review impacts on water and agriculture, very little detailed knowledge is available on the potential for complex impacts on ecological systems in the AMLR and this needs to be rectified to inform land-use planning, particularly as it relates to biodiversity conservation.
- Further work will need to examine how planning responses might increase the resilience within systems when required. For example, the associated impacts of more extreme rainfall events and sea-level rise may require the development of new flood and stormwater strategies in low-lying suburbs.
- NR research, management and planning do not generally incorporate climate change issues. It may be necessary for all NR processes within the region, to examine the importance of incorporating climate change impacts on the system under analysis as a component of their studies or actions. There are some strong examples where this type of downscaling of potential impacts has been undertaken at the sectoral level in the region, most comprehensively for the Port Adelaide Seawater Stormwater Flooding Study.
- It will be necessary to undertake socio-economic research, to examine community perceptions of climate change and risk in order to move to a point of effectively addressing the issues and learning how best to work with natural resource managers to provide them with the skills and knowledge to integrate responses to climate change within their other NRM activities. Priorities for investment and action will be partly driven by the social perceptions and economic valuations of the impacts of change.
- A next step for this work would be to examine stakeholders' perceptions of the conclusions for vulnerability and adaptation options outlined in this report, so that the document could be updated based on a broader review and used to increase awareness of climate change. By embedding responses in the community, opportunities for learning and the efficacy of management can be enhanced, because individuals and communities with the awareness and capacity to respond will do so within their own biophysical and socio-cultural contexts.

The major recommendation that emerges from this work is that all NRM planners and managers should begin to own climate change as a reality, even while the specific manifestations of such change are uncertain. They should recognise that simple responses to the complexity of climate change are likely to be lacking in the short-term. We need resilient, flexible NRM systems.

Individuals and groups will need to begin to apply a learning orientation to climate change in order to incorporate appropriate responses into their processes, rather than expecting the culture of knowledge and information to guide specific responses. To respond to the substantial uncertainty, there should be an emphasis on the need for new discoveries, ideas and responses, including:

1) Incorporation of climate change into risk management in the short-term.
2) The application of adaptive management and planning techniques and the precautionary principle, for the longer-term.

2. INTRODUCTION

2.1 THE CLIMATE CHANGE CHALLENGE

Climate change has the potential to compromise the natural resource base of the Adelaide and Mt Lofty Ranges Region (AMLR) and undermine strategic and investment planning for natural resource management (NRM) and natural resource based industries in the future.

Climate change is resulting from both natural change and human actions on a global scale. Greenhouse gases such as Carbon dioxide ($C0_2$), Methane (CH_4) and Nitrous oxide (N_20) are increasing in the atmosphere, acting like a horticultural greenhouse, warming the Earth. To date, much of the response to climate change has focused on Greenhouse gas emission reductions. While mitigation is vital, there is growing evidence that responses to an enhanced Greenhouse effect will also require immediate strategies for adaptation. It is necessary that we act now to investigate vulnerabilities and opportunities for adaptation to increase preparedness for change.

As a region, the AMLR region of SA is characterised by a range of important urban, peri-urban and rural NRM issues. Some key characteristics of the region (South Australian Government 2003) include:

- The Region covers a land area of approximately 3880 km^2, and a similar area of marine and estuarine environments.
- Human population over 1 million.
- Adelaide draws 60% of its water from local catchments in most years.
- Primary industries contribute $720 million per annum to the State's economy.
- Contains 50% of the state's native plant species and 75% of native bird species.
- 13% of its original terrestrial native vegetation remains.

The AMLR NRM Board manages a portfolio of more than thirty NRM projects, with a combined investment value in excess of $13 million. The Board, in association with the SA Government, identified the need to understand the implications of climate change in relation to its NRM program. To inform stakeholders and develop ownership of change, a product was required that provided ideas and information on impacts and adaptation options in a form that could be readily critiqued by stakeholders. This review is the first step in that process.

The details of impacts based on modelled projections from CSIRO and elsewhere are collated here, and, based on evaluations of the information available, the most vulnerable systems or aspects of systems have been articulated. This paper focuses on the science of climate change within the region, rather than on policy that is being developed.It has been designed to synthesise projected climate change impacts on NRM and to discuss major issues for particular NRM sectors of interest. The discussion below outlines key NRM assets that are likely to be most vulnerable to climate change impacts and suggests opportunities to adapt effectively to the changing conditions.

2.2 THE PURPOSE OF THIS REVIEW

This review of current knowledge of climate change impacts on NRM for AMLR has multiple aims:

- to increase the region's awareness of the need for change by reviewing projected impacts of climate change on NRM in the AMLR
- to identify research that is being undertaken to improve understanding of particular NRM impacts of climate change and opportunities for adaptation
- to inform AMLR NRM planning
- to identify key gaps in knowledge and inform future NRM research
- to inform management initiatives for NRM, agriculture, and other regional systems
- to provide a baseline of current climate change knowledge for the region, to be developed as further information becomes available and impacts become clearer
- to provide climate change analysis, awareness raising and planning material suitable to stimulate public discussion.

Greenhouse gas mitigation issues do not form a large part of the discussion here, as they are being broadly considered elsewhere (see for example Preston and Jones 2006). While mitigation is recognised as important, this review does not examine the potential impacts of policy changes aimed at mitigating greenhouse gas emissions. Such changes may significantly change regulatory environments and in consequence, affect NRM activities that produce significant amounts of greenhouse gases.

Little attempt is made within the vulnerability assessments to examine the cumulative and potentially very complex effects of wide-scale economic or socio-political change associated with climate change. However, a next step in this process may well involve broader assessments of the key vulnerabilities of a carbon-constrained society, increasingly focussing activities on managing changing socio-economic, as well as environmental conditions.

This review examines NRM vulnerabilities to climate change, with emphasis on the bio-physical opportunities for reducing the sensitivity to change in the shorter term and applying adaptation options in the longer term. Of major importance are critical biophysical, socio-economic and management thresholds, or the levels of exposure at which systems can no longer absorb the changes in climatic conditions without fundamental reductions in the provision of key products or services. For that reason, the rate and extent of climate change affecting and likely to affect the AMLR, become important aspects of its NRM vulnerability. Often such detail was beyond the scope of this review and while raised at different times, will require more in-depth scientific and socio-economic analytical research. In fact, the vulnerability analyses here are based on rational subjective analysis of the available scientific evidence, and should be seen as initial assessments to engage regional stakeholders, rather than the definitive levels of vulnerability.

3. PROJECTED CLIMATE CHANGE FOR SOUTH AUSTRALIA

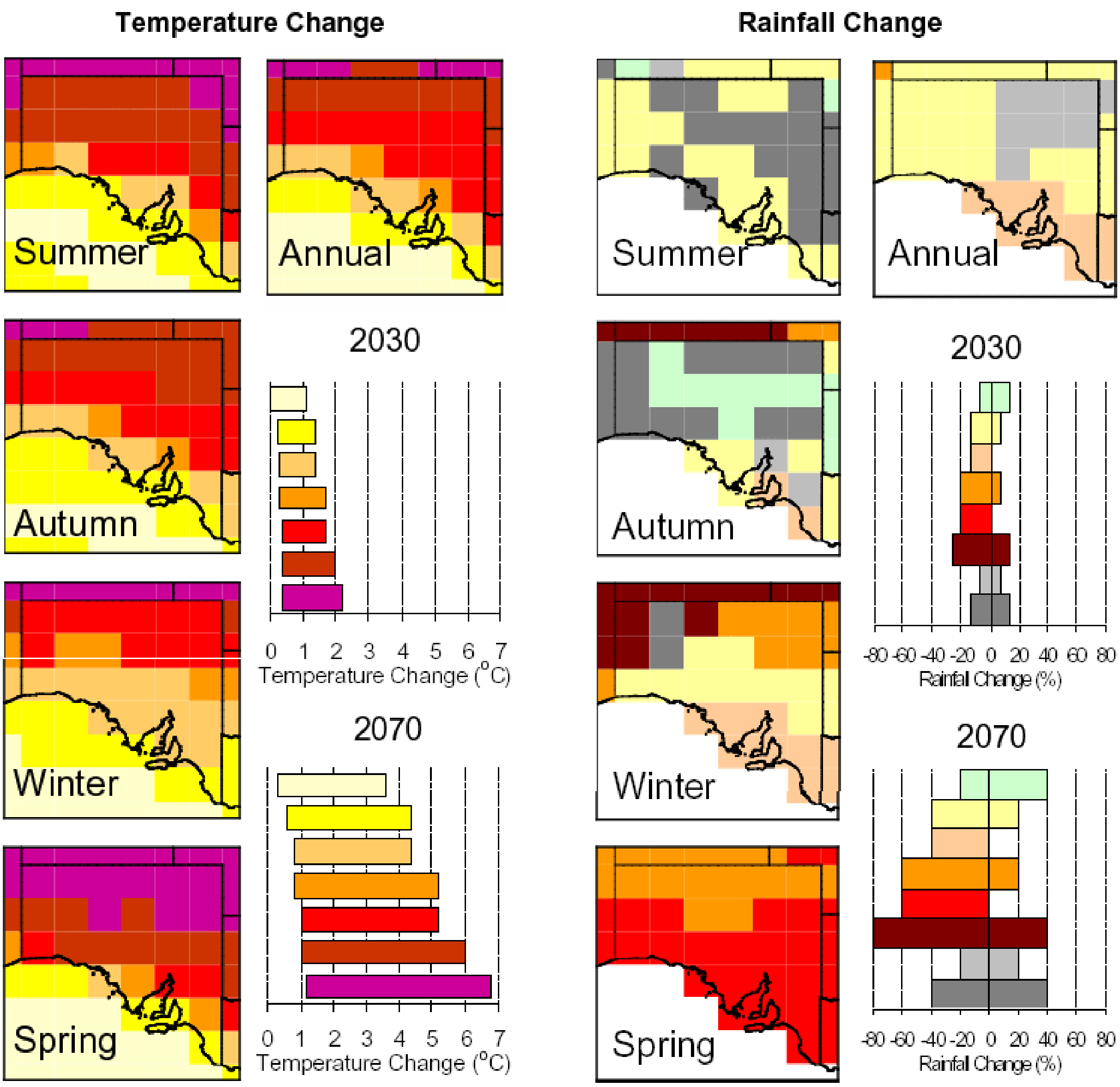
3.1 PROJECTIONS OF CHANGE

Many of the indicators of climate change are suggesting that measurable change is broadly apparent globally. In fact, evidence from around the world is suggesting that climate change is impacting on Mediterranean systems, such as ours in SA, earlier and in a manner more severe than for most other climate types. Mediterranean systems from western North America, Southern Europe, the Cape region in South Africa, Chile and south-west Western Australia have already shown substantial warming and drying trends since the 1970s (Smith et al. 2000, Cayan et al. 2001, McCarthy et al. 2001, Dünkeloh and Jacobeit 2003, Maheras et al. 2004, Piccarreta et al. 2004). The average annual rainfall in south-west Western Australia has declined by about 10% during that period. Even in the best-case scenario of the Intergovernmental Panel on Climate Change (IPCC) and CSIRO modellers, we can still expect substantial change in SA's climate in the 21st Century. Although there is significant uncertainty regarding the specific impacts of climate change on AMLR, this review examines the potential NRM impacts based largely on the projections outlined in McInnes et al. (2003).

The impacts of climate change on temperature and rainfall in SA are summarised in Figure 1. CSIRO climate projections suggest an average annual warming of 0.4^{o} to 2^{o}C over most of Australia by 2030. For SA, these changes could mean that by 2030 there will be a 10–50% increase in the number of hot days, a 20–80% decrease in frost days and substantial reductions in spring rainfall. The modelling for SA suggests that there is likely to be increasing rainfall variability, shorter growing seasons based on moisture availability, an increased risk of drought and reduced availability of water for inland regions (McInnes et al. 2003). While average rainfall is projected to decline, the intensity of rainfall events is projected to increase and extreme rainfall events to become more frequent in the AMLR region.

Historical trends in the climatic records already provide evidence of changes in climate for SA. McInnes et al. (2003, p. 4) note that, 'Since 1950, South Australia's average maximum temperature has increased by 0.17^{o}C per decade, the minimum by 0.18^{o}C per decade and the average temperature by 0.17^{o}C per decade.' While average temperatures have increased across the state, the trend in rainfall is less clear. A recent DWLBC/CSIRO study of historic rainfall and runoff data for the AMLR region (Charles et al. 2005) concluded:

- For winter (May-Oct), the 1978–2002 period experienced fewer wet-days, but shorter dry spells, similar wet spells, and higher rainfall intensities compared to the earlier 1958–77 period.
- Summer (Nov-Apr) observed precipitation for 1978–79 – 2001–02 had, in general, fewer wet-days but longer dry spells, shorter wet spells, and lower daily rainfall intensities than the 1958–59 – 1977–78 period.



(Source: McInnes et al. 2003)

Figure 1. CSIRO projections of climate change impacts on South Australia

Changes in median temperatures and evaporation rates, the timing, reliability and levels of precipitation, and the frequency and severity of extreme climatic events (see Table 2), will all have substantial impacts on industrial production and environmental management across the State. It is necessary for SA, and the important region of AMLR in particular, to begin to prepare for predicted climate change with processes for strategic adaptation.

Projections for storms and extreme winds are still unclear. While fewer low-pressure systems are expected, the intensities of the rainfall and wind associated with those systems are projected to increase in the future. Thus, while the frequency of average extreme winds, winter storms and storm surges are projected to decrease, according to McInnes et al. (2003), the spring and autumn westerlies, southerlies and south-westerlies may increase in frequency and these winds are often the most potentially destructive in the AMLR.

Table 2. Projected Climate Changes in the Adelaide and Mount Lofty Ranges

	2030					2070				
	Annual	Sum	Aut	Win	Spr	Annual	Sum	Aut	Win	Spr
Ave. range of warming (°C)	0.3–1.2	0.3–1.2	0.3–1.2	0.3–1.3	0.3–1.3	0.8–3.7	0.8–3.7	0.8–3.7	0.8–3.5	0.9–3.9
Ave. range (%) of rainfall change	-9–-1	-11–+5	-7–0	-9 – -1	-17–-2	-30–-2	-35–+15	-20–+1	-30–2	-55–4
Ave. range (%) of pot. evaporation change	2–5	1–4	1–5	2–7	2–7	4–16	3–12	4–14	6–23	6–21
Ave. range of change of moisture deficit (mm)	35–105	12–40	7–23	5–16	9–29	90–330	30–115	20–70	13–50	25–90
CO_2 (ppm) concentration current = ~380ppm	420–480					500–700				
Annual days above 35°C (Adelaide): current =14	15–20					17				
Annual spells >35°C Adelaide: current =1	2					2				
Annual days above 40°C (Adelaide): current =1	2–3					2				
Annual spells >40°C (Adelaide) current=0	0					0				

(Source: McInnes et al. 2003)

In summary, climatological research findings suggest that there has been a warming trend for the AMLR region throughout the latter part of the Twentieth Century, and projected climate change studies suggest that this trend is likely to continue. The trend regarding rainfall volume, intensity and pattern for the region is far less clear, although projections suggest a drying trend in the future.

The impacts on the AMLR of warming and drying could be substantial because much of the region is relatively humid in contrast to surrounding areas (see Fig. 2). The region is in effect an 'island' of cool, moist environmental conditions surrounded by relatively arid conditions. Many case studies indicate that such 'islands' are highly vulnerable to rapid environmental change (MacArthur and Wilson 2001). This fact emphasises the need for timely responses to the anticipated change.

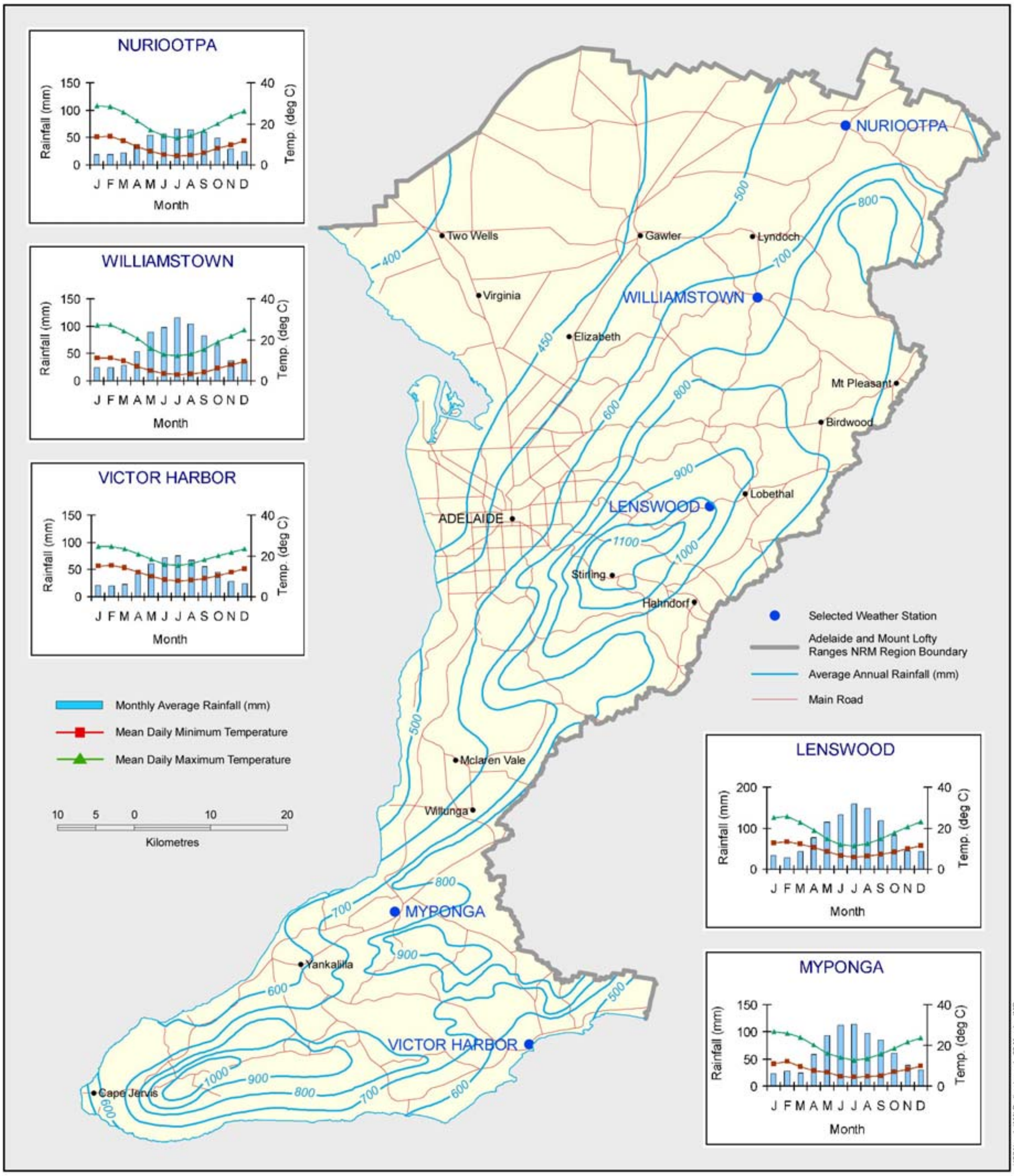


Figure 2. Rainfall isohyets for the AMLR NRM region based on averages from 1961–90

In the short-term, climate change may be difficult to detect within the region because of the high spatial, intra-seasonal and inter-seasonal variability in the local climate, especially with respect to rainfall. This variability can tend to mask subtle changes. The types of changes that might be observed include:

- later breaks in the winter growing season
- warmer days and nights
- hotter, longer hot spells
- less reliable rainfall

- less frequent, but more intense storm events
- changes in the timing of flowering and breeding cycles
- changing fire, runoff and pest management
- higher coastal storm surges.

It is important to note that there is significant scientific uncertainty in relation to climate change. While projected changes to climate are synthesised here, there are many uncertainties regarding the rates and extents of change and the form that climate change will take. McInnes et al. (2003) provides a useful guide to projected changes for SA, but because of the uncertain social responses to reducing Greenhouse gas emissions and the unpredictability of environmental reactions, the projections are only guides of possible future change (Schneider 2004; Kerr 2006). Information is being updated all the time, and the data and discussion will need to be updated as that material becomes available. The discussion here is based on current projections of possible futures, and attempts are made to incorporate the uncertainty while assessing appropriate NRM responses.

3.2 CLIMATOLOGICAL RESEARCH

There is ongoing research examining the causes, extent and potential impacts of climate change around the world and within Australia (Table 3). The review draws heavily from a report undertaken for the SA government by CSIRO on climate change, impacts and possible adaptation strategies entitled, McInnes K.L., Suppiah R., Whetton P.H., Hennessy K.J. and Jones R.N. (2003) Climate change in South Australia. CSIRO Atmospheric Research, Melbourne. The CSIRO review is being updated for SA in early 2006 and is due to be completed by mid-2006.

Table 3. Current climate change research with potential application to AMLR

Research Area	Research currently underway or in preparation
Detailed, downscaled reviews of projections on the region	• DEH, PIRSA, SARDI and DWLBC have funded CSIRO atmospheric research to update and downscale the 2003 projections for NRM Regions monthly and seasonal climate means. • SARDI is liaising with CSIRO and BOM who are examining projections for regional impacts of daily synoptic pressure conditions across south-east Australia. The project will focus on the Murray-Darling Basin, examining how climate change will affect water supply and climate forecasting 3-13 months ahead. • BOM is also undertaking some climate change downscaling for Southern Australia
Monitoring and evaluation of climate change	• There is extensive monitoring and analysis of atmospheric, weather and climate conditions through BOM. • The National Tidal Centre (BOM) monitors and analyses sea levels. • DWLBC/CSIRO is beginning to examine and model rainfall changes through time within the AMLR, primarily with the purpose of better understanding potential impacts on water resources.

There may be opportunities for the AMLR NRM region to link in with current or future research work to request assessments of impacts of climate change on particular aspects of NRM. It may also be interesting for further research to examine how microclimates have been changing and are projected to change within the different contexts of urban and rural environments within the AMLR. Such work would extend the scope of current research and enable the downscaling of vulnerability analyses to provide specific information to guide management. Probably the best example of where such work has been undertaken to date in the region is the modelling undertaken by the Port Adelaide and Enfield council, outlined further on page 22, which downscaled projected climate change impacts on coastal and stormwater flooding in their local area (Jacobi and Syme 2005).

The vulnerability analyses below provide an overview of potential impacts, vulnerabilities and adaptation options across the different NRM sectors.

4. ANALYSING VULNERABILITY OF NRM TO CLIMATE CHANGE

The effects of an enhanced greenhouse effect on NRM will probably be complex and interactive. In many ways the emerging and anticipated pressures on our natural resources enhance the need to incorporate broadly sustainable ecological management approaches into NRM more generally. SA is working to develop such an approach via an integrated NRM management model (DWLBC 2006). As climate change will be an umbrella issue that will significantly influence most NRM processes in the AMLR, it may be increasingly difficult to dissociate issues of climate change from other important NRM issues in the region.

Climate change responses should be incorporated into integrated management approaches and governance structures within urban, peri-urban, rural and coastal environments. Responses to risk and vulnerability may require fundamental and, occasionally, expensive changes to management practices across industry and regions. Such long-term planning and investment will require informed projections, particularly in sectors such as water and biodiversity management.

> If climate change is only considered as a separate issue, rather than a change that could fundamentally alter NRM, with the potential to undermine sustainable systems, it will not be widely incorporated into planning and investment until change is significantly apparent. Important negative and irreversible impacts on natural resources could result from climate change due to the lack of coordinated planning and action at regional levels.

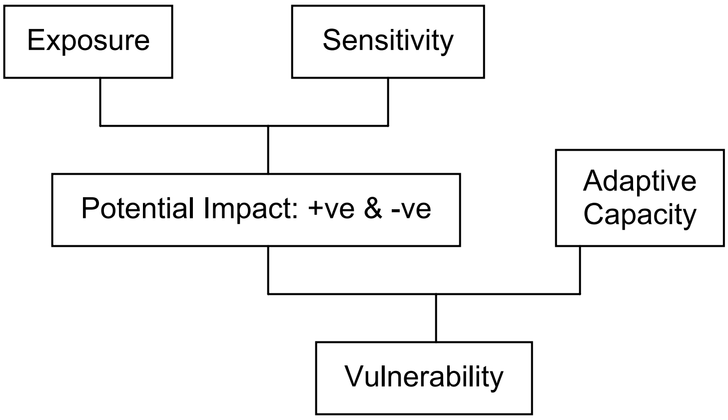
The IPPC defines vulnerability as 'The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity' (McCarthy et al. 2001). A range of approaches is available for assessing the vulnerability of systems to climate change (Dessai et al. 2005). Some of these approaches focus strongly on modelled climate projections, while others focus on adaptation to short-term climate variability based on risk assessments of current climates. Here, a methodology has been followed for vulnerability assessments (Fig. 3), which was published within a recent report for the Australian Greenhouse Office (AGO), by The Allen Consulting Group (2005). The report suggests a basic framework for initially assessing vulnerability. Beyond this vulnerability assessment methodologies are likely to vary according to the needs of the sector and may require highly detailed biophysical and socio-economic data analyses.

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)

Figure 3. Process used for vulnerability analyses

The levels of exposure and sensitivity are largely beyond the influence of any individual or group of NRM stakeholders in the region, although they can play their part in reducing greenhouse gas emissions (AGO 2005). The majority of adaptation actions are associated with developing the resilience of systems, and thereby reducing the sensitivity, and enhancing the adaptive capacity of management systems. All natural resource systems have a coping range, or some inherent level of resilience (McCarthy et al. 2001). If climatic conditions change, the coping range of systems may be exceeded and natural resources may be degraded as a result. Societal processes reliant on that resource will also be at risk.

There are still substantial uncertainties about the levels and manifestations of an enhanced Greenhouse effect (Pittock 2003, Lempert et al. 2004). There is also substantial uncertainty about the way changes to climate will affect our society: our environments, industries, settlements and lifestyles. Irrespective of this uncertainty regarding climate change, policy makers and managers need to support sustainable change management. They should attempt to act to allow for what is known, the scientific and policy uncertainties in the short-term, and begin to respond to the largely unknowable long-term requirements. A precautionary approach acknowledges that policies or actions that fail to take into account future risk could place a greater burden on societies than implementing strategies to respond to risk in the short-term. By weighing up the risks of actions and inactions, based on the cost and benefits of both, informed decisions can be made regarding the manner and extent of appropriate responses.

Due to layers of uncertainty regarding climate change science, and, yet, recognition that climate change could have major impacts on society, responses are often embedded in a broader risk management approach based on the Precautionary Principle (Fowler 2004). The Precautionary Principle advocates that just because we are uncertain of a particular situation, trend or likely outcome, planning or actions still should be taken to reduce the risks of possible hazards (UNEP 1992, Rao 2000). In other words, the Precautionary Principle should be applied and action undertaken to mitigate risk in cases where there are:

- threats of serious or irreversible damage
- lack of full scientific certainty
- cost-effective measures to prevent the impact of the hazard.

This is largely the approach that is being adopted by Australian governments, by some regions and industries, and by individual stakeholders as responses to climate change are being developed for NRM. SA is currently applying the Precautionary Principle within the context of policy and practices to mitigate greenhouse gases and adapt to climate change. A specific example is outlined in relation to sea-level rise (see page 22).

It is possible to respond to the uncertainty of climate change by considering the key processes within natural resource systems and determining whether the projected ranges of change fall within or outside critical thresholds of deleterious impact.

To date, there has been little work examining the specific risks to NRM that might eventuate from climate change in the AMLR. However, it is possible to begin to imagine the types of NRM scenarios resulting from the climate change projections. As a result, the vulnerability assessments were developed by applying a methodology outlined by The Allen Consulting Group (2005), and triangulating the available scientific evidence of climate change risks to NRM systems, with projections for change from McInnes *et al.* (2003) and input from key stakeholders. The assessments are rational subjective analyses of the available scientific evidence for projected climate change impacts on systems for 2030, which link climate change projections to respective sectoral issues and provide a baseline for discussion of the impacts that are likely to be most important to respective sectors.

While some relevant case studies were available from within the AMLR region to support more detailed analysis, in most cases that information was not available or, because the scientific information is based on projections of future scenarios, the outcomes were still highly uncertain. More work is required to define biophysical thresholds and system vulnerabilities to enable detailed assessments of the very complex issues.

Further, more targeted and detailed vulnerability analyses will be required for all key natural resource assets and industries in the future.

This review is an initial step to broaden understanding of projected climate change impacts on NRM in AMLR. The management of natural resources often involves complex processes and requires detailed supportive research to fully understand the causes, impacts and wider consequences of particular pressures. It is important also to note that there could be both negative and positive impacts on natural resource systems and management practices as a result of climate change. Therefore, in particular cases more detailed cost/benefit analyses will be required for better understanding of how responses should be targeted.

Specific impacts of climate change, issues relating to vulnerability and adaptation options for different NRM sectors are outlined below in relation to different sectors and hazards. The sectors were representative of the range of issues that were influenced by the AMLR Board's planning and investment into the management of natural resources. Several hazards including floods, bushfires, invasive species, and risks associated with land management and air quality are examined as separate key issues because they influence vital components of the AMLR Board's work. Some of these issues are not a direct responsibility of the Board, but are still of vital related interest to sustainable NRM within the region and the state of South Australia. In fact, many of these issues are national and international in scope and also raise significant NRM governance issues at those scales.

5. RIPARIAN FLOOD MANAGEMENT, SURFACE WATER AND GROUNDWATER RESOURCES

5.1 CLIMATE CHANGE IMPACTS

The management of water within and from the AMLR may become an increasingly complex issue as climate change potentially reduces the amount of average rainfall and runoff, but at the same time, increases the frequency of hazardous events leading to flood and erosion events (Schreider et al. 2000). Hydrological modelling suggests that while average runoff is likely to decline for the Mt Lofty Ranges, larger floods will become less rare.

Riparian flooding is primarily caused from significant individual falls, or from a series of substantial rainfall events over a short period within the AMLR. Rainfall must supply water beyond a threshold within a catchment to cause streamflow. Additional factors influencing the attainment of this threshold are rates of evapotranspiration, the slope, permeability of surfaces and water storage capacity of soils, and the amount and type of vegetation and surface cover.

As climate change proceeds, more intense and more frequent extreme rainfall events are expected for Adelaide in Summer, Winter and Spring (McInnes et al. 2003). Similar trends have already been recorded in regions influenced by similar climatic regimes in the western US and in southern Europe.

Table 4. Vulnerability of AMLR riparian flooding to climate change

Exposure	Sensitivity	Impact	Adaptive capacity	Vulner-ability
Medium	**Medium**	**Medium**	**Limited**	**Medium–High**
• Flood impact directly related to climatic conditions. • More extreme events increasing likelihood of flood thresholds being reached more often.	• Although only a relatively small area is at risk of flooding, the impact is significant on human welfare, infrastructure and economic activity. • Any increase in frequency in flooding will be a significant economic issue.		• Increase infiltration, reduce runoff, maintain calming areas. • Increase drainage and runoff storage capacity. • Limited as area is highly developed and space is required for adaptation options. • Significant investment required into infrastructure to bring about change.	

During extreme rainfall events, where a large amount of water is precipitated in a short period of time, threshold levels for runoff are rapidly overcome and while some deep infiltration of soils may result, direct overland flow is substantial. When these extreme events continue for a longer period of time and over impermeable surfaces, riparian and floodplain flooding is more likely to occur (Table 4). Such conditions are predicted to become more common with climate change, increasing the risk of riparian flooding in the region as drainage and effluent management systems lack the capacity to cope with the increased flows (Howe et al. 2005, Jacobi and Syme 2005). Where riparian flooding meets coastal influences, such as high tides, there is particular potential for local inundation (see page 22).

Surface water resources are used for drinking water, industrial and agricultural uses, and recreational and conservation purposes within the AMLR (South Australian Government 2000). Reviews suggest that climate change could reduce surface flow and inflows into the AMLR storage reservoirs by 2025 (Table 5) (Charles et al. 2004; Gillooly and Hutson 2005).

There is a non-linear relationship between rainfall and streamflow. That means any single unit reduction in rainfall in the Ranges is likely to lead to a 2–3 unit reduction in streamflow. Future projections are suggesting that there will be reductions in average rainfall from May to October, the most important period to generate runoff in the Mount Lofty Ranges. Modelling from Gillooly and Hutson (2005) of the Cox Creek catchment in the upper Onkaparinga catchment suggest that a 10% reduction in rainfall, the upper limit for projection by 2030, would cause a 24% reduction in stream flow. Such reduced average run-off rates could lead to a greater probability of the phenomenon of green droughts, where there is sufficient rainfall for crop and pasture growth but insufficient for run-off to fill dams and reservoirs. The quality of water could decline with reduced average flows, increasing evaporation, but with extreme erosive events increasing the sediment loads in streams. Such changes will have significant impacts on freshwater ecology (see page 26).

Work by SA Water has suggested that if a mid-point of the CSIRO projections is the eventual outcome, there will be on average a 10% reduction in in-flows, or approximately 20 GL less water, compared with current intake into Adelaide's reservoirs by 2025 (South Australian Government 2004). The 10–15% reduction in average annual rainfall in south-west Western Australia (WA) has led to an approximate halving of the amount of water flowing into Perth's reservoirs since the 1970s (Pearcey and Terry 2005). Evaporation losses from reservoirs are also likely to increase in association with rises in temperature.

Urban and industrial water supplies in the AMLR region are partly provided from local resources and partly from Murray River water. During dry years, over 80% of Adelaide's water can be supplied via pipelines from the Murray River. Projected climate change in the Murray Darling Basin is likely to result in reduced flows, and hence a reduced capacity to dilute saline groundwater accessions to the River. Climate change may also increase irrigated crop water demand in response to higher temperatures. Murray Darling Basin Commission (MDBC) has used CSIRO projections to produce indicative estimates of the impact of climate change over the Basin. This modelling suggests an 11% or 2550 GL reduction in flows and an average increase in salinity of 26 EC units at Morgan by 2023 (Andy Close, Water Resources Group MDBC). These levels of change in river condition could enhance conflicts of interest in the distribution of water resources and will continue to require careful anticipatory responses.

Groundwater resource responses to climate change are less clear, partly because the hydrology of groundwater is not fully understood. While some groundwater resources are highly sensitive to rainfall changes, others are insensitive in the short-term. Reduced rainfall could lead to reduced rates of groundwater recharge and subsequent reductions in problems associated with waterlogging and secondary dryland salinity. On the other hand, reduced water-use efficiency may result from more unreliable and variable rainfall, and occasional extreme rainfall events could lead to large slugs of water penetrating through to replenish perched aquifers (Table 6).

Table 5. Vulnerability of AMLR surface water resources to climate change

Exposure	Sensitivity	Impact	Adaptive capacity	Vulner-ability
High	**Medium**	**Medium-High**	**Significant**	**Medium**
• Direct reduction in rainfall and runoff. • Increase demand with warming, drying. • Droughts lead to reduced quality of Murray water, which buffers the AMLR catchment system.	• Buffering capacity of Murray river water significant. • Policy to increase restrictions on use work effectively.		• Technological innovation. • Reduce wasteful use, potentially through an economic rationalisation across industry including water trade-offs and market-based instruments. • Increase water holding and piping capacity in region. • Desalinisation plants.	

Table 6. Vulnerability of AMLR groundwater to climate change

Exposure	Sensitivity	Impact	Adaptive capacity	Vulner-ability
High	**Medium**	**Medium-High**	**Significant**	**Medium**
• Direct reduction in average rainfall and runoff and infiltration. • Increases in water demand with warming, drying. • Much long-term supply will remain unaffected.	• Buffering capacity of Murray river water will remain, but rights in region almost all allocated. • Increasing demand to supply horticulture and dairy production. • Policy to increase restrictions on use work effectively.		• Technological innovation. • Reduce wasteful use. • Increase groundwater recharge. • Water trade-offs to maximise use efficiencies.	

The experience of south-west WA is that reduced rainfall since the 1970s has slowed the rate of groundwater recharge and it is suggested that evidence of declining groundwater levels in some bores may be a result of this change (McFarlane & Ruprecht 2005). Salinity levels in creeks have increased as flow rates and subsequent levels of dilution have decreased in some areas.

5.2 ADAPTATION RESPONSE

Detailed vulnerability analyses need to be undertaken which incorporate the potential increase in the number and extent of floods within urban, peri-urban and rural areas. It may be a necessary adaptation response to model impacts on all key catchments and alter physical and planning management responses accordingly. There is already considerable work undertaken by Local Councils throughout the AMLR to mitigate impacts of floods. Examples of important strategies that are applied in the AMLR include the development of water-sensitive urban designs, flow-calming techniques and the establishment and expansion of wetland areas. For example, Salisbury Council has over 30 major wetlands to hold runoff.

There is a general lack of awareness of the impacts of floods, particularly within catchments that rarely flood. Already, projections of flooding along watercourses and coastal areas are sensitive issues in peri-urban and urban areas. Attempts at changes to planning rules or even the release of information concerning the potential for flooding by state government or local councils in the AMLR have led to substantial public opposition in recent times. Similar information concerning the impacts of climate change on flooding potential is likely to be similarly controversial. While soft techniques, such as reducing runoff from individual properties, have substantial potential, opportunities for improving drainage capacity in the short-term within urban areas could be limited (Howe et al. 2005).

Water should be more highly valued within SA (Cullen 2004). If the quality and quantity of surface water available declines significantly with climate change, we will need to upgrade the importance of water harvesting in the Mt Lofty catchments themselves, within the Murray-Darling Basin and on individual urban and rural properties (DWLBC 2005). As the value of water increases we will need to develop a range of mechanisms to represent that increased value within the community, while providing equity and assured supplies.

At the same time, numerous policy and technical mechanisms are available to increase supplies and improve the efficiency of those resources available to us, and many of these policy and pricing mechanisms are being applied regularly across SA. Government policy has a strong influence on water resource supply within the region, and some influence on consumption. Standing conservation measures exist on urban water use across the AMLR already, and considerable work is being undertaken to secure Adelaide's water supplies for the future. At a landscape level, there is an opportunity to harvest more water and to support programs that lead to better water management in general. The Salisbury Council has implemented the Aquifer Storage and Recovery scheme, which directs stormwater into aquifers to supplement natural recharge.

Adelaide recycles more than 20% of water from treated sewerage, the highest rates in Australia. Over 30% of Adelaide's vegetable production is irrigated with recycled sewerage, primarily via the 120 km pipeline network that distributes treated effluent from Bolivar treatment plant to Virginia market gardens. A similar system supplies water to the Southern Vales from the Christies Beach wastewater treatment plant.

Significant restrictions have been imposed on water use from ground, surface and mains water supplies in the region (DWLBC 2005). These restrictions are already changing behaviours throughout the community including changing species grown and garden types, and altering water availability for primary production.

The efficiencies of industrial, public and private uses must continue to be increased, including increasing use of rain and waste water, and the potential for increasing prioritisation of the use of high-quality water from Mt Lofty catchments. If the AMLR experiences a drying trend, the Murray-Darling Basin will increasingly act as Adelaide's lifeline, while itself coming under greater stress. Under a declining resource scenario, low-value irrigated agriculture may become increasingly vulnerable, particularly as the benefits of using that water resource for urban and other high-value uses becomes clearer.

- The AGO has recently funded a review entitled 'Development of No Regret Climate Change Adaptation Actions for Local Government', that is likely to involve analysis of costs and benefits of adaptation responses.
- The SA Bureau of Meteorology Flood Warning Centre works on research and information provision in relation to local flooding.

- Some specific work has examined impacts of climate change on surface flows within the region by Drs. John L. Hutson and Jane Gillooly (Gillooly and Hutson 2005), and flooding within the Port Adelaide-Enfield Council area (Jacobi and Syme 2005). There are also associated coastal flood impacts that are discussed below (see page 22).
- Several research groups have an interest in surface water resources impacts, including the eWater CRC, with involvement from the Adelaide University, DWLBC, SAWater and SARDI, aiming 'To be a national and international leader in the development, application and commercialisation of products for integrated water cycle management.'
- The Environmental Protection Authority (EPA) monitors water quality in the AMLR, although no specific work is being undertaken examining impacts of climate change.
- A detailed study of impacts of climate change on water resources has been undertaken for Perth (Evans and Schreider 2002). The DWLBC, Surface Water Group with CSIRO, Perth has been looking at the downscaling of global circulation models to a rainfall gauge scale to replicate daily rainfall records in the AMLR (Charles et al. 2004). Their research is being extended to downscale climate change projections within the global circulation models to produce adjusted rainfall data sets that will project climate change impacts on rainfall and hence catchment water resource availability.
- For further information regarding SA Government policy in relation to this issue refer to the State NRM Plan (2006); Tackling Climate Change: SA's draft Greenhouse Strategy (2006); Urban Stormwater Management Policy for South Australia (2005); Environmental protection (Water Quality) Policy (2003); Water Proofing Adelaide Strategy - A Thirst for Change (2003); and, State Water Plan (2000).

6. COASTAL MANAGEMENT

6.1 CLIMATE CHANGE IMPACTS

Coastal flood management will need to respond to impacts of climate change. There is evidence of historical rise of mean sea level at Outer Harbour, with an average rise of 20 cm relative to the land recorded over the century (Harvey et al. 2002). This result incorporates considerable local subsidence, however results are similar to changes globally which range from 1.1–1.8 mm per annum over the last hundred years. Approximately equal components of this rise are attributed to the melting of ice and to thermal expansion of seawater due to rising temperatures, and, according to the IPCC, 0.3–0.8 mm per annum of that rise could be attributed to global warming (McCarthy et al. 2001). Projections for sea-level rise are updated as new information is provided by the IPCC and other scientific studies. Recent scientific studies are in fact suggesting that projected rates of sea-level rise have been understated, and that rapid ice-melt at the poles and on major ice-sheets could lead to significant increases in sea level (Kerr 2006). More recent data from monitoring by the National Tidal Centre, Bureau of Meteorology suggests that since 1992 the rate of change has increased to closer to 5 mm per annum across the South Pacific.

IPCC projections of sea-level rise range from 0.09–0.88 m, with a median of 0.48 m, by 2100. The Coast Protection Board of SA (1992) has adopted a precautionary approach, and uses projected rises of 0.3 m by 2050 and 1 m by 2100 to inform planning considerations. As the Coast Protection Board SA (1992) states ‘this 1 m includes a small margin for greater than expected increase and for weather changes that could result in more storm surge and higher tides.’ In other words, they are not basing their planning on median or mean projections of sea-level rise, but rather on an upper end of the range. This is because the impacts of the rare events associated with high tides, local flooding, wave action and storm surges, in conjunction with sea-level rise at the upper end of the projected range, would have significant economic, social and environmental impacts.

For example, Jacobi and Syme (2005, p. 17) note ‘Under the Development Plan and State policy, all new development within the Port Adelaide-Enfield region is currently required to be safe from 100 year storm floods and a rise in sea level of 0.3 m. The policy also requires that new developments be adaptable to be safe to an additional sea level rise of 0.7 m.’ In conjunction with sea-level rise, as McInnes et al. (2003, pp. 43–44) note, ‘In winter, mid-latitude cyclones, which produce storm surge conducive westerly and south-westerly winds along the south coast, were found to decrease in frequency by about 20% in the South Australian region but increase slightly in intensity.’ The recent study of Port Adelaide-Enfield seawater and stormwater flooding risk by Tonkin Consulting for the Council suggests that the upper-end of the projections would translate to a 1 in 100 year sea defence threshold level (incorporating sea-level rise, tidal amplification, storm surge, wave effects, further land subsidence and 300 freeboard) to around 4.1 m (Jacobi and Syme 2005). Thus, if anticipated sea-level rises continue to materialise, climate change would significantly increase the risk of coastal flooding in the AMLR (Table 7).

Table 7. Vulnerability of coastal regions to coastal flooding due to climate change

Exposure	Sensitivity	Impact	Adaptive capacity	Vulner-ability
High	**High**	**High**	**Medium**	**High**
• Increase height of storm surge. • Increase occasional high-runoff linked to rainfall events. • Projections for extreme winds causing storm surges unclear.	• Low-lying residential and industrial areas of very high economic, social and ecological value. • Associated land subsistence.		• Protection by maintaining natural ecosystems, and establishing seawalls, embankments and floodgates. • Re-alignments, demountable flood-defences, pumps and storage in pipes and in surface ponds. • Lack of space and expensive infrastructure requirements.	

Beaches are an important recreational asset in the AMLR that will be affected by rising sea levels and other impacts of climate change. Associated dune systems are vital buffers to storm surges and erosive events. McInnes et al. (2003) suggest that the winds leading to storm surges may be less frequent, but increase slightly in intensity. In combination with increased average sea-level rise, it could be expected that individual erosive events will cause a greater impact on beaches (Table 8). Some evidence is suggesting that a one centimetre sea-level rise roughly equates to an increase in erosion of one metre of beach sand. Longshore drift may also be accentuated as wave action increases. The important function of coastal dune systems buffering the impact of storm tides and wave action would be reduced and the costs of replenishing sand on beaches will increase if beach erosion increases. This scenario of increased risk of beach erosion occurs in a context of AMLR urban beaches whose sand supply upkeep is already costly and increasingly problematical.

Wetlands, along the edges of rivers and near the coast itself, are vital for absorbing and storing floodwaters. They provide natural defences against storm surges. Of these, estuaries, mangrove ecosystems and salt-marshes along the northern section of the region's coastline perhaps offer the best example of highly sensitive ecosystems. These systems are sensitive to sea-level changes, sediment loads and the salinity of the water. While these systems can, in their natural state, keep pace with changing sea-level rise with continuing sedimentation and migration, the rate at which sea-level may rise may exceed threshold levels leading to negative impacts on ecosystem health and productivity. These ecosystems are vital components of the health of estuarine and marine systems in the gulf, and any negative impact on these systems will have repercussions for marine systems in general.

The National Tidal Centre of the Bureau of Meteorology monitors and analyses sea level. Doug Fotheringham, Coast and Marine Conservation Branch of DEH and Nick Harvey of Adelaide University have examined both historic and projected impacts of sea-level rise on coastal ecosystems. In the Barker Inlet, for example, there has been a marked trend towards mangroves extending further inland at a rate of 10–15 m per year resulting in an encroachment of the saltmarshes of approximately 4 hectares per year within the inlet (Fotheringham 1994). Significant areas of saltmarsh are unable to extend further inland as levee banks prevent inland movement of the system. Because sea-level was considerably higher in the past, many saltmarsh communities have the potential to migrate inland onto low-lying coastal fringes, but any levee banks, embankments, roads or urban development will prevent this adaptive process. As part of the Australian national coastal vulnerability

Table 8. Vulnerability of AMLR beaches to climate change

Exposure	Sensitivity	Impact	Adaptive capacity	Vulner-ability
High	**High**	**High**	**Medium**	**Medium-High**
• Direct impacts of sealevel rise apparent and projected. • Associated changes to climate and runoff regimes likely to directly impact upon coastal state and systems.	• Tidal, estuarine and dune coastal systems highly dependent on sea-level, tidal range, flooding. • Beaches, estuaries, mangroves, saltmarshes important recreational, biodiversity and industry assets. • Internal resilience restricted by historical development.		• Natural systems have ability to adjust depending on sea-level. • Spatial adjustments limited by development, fragmented and invaded systems. • Engineering solutions reduce impacts of depleted environmental services. • Problem = Very fast change predicted.	

assessments of 1995, research examined potential impacts on the Northern Spencer Gulf (Harvey et al. 1997). Again it was found that the levee bank at Pt Pirie would severely restrict the adaptation of the saltmarsh system to sea-level rises associated with climate change.

The Adelaide Coastal Water Study has drawn the link between sea-grass health and the levels and quality of runoff from the land (EPA 2006a). As seagrass seems to be negatively impacted by high levels of suspended sediment, more extreme weather events, leading to more erosive runoff, could enhance the risk for coastal ecosystems.

6.2 ADAPTATION RESPONSE

The management of coastal, intertidal and dune ecosystems will parallel much of the discussion of biodiversity conservation below. The systems need to be disturbed as little as possible so that the natural in-built resilience and adaptive responses to change are able to function effectively. For beach retention, for example, dune systems must remain accumulative, and should be disturbed as little as possible. Within inter-tidal systems, mangroves and saltmarsh should be allowed to migrate inland wherever possible. The associated impacts of more extreme rainfall events and sea-level rise may require the development of new flood and stormwater strategies, particularly in low-lying suburbs of Adelaide.

Engineered sea defence and drainage solutions will also be important. Many techniques are used already to reduce the impact of storm events and limit the impacts of coastal inundation, including sea walls and levee banks, tidal barriers, pumps and ponding areas (Coast Protection Board 1992, Jacobi and Syme 2005).

There is a broader planning question of how the vulnerable coastal strip – a prime asset for Adelaide – is managed. Some discussion internationally is suggesting that highly-valuable long-term infrastructure assets will be moved to higher ground because of similar concerns. As high value developments are undertaken near the coast, risk assessments may need to account for higher sea levels as public perception changes. The climate change implications for planners of coastal infrastructure are substantial.

- The Port Adelaide and Enfield Council have done some in-depth studies of the impacts of projected change on flooding around their council area (Jacobi and Syme 2005). The projected increased flooding potential in the Port Adelaide case is also associated with a measured sinking of the landscape (Harvey et al. 2002).
- The National Tidal Centre, Bureau of Meteorology has established an Australian and Southwest Pacific Sea Level monitoring project to improve the knowledge of sea level rise in our region. One of the monitoring stations is positioned at Port Stanvac.
- Much work is already undertaken by the Coast Protection Board SA to undertake research and maintain coastal dune and barrier systems to reduce the economic impacts of tide and wave action along a Metropolitan coastal system that would be in disequilibrium without human intervention.

For further information regarding SA Government policy in relation to this issue refer to the State NRM Plan (2006); Tackling Climate Change: SA's draft Greenhouse Strategy (2006); No Species Loss: A Biodiversity Strategy for South Australia 2006–2016 (2006); Adelaide's Living Beaches: A strategy for 2005–2025 (2005); Estuaries Policy and Action Plan (draft 2005); Living Coast Strategy (2004); and, South Australian Marine Planning Framework (In preparation).

7. BIODIVERSITY CONSERVATION

7.1 CLIMATE CHANGE IMPACTS

While many productive systems will be relatively adaptable to the different conditions imposed by climate change by means of rapid alterations in management strategies, native ecosystems are likely to be particularly vulnerable to climate change (Kappelle et al. 1999). The fact that much of the AMLR region forms a relatively isolated cool and humid biological island within a drier Mediterranean landscape, will exacerbate the risk. There will be a range of complex interactions between changing climates and ecological systems.

Terrestrial biodiversity in the AMLR is already in decline. Due to past clearance of habitat and other threatening processes, including exotic species invasion, more than 50 plant and animal species have become extinct since European settlement of SA. Currently 22% of the State's vascular terrestrial plants and 30% of vertebrate fauna are classed as endangered, vulnerable or rare (EPA 2003). The AMLR native ecosystems have been significantly altered with only 13% of the original terrestrial vegetation remaining (Bickford and Mackey 2004, Tait et al. 2005). Based on the amount and distribution of remaining habitat in the Mount Lofty Ranges, ecologists predict that 50% of the bird species that once inhabited that area will become regionally extinct (Paton et al. 2003). The medium-sized mammals have also come under significant pressure from land clearing, disease, competition and predation. Without substantial actions to regenerate degraded ecosystems, numerous species will not be able to maintain viable populations in the remaining areas of habitat.

While predictions of species survival and impact in the Adelaide Hills relate to current and historical land management, climate change will create additional pressures for such species, as well as for others not currently recognised as threatened. Already, the reserve system does not adequately represent the diversity of ecological communities or ecosystems that existed in the region before European settlement. As a result of climate change, the AMLR conservation reserves will less adequately represent local native species and ecological communities and the importance of biodiversity outside of reserves will need to be enhanced (Hannah et al. 2002, Hughes 2003, Araújo et al. 2004).

There will be variable impacts of increasing concentrations of CO_2 on vegetation germination, establishment, growth and regeneration. CO_2 fertilisation will affect species with C3, C4 and CAM photosynthetic pathways to different extents, dependant upon numerous physiological constraints (Ward et al. 1999, Dukes 2000). As most plants will be able to fix more carbon per unit water, energy or nutrient, associated physiological changes can be expected, including for example, higher carbon:nitrogen ratios in plants and seeds. Some species, including numerous invasive species may benefit from increasing concentrations of CO_2, which will alter the ecological balance (see page 33). Work by the AGO has indicated that some plant species are more susceptible to frost damage at higher concentrations of carbon dioxide.

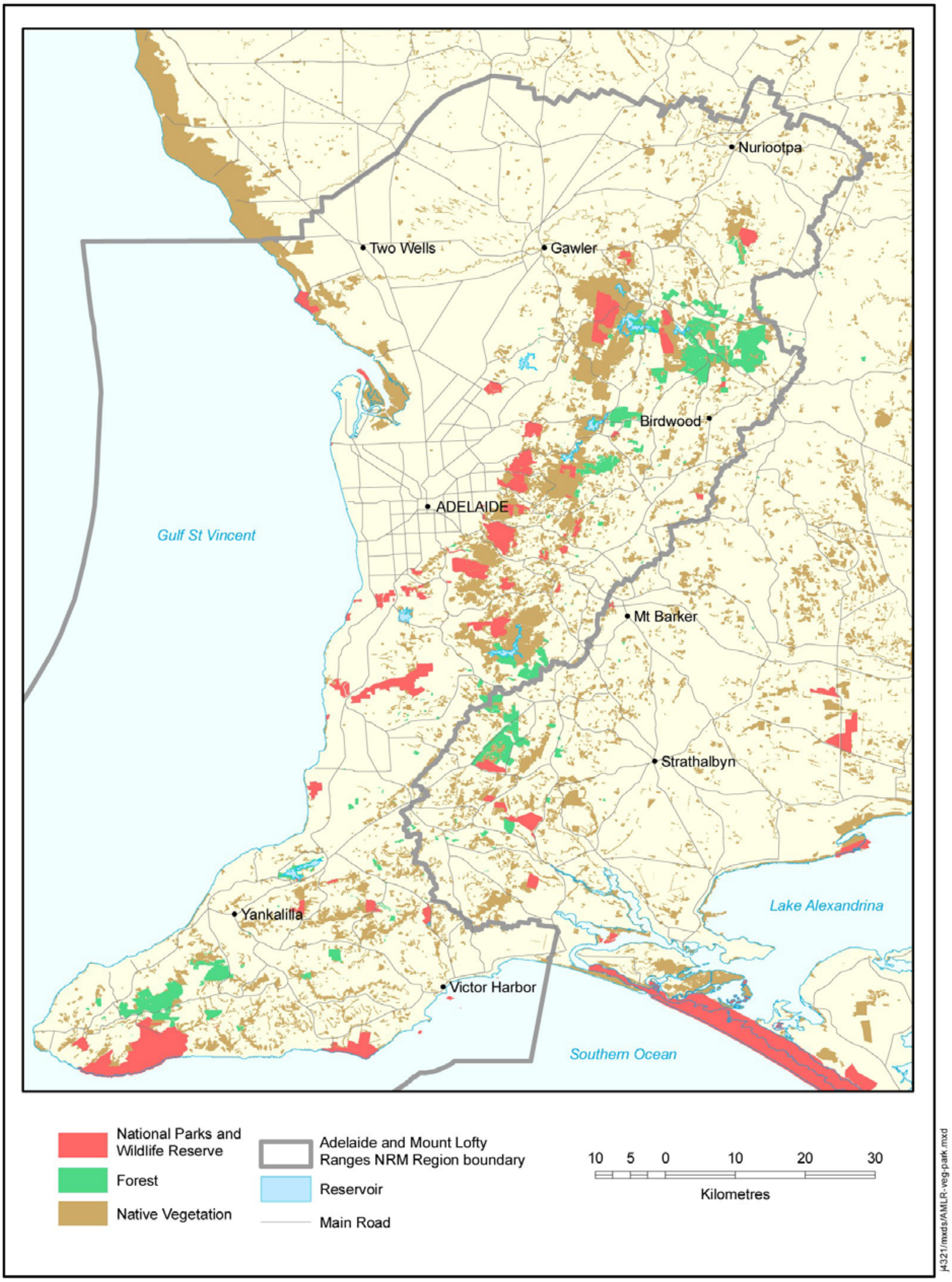


Figure 4. Significant areas of native vegetation and planted forest in the AMLR

Changes in temperature, precipitation and evaporation are likely to have impacts on ecosystems, the composition of communities, population mixes within species and the timing of activities by organisms. Flowering time in many plants will not remain stable in the face of substantial changes in the timing and intensity in their climatic triggers. Studies in the Northern Hemisphere, for example, are suggesting that the onsets of Spring, as marked by the flowering of key indicator species, are on average arriving earlier each year (Cayan et al. 2001, Root et al. 2005). Beaumont and Hughes (2002) examined potential climate change impacts on butterflies in Australia and suggested many species will be at risk as their bioclimatic envelopes and associated potential habitats shrink in size.

A review by Chambers et al. (2005, p. 15) suggests that climate change is likely to impact significantly on Australian bird populations' 'geographic range, migration patterns, morphology, physiology, abundance, phenology and community composition.' While case studies for bird species in rapidly changing climates have been undertaken, SA studies are under-represented. Worryingly for the AMLR, Chambers et al. (2005, p.2) point out that 'Montane species are predicted to be particularly vulnerable because the area of suitable habitat becomes progressively reduced with increasing altitude.' Plants that are dependent upon substantial periods of inundation in swamp communities or on damper, more-sheltered slopes of southerly aspect, are likely to be at significant risk from increased periods of drying. In one example of the complexity of potential impacts, birds that feed on amphibians could be affected as many amphibians are highly sensitive to temperature and soil and air humidity levels, so warming, drying conditions could have negative effects on their populations. In another example, AMLR plant communities dominated by *Eucalyptus obliqua* (Messmate, Stringybark) or *Eucalyptus ovata* (Swamp Gum) are mostly found on moist but well-drained slopes and poorly drained areas respectively (Costermans 1981). Such forest communities may be highly responsive to warming and drying in the AMLR. The complex responses of native species to bushfires are only partially understood, and changing bushfire regimes (see page 49) could greatly influence the composition and functioning of ecosystems.

Table 9. Vulnerability of AMLR terrestrial biodiversity assets to climate change

Exposure	Sensitivity	Impact	Adaptive capacity	Vulner-ability
High	**Medium**	**Medium-High**	**Medium**	**Medium-High**
• Climate change creating manifest change in ecological systems. • Particularly in cooler, humid valley and montane environments.	• Most local biodiversity highly adapted to variable, hot, dry conditions. • Diverse flexible ecosystems require cooler, wetter triggers for ecological and physiological processes. • Trends in climate will have significant impacts on bioclimatic niches of species, including Eucalyptus spp.		• SA Mediterranean climatic species and ecosystems highly adaptive to variable climatic conditions across time and space. • Problem = Very fast change predicted. • Spatial adjustments limited by disturbed, fragmented and invaded systems.	

It generally holds that the most vulnerable biodiversity will be those species and systems with smaller populations or a smaller adaptive range, and this principle will be reinforced under climate change. Limited populations and/or ranges suggest that a species is marginal to the area, has become isolated due to changing conditions, or has a very small niche that could become unstable quite easily. Terrestrial ecosystems will be at least risk from climate change when they can remain intact and maintain their ecological integrity within their current location. The most vulnerable species and systems are likely to be those that will need to respond to changing bioclimatic envelopes, yet cannot migrate with the changing conditions, either because they are unable to shift across the landscape by colonising new areas or there is no suitable area of an appropriate climatic range into which they could move. Unfortunately, outside of the reserve system, the majority of remnant vegetation within settled landscapes such as the AMLR is present in fragmented areas, mostly below threshold sizes necessary for many species to sustain populations to ensure survival, and often in degraded states (Geertsema et al. 2002, Hughes 2003, Opdam and Wascher 2003).

McInnes et al. (2003, p. 54) note that ‘increases in water temperature along the coasts and in the Gulf of St Vincent and Spencer Gulf could also have serious implications for coastal and marine biodiversity with possible impacts on algal recruitment, spawning and migration of marine fauna and health of sea grasses.’ Evidence from around the world is suggesting that warming seas and changing currents are leading to shifts in fish migratory patterns and populations. For example, plankton levels have declined with an average warming of the California Current off the US west coast (NAST 2000). These in turn have impacts on biological systems dependent on fish in food chains and on fishing industries. A recent review of sea bird reproduction around Scotland, for example, is drawing the link between climate change and poor reproduction levels. Other coastal biodiversity issues have been discussed previously (see page 22).

Freshwater biodiversity could be influenced substantially by the changing conditions. Some wetlands and other water dependent ecosystems are highly dependent on a relatively small amount of runoff. As frequency of rainfall events may change, rarer larger floods, lower average flows, warmer waters and longer dry periods may all significantly impact on wetland species composition and other highly moisture sensitive ecosystems. More intense erosive rainfall events play a significant role in increasing freshwater turbidity and nutrient loading, with associated impacts on the freshwater ecology, including the potential for higher levels of eutrophication or more algal blooms.

The immediate Adelaide hills and urban forest provide enormous value, in the form of biological conservation, local recreation, aesthetics and amenity to the inhabitants and visitors to Adelaide. While less easily quantified than iconic reserves and species, the value of high quality living spaces associated with the Mediterranean climate of the AMLR is substantial. Perhaps more than the negative impacts of degraded natural ecosystems on economic returns from tourism, if urban and peri-urban spaces are no longer as attractive to live in, visit, work and play, economic impacts on regions such as AMLR could be enormous. People's perceptions of liveability are likely to be a fundamental component of future development in the AMLR region.

Table 10. Vulnerability of AMLR freshwater biodiversity assets to climate change

Exposure	Sensitivity	Impact	Adaptive capacity	Vulner-ability
High	**High**	**High**	**Limited**	**High**
• Runoff variability likely to exceed rainfall variability. • Most catchments in region very short and highly dependent on regular rainfall. • Sea-level rises will influence surface flows.	• Many freshwater ecological systems already extremely marginal. • Salinity, pollution and turbidity levels will all increase with reductions in average flows.		• Limited by lack of excess water available in system. • Potential to reduce harvesting for productive uses and reduce polluting impacts to ensure environmental flows are available for ecological systems.	

7.2 ADAPTATION RESPONSE

An integrated planning response will need to recognise that species and ecosystems require time, space and resilience to adjust effectively to change. While specific studies that review projected impacts of climate change on the biodiversity of the AMLR are limited, we can work to improve the resilience of current natural systems now. This is a major focus of the first integrated State NRM Plan, which has its primary goal 'Landscape scale management that maintains healthy natural systems and is adaptive to climate change' (DWLBC 2006), and for the conservation strategy, 'No species loss - A biodiversity strategy for South Australia 2006–2016' (DEH 2006).

The ability of native species and ecosystems to remain within bioclimatic envelopes by migrating along climatic and geographical gradients will be a fundamental component of any adaptive response which aims to maintain their ecological integrity and genetic heterogeneity in an era of climate change (McIntyre and Hobbs 1999, Geertsema et al. 2002). Modelling applications can suggest potential climate change impacts on the bioclimatic envelopes in which species and communities are found (Hannah et al. 2002, Pearson and Dawson 2003, Thuiller 2004, Pyke and Fischer 2005, Saxon et al. 2005). The fossil record suggests that ecosystems have been relatively adaptable to climate change, but largely over longer time frames than predicted (Kappelle et al. 1999). The good news is that ecotones, or regions of mixed communities on the boundary of separate ecosystems, have been shown to migrate relatively swiftly across the landscape and, if linkages are maintained between natural systems, species and individuals of both plants and animals can be highly mobile (Allen and Breshears 1998).

There is a particular concern with the management of disjunct patches in the landscape of remnant vegetation and their associated fauna. Ecosystem degradation and fragmentation ensures that dispersal routes for native species will be severely disrupted without research, planning and action to create and conserve ecological linkages and buffers. Dispersing animals are particularly vulnerable to bushfires and predation by foxes and cats because they are unfamiliar with escape routes and refuges. The understanding of the relationships between biodiversity and climate change at species and community levels is generally poor and must be improved in order to develop adaptation options.

Some species/communities/ecosystems will have nowhere to move to, particularly those currently adapted to the cooler, wetter climates of hilltops, gullies, shaded slopes or southern coastal limits. Many other species will not be able to adjust in association with their ecological assemblage. Actions relating to these species could require particular planning so that they remain as intact as possible. In fact, they may demand specifically tailored intensive management programs. For example, as wet forest ecosystems on the tops of hills in the Mt Lofty Ranges experience a drying and warming trend they will have nowhere to migrate and local extinctions might be expected. Many species will still be able to survive and reproduce within their less-than-optimal range, but their competitive ability will be substantially reduced. Where in situ conservation programs are seen to be at risk, contingency ex situ conservation plans for the strict preservation of native species may need to become a larger component of management approaches for these species.

Conservation priority should be given to the protection and revegetation of areas with indigenous species adjacent to large, relatively undisturbed areas, with cores remote from mechanical access and edge effects. In general terms, larger areas contain more species, are more likely to sustain stable species populations, and will be least affected by hazards such as fires, disease or human disturbance as climate changes. The shapes of conservation areas and connections to other populations of species have become important components of landscape management to improve the resilience of ecosystems. A need exists to identify key conservation priorities within different bioregions under changing climatic conditions, to protect remnants and to provide suggestions of the methods or extent of revegetation required to meet threshold levels of conservation within different ecosystems. This may be a particular challenge for the AMLR because, like most SA regions, native ecosystems have been selectively cleared in the most productive or habitable areas, and planning for biodiversity outcomes must account for numerous other interests.

Conservation reserves with linkages and buffers in the landscape will not be the adaptation solution for all species, in all locations. However, any adaptation strategy will need to strengthen biodiversity linkages and buffers in the landscape to allow or even support invasivity of desirable native species along temperature and precipitation gradients. Reserves and associated native vegetation on private land with substantial topographic and edaphic variability, and resultant habitat variability in the AMLR, could be more advantageous than simple, uniform regions. In diverse regions there will be more opportunities for any particular species or systems to find refuge as climate changes, which could lead to conservation advantages in the Mt Lofty Ranges (Hannah et al. 2002).

As climate change will be comparatively rapid in an ecological sense, many species, communities or ecosystems will have to adapt or move quickly in that context. As mentioned above, some species, especially animals are likely to be able to move relatively quickly, while other, particularly long-living plant species with little dispersal ability and specific establishment requirements are unlikely to move quickly, if at all. There is also the risk that linkages in the landscape may benefit species such as invasive plant and animals, and feral predators in particular, over native species (see page 33).

A broad strategy for biodiversity conservation in an era of rapid climate change might involve elements such as:

- research to identify biophysical and ecological components vulnerable to climate change (see for example Sutherst et al. 1998)

- stricter protection of relatively undisturbed, contiguous ecosystems by extending, redefining and possibly supplementing reserves
- reduction of external pressures on reserves and remnants
- creation of mosaics, linkages and buffer zones across the landscape
- upgrading the importance of invasive species management.

Impacts on biodiversity might be minimised by applying a range of approaches, most of which would bolster current approaches to biodiversity management in general, by reducing external pressures, creating buffers, mosaics, linkages, extending and redefining reserve areas.

- Some biodiversity vulnerability assessments are being undertaken by DEH's Science and Conservation Directorate in some key wetland areas of the AMLR, in particular the sphagnum moss wetlands within the Region.
- Doug Fotheringham for the Coast Protection Board has done some work on mangrove/salt-marsh succession resulting from coastal impacts.
- Mark Lethbridge, Flinders University has utilised details of solar radiation and many other soil, rainfall, topographical and geological data to predict bird and plant distributions. Work is currently underway at Flinders to examine how projected climate change will influence these distributions.
- The Bureau of Meteorology, Macquarie University and Monash University are developing a national database on the ecological impacts of climate change (www.bom.gov.au/bmrc/clfor/cfstaff/lec/NEMD.htm).
- For further information regarding SA Government policy in relation to this issue refer to the State NRM Plan (2006); Tackling Climate Change: SA's draft Greenhouse Strategy (2006); No Species Loss: A Biodiversity Strategy for South Australia 2006-2016 (2006); NatureLinks (2003); and, Farm Forestry: Designing for Increased Biodiversity (2002).

8. INVASIVE SPECIES

8.1 CLIMATE CHANGE IMPACTS

With rapid climate change, highly invasive, exotic species are likely to have greater ecological and aesthetic impacts in many landscapes. As most exotic weeds and animals are good colonisers after disturbance and within stressed ecosystems, they are predicted to respond favourably to climate change as local ecosystems and species are threatened by changing conditions. Important insects, such as biological control agents, could also be affected as changing climates alter the populations and activities of vectors such as mosquitos. This issue also raises questions of the impact of climate change on infectious disease and other aspects of human health, which are beyond the scope of this study.

Many of the most important invasive species are derived from particular agricultural, pastoral, garden and forestry systems and their ranges are often associated with these production systems. The distributions of these invasives are not likely to change markedly, except where they are linked to geographical shifts in the agro-ecosystems themselves. Many exotic weeds in SA are C4 photosynthesis-type species, so the comparative impacts of elevated CO_2 concentrations and climate change on species with C3 or C4 photosynthesis types are likely to be important (Dukes 2000). Elevated CO_2 could make perennial weeds that reproduce from rhizomes harder to control with herbicides (Ziska et al. 2004). If climate change impacts disturb native species, it may create opportunities for agricultural weeds to become more invasive within native vegetation reserves and remnants. Other specific impacts may be important. For example, more summer rain could change population dynamics of pest animals such as rabbits and mice.

Several invasive species are restricted in their range within the AMLR, but with a warming, drying trend, increased summer rainfall and more regular flooding they have the potential to disperse further throughout the region.

Many species have the potential to invade natural systems but are restricted in their range by an inability to spread into intact natural systems or they are adapted to a particular climate. This is true for terrestrial, coastal and marine systems. Golden wreath wattle (*Acacia saligna*), a native of WA, is currently restricted in its range to the Adelaide Hills face zone and the lower rainfall eastern hills zone (Virtue and Melland 2003). However, with a warming, drying trend it may be able to colonise large or new areas of the AMLR, particularly in the southern Fleurieu Peninsula (Knapp & Canham 2000, Buckland et al. 2001). For example, modelling of the potential distribution of an Indian native, *Acacia nilotica* suggests that under some climate change scenarios that species may be climatically adapted to areas of southern SA (Kriticos et al. 2003). Some feral animals may become more prevalent if conditions become more favourable. For example, mice populations reduce in cold weather, which may become less common.

Table 11. Vulnerability of AMLR to invasive species due to climate change

Exposure	Sensitivity	Impact	Adaptive capacity	Vulner-ability
Medium	**Medium**	**Medium**	**Medium**	**Medium**
• Uncertain impacts, although many invasive species are good competitors in changing environments. • More drought, storm and fire impacts will increase disturbance in terrestrial, freshwater and marine ecosystems.	• Invasive species already present and having significant impacts. • Increased systems disturbance would enhance opportunities for invasion. • Currently largely intact systems are likely to be able to resist further invasion.		• Invasive species control is already difficult in many cases. • Integrated pest management techniques are improving. • Dependent upon broader conservation processes.	

Fires in natural systems change species composition and structure for both flora and associated fauna. Many important invasives, such as Cape broom (*Genista monspessulana*) and boneseed (*Chrysanthemoides monilifera*) are good colonisers after disturbance, and such invasive species should be closely monitored. Other native species, such as kangaroos, may be advantaged over other more vulnerable native species and for that reason, specific native ecological assemblages may be disrupted.

8.2 ADAPTATION RESPONSE

An assessment of the vulnerability of native vegetation and productive systems to invasive systems under different climate change projections will be fundamental. Modelling of the types and ranges of impacts climate change will have on species and systems would provide important guides for planning. This process will involve detailed assessments of climate change impacts on fire regimes (see page 49).

Early recognition of, and responses to, potentially invasive species would enhance effective management. A major focus of plant and animal control programs for biodiversity conservation in an era of climate change will be the focussed management in and adjacent to native ecosystem fragments and migration corridors. Biosecurity strategies, such as risk management assessments, should incorporate climate risk assessments that take into account climate change predictions. The availability and use of different potentially invasive species in nurseries and gardens may need to be re-evaluated as climate change may increase the numbers of potentially invasive species.

- Some work within DWLBC Pest Animal and Plant Control and the CRC for Weed Management is examining the risks of current and potential weeds.
- For further information regarding SA Government policy in relation to this issue refer to the State NRM Plan (2006); Tackling Climate Change: SA's draft Greenhouse Strategy (2006); No Species Loss: A Biodiversity Strategy for South Australia 2006–16 (2006); A Biosecurity Strategy for SA (2005); and, Weed Strategy for South Australia (2003).

9. PARKS AND GARDENS

9.1 CLIMATE CHANGE IMPACTS

The cultural heritage of many gardeners in the region is associated with European traditions, and as a result many people cultivate and enjoy species from the temperate Northern Hemisphere (Tait et al. 2005). Similarly, many parks and recreation areas across the AMLR have been created to mimic a European historical context that requires extensive management and high levels of irrigation. In particular, temperate park and garden arrangements, including the maintenance of extensive green lawns throughout summer, are rarely well adapted to the region's Mediterranean climate without significant additional watering. Private and public gardens could be placed under increasing stress by a combination of a warming, drying trend, more variable rainfall and increasing restrictions on water use within urban settings.

Table 12. Vulnerability of AMLR parks and gardens due to climate change

Exposure	Sensitivity	Impact	Adaptive capacity	Vulner-ability
Medium	**Low**	**Low-Medium**	**Significant**	**Low**
• Hot spells are likely to increase. • Water restrictions are a major policy response of government in relation to reduced runoff.	• Different gardens types. • Many European garden types, including vegetable gardens sensitive to hot spells or water use restrictions. • Ovals, golf courses and other lawned spaces highly sensitive to changes in irrigation.		• Micro-managed home gardens can be rapidly adjusted to respond to resource availability. • Indigenous and other gardens adapted to low rainfall available. • Traditional European style garden may be less adaptable to change. • Broader application of water conservation technologies, such as drip irrigation systems. • Water re-use strategies allow for irrigation of public areas.	

9.2 ADAPTATION RESPONSE

For some time there has been a move in nurseries to promote xerophytic species, which may or may not be native/indigenous. Such a trend away from gardens that are highly dependent on additional watering may be the principle adaptation response. Improving irrigation systems, including the use of drip irrigation systems and irrigation during times of lower evapotranspiration, creates significant efficiencies.

Many councils have introduced water re-use strategies from sewerage treatment and stormwater (see page 17). Keen gardeners are able to use grey water or collect water in tanks to ensure a supply or protect sensitive species during hot spells. Another noticeable change includes a trend away from gardens altogether into higher-density housing.

- For further information regarding SA Government policy in relation to this issue refer to the State NRM Plan (2006); Tackling Climate Change: SA's draft Greenhouse Strategy (2006); and, Permanent Water Conservation Measures (2003).

10. REVEGETATION AND FORESTRY

10.1 CLIMATE CHANGE IMPACTS

As bioclimatic envelopes for revegetation and forestry change, the species used for these activities might also need to be altered. There is a particular concern with the management of disjunct patches of remnant native vegetation in the landscape. Where native vegetation has historically responded to climate variability and change with migrations back and forth in the landscape, what will happen if they are restricted by fragmentation from moving along temperature and precipitation gradients as the climate changes? Many of those issues were discussed earlier in relation to biodiversity in general (see page 26), however revegetation processes themselves are likely to be affected by climate change.

Seedlings are often highly vulnerable to a lack of rainfall before they become fully established. Shrub and tree species are also dependent on sufficient rainfall at the right times for reproduction and high growth rates. Mallee can tolerate substantial variability in rainfall, and can survive extensive periods of drought, but still needs the flush years to survive and reproduce. A big question is what will happen if such wetter years become considerably less frequent. Radiata pine (*Pinus radiata*) is able to survive in lower rainfall environments than they are currently planted for commercial forestry, but the productivity levels are much lower. Higher CO_2 concentrations may act to stimulate forestry growth rates or, at least partially, compensate for warmer, drier conditions.

Table 13. Vulnerability of AMLR revegetation and forestry due to climate change

Exposure	Sensitivity	Impact	Adaptive capacity	Vulner-ability
High	**Medium**	**Medium**	**Significant**	**Medium**
• Most revegetation programs aim to grow species that are adapted to particular bioclimatic conditions. • Bioclimatic envelopes will be in flux with rapid climate change.	• Seedlings highly susceptible to drought. • Re-establishment, reproduction and productivity depend on species experiencing appropriate environmental conditions. • Water supplies for forestry could become increasingly restricted.		• Replanting programs can adjust species mixes. • Long term and rapid change will require modelled projections of how climate change will influence future growth and reproduction of native species.	

10.2 ADAPTATION RESPONSE

Revegetation and forestry will increasingly need to take into account changing future bioclimatic envelopes for ecological assemblages and industrial species (see also page 46). A significant area of opportunity exists to recognise the value of carbon biosequestration within revegetation programs (Shea 2003, AGO 2005). By reducing emissions of Greenhouse gases, we can assist to reduce the rate of climate change. For example, carbon dioxide is fixed and held by perennial plants in a process known as biosequestration. This process might provide a significant opportunity for NRM in the Mount Lofty Ranges.

Opportunities are emerging for private landholders to be compensated for carbon biosequestration activities. Some companies are starting to provide financial incentives to landholders to sequester CO_2 on their properties. If managed effectively, planting vegetation to sequester carbon has the potential to align with other NRM goals such as the conservation and re-establishment of biodiversity, reduction of dryland and irrigation-induced salinity, and other uses of plant products. Furthermore, should sequestered carbon become a tradeable entity, it would provide a significant market mechanism for achieving large-scale increases in perennial vegetation in the landscape, whether for commercial purposes or biodiversity conservation. In particular, it may be possible to link financial incentives derived through carbon credits directly to land-use change aimed at improving resilience of systems to climate change.

A number of major opportunities for linking biosequestration (plant-based carbon sinks) to the expansion of perennial vegetation across the state have been identified:

- Tradeable carbon rights associated with a carbon trading scheme would provide incentives to expand the commercial forestry industry, particularly in the higher rainfall areas of the state. Timber production rates may be reduced as *Pinus* and *Eucalyptus* plantation species come under drought stress. However, these may be more than compensated for by the additional value of forestry activities associated with carbon credits and increasing carbon dioxide concentrations are predicted to provide a fertilisation effect.
- Forestry and farm-forestry for conventional forestry products have the potential to expand in areas with rainfall below that for traditional forestry if carbon credits improve the economic viability of these activities.
- Short rotation woody ‘crops’ could be planted in lower rainfall areas for a mix of traditional and non-traditional uses including biomass production for green energy opportunities. In this case, tradeable carbon rights would probably be essential to achieve marginal economic viability.
- Perennial fodder crops can be used effectively to buffer grazing systems in lower rainfall agricultural areas with greatest risk of failure of traditional agriculture due to climate change.
- All revegetation activities might provide some additional NRM benefits in agricultural lands such as salinity mitigation, soil protection and habitat improvement. For example, biosequestration and salinity control are readily compatible objectives since both require vegetation over large areas and for the long-term. Substantial percentages of any catchment area must be revegetated with deep-rooted perennials to effectively manage dryland salinity and the tradeable carbon rights might improve the viability of such revegetation programs.
- Revegetation might be able to support extensive habitat re-establishment to buffer and provide linkages between reserve areas and further protect and enhance remnant biodiversity resources in agricultural landscapes. Tradeable carbon rights would be an integral component of the innovative markets needed to achieve biodiversity enhancement over such large areas.

At the moment there is significant discussion of the role of biosequestration in reducing net carbon emissions, but not specifically within the AMLR.

- CSIRO Land and Water has examined options for carbon sequestration in the Murray-Darling Basin for DWLBC using a Spatial Market Based Instruments Investment Model.

- There are numerous revegetation programs around the region, most importantly perhaps the One Million Trees SA government program, private Farm forestry programs and industry links through the Adelaide Blue Gum Co.
- The FloraSearch program of DWLBC in conjunction with Adelaide University is undertaking work in commercial native species options (Bennell et al. 2003).
- Other states have introduced more formal schemes, including the NSW Greenhouse Gas Benchmark Scheme, and the Victorian schemes, CarbonTender and Plantations for Greenhouse.
- For further information regarding SA Government policy in relation to this issue refer to the State NRM Plan (2006); Tackling Climate Change: SA's draft Greenhouse Strategy (2006); No Species Loss: A Biodiversity Strategy for South Australia 2006-2016 (2006); NatureLinks (2003); Farm Forestry: Designing for Increased Biodiversity (2002); Revegetation strategy for South Australia (2001); and, Forestry Property Act (2000).

11. AGRICULTURAL PRODUCTION

11.1 CLIMATE CHANGE IMPACTS

There is a significant amount of other work available and underway examining climate change vulnerability for agricultural industries including work being undertaken by PIRSA, SARDI, CSIRO, publications by the AGO (2002) and the Bureau of Rural Sciences (2004), and reviews by French (1991), Hutchins et al. (1993), and Woods and Wilder (2005). For that reason, only a brief summary of the numerous, complex impacts on agricultural production is outlined here.

Projection studies are suggesting that climate change is likely to have net benefits on agriculture in the US, Canada and northern Europe, as much of their production is limited by cold, rather than water availability (Olesen and Bindi 2002, Easterling et al. 2004, Rosenzweig et al. 2004, Wall et al. 2004).

The impacts on agriculture in the AMLR are less clear. Agriculture probably will be less vulnerable due to higher adaptability to change than some other NRM sectors, but that doesn't mean that there won't be significant costs for landholders.

Annual crop production will be affected by changing climate variability in the shorter term. SARDI has modelled projections of the impacts on wheat yields of climate change. Due to the conflicting impacts of more variable, warmer conditions on one hand, and the fertilising effects of atmospheric higher CO_2 concentrations leading to improved water-use efficiencies due to stomatal closure on the other, there are uncertain impacts on plant growth (Luo et al. 2003).

It is the drier fringe of temperate systems that are likely to suffer the greatest negative impacts from reductions in the total rainfall, increasing rainfall variability and increasing heat and evaporation. Agricultural products with wider quality ranges are likely to be produced if variability in climate increases as expected. For example, drier Spring weather could result in more shrunken grains and heat stress could effect grain protein development. On the other hand, higher nitrogen/protein levels in grain might be expected from effective management under lower rainfall conditions.

Over the longer term, depending on the rate and extent of climate change, substantial transformation costs and reduced profits could be expected for agricultural industries in the AMLR. Vulnerability analyses should be undertaken for each industry to examine the specific economic impacts of change, which is beyond the scope of this review. For example, increased cropping on the wetter margins for crop production could benefit growers financially on the wetter cropping fringe. Some areas of the AMLR could provide important examples of this. Farms on the drier fringe may utilise more extensive rotations, rely on opportunity cropping and in some cases, avoid annual crops altogether.

Horticulture is a major water user in the AMLR and in turn, horticulture management can have significant impacts on water quality. These facts could make horticulture particularly vulnerable to increasingly variable supplies and changing water policies focussing on rationalising water use in a drying era (Cullen 2004).

Table 14. Vulnerability of AMLR annual crop production to climate change

Exposure	Sensitivity	Impact	Adaptive capacity	Vulner-ability
High	**Medium**	**Medium-High**	**Significant**	**Medium**
• Most cropping systems are dryland and directly dependent on the reliability and amount of precipitation.	• Farming systems are quite resilient to climate variability due to improved agronomic practices, however significant thresholds remain. • Examples of key issues: date of planting highly dependent on timely rainfall, and fertility and grain filling is highly dependent on moisture availability and a lack of heat stress in Spring.		• Annual cropping systems can be adjusted relatively quickly. • Crop varietal choice and management techniques offer substantial opportunity. • Both between and within-season variability are predicted to increase, making crop production decisions difficult.	

The development of water allocation plans that secure water rights within prescribed water resource zones under the SA NRM Act 2004, could be a significant issue for many horticultural producers in the AMLR if reduced rainfall, increasing evaporation and greater local demand result from climate change (South Australian Government 2000; DWLBC 2005).

The establishment of horticultural plantations may be affected by hot, dry spells, as may other key points in the production cycle such as flowering, pollenisation and fruit set (Bureau of Rural Sciences 2004). For example, fewer chilling periods may effect vernalisation requirements and fruit set of some crops, especially cherries and pome fruits. Vegetable production may also increasingly suffer from extreme weather conditions, such as flooding or extended hot spells, which lead to crop losses or downgrades. Impacts on the quality of horticultural products, including wine, fruits and vegetables, have been flagged as important issues to consider by other researchers partly for these reasons (Jones et al. 2005; Preston and Jones 2006).

Pest numbers and fungal diseases on horticultural and annual crops could be exacerbated due to higher temperatures and increasing humidity in the summer months. For example more humid summer conditions would increase the risk of fungal disease on grapes. Insect pests respond to extended warm, damp periods, which may become more common in the summer months. More extreme storm events could lead to increased storm and hail damage of horticultural crops.

Livestock production is one of the highest water uses per unit return of any industry in SA and could therefore come under pressure in the AMLR in a warming/drying trend. Pastures are, in general, less susceptible to rainfall variability than crops and may become more common on the drier margins. Rates of pasture growth could be significantly affected by greater variation in water availability, rainfall and other climatic conditions, as could water supplies that lead to 'green drought' conditions where surface water for stock is limited.

Table 15. Vulnerability of AMLR horticultural production to climate change

Exposure	Sensitivity	Impact	Adaptive capacity	Vulner-ability
Medium	**High**	**Medium-High**	**Medium**	**Medium-High**
• Horticultural systems are buffered by significant external inputs, especially irrigation water. • Temperature and rainfall extremes may be of greater importance.	• Some systems including wine grapes, cherries and vegetables highly sensitive to temperature extremes. • Flooding impacts, eg. on Adelaide plains, cause significant losses. • Longer-term impacts of regulatory restrictions on water-use.		• Adjust to change, including different species, varieties and water requirements. • Horticultural systems require significant time to change and adjust. • Limited water resources.	

Intensively raised animals, particularly when held in confined spaces, can suffer from heat stress. Cattle, sheep and goats in feedlots, transportation or paddocks without inadequate shade can suffer from stress, particularly when very young or freshly shorn. Adult pigs, ducks and chickens are all susceptible. As the number of hot days and hot spells are projected to increase for the AMLR, the potential for enhanced stress conditions within intensive livestock systems, without adequate ventilation or air conditioning, could be substantial (Turnpenny et al. 2001).

Table 16. Vulnerability of AMLR livestock to climate change

Exposure	Sensitivity	Impact	Adaptive capacity	Vulner-ability
Medium	**High**	**Medium–High**	**Significant**	**Medium**
• Grazing systems reliant on spring growth to determine stocking rates. • Heat and reduced rainfall will stress livestock.	• Spring drying could have significant impact on levels of pasture productivity. • Limits to surface water supplies. • Some livestock tolerate weather extremes, others are highly sensitive.		• Significant opportunities to adjust stocking rates and introduce diverse grazing and fodder options. • Better water harvesting on farms. • Better shade and shelter. • Wider use of temporary stock feeding.	

11.2 ADAPTATION RESPONSE

For many primary producers the management of climate change issues will involve a management of climate variability in the shorter-term (Hayman and Cox 2003). In the longer-term, adaptive management that adjusts before or with changing circumstances will continue to be vital. As variability increases, the focus on yield reliability, rather than high productivity during the best years, could become more of a priority for producers and scientists. Varieties that are adapted to shorter growing seasons or more variable intra-seasonal conditions may be increasingly incorporated into rotations, particularly if early rains have failed. Precision agricultural technologies that improve the efficiencies of land, water and labour use, such as detailed yield recording and fertiliser applications, would continue to improve the profitability of production systems.

Due to shorter growing seasons and higher climatic variability leading to reduced levels of soil moisture available to crops at some times, traditional rates of fertiliser application may need to be reviewed. By reducing the nitrogen and phosphorus applied to the crop, initial vegetative growth will be reduced. Similarly, by reducing the sowing rates the competition for water within crop throughout the growing season could be substantially reduced. The importance of reduced tillage systems may be reinforced in regions that experience more extreme summer rainfall events and reduced growing season rainfall (see page 46). The clever use of short fallows associated with a reduced risk of water and wind erosion in some districts improves crop water use and could be supported in some cases. However, increased intensity and frequency of summer storms across agricultural districts could make longer-fallows even riskier than they are now.

A better understanding of weather patterns and the use of different crop species, not just varieties, will form part of the response (see SARDI's Climate Risk Management unit). Turner (2004) suggests that even as Mediterranean climatic regions of Australia have experienced a net drying trend in recent years, better agronomic practices have allowed cereal production levels to increase. In the longer term, an important adaptive capacity of some industries may be to move across the landscape, reducing production or retiring land on the drier fringe and increasing production intensity on the wetter fringe. Irrespective of other concerns regarding genetically modified organisms, the applications of biotechnologies have the potential to create more drought-tolerant varieties.

A reduction in the use of scarce irrigation water resources for low value crops could be a priority for horticulture. Flexible integrated pest management approaches may need to be further developed as changing conditions may increasingly favour invasive species (see page 33). Horticultural crop management may require changes in the timing and methods of pest management. Efficiencies will involve better monitoring of soil-water conditions to improve the timeliness and quantity of irrigation. Effective use of water management technologies, varietal choices and site management will be important. Specific management responses will be required. For example, a more humid late summer may lead to the choice of grape varieties with looser bunching becoming more appropriate.

Significant impacts on animal husbandry will result from increasing frequency of hot days and hot spells in grazing districts of SA. To avoid stock losses or forced sales during low-rainfall periods, stocking rates and grazing regimes in general could be managed for climate risk. A focus on high-quality production, rather than high quantity could be emphasised to reduce the pressure on resources. Reducing heat-stress and sunburn of stock might also become more of a priority. Improved summer rainfall could extend periods of foraging or allow extra hay/silage cuts. The greater use of hay, silage and grains to buffer feed reserves could be an advantage. Storage of feed over more extended periods, by burying silage or using silos could be useful. In conjunction with other grasses and legumes, salt-tolerant wheatgrass can produce silage of reasonable quality. Improving quality of silage via use of additives could be a useful forage management response.

The specialisation of production of a single or a few similar products on a farm is often associated with efficiencies of technology investment, knowledge, systems development and production scale. Some areas may increasingly specialise their production systems to make the most of efficiencies and economies of production. However, the reliance on a single crop or product could be increasingly risky under changing conditions. Temporal flexibility will be important so that producers are able to maximise returns during the good years.

Others may aim to buffer household income by diversifying their production systems and thereby increasing the range of options for resilience and change (Bardsley 2003). Some ideas of diversification have been discussed above in the form of crop substitution or varietal choices. However, responses to irreversible or substantial shifts in climate could also require fundamental changes in land uses and increasing focus on alternative sources of income. A dominant response in some parts of the AMLR could be the greater use of perennial crops that offer particular water use efficiencies. Other adaptation options could involve broader use of Farm management deposits and Mutual funds by farmers to stabilise incomes across a series of years.

Exceptional circumstances assistance packages are available from the Commonwealth Government to address severe and sustained drought responds to 'rare events': those that occur on average once every 20–25 years and are not considered part of normal risk management (Laughlin and Clark 1999).

The Drought Review Panel (2004, p.18) defines:

Meteorological drought: 'on the basis of the degree of dryness, in comparison to an average amount of rainfall, and the duration of the dry period.'

Hydrological drought: 'in terms of the effects of below average rainfall on water supplies, which include streams, dams reservoirs and ground water supplies.'

Agricultural drought, on which the Exceptional Circumstances definition is based, incorporates the effects of meteorological and hydrological drought on agriculture (The Drought Review Panel 2004). The definition of agricultural drought could change with changing climates. Drought is defined as a situation where the three-month average rainfall is within the lowest 10% on record and terminated when monthly total rainfall exceeds the average for three months commencing that month or the three month total is above average. There are substantial questions as to whether current rainfall averages will remain valid in a changing climate, and whether drought relief via direct economic assistance should support practices that could be perceived as unsustainable in the long-term (Heathcote 2002).

If the form of financial support could be modified effectively, instead of a risk mitigation approach alone, support mechanisms could increasingly evolve important mechanisms by which risk could be reduced. In fact, the assistance programs are increasingly supporting rural communities to understand, respond to and manage risk (Botterill and Fisher 2003).

A strategy may be required which further examines opportunities for SA agricultural industries to build resilience and capacity for adaptation to climate change. Major competitors for many agricultural products from temperate zones are likely to suffer fewer early impacts on their climate systems. SA projections are indeterminate and therefore, require further in-depth modelling of impacts on agro-industries based on further applications of IPCC data to local contexts. Such futuring may need to incorporate broader issues such as impacts on future demand and policies that limit carbon emissions and high oil price impacts on production and transport. For example, one concerning discussion currently underway internationally in key market areas, is that if local producers are carbon-restricted, they may be able to impose trade restrictions on non-carbon restricted producers based on unequal costs on production processes.

Alternative income sources for natural resource managers could be linked to recognition of the multifunctional aspects of effective NRM to society, which are often not recognised in direct financial terms. North American and EU countries have explicitly defined values associated with multiple outcome primary production and responded by providing payments, protection or subsidies that support these multifunctional aspects of NRM (Olesen and Bindi 2002, Bardsley and Thomas 2004). Such financial recognitions of environmental and social services of agriculture are linked to perceptions of place, landscape, culture and space. The effective marketing of products to represent the values of sustainable, resilient farming systems, through environmental management systems, can also increase margins for producers.

- Some key detailed research and modelling of projected impacts on cereal and wine production is underway in SARDI, PIRSA, the University of Adelaide and CSIRO concerning these issues.
- SARDI's Climate Risk Management unit work with primary producers to assist with management of climate variabilit, for more information on this program see the website - http://www.sardi.sa.gov.au/pages/climate/bronya/crimfa/crimfa_info.htm:sectID=9.
- DWLBC is examining methodologies for supporting the management of sustainable landscapes.
- For further information regarding SA Government policy in relation to this issue refer to the State NRM Plan (2006); Tackling Climate Change: SA's draft Greenhouse Strategy (2006); Soil Conservation and Land Management: Directions for the Agricultural Lands of South Australia (2004); State Food Plan (2004–2007); and, Industry plans.

12. LAND MANAGEMENT

12.1 CLIMATE CHANGE IMPACTS

There are likely to be complex interrelationships between land degradation and climate change associated with changing environmental conditions and management responses (Gisladottir and Stocking 2005). Limited changes in crop rotations and the application of minimum tillage/direct drilling can enhance protection of soil surfaces, enhance organic matter and improve water-holding capacities of soils. As rainfall reliability is expected to decrease in some areas, the value of effective land management is likely to become more apparent to many landholders across the Region.

Research is suggesting that changes in atmospheric circulation may alter the timing and intensities of water and wind erosion across southern Australia (Ekström et al. 2004). Three areas stand out here:

1. The risk of enhanced water erosion if rainfall intensity increases.
2. The risk of increased wind erosion if paddocks are left bare for longer periods in autumn.
3. The potential for reduced impacts of dryland salinity as a result of reduced groundwater recharge.

Within the AMLR, inappropriate management can lead to erosion of all agricultural land types and opportunities exist for improvement (McCord and Payne 2004). Water erosion, in particular, is of moderately to high risk across large sections of the Mt Lofty Ranges. While average rainfall is projected to decrease, once again, rainfall intensity may increase along with the force associated with any particular rainfall event. Some grazing systems increase the erosion risk, as land is exposed for long periods particularly on steeper slopes. As the infiltration of water becomes increasingly important, soil water repellence might become more of a problem. Over-stocking on denuded lands will increase the chances of soil erosion. Managing stock according to the capability of the land, effective use of perennial vegetation and water retention structures, and tillage management systems that involve the retention of stubble, such as direct-drill and no-till techniques, offer substantial opportunities for reducing water erosion. The risk of enhanced water and wind erosion is linked to the reduction in vegetative cover at different times of the year, particularly where livestock graze paddocks heavily in dry autumn conditions or fields are cultivated and the rains fail to arrive.

Merrill et al. (1999, p. 1769) note that 'the ability of wind to cause erosion is strongly and nonlinearly dependent on wind energy.' In fact, the direction, speed and duration of winds are important factors influencing the levels of soil erosion (McTainsh et al. 1998; Bennell and Cleugh 2002). Droughts are also correlated with severe wind erosion events. The impacts of climate change on future wind speeds are highly uncertain from current projections, although a slight increase in the frequency of westerlies, south-westerlies and southerlies are projected from autumn and spring (McInnes et al. 2003). Land is most often at risk to wind erosion in SA in the late autumn-early winter, when pastures and crop stubbles have been grazed and/or paddocks cultivated and prior to substantial vegetative growth (McCord and Payne 2004). There is some suggestion that average winter wind speeds will reduce, which could reduce soil erosion risk, but once again it is the extreme events that are important.

Table 17. Vulnerability of AMLR land management to climate change

Exposure	Sensitivity	Impact	Adaptive capacity	Vulner-ability
Medium	**Medium**	**Medium**	**High**	**Medium-Low**
• Climate has direct influence on numerous aspects of land management. • Enhanced wind speeds and extreme rainfall events could increase erosive forces. • Changing climates will impact on surface cover.	• Sudden extreme rainfall events combined with reduced early-season cover could substantially enhance erosion risk. • Reduced groundwater recharge could deplete salinity risk, but restricted water-use in fields could exacerbate re-charge. • Crops, pastures and native vegetation are all sensitive (to a declining degree) to climate variability, change and drought.		• Changed management can reduce exposure of farming systems to land degradation. • Land management in region is increasingly effective. • Opportunities for retaining and supporting the commercial use of perennial vegetation.	

Reduced winter rainfall could lead to reduced rates of groundwater recharge and subsequent reductions in problems associated with waterlogging and secondary dryland salinity (John et al. 2005). On the other hand, reduced water-use efficiency may result from more unreliable and variable rainfall, increasing summer rainfall, or increasing frequency of extreme events, leading to large slugs of saline water penetrating through to replenish perched aquifers. For example, if rainfall declines to such an extent that perennial pastures are replaced by annual systems, water-use efficiency could decline significantly. The experience of south-west WA is that reduced rainfall since the 1970s has slowed the rate of groundwater recharge and consequent dryland salinisation of agricultural lands (McFarlane & Ruprecht 2005). The warming/drying trends are expected to result in complex changes in soil enzyme activity. For example, studies have shown a reduction in rainfall within Mediterranean systems can lead to a reduction in urease and phosphatase enzymes, which in turn can lead to reductions in the amount of available nitrogen and phosphorus in soils (Sardans and Peňuelas 2005).

12.2 ADAPTATION RESPONSE

Good land management becomes an important response to climate change risk. Land is most at risk to water erosion when it is clear of vegetation prior to the break of the season. Similarly, as McCord and Payne (2004, p. 32) state, ‘almost 70% of soil loss due to wind erosion is currently likely to occur because of cultivation and grazing carried out before May’. Alternative land management options, which reduce the exposure of the soil to erosive events, such as stubble retention, clay spreading when appropriate, and reduced fallowing times and grazing pressures will all be come more important with increasing climate variability associated with climate change (Turner 2004). Farmers that are able to apply minimum tillage practices will able to maintain cover on the soil surface and minimise the disturbance of the soil structure. The temptation may be to use a short-fallow in the autumn to enhance soil water retention to support crop growth, however the trade-off may be a substantial increase in erosion risk where cultivated fallows are used. Dry sowing is a response used by some crop producers to later breaks in the growing season, but this practice can increase the vulnerability of soil to erosion as soil aggregates are broken up and vegetation cover is ploughed in. These risks can be alleviated with awareness of the possibilities of late breaks in autumn, not working the paddock earlier than required and the need to take care in managing feed and forage for stock.

Deep-rooted perennials have the potential to improve water-use efficiencies of vegetation, reduce watertables, minimise erosion, improve soil-carbon inputs, provide shelter and shade and provide forage for stock (Lefroy and Stirzaker 1999). Agroforestry offers substantial direct benefits to landholders by way of diversifying production outputs and providing environmental services. Research has been undertaken on how mixed forestry-agriculture-pastoral systems have the potential to improve the resilience of land use practices to environmental change (CSIRO Land and Water 2001, RIRDC 2004). Effective use of indigenous species for the production of wood, fodder, biomass, oils, flowers and fruits, are likely to provide increasing niche diversification opportunities in the near future. Opportunities to provide financial capital for ecosystem services associated with revegetation are becoming available for farmers to implement carbon sequestration programs (see discussion of C biosequestration on pages 37–39). Due to the recognised risks to biodiversity, it will become increasingly important that the plantations lead to simultaneous net biodiversity benefits. Monoculture plantations, whether they are exotics or native species, provide fewer ecosystem benefits than indigenous mixed forest systems (Schulze et al. 2002; Lindenmayer et al. 2003). Consideration of what types of ecosystems are recreated in the process of revegetation, not just the extent of plantations, needs to be of primary importance for habitat re-establishment and preparedness for change.

- The FloraSearch program of DWLBC in conjunction with Adelaide University is undertaking work in commercial native species options (Bennell et al. 2003). The project is focused on species that are suited to dryland cultivation in the recharge (non-saline) part of land systems and can be developed to supply feedstock for the large-scale markets of wood products (MDF, Pulp and paper), fodder, essential oils (WA oil mallee concept) and bioenergy products (electricity generation and transport fuels). New crops will utilise agroforestry techniques based on short-cycle woody coppice and phase crops in belts or plantations.
- For further information regarding SA Government policy in relation to this issue refer to the State NRM Plan (2006); Tackling Climate Change: SA's draft Greenhouse Strategy (2006); Soil Conservation and Land Management: Directions for the Agricultural Lands of South Australia (2004); and, SA Dryland Salinity Management Strategy (2001).

13. BUSHFIRES

13.1 CLIMATE CHANGE IMPACTS

Global climate change would alter the intensity, frequency, duration and extent of bushfires. How fires in the AMLR will be affected is uncertain, but modelling of similar climatic areas in other parts of Australia and the US suggest that reduced humidity could lead to an increased number of days of high fire danger (Brown et al. 2003, Hennessy et al. 2005). Wind intensity and direction are other key components of bushfire severity, which are likely to be altered by climate change. McInnes et al. (2003) indicate that reductions in average wind speeds may be an outcome of climate change. Kevin O'Loughlin from the Bushfire CRC (Planet Ark 2006) has stated, 'There is a clear trend – hotter weather in Australia, more frequent bushfire seasons, more frequent serious bushfire incidents.'

Opportunities for prescribed burning of vegetation could also become restricted if there are more longer, hotter dry periods. On the other hand, a warming, drying trend could lead to reduced productivity within forests and grasslands in the region, leading to reductions in the fuel load for bush fires. There is also the possibility that increasing summer rainfall could reduce the dryness of vegetation and as a result the forests may be less combustible.

To add to the complexity of potential fire risk, longer-term changes in species composition will affect the rate and intensity of fire events. Invasives plants such as Olives (*Olea europaea),* Gorse (*Ulex europaeus) and* Cape Broom (*Genista monspessulana)* are common in the region and can enhance fire hazard as they are highly combustible. If the disturbance regimes of native ecosystems are disrupted by an increase in fire pressure, ecological assemblages will change accordingly. As many invasive species are good colonisers, the invasion pressures on some ecosystems could be enhanced. The effective management of fire risk may involve the effective control of such species.

Table 18. Vulnerability of AMLR bushfires to climate change

Exposure	Sensitivity	Impact	Adaptive capacity	Vulner-ability
High	**High**	**High**	**Medium**	**Medium-High**
• Bushfires are one of the most significant natural hazards in the region. • More extreme weather conditions and/ or prolonged warmer/drier spells are projected.	• Changing climates will alter the productivity of natural systems, and hence the fuel loads, but also the rate and intensity of fires. • Fires will respond directly to a drying, warming trend and long dry autumns have historically enhanced fire risk. • Fires are highly sensitive to specific weather conditions such as long, hot hot-spells, strong winds blowing for long periods and rainfall.		• There is much that can be done to reduce fire risk, much of which involves landscape planning and investment into vegetation management. • Adaptation restricted by behavioural change, especially as there is increasing urban development in zones of high fire risk. • Prescribed burning opportunities may become less frequent.	

13.2 ADAPTATION RESPONSE

A warming, drying trend for the Mt Lofty Ranges should be factored into planning and operational responses by the Country Fire Service. Some detailed modelling of the predicted impacts of climate change on fire regimes may be required to inform planning for fire management. There is much that can be done to adjust fire risk, but again adaptation will be restricted by willingness to change behaviour: people like embedding their houses in the bush! An increasing recognition of the risk of bushfire in the AMLR may be a significant component of any adaptation response.

- Planning SA has incorporated projected climate change into the development of the Forest Fire Danger Index, which is an indicator of the bushfire risk level for SA. In particular, the Forest Fire Danger Index (FDI) was increased from a maximum of 63 to 80 in part to account for the more extreme conditions projected in relation to climate change (Planning SA 2005).
- DEH is trialling different prescribed burning regimes to reduce bushfire risk.
- Other research work is being undertaken by the CSIRO and the Bureau of Meteorology within the CRC for Bushfire Management, but this work does not have a SA focus (Hennessy et al. 2005).
- For further information regarding SA Government policy in relation to this issue refer to the State NRM Plan (2006); Tackling Climate Change: SA's draft Greenhouse Strategy (2006).

14. AIR QUALITY

14.1 CLIMATE CHANGE IMPACTS

Adelaide has relatively good air quality in relation to other Australian cities. Air pollutants are divided into three major types including:

- Primary (eg. Particulates, CO_2, carbon monoxide, sulphur dioxide).
- Secondary (eg. Ozone, nitrogen dioxide).
- Toxicants (eg. Lead – which used to be a problem in Adelaide but unleaded petrol has significantly reduced levels).

The major issue for Adelaide is particulates and photochemical smog, both of which could be significantly influenced by changing weather patterns (EPA 2006b).

Particulates may be solid matter or liquid droplets and are measured in micrometres (micro m), which equals 1/1000 of a millimetre. PM10, particles of 10 micro m in size and smaller, are the most dangerous to human health as they are small enough to penetrate deeply into the lungs. Most particulates in AMLR are airborne dust and organic solids such as carbon (soot) and hydrocarbons from combustion and industrial processes. Dougherty (2005) notes that 'in 2004, the Air NEPM standard of 50 micrograms per cubic metre ($\mu g/m^3$) as a 24-hour average was exceeded once at the Elizabeth monitoring site, four times at the Gawler monitoring site, once at the Kensington Gardens monitoring site, three times at the Netley monitoring site and three times at the Northfield monitoring site.'

Of particular issue regarding climate change could be increased dust from wind erosion in the autumn as a result of late breaks and strong northerly winds, increasing smoke from bushfires, and particles from motor vehicles and industry being held into the Adelaide 'bowl' between the sea and ranges on still, hot days in summer. For example, a strong correlation has been shown between prevailing climatic conditions and dust storms in eastern Australia (McTainsh and Lynch 1996, McTainsh et al. 1998).

Photochemical smog is an air pollutant in Adelaide, although levels have not exceeded the National Environmental Protection Measure guidelines since the early 1990s. It is predominantly caused when nitrogen oxide reacts with oxygen in the air via high temperature oxidative combustion to produce the harmful nitrogen dioxide and ozone.

Ozone, in particular, is at highest levels in the lower atmosphere on still, sunny days. Higher temperatures could increase the number of days that these chemical reactions cause problematic pollution levels. Projections of extensive high-pressure systems and longer, hotter hot spells could enhance problems with photochemical smog, particularly during Summer and Autumn.

Table 19. Vulnerability of AMLR air quality to climate change

Exposure	Sensitivity	Impact	Adaptive capacity	Vulner-ability
High	**Low**	**Medium-Low**	**Significant**	**Medium-Low**
• Direct relationship between air quality in Adelaide and weather conditions. • Projections suggest hot, dry conditions with high-pressure may become more common in summer-autumn.	• Vehicle and industry pollution could lead to more smog that is held in Adelaide plains by calm, hot weather. • Wind erosion risk may be exacerbated by later breaks and more extreme weather events. • Bushfire risk is projected to be enhanced by more warmer/drier weather particularly in late summer-autumn.		• Numerous policy changes can be applied to reduce emissions by vehicles and industry, support conservation tillage and grazing practices and manage the bushfire risk.	

14.2 ADAPTATION RESPONSE

Opportunities for adaptation are partly linked to broader issues of land management and bushfires covered in earlier sections. The EPA is already significantly involved with monitoring air quality conditions, researching air quality and supporting policy development in the area. Specific adaptation to high-risk air pollution conditions including specific policy responses to the causes of the pollution, such as traffic calming and controls of industrial emissions, may need to become more directly applied, especially in high-risk conditions.

- Although there is considerable work monitoring and evaluating air quality within the region, there does not appear to be any particular work examining the relationship between air quality and climate change in SA.
- For further information regarding SA Government policy in relation to this issue refer to the State NRM Plan (2006); Tackling Climate Change: SA's draft Greenhouse Strategy (2006); and, Environment Protection Act (1993).

15. WHERE TO FROM HERE?

The evidence supporting the enhanced Greenhouse effect theory of Climate Change is now overwhelming, such that it is supported at all levels of government. In order to develop appropriate and timely planning responses, comprehensive, science-based, assessments of vulnerability that are transparent and accurate should be developed, published, discussed and regularly updated, both to incorporate new knowledge and to respond to any possible future criticisms of planning strategies and actions.

This review of current knowledge suggests that impacts on our natural resources and associated industries could be substantial within the AMLR. We should examine these impacts in detail and respond accordingly. There are several steps to provide for **RIPPLES** of change in response to climate change.

Research is required in many areas of NRM that draws the climatology work down to local and regional scales. Such downscaling of climate projections need to be applied within particular societal contexts so the projections for climate change have meaning in peoples' lives.

A basic yet significant question is whether climate change research should be a separate area of research or whether climate change will be so pervasive that much research will need to incorporate a climate change component. Ideas are required for integrated adaptation solutions and innovative ideas that could lead to sustainable development opportunities. 'Threat abatement management' involves targeting investment for adaptation within systems that are vulnerable and will require that work to increase resilience levels. There are significant differences in the scale and scope of those threats and that is why vulnerability analyses are a useful guide to provide strategic direction. The CSIRO is updating the projections for SA by McInnes et al. (2003), referred to extensively in this document, based on new IPCC models and this work should be available in 2006. This document may require re-drafting in response to that CSIRO update.

Research is also required to suggest and provide opportunities to respond to risk and to benefit from change. As the SA draft Greenhouse Strategy (2006) states 'new thinking, new ideas, new technologies' are required: these are the opportunities that emerge from change, even quite negative change. Without multi-disciplinary research and applications we are only providing part of a necessarily complex story.

For effective NRM in a changing climate we need tools and methodologies to:

- Build resilience into our natural resource systems, in part by overcoming fragmented landscapes.
- Support sustainable change within marginal agricultural regions and communities.
- Reduce the vulnerability of primary industries and productive systems.
- Enhance and protect the productivity of other key assets.
- Develop alternative income sources.
- Incorporate appropriate responses to climate change in all policy and planning.

Further work must incorporate more of the complexity of climate change projections, including for example the rate and extent of changing climatic conditions, and the likely responses of our natural, productive and social systems.

Information, understanding and awareness-raising is required to plan for wise investment by the AMLR Board, State and Federal governments and to ensure community acceptance of change. A base-line target for regional responses to climate change in NRM is the ownership of climate change by stakeholders (see App. 1 and comment below).

Policies and planning: There have been significant advances in climate change policy relevant to the region in recent years and many of those have been mentioned in the text, most importantly SA's draft Greenhouse Strategy (2006) and the State NRM Plan (2006).

There will necessarily need to be some innovative policy to respond to changing climates. Already in the literature, there are discussions of a 'Triage' approach to management: where extremely vulnerable systems will not be managed for adaptation; vulnerable systems will receive significant investment because results can be expected; and those systems with low vulnerability will be managed as usual. In relation to many of the issues discussed above, 'no regrets' actions can be advocated, which can be incorporated into ongoing management and policy. This area of work is significant as embedding responses to risk into NRM policy, particularly in relation to uncertain change, is complex and often difficult to implement.

Participatory research and adaptive management are required that allow responses to be based on flexibility, diversity and learning, because of the uncertainty surrounding how climate change will affect us.

Informed local managers, aware of the importance of climate change and grounded in the local cultural interpretations of place and environment, are the most effective managers of the diversity of local ecological issues. Impacts of climate change on ecosystems and landscapes remain uncertain. To respond to this uncertainty, the Board and governments could support the establishment of resilient and flexible systems by empowering regional stakeholders to manage the local complexity of their systems (Berkes 2003).

By embedding responses in the community, the effectiveness of management can be enhanced, as many individuals and communities with the awareness and capacity to bring about change will respond within their own biophysical and socio-cultural contexts. In this manner, the diversity of management responses across and between regions will be enhanced, as will opportunities for further learning as environment change impacts on the AMLR. To assist this process, 'The Adaptation Challenge' is a workshop tool developed to raise awareness of and to support discussions on the types of impacts of climate change on NRM systems (App. 1).

A key area of participatory work will be to examine in greater depth, specific vulnerabilities for sectors and landscapes in the AMLR region, through more detailed local case study analyses and stakeholder discussions. Questions of planning horizons, coping ranges of particular NRM systems and critical thresholds at which those systems become vulnerable, become particularly important to work through and analyse with local stakeholders.

Leadership: the story of environmental management is strewn with examples where a catastrophe or at least a major imposition of the costs of environmental degradation has occurred before remedial action is undertaken by individuals, organizations and government. Leadership is required on climate change that articulates, presents and invests in opportunities to respond to climate change prior to a time when the impacts of change are so negative that many lose the capability to adapt effectively.

The South Australian government has developed some important planning to respond to climate change in the last few years. Key documents include:

- The South Australian Strategic Plan (2004) – http://www.stateplan.sa.gov.au.
- South Australia's State NRM Plan (2006) – http://www.dwlbc.sa.gov.au/nrm/nrmplan.
- Tackling Climate Change: SA's draft Greenhouse Strategy (2006) – http://www.climatechange.sa.gov.au.

Economics: There is money to be made from early and effective adaptation to change, and climate change will not be any different (Preston and Jones 2006). If the region can become a leader in innovation and technical development, such as it is already in wind energy production, there are opportunities for economic growth associated with sustainable development. Innovation for sustainability could provide a niche for development and there are substantial future R&D, education and sustainable development opportunities to exploit.

Sustainability requires people to become a part of an ecological management process and this will be an imperative of effective adaptation to climate change. Climate change is such an over-riding, all-encompassing issue that responses to climate change could become umbrella approaches that stimulate a significant increase in interest in sustainable production and ecological sustainability in general. At very least, it will be a major driver for building greater resilience into our NRM systems.

APPENDIX 1. THE ADAPTATION CHALLENGE

1. The youngest person starts.
ROLL the dice and MOVE counter to the particular scenario envisaged for climate change in 2030.

2. After landing, DISCUSS the impact of the specific climate change issue on your system. LIST ideas in **Table A** (on separate sheet below).
Then, try to ESTABLISH the overall impact level of the issue according to the Impact Level. NOTE the impact level in **Table A**.

Impact Level

4	3	2	1	0	-1
High	Medium-High	Medium	Low-Medium	Low	Benefits

3. DISCUSS adaptation options as a group. LIST ideas in **Table A**.
RATE the potential for adaptation according to the Adaptive Capacity & Note in **Table A**.

Adaptive Capacity

4	3	2	1	0
Highly significant	Significant	Medium	Limited	None

4. CALCULATE the vulnerability of your system to the issue. ADJUST the impact level according to the adaptive capacity.
NOTE the vulnerability level in **Table A.**

Vulnerability of System to Impact = Impact Level – Adaptive Capacity

Vulnerability Level

4	3	2	1	0	-1	-2	-3
High	Medium-High	Medium	Low-Medium	Low	Some Benefit	Benefit	Great Benefit

5. MOVE to next player.
ROLL the dice again & REPEAT process.

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

The Adaptation Challenge: a conversation in climate risk for 2030

Please contact Douglas Bardsley to develop an Adaptation Challenge for your place or system:

Email: bardsley.douglas@saugov.sa.gov.au

Finish by describing the major vulnerabilities of your system

8. Autumn rainfall variability increases

9. Spring rainfall decreases by 10%

7. High intensity rainfall events increase by 10%

Primary impact

Secondary impacts

6. Annual rainfall decreases by 9%

5. Number of frosts decrease by 50%

4. Number of hot spells (3 days in a row >35°C) double

3. Winter temperatures increase by

2. Annual days above 35°C increase from

1. CO_2 concentration increase from

Youngest person starts

10. Sea level rises on average by 10cm

11. High tides increase in conjunction with storms and flooding

12. High temperatures increase stress to animals & humans

13. More frequent, intense, longer & widespread bushfires

14. Increased die-back and disturbance of native ecosystems

15. Annual evaporation increases by 5%

16. Pest plants increase invasivity after disturbance

17. Erosive rainfall events become more common in Autumn/Spring

18. Increase in Murray River salinity levels by 26EC units at Morgan

19. Reduced in-flows into Mt Lofty catchment areas by 23%

20. 12% reduction in average flows down Murray River

21. Demand for irrigation water increases by 20%

22. 15% reduction in groundwater recharge

23. 1:100 year flood events become 1:30 year events

24. More regular later breaks to growing season

25. Reduced flows & erosive events reduce freshwater quality

26. Increase frequency of poor quality freshwater outflows

27. Average temperature increase in Gulf waters by 0.5°

28. Increasing erosion of beaches

Hypothetical Regulatory impacts

Secondary impacts

29. Reduced access to irrigation water supplies

30. Caps on agricultural Greenhouse gas emissions

31. Value of sequested CO_2 increases to $15.00 a tonne

32. Planning prioritisation of production and conservation assets

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Table A			
Issue (use number)	**Impact Level**	**Adaptive Capacity**	**Vulnerability Level**
Eg. 10 Sea level rises on average by 10 cm	• Increasing seawater incursions in streams/inlets • Higher salinity levels will significantly alter estuarine ecological balance 3	• Control of sea-water incursion with barrages • Difficult and expensive to implement • Will create further ponding of streams/inlets 1	2

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
degrees celcius	^{o}C		temperature
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	356 or 366 days	time interval

CO_2	carbon dioxide (parts per million volume)
EC	electrical conductivity (µS/cm)
pH	acidity
ppm	parts per million

GLOSSARY

Act (the). In this document, refers to The *Natural Resources Management Act* (South Australia) 2004.

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 systematic process for continually improving management policies and practices by learning from the outcomes of operational programs.

AGO. Australian Greenhouse Office.

Algal bloom. A rapid accumulation of algal biomass (living organic matter) which can result in deterioration in water quality when the algae die and break down consuming the dissolved oxygen and releasing toxins.

AMLR. Adelaide-Mount Lofty Ranges.

Biodiversity (biological diversity). The variety of life forms: the different life forms including plants, animals and micro-organisms, the genes they contain and the ecosystems they form. It is usually considered at three levels — genetic diversity, species diversity and ecosystem diversity.

Biosecurity. The protection of the economy, environment and public health from native impacts associated with pest animals, plants and diseases.

Biosequestration. A biological process that removes greenhouse gases from the atmosphere, such as the absorption of carbon dioxide by growing trees.

BOM. Australian Bureau of Meteorology.

Carbon sink. A biological or other process that removes carbon dioxide from the atmosphere, such as the absorption of carbon dioxide by growing trees.

Carbon trading scheme. Parties with emissions commitments trading their emission allowances with other parties.

Catchment. A catchment is that area of land determined by topographic features within which rainfall will contribute to runoff 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 eg. regarding how future technological and economic trends may affect emissions.

Community. All South Australians including institutions and organizations.

CSIRO. Australia's Commonwealth Scientific and Industrial Research Organisation.

Cumulative effects. The combined impacts of activities and resource uses within an area and over time.

DEH. Department for Environment and Heritage. Government of South Australia.

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

Ecological integrity. A measure of an ecosystems' functional (process) intactness and ability after a disturbance to a stable state.

Ecological processes. Dynamic interactions among and between biotic and abiotic components of the biosphere.

Ecological values. The habitats, the natural ecological processes and the biodiversity of ecosystems.

Ecologically sustainable development. Using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased.

Ecology. The study of the relationships between living organisms and their environment.

Ecosystem. A dynamic complex of plant, animal, fungal and microorganism communities and the associated non-living environment interacting as a functional unit.

Ecosystem Services. The full suite of benefits that human populations gain from a particular type of ecosystem**,** such as maintenance of climates; provision of clean water and air; pollination of crops and native vegetation; fulfillment of people's cultural, recreational, spiritual, intellectual needs; and provision of options for the future, for example though maintaining biodiversity**.**

Effluent. Domestic wastewater and industrial wastewater.

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^{o}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.

Environmental flow. Any managed change in a river or watercourse's flow pattern intended to maintain or improve the health of the river or watercourse.

EPA. Environment Protection Agency.

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

Estuary. Semi-enclosed waterbodies at the lower end of a freshwater stream that are subject to marine, freshwater and terrestrial influences and experience periodic fluctuations and gradients in salinity.

Eutrophication. Degradation of water quality due to enrichment by nutrients (primarily nitrogen and phosphorus), causing excessive plant growth and decay. *(See algal bloom).*

Evapotranspiration. The total loss of water as a result of transpiration from plants and evaporation from land, and surface waterbodies.

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.

Fire regime. The intensity, frequency and season of fire in the landscape.

Fragmentation. The division or separation of natural areas by the clearance of native vegetation for human land uses, isolating remnants and species and affecting genetic flow.

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.

Groundwater. Water occurring naturally below ground level or water pumped, diverted or released into a well for storage underground.

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

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.

Integrated natural resource management. A holistic, long-term approach to natural resource management that, while retaining the benefits and efficiencies of sectoral management and associated expertise, also brings together the considerations and expertise of all sectors.

Intensive farming. A method of keeping animals in the course of carrying on the business of primary production in which the animals are confined to a small space or area and are usually fed by hand or by mechanical means.

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).

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.

Natural Resources Management (NRM). 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.

Nature Links. A biodiversity conservation concept and program of the South Australian Government that promotes ecological restoration at broad landscape scales through community partnerships.

'No regrets' measure. 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.

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. (Department of) Primary Industries and Resources 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.

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* (South Australia) 2004.

Reserve area. An area of land and/or sea especially dedicated to the protection and maintenance of native biodiversity, and associated natural and cultural resources, that is managed through legal or other effective means.

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

Riparian zone. 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.

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. Runoff in an urban area.

Surface water. Water flowing over land or collected in a dam or reservoir.

Sustainable (Sustainability). Comprises the use, conservation, development and enhancement of natural resources in a way, and at a rate, that will enable people and communities to provide for their economic, social and physical well-being while: sustaining the potential of natural resources to meet the reasonably foreseeable needs of future generations and safeguarding the life-supporting capacities of natural resources and avoiding, remedying or mitigating any adverse effects of activities on natural resources.

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.

WA. Western Australia.

Water allocation plan. A plan developed to manage prescribed water resources through providing a system for the allocation and transfer of water via water licences at a sustainable rate of use that establishes an equitable balance between environmental, social and economic needs for the water. Water allocation plans may also set up rules to regulate water affecting activities such as the drilling of wells and construction of dams through permits.

Water-dependent ecosystems. Those parts of the environment, the species composition and natural ecological processes, which are determined by the permanent or temporary presence of flowing or standing water, above or below ground. The in-stream areas of rivers, riparian vegetation, springs, wetlands, floodplains, estuaries and lakes are all water-dependent ecosystems.

Water sensitive urban design. The aim of water sensitive urban design is to ensure that development is designed, constructed and maintained to minimize negative effects of urban development on natural hydrological regimes and water quality while minimising water consumption and maximising opportunities for water harvesting and re-use.

Wetlands. An area that comprises land that is permanently or periodically inundated with water.

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