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Future Climate Impacts

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List of abbreviations

A1B	IPCC A1B scenario
A1FI	IPCC A1FI scenario
ABARES	The Australian Bureau of Agricultural and Resource Economics and Sciences
ACCU	Australian carbon credit unit
ACT	Australian Capital Territory
Ag	Agriculture
AGFACE	The Australian Grains Free Air CO_2 Enrichment
AI68	AR5 Action Item 68
AI70	AR5 Action Item 70
ANPP	Aboveground net primary production / productivity
AR4	IPCC Fourth Assessment Report
AR5	IPCC Fifth Assessment Report
ASDM	Analogue statistical downscaling method
AWD	Available water determination
B1	IPCC B1 scenario
BOM	Bureau of Meteorology
C3, C4	These terms refer to the *different pathways that plants use to capture carbon dioxide during photosynthesis*.
CAP	Catchment Action Plan
CC	Climate change
CCAM	Cubic Conformal Atmospheric Model
CCRP	The Climate Change Research Program
CCSM3	The Community Climate System Model Version 3 (2007), also NCCCSM
CFI	Carbon Farming Initiative
CGCM	Coupled Global Climate Model
CH_4	Methane
CMA	Catchment Management Authority
CMIP3	Phase 3 of the Coupled Model Intercomparison Project
CMIP5	Phase 5 of the Coupled Model Intercomparison Project
CO_2	Carbon dioxide
CP	Crude protein
CSIRO	The Commonwealth Scientific and Industrial Research Organisation
DAFF	The Department of Agriculture, Fisheries and Forestry
DCCEE	The Department of Climate Change and Energy Efficiency
DECCW	The Department of Environment, Climate Change and Water
DM	Dry matter
DMI	Dry matter intake
DPI	New South Wales Department of Primary Industries

DSE/ha	Dry sheep equivalent per hectare
EAC	East Australian Current
ECHAM5	The fifth-generation atmospheric general circulation model developed at the Max Planck Institute for Meteorology (MPIM)
ENSO	El Nino-Southern Oscillation
GCMs	General Circulation Models
GFDL-CM2.1	Geophysical Fluid Dynamics Laboratory-Coupled Model, version 2.1
GHG	Greenhouse gas
GM	Genetically modified
GRAZPLAN	CSIRO Plant Industry's decision support systems for Australian grazing enterprises. The tools are available commercially as separate software packages; MetAccess®, LambAlive®, GrazFeed®, GrassGro® and AusFarm®
HAL	Horticulture Australia Limited
ICM	Integrated Catchment Management
IPCC	Intergovernmental Panel on Climate Change
IWRM	Integrated Water Resources Management
LGA	Local government area
MDB	Murray-Darling Basin
MIROC	Model for Interdisciplinary Research on Climate
ML	Megalitre
MLA	Meat and Livestock Australia
MPI-OM	The Max-Planck-Institute Global Ocean/Sea-Ice Model
Mt	Metric Ton
N_2O	Nitrous Oxide
NARCliM	The NSW / ACT Regional Climate Modelling project
NE	North-East
NFI	Net feed intake
NHMM	Nonhomogeneous Hidden Markov Model
NPWS	NSW National Parks and Wildlife Service
NRC	National Research Council
NRM	Natural resource management
NSW	New South Wales
NW	North-West
OEH	NSW Office of Environment and Heritage
PI	primary industries
PICCC	The Primary Industries Climate Challenges Centre
Ppm	parts per million
RCP	Representative Concentration Pathway
SA	South Australia
SDM	Species Distribution Modelling
SE	South-East
SEACI	The South Eastern Australian Climate Initiative
SLA	Southern Livestock Adaptation 2030
SLR	Sea level rise
SRES	IPCC's Special Report on Emissions Scenarios

SREX	IPCC's Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation
SW	South-West
TC	Tropical cyclone
THI	Temperature Humidity Index
TIA	The Tasmanian Institute of Agriculture
UK	United Kingdom
UKMO-HadGEM1	United Kingdom, Met Office, Hadley Centre Global Environmental Model, version 1
USA	United States of America
WGI	IPCC Working Group I
WRF	The Weather Research and Forecasting Model

Executive Summary

Executive Summary

The Riverina region faces a range of challenges in agriculture and natural resource management (NRM), not the least of which is managing the impacts of a changing climate. This review aims to investigate climate change and climate variability impacts, adaptation and mitigation strategies in regional NRM planning for the Riverina region of NSW. The Murrumbidgee Catchment Action Plan (CAP) 2013 sets a regional strategic plan for NRM in the Murrumbidgee catchment, aligned with NSW 2021, state NRM targets and the principles for regional NRM planning for climate change. There are important synergies between being well positioned for climate change adaptation and best practice regional NRM. The CAP 2013 provided a framework for integrating a range of responses to a range of pressures, and for managing risks, and thus remains appropriate for adapting to and managing climate change impacts. However, business as usual NRM planning will not suffice as an adequate long-term climate change response.

This review aims to provide a synthesis of the most recent information (2007-2014) available and pertinent to NRM planning in the context of climate change. A workshop with the Riverina Local Land Services reference group was held in June 2014 to solicit inputs, discuss findings and refine the first draft of this review. The review will serve as background document and provide scope for Local Land Services in the Riverina region to carry out consultations, develop its overall climate change strategy, and contribute to a State Strategic Plan and Local Strategic Plans.

While responses to climate change involve both mitigation and adaptation, measures for mitigation receive less focus in this document due to the lack of practical and cost-effective options available from research as yet. The information presented here is based upon recent technical reports produced by the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report; the State of Climate Change 2014; other reports by CSIRO and data from the Australian Bureau of Meteorology; NSW government data; as well as peer-reviewed scientific studies. The resultant literature of almost 250 references spans many disciplines and fields. Nevertheless, the review also does not claim to be, and could not be, exhaustive. In terms of its spatial scope, the review covers as much information on climate projections, impacts and adaptation specific for the Riverina region as possible. However, the review was also expanded to include information available for New South Wales, the south east region, the Lower Murray-Darling, Murrumbidgee and Lachlan catchments. Information on adaptation and mitigation options are discussed under different types of land-use and industries including grazing, broadacre, intensive livestock, horticulture and non-agriculture use.

Key findings

The Riverina region is considered likely to be one of the regions of New South Wales, most severely impacted by climate change because of increasing temperatures, changes in the volume and distribution of rainfall, reduced snowfalls, and decreases in river flows. The latter is particularly important given the dependence in this region on irrigation.

Climate Projections: Consistent with national projections, the temperatures in the Riverina Murray region are predicted to rise with average daily maximum temperatures of 1.5–3.0°C higher in all seasons by 2050. Rainfall in the Riverina is likely to increase moderately in summer but decline substantially in spring, autumn and winter with a high risks for increases in extreme rainfall events. The number of extreme fire-weather days is also projected to grow in southern Australia. For example, a warming of 1.5°C and an 8% decrease in rainfall (a moderate scenario for 2030) would make the climate of Wagga Wagga similar to the current climate of Forbes.

Grazing: South eastern Australian broadacre livestock production is highly sensitive to climatic factors and variability due to its dependence on the supply of forage from dryland pastures. However, impacts vary significantly within and between regions - being most severe in the lower rainfall parts of the wheat sheep zone, but positive for some currently higher rainfall/colder areas. Relatively modest changes in rainfall and pasture production under climate change will result in much larger reductions in sustainable stocking rate and profitability. It is important to note that no single adaptation provides all the answers, with a combination of adaptations likely to work best. Combinations of adaptations will be required to maintain the productivity of livestock production across southern Australia to 2030. By 2050 and 2070, on the other hand, it is likely that new technologies or systems will need to be found if livestock production at the drier end of the farming zone is to remain viable.

While mitigation options exist for intensive dairy systems (e.g. feeding dietary supplements), options to reduce net emissions of methane (CH4) and nitrous oxide (N_2O) are limited in more extensive grazing systems. There are some obvious options that will both reduce emissions intensity and improve overall productivity including animal (e.g. early finishing, improved weaning %) and dietary manipulation. However, while offset methods are being developed, opportunities for graziers under the Carbon Farming Initiative (CFI) are currently limited.

Broadacre Cropping: Impacts on crops vary and regional variability plays a key role. Effects of climate change on crops (i.e. grain, cotton and rice) include the positive effect of higher carbon dioxide (CO_2) concentrations impacts on plant and crop growth, impacts on the water-use efficiency of dryland and irrigated crop production, and potential effects on biosecurity, production and quality of product via impacts on endemic and introduced pests and diseases, and tolerance to these challenges. There are a range of technical adaptations available such as changed crop management practices, selecting new varieties, altered rotations and improved water management. Maintaining a flexible research and development base to inform policy adaptations as well as farm-level changes is essential to deliver potential adaptation benefits. Mitigation options under the Carbon Farming Initiative are currently limited for broadacre cropping.

Intensive Livestock: Warmer and drier conditions are projected for most intensive livestock-producing regions, raising the likelihood and incidence of heat stress in stock and challenges to irrigation and stock water. To achieve effective adaptation, stock shade and shelter will be essential, water use efficiency will need to improve and low emissions and alternative energy options should be identified and developed. Livestock enterprises must have the flexibility to rapidly change management systems in response to dynamic environmental, economic and social conditions. Farmers and producers need to have a greater awareness of environmental, economic and social conditions beyond their farm gates than ever before. Mitigation options for intensive livestock are either focused on manure management or diet supplementation. These are detailed in the livestock section or manure management for feedlots, pigs and poultry.

Horticulture: Site suitability may change for some horticultural crops as a result of climate change. There will be effects on flowering, pollination, harvest dates, sunburn incidence, colour development and fruit size. Varietal selection can be used to match crops to new climate regimes. Utilising existing varieties or breeding new varieties can facilitate adaptation. Specifically for wine grape, shifting to cooler sites will alleviate some warming impacts. As vineyard blocks have an average life of 30+ years, this option will need to be considered with some urgency. Options for mitigation are limited to improved nitrogen fertiliser management for the horticulture industries at this stage.

Non-Agriculture Land-use: Higher temperatures and drier conditions are likely to cause major changes in ecosystems. Riverine, floodplain and wetland ecosystems are highly vulnerable. Freshwater resources and stream flows in south eastern Australia are predicted to decline. The river flows in the south eastern section of the Murray Darling Basin (MDB) are expected to further decline by 5–15% over the next 20–50 years. Wetland-dependent colony birds are therefore likely to decline. The decline of wetland ecosystems in the Riverina is likely to affect ecosystem services. The Riverina’s reduced vegetation cover, caused by a reversal of seasonal rainfall patterns and overall drier conditions, is likely to leave many soils vulnerable to increased erosion, making these more vulnerable in extreme events. Vulnerable areas include the alluvial plains of the Riverina and susceptible gullies on the south west slopes and plains. Extreme heat and reduced water availability will be significant drivers of future biodiversity loss and will increase the risk of local species extinctions.

Executive Summary

Effectively integrating climate change projections into regional NRM planning processes is challenging as it is often not possible to apply standard probability-based approaches to water infrastructure planning or other decisions. Concepts such as Integrated Catchment Management (ICM) and Integrated Water Resources Management (IWRM) appear to embrace a more holistic approach. Significant opportunities exist under the Carbon Farming Initiative for establishment of carbon sinks in trees and vegetation, and these should be further explored.

Recommended Interventions for Local Land Services

The focus of government has shifted more towards managing the short-term impact of extreme events on agriculture, rather than long-term plans for transformational adaptation. However, as these impacts are local and regional, there is a clear role for Local Land Services to identify assets, systems, industries and regions at risk and to work with land managers to raise awareness of these risks and facilitate implementation of regionally relevant adaptation and mitigation options.

Local Land Services also has a role in using their engagement with land managers to identify opportunities that require more regionally relevant mitigation and adaptation research, bridging this knowledge with relevant research providers and industry. In such a complex policy environment where land managers find it hard to navigate, Local Land Services could provide support to ensure a consistency in mitigation and adaptation extension messages, thus avoiding conflicts and confusion around good practice guidelines.

Local Land Services regional adaptation efforts should focus on empowering of stakeholders in a way that increases resilience of the landscape system, involving both people and natural systems. Transfer of information needs to be supported by acceptance and ownership of the concept of change.

Chapter 1: Introduction

Chapter 1: Introduction

The evidence of warming of the Earth's climate system is unequivocal (IPCC, 2013). One of the key sectors that is already and will increasingly be affected by climate change is agriculture. Australia has the world's most variable climate. Since European settlement, managing the impacts of climate variability on agricultural systems has been a major challenge although positive progress has been made (Stokes & Howden, 2010a). Now in the context of climate change, there will be likely a range of impacts on Australian agriculture with a consequent need for mitigation and adaptation responses to emergent risks and opportunities.

Climate change also has major implications for the way that natural resources are managed at the regional level. Specifically, the implications of climate change for water availability, use and management are profound. Changes in water availability will in turn have, for example, major implications for vegetation management. Adaptations among this unique biota and distinctive farming systems in Australia have been shaped by climate variability; a fundamental driver of ecological processes and land use (Campbell 2008).

There are two broad categories of climate change responses: mitigation (avoiding or reducing greenhouse gas emissions and increasing sequestration of carbon in soils and vegetation); and adaptation (coping with climate change and increased variability). Climate change adaptation is defined as adjustments in ecological, social or economic systems in response to observed or expected changes in climatic parameters, such as temperature, rainfall and humidity (McCarthy 2001 and Adger 2005 #119). Seen from this perspective, the main purpose of adaptation is to reduce or alleviate negative impacts of climate change, or to exploit new opportunities arising from such change. Adaptation complements emission reduction measures and is a necessary part of addressing the climate change challenge.

Many regional NRM bodies are considering their potential involvement in carbon trading, specifically through facilitating recognition of revegetation work as sinks to offset greenhouse gas emissions. Adaptation to climate is not new. Australian farmers have been adapting to past changes in prices, technologies and climate variations as well as institutional factors (G. McKeon, Hall, Henry, Stone, & Watson 2004). However, changes are now likely to be far-reaching, systemic and to some extent, able to be foreseen (Stokes & Howden, 2010a). For example, the IPCC Fifth Assessment Report concludes with *high confidence* that without adaptation, further climate changes are projected to have substantial impacts on water resources, coastal ecosystems, infrastructure, health, agriculture and biodiversity for Australia (IPCC 2014). Therefore, it is important to channel further attention and focus to adaptation, given the case for advanced preparation. Stokes & Howden (2010a) argued that there is a need to start developing and implementing adaptation strategies now.

Chapter 1: Introduction

A report in March 2014 by CSIRO and University of Technology, Sydney (CSIRO and UTS, 2014) reviewed past adaptation activities currently and recently undertaken within NSW, as well as informative examples worldwide, to distil lessons for next generation adaptation initiatives. The key adaptation principles relevant for NSW in designing adaptation approaches are:

- Importance of local and other scales: Local government is crucial for on-ground adaptation, but needs to be effectively linked to national scale issues.
- Importance of deliberative processes and multiple partnerships: Multiple partnerships are necessary to manage multiple drivers, and new partnerships are needed between government, science, private sector and local communities to support local adaptation. A range of deliberative processes are needed to engage effectively. Leadership needs to be strong, and appropriate resources are required.
- Managing “climate change” versus specific events: There is a danger that the agenda gets side-tracked and too broad if the emphasis is on “climate change” alone. A suggested approach is to focus on specific issues that are locally relevant.
- Lack of information: Limited information about vulnerability of municipalities to climate impacts can be a constraint. The degree of information needed for adapting to climate change depends on the type of response in focus and needs to be locally relevant.
- Institutional limitations, resource constraints and competing agendas: The ability of local institutions to adapt to climate change concerns the policy framework in which local government operates, their financial capacity and competition for finite resources. Policy makers need to be aware of potential mismatches between current organisational roles and scale of adaptation and institutional support.

The “*NSW 2021: A plan to make NSW number one*” includes a commitment from the Government to minimise the impacts of climate change on communities. Thus, climate change responses need to be hard-wired into the core business of regional NRM bodies. It should be considered not as a separate issue but as a core feature of the operating environment (Campbell, 2008). This review provides relevant information for the LLS in the Riverina region to support the integration of climate change responses into their core business.

Specifically, this review synthesizes information on climate projections, expected trend in climate variables under various emissions scenarios and the anticipated quantum of change. It discusses direct and indirect impacts on different types of land-use and industries. The review also outlines key adaptation and mitigation options and identifies research gaps. Finally, the review offers recommendations on areas of interventions where Local Land Services could develop their responses, leverage impacts in the context of climate change and contribute to the NSW 2021.

Chapter 1: Introduction

This review is structured around 8 chapters. Following the Introduction, Chapter 2 presents key information on climate projections at national, state and the Riverina region. Chapters 3 to 7 discuss climate change impacts, adaptation and mitigation options for Grazing, Broadacre, Intensive Livestock, Horticulture and Non-agriculture use. Chapter 8 concludes with recommendations for Local Land Services on strategic interventions under a broad policy framework.

Chapter 2: Future Climate Scenarios

Chapter 2: Future Climate Scenarios

Climate change projections are useful tools to guide decision-making about climate risks. They indicate the expected trend in climate variables under various emissions scenarios and the anticipated quantum of change. However, their reliability varies. In general, global projections are more certain than regional projections and temperature projections are more certain than those for rainfall. Changes in average conditions are also more certain than changes in extremes (IPCC, 2013).

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) (IPCC, 2013) states that warming of the climate system is unequivocal, and has been since the 1950s. The report concludes that it is "extremely likely" that human influence has been the dominant cause of the observed warming since the mid-20th century, and that the observed changes "are unprecedented over decades to millennia". As a result, the global climate system will very likely see changes that exceed those observed over the past century. This section reviews these projections, limited to a set of climate variables: rainfall, temperature changes and extreme weather events. Annex 2.1 of this chapter contains information on observed and projected changes in key climate variables, and the contribution of human activities to observed changes for Australia.

2.1. Temperature

Chapter 11 and chapter 12 of the IPCC Report (IPCC, 2013) show near-term (2016-2035) and long-term (2081–2100) projections of climate change. Changes are expressed with respect to a baseline period of 1986–2005. Under the near-term projections, the change in global mean surface air temperature will likely be in the range 0.3 to 0.7°C (*medium confidence*). Under the assumptions of the concentration-driven Representative Concentration Pathway (RCP), global mean surface temperatures for 2081–2100 (long-term), will likely be in the 5 to 95% range of the CMIP5[1] models; 0.3°C to 1.7°C (RCP2.6), 1.1°C to 2.6°C (RCP4.5), 1.4°C to 3.1°C (RCP6.0), 2.6°C to 4.8°C (RCP8.5) as seen in Figure 1.

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[1] Coupled Model Intercomparison Project Phase 5

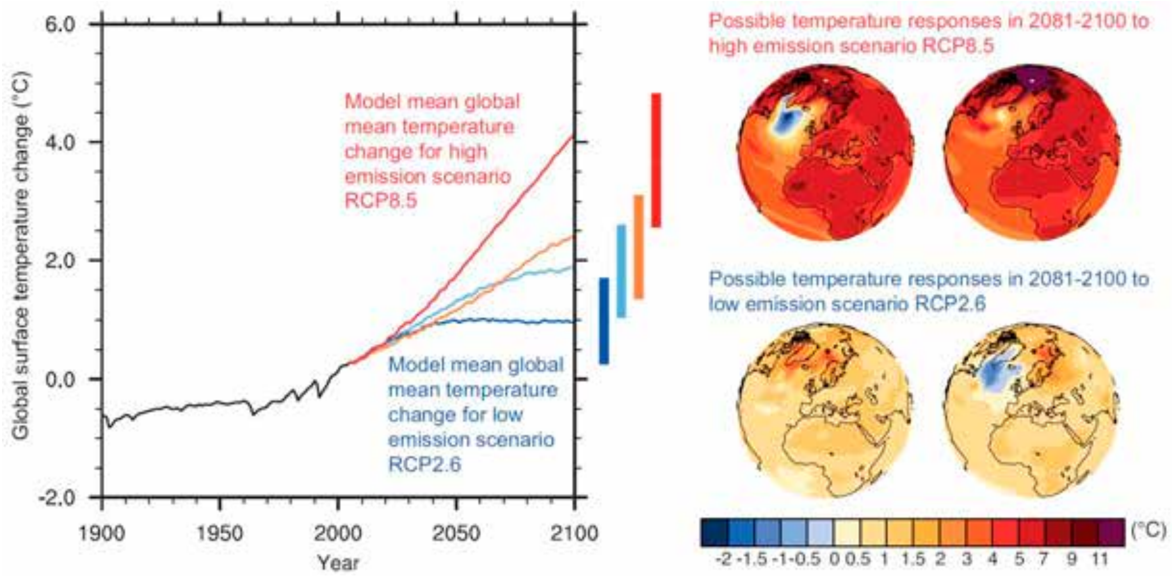

Figure 1: Global mean temperature change averaged across all Coupled Model Intercomparison.

Project Phase 5 (CMIP5) models (relative to 1986–2005) for the four Representative Concentration Pathway (RCP) scenarios: RCP2.6 (dark blue), RCP4.5 (light blue), RCP6.0 (orange) and RCP8.5 (red); 32, 42, 25 and 39 models were used respectively for these four scenarios. Likely ranges for global temperature change by the end of the 21st century are indicated by vertical bars. Note that these ranges apply to the difference between two 20-year means, 2081–2100 relative to 1986–2005, which accounts for the bars being centred at a smaller value than the end point of the annual trajectories. For the highest (RCP8.5) and lowest (RCP2.6) scenario, illustrative maps of surface temperature change at the end of the 21st century (2081–2100 relative to 1986–2005) are shown for two CMIP5 models. These models are chosen to show a rather broad range of response, but this particular set is not representative of any measure of model response uncertainty (IPCC, 2014).

Consistent with global trends, Chapter 25 on Australasia of the IPCC Working Group II, recently released in March 2014, found that **Australia had experienced warming of 0.4 to 0.7°C since 1950, with a greater frequency and intensity of droughts and heat waves**, reduced seasonal snow cover and glacial retreat (IPCC, 2014).

Australian temperatures are projected to continue to increase, with more hot days and fewer cool days (BOM and CSIRO, 2014).

Australia has exhibited warming to the present (*very high confidence*) and it is virtually certain that Australian temperatures are projected to continue to warm, rising by 0.6 to 1.5°C by 2030 compared with the climate of 1980 to 1999; noting that 1910 to 1990 warmed by 0.6°C. Warming by 2070, compared to 1980 to 1999, is projected to be 1.0 to 2.5°C for low greenhouse gas emissions and 2.2 to 5.0°C for high emissions (BOM and CSIRO, 2014).

Projected regional warming is significant and will be accompanied by a large increase in the frequency of high-temperature extremes and a decrease in the frequency of low-temperature extremes (Whetton et al. 2013). The year of 2013 was Australia's warmest year on record, being 1.2°C above the 1961–1990 average of 21.8°C and 0.17°C above the previous warmest year in 2005. Seven of the ten warmest years on record have occurred since 1998 (BOM and CSIRO, 2014).

2.2. Rainfall

Since 1950, Australia has experienced changed rainfall patterns across the region.

According to the State of Climate Change 2014, rainfall averaged across Australia has slightly increased since 1900, with a large increase in north west Australia since 1970.

Since the mid-1990s, **the south east region** has experienced a 15 per cent decline in late autumn and early winter rainfall, with a 25 per cent reduction in average rainfall across April and May. Autumn and early winter rainfall has mostly been below average in the south east since 1990 (BOM and CSIRO, 2014)

Global climate models project significant changes in Australian rainfall under enhanced greenhouse conditions. However, the projected patterns of change (including areas of increase and decrease) differ considerably between models. In addition to these large ranges of uncertainty in projected rainfall provided by the climate models, it should be noted that local rainfall changes can be significantly modified by mountain ranges. This is not adequately represented by the models. Other authors (McBride and Nicholls, 1983; Power et al. 1998; Risbey et al. 2009 as cited in Whetton et al. (2013)) found that natural climatic variability is very high, especially for rainfall with the El Nino-Southern Oscillation (ENSO) being the most important driver.

This is reiterated by the IPCC (IPCC, 2014) that while climate model projections have improved in recent years, some important climatic influences, including the El Nino Southern Oscillation (ENSO), were not well represented in climate modelling for IPCC Fourth Assessment Report (AR4). For example, changes in ENSO in response to anthropogenic climate change are uncertain (AR5 WGI Ch14) but other authors claimed that given current ENSO impacts, any changes would have the potential to significantly influence rainfall and temperature extremes, droughts, tropical cyclones, marine conditions and glacial mass balance (Mullan, 1995; Chinn et al. 2005; Holbrook et al., 2009; Diamond et al., 2012; Min et al., 2013 cited in IPCC 2014).

Chapter 2: Future Climate Scenarios

In Australia, understanding of observed and projected climate change has received much attention since the Fourth Assessment Report. In 2010, the NSW Office of Environment and Heritage claimed that average rainfall in NSW has declined over the past 50 years, but whether this is linked to climate change is unclear (DECCW, 2010). The need for further understanding of the causes of observed rainfall changes and more systematic analysis of projected changes from different models and approaches has given a new focus to the AR5 (IPCC, 2014).

In 2013, the AR5 report found that large uncertainty persists in terms of projected rainfall changes for many parts of Australia, which creates significant challenges for adaptation. For example, projections for average annual runoff in far south-eastern Australia range from little change to a 40% decline for 2°C global warming above current levels. The projected seasonal rainfall changes for Australia also show very broad ranges of change at 4°C global warming. Summer rainfall changes range from -50% to +50% across most of Australia. The range is also broad in winter, but in southern areas is skewed to decrease and the range is typically around -40% to +10% (Whetton et al. 2013).

According to the State of Climate Change 2014, since 1970, there have been large increases in annual rainfall in the north west of Australia and decreases in the south west of Australia. Autumn and early winter rainfall has mostly been below average in the south east since 1990 (BOM and CSIRO, 2014). Average rainfall in southern Australia is projected to decrease with most of its rainfall during the cooler months and a likely increase in drought frequency and severity. In recent decades declines in rainfall have been observed in the south west and in the south east of the continent (IPCC, 2014). Further decreases in average rainfall are expected over southern Australia compared with the climate of 1980 to 1999: a 0-20% decrease by 2070 for low emissions; and a 30% decrease to 5% increase by 2070 for high emissions, with largest decreases in winter and spring. Droughts are expected to become more frequent and severe in southern Australia (BOM and CSIRO, 2014).

2.3. Extreme weather event

In Canberra, extreme fire-weather days are projected to increase from the current 17 days per year to 18-23 days in 2020 and 20-33 days in 2050 (Lucas et al. (2007) cited in IPCC (2014).

Extreme fire-weather days have become more extreme at 24 of the 38 climate reference sites from 1973–2010 (IPCC, 2014). The number of extreme fire-weather days is projected to grow in southern and eastern Australia; by 10 to 50 per cent for low emissions and 100 to 300 per cent for high emissions, by 2050 compared with the climate of 1980 to 1999. Droughts are expected to become more frequent and severe in southern Australia. The frequency and intensity of extreme daily rainfall is projected to increase. An increase in the number and intensity of extreme rainfall events is projected for most regions (BOM and CSIRO, 2014).

Fewer tropical cyclones are projected for the Australian region, on average, with an increased proportion of intense cyclones (IPCC, 2014). However, confidence in tropical cyclone projections is low. Tropical cyclones are projected to decrease in number but increase in intensity (BOM and CSIRO, 2014).

The duration, frequency and intensity of heatwaves have increased across large parts of Australia since 1950. There has been an increase in extreme fire weather, and a longer fire season, across large parts of Australia since the 1970s. Days where extreme heat is widespread across the continent have become more common in the past 20 years. The largest increase in fire weather has been in the south east, away from the coast (BOM and CSIRO, 2014).

2.4. Projections from the Regional Climate model NARCLiM[2]

The NSW/ACT Regional Climate Modelling (NARCLiM) project is producing an ensemble of regional climate projections for south east Australia. This ensemble is designed to provide robust projections that span the range of likely future changes in climate.

In collaboration with the NSW Office of Environment and Heritage (OEH) and to support the Sydney Adaptation Strategy, an experimental very high resolution (2km) climate projection is being performed. NARCliM uses the Weather Research and Forecasting (WRF) model, a dynamic regional climate model that gives high resolution projections of temperature, rainfall and many other meteorological variables.

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[2] ccrc.unsw.edu.au,. (2014). NARCliM. Retrieved 4 September 2014, from http://www.ccrc.unsw.edu.au/NARCliM/

WRF will be run with four separate General Circulation Models (GCMs) (MIROC-medres 3.2, ECHAM5, CGCM 3.1 and CSIRO mk3.0). Each will be repeated three times for a total of 12 runs, using a single, representative emissions scenario: the IPCC high emissions scenario A2. Projections will be produced for several variables, including temperature, rainfall, wind, relative humidity, sea surface temperature and soil temperature.

A report synthesising and interpreting the projected changes in climate across NSW will be jointly completed by staff from OEH and the Climate Change Research Centre at the University of NSW (expected to complete at the end of 2014). It is recommended that while developing a climate change adaptation strategy for the Riverina, this report with NARCliM data needs to be considered and incorporated.

2.5. New South Wales[3]

The NSW Climate Impact Profile (DECCW, 2010) indicates that NSW is expected to become hotter (1-3°C), with the greatest increases in maximum temperatures expected to occur in the north and west of the state. In NSW, recent climate records which exclude historic variability show an accelerating increase in average annual temperatures. Between the 1950s and 1980s, average annual temperature rise was around 0.1°C per decade, but since 1990 it has been about 0.5°C per decade (DECCW, 2010). Additionally, from 1997 to 2007, all years were warmer than average, an unprecedented sequence in the historical records.

As seen in Table 1 below, NSW is expected to be warmer by +0.2– +2.1°C by 2030, and by +0.7– +6.4°C by 2070. The higher temperatures are likely to result in higher evaporation across much of the state, offsetting most of the expected increases in summer rainfall. The seasonal pattern of rainfall varies across Australia, particularly in NSW where four of the six major climate classes occur. The rainfall regime in NSW includes regions where winter (south) or summer (north) rainfall dominates as well as large areas with a uniform rainfall distribution (BOM 2010). In northern NSW these changes to rainfall and evaporation appear to be within recorded levels of variability. The south western regions are likely to experience a significant decline in winter rainfall (20-50%). Many parts of the state will experience a shift from winter-dominated to summer-dominated rainfall (DECCW, 2010).

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[3] http://www.environment.nsw.gov.au/resources/biodiversity/10771prioritiesbioadaptcc.pdf

Table 1: Annual and Seasonal Climate Projections for New South Wales (CSIRO, 2007).

Season	2030	2070
Annual	Warmer by +0.2– +2.1°C Rainfall change of -13 – +7%	Warmer by +0.7– +6.4°C Rainfall change of -40 – +20%
Summer	Warmer by +0.2 – +2.3°C Rainfall change of -13 – +13%	Warmer by +0.7– +7.1°C Rainfall change of -40 – +40%
Autumn	Warmer by +0.2 – +1.9°C Rainfall change of -13 – +13%	Warmer by +0.7 – +5.6°C Rainfall change of -40 – +40%
Winter	Warmer by +0.2 – +2.3°C Rainfall change of -13 – +7%	Warmer by +0.7 – +5.6°C Rainfall change of -40 – +20%
Spring	Warmer by +0.2 – +2.1°C Rainfall change of -20 – +7%	Warmer by +0.7 – +7.1°C Rainfall change of -60 – +20%

NSW also experiences climate extremes, such as widespread flooding and prolonged drought. These climate patterns have been attributed to the combined influences of the El-Nino Southern Oscillation, Southern Annular Mode and the Indian Ocean Dipole (DECCW, 2010).

2.6. The Riverina region

The climate of the Riverina region has a strong seasonal cycle, with cool to cold winters and warm to hot summers. It is considered likely to be one of the regions of New South Wales most severely impacted by climate change because of increasing temperatures, changes in the volume and distribution of rainfall, reduced snowfalls, and decreases in river flows (DECC NSW 2008).

While much research has been carried out to estimate future climate on a global and continental scale, most policy and management decisions need to be made at regional and local scales. It is important to note that climate variability increases with decreasing space and time scales, so as the area of interest of climate projections decreases, uncertainties increase (CSIRO, 2010). Furthermore, global climate models do not represent all of the climatic features for this region well. For example, most climate models fail to reproduce the correlation between the sub-tropical ridge intensity and south-eastern Australian rainfall (CSIRO 2012a). Since climate change projections for the Riverina are not directly available, more information in this section will be drawn from materials on southern murray or the south eastern regions.

According to the IPCC (2014), since the 1990s changes in precipitation have been observed with very high confidence in south east Australia. This pattern of projected rainfall change is reflected in annual average CMIP5[4] model results. Examples of the magnitude of projected annual precipitation change for the Murray Darling Basin from 1990 to 2090 (percent model mean change +/- intermodel standard deviation) under RCP8.5 from CMIP5 is -2±21%.

Within the framework of Phase 1 of the South Eastern Australian Climate Initiative (SEACI), researchers used statistical methods including the non-homogeneous hidden Markov model (NHMM)[5]; analogue statistical downscaling method (ASDM)[6] and dynamical modelling including the Cubic Conformal Atmospheric Model (CCAM)[7] for estimating regional climate change. SEACI researchers applied the NHMM to the output of four global climate models to investigate the possible future climate conditions across south east Australia under different climate change scenarios. Their projections out to 2030 suggest rainfall and stream flow will decrease across south east Australia (CSIRO, 2010). This finding is further supported by the SEACI Phase 2, focusing on climate and water availability in south east Australia. SEACI Phase 2 researchers found that despite the exceptional rainfall experienced across much of Australia, during the spring and summer of 2010/11 and 2011/12, caused by consecutive La Nina events, across south east Australia there was a continuation of below average rainfall during the cool season (April to October). Their conclusions using other alternative models, all indicated that southern Australia will have a drier future.

A warming of 1.0°C and a 5% decrease in rainfall (a moderate scenario for 2030) would make the climate of Wentworth similar to the current climate of Pooncarie, around 100km to the north (CSIRO, 2007)

A warming of 1.5°C and an 8% decrease in rainfall (a moderate scenario for 2030) would make the climate of Wagga Wagga similar to the current climate of Forbes (CSIRO, 2006)

Specifically, across the southern part of south east Australia (south of 33° S latitude), with 1°C of global warming, average annual rainfall is expected to decline by 0 to 9% (median of 4%), and average annual runoff is expected to decline by 2-22% (median of 12%). For 2°C of global warming, the reductions in both rainfall and runoff are approximately double these. The situation is less clear in the northern part of the region (CSIRO, 2012a).

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[4] Phase 5 of the Coupled Model Intercomparison Project

[5] NHHM model assumes that the rainfall patterns can be classified into a small number of discrete weather patterns or weather states. The model uses atmospheric circulation data to estimate the sequences of these weather states and hence can simulate realistic sequences of daily rainfall.

[6] ASDM is based on the historical relationship between large-scale weather patterns and surface climate variables (such as temperature and rainfall)

[7] CCAM has been used extensively to provide dynamical downscaling of output from global climate models for many regions of the world (Watterson et al., 2008)

Chapter 2: Future Climate Scenarios

According to the NSW Department of Environment, Climate Change and Water (DECCW, 2010), rainfall in the Riverina is likely to increase moderately in summer but decline substantially in spring, autumn and winter. Rainfall projections show a similar pattern for both spring and autumn, a decrease of up to 50%, with the severity of the deficit rising sharply with latitude. A 20–50% decrease in winter rainfall is likely, the deficit being greater in the south, whereas most of the region is likely to receive a 10–20% increase in summer rainfall. The eastern Riverina and south west slopes are likely to have the greatest increase, although these areas currently receive relatively low rainfall.

Consistent with national projections, temperatures in the Riverina Murray region are virtually certain to rise.

Table 3 illustrates that average daily maximum temperatures are very likely to be 1.5–3.0°C higher in all seasons. Daily minimum temperatures are also projected to increase, but to a lesser extent than maximum temperatures. Historically, the region experiences over 30 very high to extreme fire danger days a year. Very high to extreme fire danger days are projected to increase by 10–50% and the conditions conducive to large and intense fires (such as prolonged drought, low humidity, number of days with high temperature and high wind speeds) are likely to increase (DECCW, 2010). Further in Table 2, projected climate change in Temora local government area (LGA) by 2050 is consistent with the data found in Table 3. While the summer rainfall is likely to increase, Temora will experience a decrease in winter rainfall.

Since 1950, the Lower Murray region has experienced warming of around 0.8°C (CSIRO, 2007). Average daily maximum temperatures are very likely to be 1.5–3.0°C higher in all seasons while daily minimum temperatures are also projected to increase, but to a lesser extent. The future climate of the Lower Murray-Darling catchment is likely to be warmer and drier. Such conditions would increase evaporation, heat waves, extreme winds and fire risk. Nevertheless, despite this trend toward drier conditions, there is also potential for increases in extreme rainfall events (DECC NSW, 2008).

Table 2: Examples of projected climate change in Temora LGA (Riverina) by 2050 (DECCW, 2010)

The current average daily maximum temperature in summer is 30.8°C. This is very likely to increase to between 32.3 and 33.8°C.
The current average rainfall over summer is 120 mm. This is likely to increase to between 144 mm and 180 mm.
The current average rainfall over winter is 158 mm. This is likely to decrease to between 79 mm and 126 mm.

Table 3: Summary of temperature and rainfall changes in the Riverina Murray region to 2050 (DECCW, 2010)

Season	Minimum temperatures	Maximum temperatures	Precipitation	Evaporation
Spring	1.0–2.0°C warmer (warmer in the eastern Riverina and south west slopes)	2.0–3.0°C warmer	Up to 50% decrease, more severe in the south and west	No change in the south grading to 10–50% increase in the north
Summer	0.5–1.5°C warmer	1.5–3.0°C warmer	10–50% increase, higher in the eastern Riverina and southwest slopes	20–50% increase
Autumn	0.5–1.5°C warmer	1.5–3.0°C warmer	Up to 50% decrease, more severe in the south and west	5–20% increase
Winter	0.5–1.0°C warmer	2.0–3.0°C warmer	20–50% decrease	20–50% decrease in the south grading to 10–20% decrease in the north

Annex 2.1

Table 4: Observed and projected changes in key climate variables, and (where assessed) the contribution of human activities to observed changes for Australia (IPCC, 2014)

Climate variable	Observed change	Direction of projected change	Examples of projected magnitude of change (relative to ~1990, unless otherwise stated)	Additional comments
Mean air temperature	Increased by 0.09 ± 0.03°C per decade since 1911[1] (***)	Increase[3-8] (****); greatest over inland Aus (***)	0.6-1.5°C (2030 A1B), 1.0-2.5°C (2070 B1), 2.2-5.0°C (2070 A1FI)[3] *CMIP5 RCP4.5, rel. to ~1995[9]:* ***N*** 0.3-1.6°C (2016-2035), 0.7-2.6°C (2046-2065) ***S Aus:*** 0.1-1.0°C (2016-2035), 0.6- 1.7°C (2046-2065)	A significant contribution to observed change attributed to anthropogenic climate change[10] (**) with some regional variations attributed to atmospheric circulation variations[11,12]
Sea surface temperature	Increased by about 0.12°C per decade for NW&NE Aus and by about 0.2°C per decade for SE Aus since 1950[14,15] (***)	Increase[3,7,8] (***) with greater increase in the Tasman sea region (*) [3,7]	0.6-1.0°C (2070 B1) and 1.6-2.0°C (2070 A1FI) for southern coastal and 1.2- 1.5°C (2070 B1) and 2.2-2.5°C (2070 A1FI) elsewhere[3]	
Air temperature extremes	Significant trend since 1950: cool extremes have become rarer and hot extremes more frequent and intense[16-19] (**).The Australian heatwave of 2012/13 was exceptional in heat, duration and spatial extent [20].	Hot days and nights more frequent and cold days and cold nights less frequent during the 21st century[3,5,21-24] (**)	Hot days in Melbourne (>35°C max.) increase by 20-40% (2030 A1B), 30-90% (2070 B1) and 70-190% (2070 A1FI)[3]	Observed trends partly attributable to anthropogenic climate change (**) as they are consistent with mean warming and historical simulations[18,19,21,25], although other factors may have contributed to high extremes

				during droughts[26-28]
Precipitation	Late autumn/winter decreases in SW Aus since the 1970s and in SE Aus since the mid-1990s, and annual increases in NW Aus since the 1950s[29-31] (***)	Annual decline in SW Aus (**), elsewhere on most of the southern (*) and NE (*low confidence*) continental edges, with reductions strongest in the winter half year[3,4,9,33-35] (**). Direction of annual change elsewhere is uncertain[3,35,36](**)	For 2030 A1B, annual changes of-10% to +5% (N Aus) and -10% to 0% (S Aus), for 2070 B1, -15% to +7.5% (N&E Aus) and -15% to 0% (S Aus), and for 2070 A1FI, -30% to +20% (N&E Aus) and -30% to +5% (S Aus), with larger changes seasonally[3]	Observed decline in SW is related to atmospheric circulation changes[38-40] (***), other factors[41], and partly attributable to anthropogenic climate change[40-43] (**). The recent SE rainfall decline is also related to circulation changes[31,44-46] (**), with some evidence of an anthropogenic component[47]
Precipitation extremes	Indices of annual daily extremes (e.g. 95th and 99th percentile rainfalls) show mixed or insignificant trends[21,48], but significant increase is evident in recent decades for shorter duration (sub-daily) events[49,50] (**)	Increase in most regions in the intensity of rare daily rainfall extremes (i.e. current 20 year return period events) and in short duration (sub-daily) extremes (*) and an increase in the intensity of 99 percentile daily extremes (*low confidence*)[5,8,21,51-56]	For 2090 A2, CMIP3 give increases in the intensity of the 20 year daily extreme of around +200% to -25% depending on region and model[52]	The sign of observed trends mostly reflects trends in mean rainfall (e.g. there is a decrease in mean and daily extremes in SW Aus)[21,32,49]. Similarly, future increases in intensity of extreme daily rainfall are more likely where mean rainfall is projected to increase[3,5]
Drought	Defined using rainfall only, drought occurrence over the period 1900-2007 has not changed significantly[57] (**)	Drought frequency is projected to increase in southern Australia [8,54,57,59,60] (*) and in many regions of New Zealand[58,61] (*)	Occurrence under 2070 A1B and A2 ranges from a halving to 3 times more frequent in N. Aus, and 0-5 times more frequent in southern Aus[60]	Regional warming may have led to an increase in hydrological drought (*low confidence*)[62,63]

Winds	Significant decline in storminess over SE Aus since 1885[64] (*), but inconsistent trends in wind observations since 1975[65,66]	Increases in winds in 20-30°S band, with little change to decrease elsewhere, except for winter increases over Tasmania. Decrease to little change in extremes (99th percentile) over most of Australia except Tasmania in winter[69] (*)	Magnitude of simulated mean changes may exceed 10% under A1B for 2081-2100 relative to 1981-2000 [69]	Many of past and projected changes in mean wind speed can be related to changes in atmospheric circulation[43,67,68]
Mean sea level	From 1900-2011 the average rate of relative sea level rise (SLR) was 1.4±0.6 mm/yr[72] (***)	Regional sea level rise will *very likely* exceed the 1971-2000 historical rate, consistent with global mean trends[74]. Mean sea level will continue to rise for at least several more centuries[74] (***)	Off shore regional sea level rise may exceed 10% more than global SLR, see AR5 WGI Chap13, Figure 13.21[74]	Satellite estimates of regional SLR for 1993-2009 are significantly higher than those for 1920-2000, partly reflecting climatic variability[72,73,76,77]
Extreme sea level	Extreme sea levels have risen at a similar rate to global SLR[79]	Projected mean SLR will lead to large increases in the frequency of extreme sea level events (***), with other changes in storm surges playing a lesser role[80-83]	An increase of mean sea level by 0.1m increases the frequency of an extreme sea level event by a factor of between 2 and 10 over south eastern Australia depending on location [80-82],	
Fire weather	Increased since 1973(**) with 24 out of 38 sites showing increases in the 90th percentile of the McArthur Forest Fire Danger index[84]	Fire weather is expected to increase in most of southern Australia due to hotter and drier conditions (**), based on explicit model studies carried out for SE Australia [85-88], and change little or decrease in NE[88] (*)	Increase in days with very high and extreme fire danger index by 2-30% (2020), 5- 100% (2050) (using B1 and A2 and two climate models, and 1973-2007 base)[85]	For the example of Canberra, the projected changes represent the current 17 days per year increasing to 18-23 days in 2020 and 20-33 days in 2050[85]
Tropical cyclones and other severe storms	No regional change in the number of tropical cyclones (TCs) or in the proportion of intense TCs over 1981-2007[90] (*), but frequency of severe landfalling TCs in NE Aus has declined significantly since the late 19th Century[91] and east-west distribution changed	Tropical cyclones are projected to increase in intensity and stay similar or decrease in numbers[9,94], and occur further south[94] (*low confidence*)	Modelling study shows a 50% reduction in TC occurrence for 2051-2090 relative to 1971-2000, increases in intensity of the modelled storms, and occur around 100km further south[94]	Regional research on convective storms is limited but studies have shown a projected decrease in the frequency of cool-season tornadoes[95] and hail[3] in southern Australia, and increases in the frequency and intensity of hail in the Sydney region[3,96]

	since 1980.[92] There has been no trend in environments suitable for severe thunderstorms[93]		
Snow and ice	Late season significant snow depth decline at three out of four Snowy mountain sites over 1957-2002[97] (**)	Both snow depth and area are projected to decline[97] (***)	Area with at least 30 days cover annually projected to decline 14-54% (2020) and 30-93% (2050)[97]

References: [1] Fawcett *et al.* (2012); [2] Mullan *et al.* (2010); [3] CSIRO and BoM (2007); [4] Moise and Hudson (2008); [5] MfE (2008b); [6] AR5-WGI-Atlas-AI68-69; [7] AR5-WGI-Ch11; [8] AR5-WGI-Ch12; [9] AR5-WGI-Ch14; [10] Karoly and Braganza (2005); [11] Hendon *et al.* (2007); [12] Nicholls *et al.* (2010); [13] Dean and Stott (2009); [14] Lough (2008); [15] Lough and Hobday (2011); [16] Chambers and Griffiths (2008); [17] Gallant and Karoly (2010); [18] Nicholls and Collins (2006); [19] Trewin and Vermont (2010); [20] BOM (2013); [21] Alexander and Arblaster (2009); [22] Tryhorn and Risbey (2006); [23] Griffiths *et al.* (2005); [24] Tait (2008); [25] Alexander *et al.* (2007); [26] Deo *et al.* (2009); [27] McAlpine *et al.* (2007); [28] Cruz *et al.* (2010); [29] Hope *et al.* (2010); [30] Jones *et al.* (2009); [31] Gallant *et al.* (2012); [32] Griffiths (2007); [33] Timbal and Jones (2008); [34] AR5-WGI-Atlas-AI70-71; [35] Irving *et al.* (2012); [36] Watterson (2012); [37] Reisinger *et al.* (2010); [38] Bates *et al.* (2008); [39] Frederiksen and Frederiksen (2007); [40] Hope *et al.* (2006); [41] Timbal *et al.* (2006); [42] Cai and Cowan (2006); [43] Frederiksen *et al.* (2011); [44] Cai *et al.* (2011); [45] Nicholls (2010); [46] Smith and Timbal (2010); [47] Timbal *et al.* (2010a); [48] Gallant *et al.* (2007); [49] Westra and Sisson (2011); [50] Jakob *et al.* (2011); [51] Abbs and Rafter (2009); [52] Rafter and Abbs (2009); [53] Kharin *et al.* (2013); [54] IPCC-SREX-Chapter-3; [55] Westra *et al.* (2013); [56] Carey-Smith *et al.* (2010); [57] Hennessy *et al.* (2008a); [58] Mullan *et al.* (2005); [59] Kirono and Kent (2010); [60] Kirono *et al.* (2011); [61] Clark *et al.* (2011); [62] Cai and Cowan (2008); [63] Nicholls (2006); [64] Alexander *et al.* (2011); [65] McVicar *et al.* (2008); [66] Troccoli *et al.* (2012); [67] Parker *et al.* (2007); [68] Mullan *et al.* (2001); [69] McInnes *et al.* (2011a); [70] Mullan *et al.* (2011); [71] Salinger *et al.* (2005); [72] Burgette *et al.* (2013); [73] Hannah and Bell (2012); [74] AR5-WGI-Ch13; [75] Ackerley *et al.* (2013); [76] CSIRO and BoM (2012); [77] Meyssignac and Cazenave (2012); [78] Hannah (2004); [79] Menendez and Woodworth (2010); [80] McInnes *et al.* (2009); [81] McInnes *et al.* (2011b); [82] McInnes *et al.* (2012); [83] Harper *et al.* (2009); [84] Clarke *et al.* (2012); [85] Lucas *et al.* (2007); [86] Hasson *et al.* (2009); [87] Cai *et al.* (2009a); [88] Clarke *et al.* (2011); [89] Pearce *et al.* (2011); [90] Kuleshov *et al.* (2010); [91] Callaghan and Power (2011); [92] Hassim and Walsh (2008); [93] Allen and Karoly (2013); [94] Abbs (2012); [95] Timbal *et al.* (2010b); [96] Leslie *et al.* (2008); [97] Hennessy *et al.* (2008b); [98] Hoelzle *et al.* (2007); [99] Ruddell (1995); [100] Chinn (2001); [101] Chinn *et al.* (2012); [102] Fitzharris (2004); [103] Hendrikx *et al.* (2012); [104] Purdie *et al.* (2011); [105] Willsman *et al.* (2010)

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Chapter 3: Climate Change Impacts, Mitigation and Adaptation Options for Grazing

Chapter 3: Climate Change Impacts, Mitigation and Adaptation Options for Grazing

Given the changes in climatic and atmospheric factors as outlined in Chapter 2: Future Climate Scenarios, there are likely to be many direct and indirect impacts on livestock systems, including impacts on feed production and hence grazing management, feed quality, exposure to heat and cold stress, pest and disease impacts, land use, degradation of the natural resource base and international trade (S. M. Howden, Crimp, & Stokes, 2008). Pastures in the rangelands and parts of the wheat sheep zone are likely to be more severely affected by anticipated climate changes than in the high rainfall zone, since below a threshold of about 300-500mm per annum, the effect of elevated carbon dioxide (CO_2) in offsetting the impact of reduced precipitation through increased water use efficiency is diminished (Harle, Howden, Hunt, & Dunlop, 2007).

At the Australian national level, the net effect of a 3°C temperature increase (from a 1980-99 baseline) is expected to be a 4% reduction in gross value of the beef, sheep and wool sector (G. M. McKeon et al. 2009). Under the climate projection of a 1°C increase by 2030, dairy output in all regions of Australia (except Tasmania) is projected to decline (Hanslow, Gunasekera, Cullen & Newth, 2014). The impacts of increased heat stress in cattle include reduced grazing time, reduced feed intake, increased body temperature, increased respiration rate and weight loss. In dairy cows, heat stress reduces milk yield, reduces milk fat and protein content, and decreases reproduction rates (R. Jones & Hennessy, 2000). Further increases and reductions in milk production are projected for the Murray Dairy region due to the increased potential heat stress for animals (Nidumolu et al. 2011).

Southern Australian broadacre livestock production is highly sensitive to climatic factors and variability due to its dependence on the supply of forage from dryland pastures (S. M. Howden et al. 2008). However, impacts vary significantly within and between regions: being most severe in the lower rainfall parts of the sheep/wheat zone, but positive for some currently higher rainfall/colder areas. These industries are expected to undergo systemic change in response to projected future alterations in the climate (Moore & Ghahramani, 2013). Heyhoe et al. (2007) estimated the impact of climate change at 2030 on total factor productivity and production of broadacre industries for the central west slopes and plains of NSW, and concluded that there is a real potential for negative impact on regional economies.

Information in this section is mostly derived from the Southern Livestock Adaptation 2030 (SLA 2030)[8]. SLA 2030 used the GRAZPLAN[9] simulation models, combining with Global Circulation Models

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[8] Southern Livestock Adaptation 2030, a program of research, development and extension into adaptation options for southern Australian livestock producers that formed part of the Australian Government's Climate Change Research Program. A key feature of SLA 2030 has been collaboration between research organizations (including CSIRO) and State government extension agencies from all 5 states in southern Australia.

[9] The GRAZPLAN simulation models of the dynamics of grazed temperate grasslands. It is widely used in research and as a decision making tool (Moore & Ghahramani, 2013)

(GCMs), local weather data and producers' own production and financial data. Modelling was undertaken in 46 distinct locations (country towns) across southern Australia. A further 43 locations were modelled by University of Melbourne, CSIRO and the Tasmanian Institute of Agriculture (TIA) to assess the impacts of climate change under the SRES A2 scenario across southern Australia. Both spatial (25 representative locations including 8 sites in NSW) and temporal scales (1970–99, 2030, 2050 and 2070 climate) were examined for each of five livestock enterprises (i.e. Merino ewes, crossbred ewes, wethers, beef cows, steers).

Information is also derived from the three papers in the series "Climate change and Broadacre livestock production across southern Australia" by Ghahramani & Moore (2013); Moore & Ghahramani (2013, 2014). According to these authors, apart from this study, there is no other agricultural climate change research that has simultaneously addressed the dimensions of geography, industry segment and time while also taking into account financial outcomes, natural resource management constraints and climate projection uncertainty (Moore & Ghahramani, 2013).

3.1. Impacts on pasture production and forage quality

While research has shown that a rise in carbon dioxide tends to promote pasture growth, this could be counteracted by reduced rainfall. If rainfall declines by more than 10%, the likely impact will be reduced pasture growth, which is not only important for animal production, but could also lead to potential environmental degradation of some grazing lands (DPI, 2013).

Reductions in rainfall, higher temperatures, and higher evaporation rates in southern Australia will lead to lower and more variable pasture production and possibly shorter growing seasons (Crimp, Australian Greenhouse Office, & Queensland. Dept. of Natural Resources and Mines, 2002), especially in the case of livestock enterprises heavily dependent on irrigation water (S. M. Howden et al. 2008). Total annual pasture production in southern Australia is generally resilient to climate changes of +1° with 10% less rainfall, but further changes are likely to reduce annual pasture growth (DAFF, 2012b). In addition, changes in the production of locally important ephemeral pastures on floodplains, due to changes in river flow regimes and beneficial flooding, are likely to magnify any changes in rainfall (Stokes & Howden, 2010a). Forage quality is expected to decrease due to the combined effect of CO_2 and temperature increases. This will ultimately lead to decreased live weight gain and increases in methane emissions from ruminant livestock.

Another impact of climate change is on vegetation cover, which is essential to maintain perennial grasses and shrubs to provide dry season and drought feed and surface cover to protect soils. Potential of climate extremes to cause widespread plant mortality has been observed during drought episodes (Fensham 1998 cited in Stokes & Howden (2010a)). Further changes in rangeland vegetation are expected in response to rising atmospheric CO_2 concentration (Warwick et al. 1998; Howden et al.1999b; Howden et al. 2001b cited in Stokes & Howden (2010a)). The nutritional quality of pastures is likely to decline, through a reduction in foliar nitrogen concentration due to elevated CO_2, reflected in the impact on crude protein and water-soluble carbohydrates (DPI, 2013). In southern pastures with mixed C3 and C4 grasses, rising temperatures may favour an increase in C4 species (Cullen et al. 2009), which generally provide a less nutritious forage than C3 grasses. In regions where C4 grasses are not currently grown, substantial warming is still required before C4 grasses will be more productive than the current C3 species. The NSW DPI stated that it is not inevitable; a shift towards C3 species with increased CO_2 may be equally likely, and has been suggested as an underlying mechanism of the worldwide encroachment of C3 'woody weeds' in semi-arid rangelands. In short, changes in vegetation will have to be monitored in order to adapt appropriately (Stokes & Howden, 2010a).

Moore & Ghahramani (2013) predicted a general reduction in pasture growth throughout the year for southern Australia. According to the SLA 2030, changes in rainfall are the single most important driver of climate change impacts on broadacre livestock. Data also suggests that the drier farming zones will be hit hardest. Modelling conducted by the SLA 2030 showed in most locations that future production systems will see increased temperatures and reduced rainfall, leading to lower productivity (potentially 15-20% lower by 2030) and even larger impacts on profitability. Declines in production and profitability can be expected to be significantly larger than declines in total pasture growth. This differential is caused by the need to leave herbage unconsumed to protect the soil resource, and is probably exacerbated by increased variability in future climates. An average 15-20% reduction in pasture production can lead to a 20-50% reduction in livestock production and profitability. Reductions in profitability are greater in 2070 than 2030. Under the drying projected climate, there is a progressive reduction in the peak growth rate in spring, a shortening of the growing season and an increase in winter growth rates at eight studied locations in NSW (CSIRO, 2012c).

Another study by Cullen et al. (2009) concluded that pasture production at two locations in south eastern Australia would be reduced if rainfall decreased by more than about 10%. G. M. McKeon et al. (2009) found in south eastern Australia that increasing temperatures by 3°C increased pasture growth in the relatively mesic environments but decreased it by 10–20% in drier climates.

Stocking rates, livestock productivity and value

The SLA 2030 stated that increased temperatures and decreased rainfall across many locations in southern Australia, will result in shorter growing seasons and reduced stocking rates in order to maintain ground cover. Projections derived from the CCSM3 global circulation model indicate that rainfall tends to increase and so stocking rate, gross income and profit all tend to rise (at least in 2050 in 2070). For the other three general circulation models, however, rainfall declines in all three future years translate into corresponding or somewhat larger declines in pasture growth. Stocking rates decline by a larger relative amount, since the sustainable optimum stocking rate generally declines with decreasing pasture production.

The SLA 2030's modelling show profitability decline at most sites by the 2050s, because of a shorter growing season due to changes in both rainfall and temperature (Moore & Ghahramani, 2013). As seen in Table 5, the overall value of broadacre livestock production across southern Australia, in the absence of adaptation, is projected to significantly reduce in all four GCMs (DAFF, 2012b). A preliminary analysis of impacts of climate change to 2070 on livestock at eight locations across southern New South Wales showed that for two of the general circulation models (ECHAM5/ MPI-OM and UKMO-HadGEM1), the projected climates would result in widespread financial unviability of livestock production in the absence of further adaptation or price changes (CSIRO, 2012c). While it appears that impacts on beef breeding will be somewhat smaller in relative terms than the impacts on other enterprise types, these differences are unlikely to be large enough to make beef cattle more economically attractive than other enterprises. The uncertainty associated with these projected changes in livestock production is large – and is caused by uncertainty in rainfall projections – but the above trends are discernable nonetheless (DAFF, 2012b).

Table 5: Projected changes in the overall value of broadacre livestock production across southern Australia, in the absence of adaptation, for 4 global circulation models (GCMs) (DAFF, 2012b).

Global Circulation Models	2030	2050	2070
CCSM3.0 (2030 Climate USA 2)	-22%	-21%	-25%
ECHAM5 (2030 Climate Germany)	-37%	-39%	-51%
GFDL2.1 (2030 Climate USA 1)	-37%	-42%	-61%
UKMO HadGEM1 (2030 Climate UK)	-3%	-29%	-48%

Moore and Ghahramani (2013) found that the magnitude of climate change impacts on net primary productivity (ANPP) and profitability of broadacre livestock production across southern Australia increased over time. There is a potential for a significant decrease in the total value of livestock production over the next 20 years. The key findings in the paper include the following:

- At lower-rainfall locations, declines in impacts on net primary productivity (ANPP) were larger.
- Sensitivity of ANPP to growing-season rainfall change is higher at lower rainfalls and at intermediate temperatures. Sensitivity of ANPP to CO_2 change increased with increasing rainfall and decreased with increasing temperature. ANPP is estimated to decrease with increasing temperature at 18 of the 25 locations studied.

The results of this study are broadly similar to the results reported for pasture growth changes by (Cullen et al. 2009), who used different climate projections, a different downscaling technique and a different pasture growth model. For example, Cullen et al. (2009) report a 5% increase in annual ANPP for Wagga Wagga at 2030 based on a 0.7°C temperature increase and an 8% rainfall decrease; this can be compared to a 4% increase found for Culcairn (also in the Riverina) using projections for 2030 from GFDL-CM2.1, which imply 1.0°C temperature increase and a 3% rainfall decrease (CSIRO, 2012c).

Moore & Ghahramani., (2013) study concluded that relatively modest changes in rainfall and pasture production under climate change will result in much larger reductions in sustainable stocking rate and profitability.

3.2. Adaptation options

As the impacts vary, so to do the adaptations which may help alleviate or enhance these impacts. Climate change impacts, and hence the need for adaptive responses, are greatest in the lower-rainfall parts of the cereal-livestock zone and tend to be less severe in the south eastern parts of the high-rainfall zone. It was found that deep rooting and heat tolerant traits will be important adaptations for pasture species in future warmer and drier climates (DAFF, 2012b).

In higher rainfall environments it may be possible to adapt to climate change, in terms of forage quantity and quality, by breeding of adapted lines of key forage species or by carefully selecting existing genotypes to suit more clearly differentiated niches in a heterogeneous landscape. In rangelands, however, the capacity of native communities to continue to support economic levels of livestock production will depend critically on the capacity of species to cope with the interaction between grazing and changed environmental conditions, particularly given the increasing adoption of shedding sheep breeds in the Western Division with the reputed capacity to survive at very low levels of forage availability (Hacker et al. 2007)

While climate scenarios show that grazing systems will still be viable in southern Australia in 2030, there is strong evidence that shows with some adaptation these systems can maintain or even increase profitability. Table 6 below shows relative effectiveness of a range of different potential adaptations in recovering the impact of climate change on the total profitability of livestock production across southern Australia. Adaptations were only applied to those location by enterprise combinations where they increased profit at the sustainable optimum stocking rate (values are averages over 4 GCMs).

Table 6. Relative effectiveness of a range of different potential adaptations in recovering the impact of climate change on the total profitability of livestock production across southern Australia (0% = no benefit; 100% = a return to the 1970-99 baseline value of production). (DAFF, 2012b)

	2030	2050	2070
Higher soil fertility	62%	67%	44%
No annual legumes	1%	1%	1%
Add lucerne to the feedbase	45%	50%	41%
Confinement feeding	15%	21%	24%
Increased livestock size	11%	27%	28%
Increased ram size	3%	6%	5%
Increased fleece weight	7%	16%	16%
Increased conception rate	15%	32%	31%

It is important to note that no single adaptation provides all the answers, with a combination of adaptations likely to work best. Combinations of adaptations can probably be found to maintain the productivity of livestock production across southern Australia to 2030. By 2050 and 2070, on the other hand, it is likely that new technologies or systems will need to be found if livestock production at the dry edge of the farming zone is to remain viable.

It was found that some of the best strategies or practices that are already known to many producers (e.g. increasing soil fertility, genetic improvement of livestock) are as applicable today as they will be in the future. Other adaptations which may not be applicable today may become so depending on the degree to which climates change in the future (DAFF, 2012b).

Stokes & Howden (2010a) claimed that significant changes in management will have to take place in adapting to climate change though there may be winners and losers at national industry level. (Harle et al. 2007) considered that early adaptation through development of low emission grazing systems, more sustainable management especially in the rangelands, and improved management of climate variability could significantly reduce the downsides of climate change impacts. The SLA 2030 concluded that there are changes to management – in particular management for increased soil fertility and the adoption of systematic genetic improvement of flocks and herds – that are (i) likely to be sound adaptations to changing climates, (ii) need to be carried out over the long term and (iii) are likely to be sound investments in the present-day climate. The study emphasized that the case for these adaptations should be made by industry bodies with renewed force (CSIRO, 2012b).

Adger et al. (2003) and Howden et al. (2007) as reviewed in Ghahramani & Moore (2013) proposed several adaptation options: *changes to grazing rotations, grazing times, timing of reproduction, forage, and animal genetics, including the use of forage crops in mixed farming systems, reassessing fertiliser applications, and supplementary feedings*. (Ghahramani & Moore 2013) suggested four adaptation options at different levels aiming at management of grassland. For most of the southern Australian livestock industry, in particular in the lower rainfall parts of the cereal-livestock zone, different strategies for adaptation include combinations of incremental adaptations, transformational adaptations, new technologies, or a complete re-thinking of the feed base; and sustained price increases (if they were to arise) to keep livestock production of the study area viable in the context of changing climates past 2050. The authors, however, claimed that there has not been published literature which have provided quantified effectiveness of these options in tackling challenges, or tapping the opportunities posed by changing climate to southern Australian livestock production (Ghahramani & Moore 2013).

According to CSIRO (2012c), a range of different adaptations, based on currently available technologies, are potentially effective in ameliorating the impacts of projected climate changes. In the study, adaptation options were modelled at 25 locations and for each of the 5 livestock enterprises for which they were meaningful. Table 7 below gives a summary of these options in three categories: feedbase, genetic and management.

Table 7: Summary of adaptation options by SLA 2030 (CSIRO, 2012b)

Feedbase adaptations	Genetic adaptations	Management adaptations
1. Higher soil fertility	4. Increased breed standard reference weight	8. Confinement feeding in summers with low pasture mass
2. Management to remove annual legumes, in order to slow the loss of ground cover	5. Increased wool production at constant standard reference weight	9. Altered stocking rate
3. Sowing a portion of land to Lucerne pastures	6. Increased sire standard reference weight	
	7. Increase conception rate	

Stokes & Howden (2010a) suggested that if current levels of productivity are to be maintained, the practice of selecting cattle lines with effective thermoregulatory controls or adaptive characteristics within breeds, such as feed conversion efficiency and coat colour, would need to continue. Additional adaptation strategies such as modifying the timing of mating could also serve to match nutritional requirements of cow and calf to periods with favourable seasonal conditions. Moore & Ghahramani (2014) assessed selection of five traits of sheep and cattle as adaptation options and found that for three sheep enterprises, breeding for greater fleece growth was the most effective genetic adaptation option; for beef cow and steer enterprises, breeding for larger body size was most effective. A viable adaptation option in beef cow and crossbred ewe enterprises is the increased conception rates though it proved to be less effective. The study also claimed that breeding for tolerance of heat stress is unlikely to improve the performance of livestock production systems even at 2070. In drier locations, the need for adaptation is likely to be greatest because genetic improvement of livestock was able to recover much less of the impact of climate change on profitability. It is suggested to combine feedbase and livestock genetic adaptations (Moore & Ghahramani, 2014).

There were high uncertainties of applying any given adaptation approach across southern Australia, because of high variation of rainfall, CO_2 concentration and temperature under different GCMs. This will cause challenges for implementing adaptation strategies, and require the adoption of more complex and combined adaptation strategies, which will differ among locations due to the site characteristics and projected climate. It is likely that in 2030, combinations of adaptations can be found to return most livestock production systems to profitability. By 2050 and 2070, on the other hand, SLA 2030’s findings suggest that the lower-rainfall parts of the cereal-livestock zone will require either new technologies, a complete re-thinking of the feedbase or else sustained price increases in order for livestock production to remain viable.

In conclusion, SLA 2030’s modelling suggests that, with some adaptive breeding, current forage species will still be the most suitable into 2050, and there would be no production advantage moving to more tropical species within this timeframe (DAFF, 2012b).

3.3. Mitigation options

3.3.1. General observation

In 2010, agriculture emissions accounted for 79 million tonnes of carbon dioxide equivalent (Mt CO_2-e), 15% of Australia’s total emissions. To achieve Australia's unconditional 2020 target of 5% below 2000 levels, Australia must reduce its emissions by 131 Mt CO_2-e by 2020. Agriculture emissions are projected to be 91 Mt CO_2-e in 2020 with the carbon price and Carbon Farming Initiative (CFI). The biggest driver of the agriculture projections is growth in livestock populations due to increased export demand from Asia and the Middle East. Emissions from livestock are projected to account for 72% of total agriculture emissions in 2020, with the carbon price and CFI (DCCEE, 2012).

Therefore, it seems unlikely that the NSW Government's target of a 60% reduction in emissions by 2050 could be achieved without attention to these sources, especially given that reductions in the agriculture sector may be achieved more cost effectively than in other sectors (Keogh 2007 cited in DPI, 2013)). There has to date been little research to explicitly address the modelling, mitigation or adaptation issues as they relate to extensive livestock production. This area now displays some significant gaps but also provides substantial opportunities for NSW DPI (Hacker et al. 2007). Key findings from the SLA 2030 include the following:

- A comparison of whole farm GHG emissions from different farm types in south eastern Australia showed dairy farms producing the highest emissions/ha, followed by beef, sheep and grains. When compared on an emissions intensity basis, cow/calf farms emitted more GHG/unit product than wool, followed by prime lamb, dairy, steers and finally grains.
- A range of currently available GHG abatement strategies will lower the emission intensity of production, but for these mitigation strategies to be widely adopted they must be profitable in their own right.
- Whole system mitigation modelling showed that the emissions intensity per unit product can be minimised simply by maintaining a productive pasture base.
- Inclusion of residual feed intake in national breeding schemes should reduce emissions intensity of ruminant production systems, over and above on-going reductions in emission intensity being achieved by the current production and fitness trait breeding goals used.
- Modelling of dung and urine distribution showed that the non-uniform distribution of excreta significantly influences the annual nitrogen losses through leaching and denitrification from a grazing system. When modelling nitrous oxide (N_2O) emissions from grazing systems it is imperative therefore that dung and urine distribution be explicitly modelled and not assumed to be evenly spread across the pasture.
- While methane emissions will mainly change with livestock numbers, N_2O emissions may increase with warmer climatic conditions in the medium-high rainfall zone of southern Australia, particularly in less free draining soils. This emphasises that mitigation modelling must include consideration of adaptation and vice versa.

3.3.2. Relevant mitigation options for livestock in this region

While mitigation options exist for intensive dairy systems, options to reduce net emissions of CH4 and N_2O are limited in more extensive grazing systems. Grasslands play a role in the sequestration of existing and new carbon stocks. Estimates indicate a potential sequestration of 409 mln tonnes CO_2-eq of carbon and a 176 mln tonnes CO_2-eq of sequestered carbon per year over a 20-year period. The effects of carbon sequestration are still hard to measure and verify. The effects also depend on the longevity of the soil carbon stock. Carbon stocks are not stable, e.g. in case of flooding, soil carbon can evaporate. Despite the high uncertainty of this measure, there are a few principles that can increase sequestration of carbon in grasslands:

- reduced grazing on intensively grazed lands: a balance between grazing and rest periods lead to a positive impact of forage production and soil carbon sequestration
- sowing of improved grass varieties (e.g. deep rooted grasses)
- prevention of fires
- introduction of earthworms to reduce grassland degradation and soil erosion

In these systems, however, there are some obvious options that will both reduce emissions intensity and improve overall productivity. These options are summarized below.

Animal manipulation

A number of experiments have reported variation between animals in CH_4 emissions per unit of feed intake. In a trial involving 302 grazing dairy cows mean CH_4 emissions of 19.3 ±2.9 g/kg dry matter intake (DMI) were reported (H. Clark, Pinares-Patino, & dẽ Klein, 2005); thẽ 15% variance suggesting̃ heritable differences in methanogenesis. Similar responses were reported in sheep on an unlimited pasture diet (Pinares-Patino et al. 2003). However, while Hegarty et al. (2007) also reported a significant ($P = 0.01$) positive relationship between CH_4 production and net feed intake (NFI) in Angus steers (slope of 13.38), this explained only a small proportion of the observed variation in CH_4, perhaps indicating a genotype x nutrition interaction. These data suggest that animal breeding could achieve a 10-20% reductioñ in CH_4 losses from DM during digestion (Waghorn et al. 2006). However, breeding for reduced methanogenesis is unlikely to be compatible with other competing breeding objectives. In contrast, breeding for improved feed conversion efficiency (or lower Net Feed Intake) should be compatible with existing breeding objectives and likely to both reduce CH_4 and the ratio of CH_4 per unit of product produced.

Reducing the number of unproductive animals on farm has potential to both improve profitability and reduce CH_4. Through earlier finishing of beef cattle in feedlots, slaughter weights are achieved at a younger age, with reduced lifetime emissions per animal and thus proportionately less animals producing CH_4 (Smith et al. 2007). In both sheep and beef grazing systems, earlier mating and selecting for improving fertility has been shown to reduce emissions intensity and improve profitability.

A number of options therefore exist: to either breed ruminants with lower CH_4 production, to minimise unproductive animal numbers on-farm and possibly shift to more novel production systems, all of which have potential to both reduce total CH_4 emissions and improve on-farm profitability.

Dietary Manipulation

Forage quality

Improving forage quality, either through feeding forages with lower fibre and higher soluble carbohydrates, changing from C4 to C3 grasses, or even grazing less mature pastures can reduce CH_4 production (Beauchemin et al. 2008; Ulyatt et al. 2002). Methane production per unit of cellulose digested has been shown to be three times that of hemicellulose (Moe & Tyrrell 1979), while cellulose and hemicellulose ferment at a slower rate than non-structural carbohydrate, thus yielding more CH_4 per unit of substrate digested (McAllister et al. 1996). Consequently, adding grain to a forage diet increases starch and reduces fibre intake reducing rumen pH and favouring the production of propionate rather than acetate in the rumen (McAllister & Newbold 2008). Improving forage quality also tends to increase voluntary intake and reduces retention time in the rumen, promoting energetically more efficient post-ruminal digestion and reducing the proportion of dietary energy converted to CH_4 (Blaxter & Clapperton 1965). Methane emissions are also commonly lower with higher proportions of forage legumes in the diet, partly due to lower fibre contact, faster rate of passage and in some case the presence of condensed tannins (Beauchemin et al. 2008).

Improving diet quality can both improve animal performance and reduce CH_4 production, but also improve efficiency by reducing CH_4 emissions per unit of animal product. Plant breeding therefore offers potential to improve digestibility as well as reduce CH_4 production. However, many of these strategies may also lead to increased DM intake per animal, or may also provide the farmer with an opportunity to increase stocking rate, resulting in either no net change or even a net increase in CH_4 production. Likewise, adding more grain to the diet will incur additional N_2O and transport emissions from the grain production. Further research and modelling is therefore required to understand the likely relationships between improving diet quality and voluntary intake, stocking rate and net CH_4 production, for a range of production systems.

Breeding and diet

Improving nitrogen (N) efficiency and reducing excess urinary N can be achieved through either breeding animals with improved N efficiency, breeding forages that utilise more N more efficiently, plus have a higher energy to protein ratio, or balancing high protein forages with high energy supplements.

Genetic manipulation or breeding of animals may provide improvements in the N conversion efficiency within the rumen, animals that urinate more frequently or animals that walk while urinating, all leading to lower N concentrations or greater spread of urine (de Klein & Eckard 2008). Coffey (1996) reported that an improvement in feed conversion efficiency of 0.01 could result in a 3.3% reduction in nutrient excretion, assuming similar growth rate and nutrient retention. Breeding animals for increased feed conversion efficiency should therefore lead to animals that partition more of their intake to production and less to N excretion, thereby reducing potential N_2O losses.

Ruminants on lush spring pasture may ingest protein in excess of requirement, but are usually energy limited, resulting in higher ruminal ammonia concentrations being excreted in the urine as urea (Whitehead 1995). Balancing protein-to-energy ratios in the diet of ruminants is therefore important to minimise N_2O emissions resulting from excess urinary N excretion. Misselbrook et al. (2005) showed that dairy cows fed on a 14% crude protein (CP) diet excreted 45% less urinary N than dairy cows on a 19% CP diet. Similarly, van Vuuren et al. (1993) showed that supplementing cows on a perennial ryegrass diet with low protein/high sugar supplements reduced the amount of total N and urine N excreted by 6–9% and 10–20%, respectively, compared with an all-grass diet. More recently, Miller et al. (2001) found that dairy cows on a novel ‘high sugar’ variety of perennial ryegrass excreted 18% less N in total and 29% less urine N.

It appears, however, that the balance of risk is on the downside and that such adaptive management changes (or ways of increasing product prices relative to input costs) will need to be found and put into practice by livestock producers across southern Australia.

Opportunities under the Carbon Farming Initiative CFI

The CFI allows farmers and land managers to earn Australian carbon credit units (ACCUs) by storing carbon or reducing greenhouse gas emissions on the land. These credits can then be sold to people and businesses wishing to offset their emissions. The CFI draft legislation in May 2014 proposed that the existing carbon farming legislation will be expanded to include any type of approved emissions reduction project under this category.

Table 8 below shows feeding dietary oils in dairy is an offset method under agriculture. Emissions avoidance by reducing CH4 generated from manure by feeding eligible additives to milking cows is eligible under CFI. Eligible additives include canola meal, cold-pressed canola meal, brewer's grain, hominy meal or dried distiller's grain, and are used to increase the fat content of a milking cow's diet. Improving feed quality for milking cows in this way means the animals can use energy from the feed more efficiently while enabling faster feed passage through the rumen. This reduces the amount of methane released, avoiding emissions into the atmosphere. However, there have not been any projects under this category.

Table 8: Listing of registered Carbon Farming Initiative offset methods and the number of projects registered against these and Australian carbon credit units (ACCU) issued

Agriculture	**Projects**	**ACCUs issued**
Piggery manure	4	0
Piggery biodigesters	1	0
Feeding dietary oils in dairy	0	0
Dairy anaerobic ponds	0	0
Vegetation	**Projects**	**ACCUs issued**
Avoided deforestation	5	72,301
Regeneration of a permanent even-aged native forest	1	0
Environmental Plantings	8	0
Savanna burning	9	0
Reforestation and Afforestation	7	0
Native mallee eucalypt	0	0
Landfill	**Projects**	**ACCUs issued**
Capture and combustion of landfill gas from legacy waste	62	78,647
Diverting legacy waste from landfill to fuel	1	64,103
Diverting waste to an alternative treatment facility	3	8,020
Enclosed mechanical processing and composting alternative waste treatment	2	0
Capture and combustion of landfill gas		

3.4. Further implications and research gaps

- How best can an individual producer adapt to changes which, on average will be gradual, but the incidence of extreme events may increase?
- Does the industry have the right tools to understand the impact of extreme events?
- When is the right time to change farming practice, and how will individuals know when to start? As science continues to provide more answers, especially in relation to climate change predictions, will the findings found so far change dramatically?
- Global food demand is increasing, there is more pressure on producers to mitigate changes in climate, and yet a changing climate could negatively affect production.
- What policy approaches should government and industry seek to best align these competing interests?
- Are there implications for service industries to agriculture and local governments that may need to be considered?
- Extreme events: Modelling of the impact of, plus strategies to recover from extreme events like flooding, heat waves and drought. Future model developments should aim to include this capability in our existing biophysical models where possible. However, not all extreme events lend themselves to biophysical modelling and these should be identified, with an alternative response pathway identified.
- Adaptation modelling: Future adaptation modelling needs to move from impacts analysis to adaptation and a range of scales. Modelling also needs to consider the appropriate counterfactual, when modelling the benefits of a specific adaptation e.g. using a prediction of what pastures may have been like in 2050 in the absence of climate change as the baseline and modelling specific adaptations against these.
- Future modelling should consider the balance between adaptation, sequestration and mitigation impacts of proposed farming systems changes.
- Since the sensitivity of livestock production to changes in forage supply under climate change has not yet been analysed in any detail, Stokes & Howden (2010a) highlighted the need to carry out a study on the regional variation in impacts of climate change.

- The overall importance of heat stress in future southern Australian climates once behavioural adaptations and the annual cycle of energy supply are taken into account, and the relative importance of heat stress to cattle and sheep, are questions needing further examination.

Annex 3.1: Climate change impacts on livestock and adaptation options in three LGAs in the Riverina

COOTAMUNDRA

Enterprises modelled:	Sheep – wool / prime lambs
Rainfall:	Average 9% lower in 2030, but variable
Production Impact:	Pasture production down 5% on average, but one scenario sees an increase
Financial Impact:	Profitability 28% down in 2030, but range from +15% to -66%, adaptations help

Impacts

Compared to the period 1970–1999, in 2000–2009: Annual pasture production was down by 24%, requiring stocking rate to be reduced by just 2% to maintain ground cover, but profitability was down by 42%.

Looking forward to 2030, compared to the base period 1970–1999, the four different climate scenarios showed:

- Annual pasture production was down by 5%, requiring stocking rate to be reduced by an average of 17% to maintain ground cover, but one climate scenario (English) saw an increase in pasture production and stocking rate.
- Winter pasture production is increased but autumn and spring drops.
- Profitability was down by 28% on average, but with a huge range (+15% to -66%).

Adaptation options

- Continued genetic improvement between now and 2030 is critical to offsetting the decreased stocking rate impacts. Genetic gain alone can largely offset climatic impacts.

- The use of a summer feedlot helps balance the compressed pasture production and allows stocking rates to recover to near base levels but with the extra cost of grain feeding . This site has one of the best responses to the use of feedlots, when required.
- Decreasing the lamb age of turn off was better than increasing lamb turn off weights.
- The use of summer feedlots when required and current genetic improvement has benefits now and in the future – at Cootamundra profitability can actually be increased when these adaptations are combined.
- Other changes will need to be implemented over time as pasture conditions change, but not now. A combination of factors will give the best outcome.
- In meat base enterprises, increasing the mature size of the females places additional pressure on the potential stocking rate.

Table 9: Impact of various adaptations on the profitability of a wool sheep and prime lamb enterprise in Cootamundra[10]

	Adaptations	Profit ($/Ha) 1970–1999	Profit ($/Ha) 2030 Average of 4 GCMs	Profit ($/Ha) 2030 as a % of 1970–1999
1.	Business as usual – merino	189	136	72%
2.	Use summer feedlot – cost of grain included		170	90%
3.	Business as usual – prime lambs	225	180	80%
4.	Genetic gains – decrease lamb turn off date by 10 days		207	92%
5.	Genetic gains – gain above + 2% improvement in dressing percentage		225	100%
6.	Combine the genetics and feedlot		267	119%

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[10] Sla2030.net.au,. (2014). Cootamundra – Sheep – Wool Impacts & Adaptations – Southern Livestock Adaptation 2030. Retrieved 22 June 2014, from http://sla2030.net.au/producer-locations/new-south-wales/cootamundra/cootamundra-sheep-wool-impacts-adaptations/

TEMORA

Enterprises modelled: Sheep – wool

Rainfall: Average 8% lower in 2030, but variable

Production Impact: Pasture production down 9% on average, but variable

Financial Impact: Profitability down 33% in 2030, but wide variation

Impacts

Compared to the period 1970–1999, in 2000–2009 annual pasture production was down by 31%, requiring stocking rate to be reduced by 9% to maintain ground cover. But profitability was down by 66%.

Looking forward to 2030, compared to the base period 1970–1999, the four different climate scenarios showed:

- There is, on average, a decrease in annual pasture production of 9% and to maintain minimum ground cover a decrease in stocking rate is needed (DSE/ha).
- The lower stocking rate (13% decrease), lowers profits by 33% on average, but with a range of +37% to – 102%.

The big variation between the models in profitability relates largely to the timing of the rain within the year and the role of lucerne in the pasture.

Adaptation options

The improvement from the summer feedlot is less than other sites due the year round pasture production being more even as a result of the lucerne component. If this was an annual pasture the overall profit would be lower but the percentage improvement from the feedlot would be greater.

- The impact of grain prices on feedlot benefits is obvious.
- Although not modelled the continued genetic improvement between now and 2030 is critical to offsetting the decreased stocking rate.

- The following management changes – earlier selling of wether lambs, an earlier lambing date, changing ewe age structure – only had small effects by themselves but could be combined.
- The use of summer feedlots when required and current genetic improvement have benefits now and in the future. Other changes will need to be implemented over time as pasture conditions change but not now. A combination of factors will give the best outcome.

Table 10: Impact of various adaptations on the profitability of a Merino sheep enterprise at Temora[11]

	Adaptations	Profit ($/Ha) 1970–1999	Profit ($/Ha) 2030 Average of 4 GCMs	Profit ($/Ha) 2030 as a % of 1970–1999
1.	Business as usual	86	58	67%
2.	Summer feedlot – grain $240/tonne farm		61	71%
3.	Summer feedlot – grain $210/tonne farm		71	83%

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[11] Sla2030.net.au,. (2014). Temora – Sheep – Wool Impacts & Adaptations – Southern Livestock Adaptation 2030. Retrieved 22 June 2014, from http://sla2030.net.au/producer-locations/new-south-wales/temora/temora-sheep-wool-impacts-adaptations/

Chapter 3: Climate Change Impacts, Mitigation and Adaptation Options for Grazing

NARRANDERA

Enterprises modelled: Sheep – wool / prime lambs

Rainfall: Average 9% lower in 2030, but variable

Production Impact: Pasture production down 23% on average (more work needed)

Financial Impact: Profitability 86% down in 2030 (more work needed)

Impacts

Compared to 1970–1999, over the period 2000–2009 rainfall was 23% lower, average maximum temperature was 3% higher and pasture production 30% lower.

For 2030:

- The temperature increases are consistent (+8%) but the rainfall forecast is variable ranging from a 2% to a 19% decrease and averaging an 8% reduction.
- This leads, on average, to a decrease in annual pasture production of 23% and to maintain minimum ground cover a decrease in DSE/ha.
- The drop in pasture production (and subsequently stocking rate) is severe compared to other sites. A range of local soil types have been tried with no major beneficial effect. At present this site would appear to be an outlier and more works needs to be done.

Adaptation options

- The usual positive effects of summer feedlots and current genetic improvement found at other sites has not been as effective here. Profitability has been scaled back by the large drop in stocking rate. Most sites have had a stocking rate reduction of 20 to 30% compared to 47% here.
- The key adaptation requirement for this site is to be able to run more stock without having a negative effect on the pasture / soil.
- The prime lamb enterprise was slightly more profitable in absolute numbers but was equally negatively impacted.

- Care needs to be taken in the interpretation of this site.

Table 11: Impact of various adaptations on the profitability of a sheep / prime lamb enterprise at Narrandera[12]

	Adaptations	Profit ($/Ha) 1970–1999	Profit ($/Ha) 2030 Average of 4 GCMs	Profit ($/Ha) 2030 as a % of 1970–1999
1.	Business as usual – merino	82	11.8	14%
2.	Use summer feedlot – cost of grain included		20	24%
3.	Ensure genetic gain from now to 2030- +1 kgflc wt, -0.8µM		29	35%
4.	Combine the genetics and feedlot		47	57%
5.	Business as usual – prime lambs	139	38	27%
6.	Decrease lamb turn off time and increase dressing % by 2%		48	35%

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[12] Sla2030.net.au,. (2014). Narrandera – Sheep Impacts & Adaptations – Southern Livestock Adaptation 2030. Retrieved 22 June 2014, from http://sla2030.net.au/producer-locations/new-south-wales/narrandera/narrandera-sheep-impacts-adaptations/

Annex 3.2: Summary of climate change adaptation options for the grazing industry. Priority 1 (high), 2 (medium) and 3 (low) (Stokes & Howden, 2010a)

Adaptation option	Priority
Broad-scale adaptation	
Modify existing Federal and State Drought Schemes to encourage adaptation	1
'Mainstream' climate change considerations into existing government policies and initiatives, e.g. Greenhouse Challenge, salinity, water quality and Landcare activities	1
Work with the pastoral industry to evaluate potential adaptive responses to the system-wide impacts of a range of plausible climate change scenarios	1
Continuously monitor climate change impacts and adaptation responses, adjusting actions to support and ensure effective and appropriate adoption	2
Grazing and pasture management	
Introduce responsive stocking rate strategies based on seasonal climate forecasting (and which include consideration of climate change trends)	1
Progressively recalculate and adjust safe stocking rates and pasture utilisation levels taking into account observed and projected climate change	1
Accept climate-induced changes in vegetation and modify management accordingly	2
Make greater use of strategic spelling	2
Improve on-property water management, particularly for pasture irrigation	2
Improve nutrient management using sown legumes and phosphate fertilisation where appropriate	2
Develop software to assist proactive decision-making at the on-farm scale	2
Expand routine record keeping of weather, pests and diseases, weed invasions, inputs and outputs	2
Diversify on-farm production and consider alternate land uses	3
Managing pests, diseases and weeds	
Improve predictive tools and indicators to monitor, model and control pests	2
Increase the use of biological controls (with caution)	2
Incorporate greater use of fire and alternative chemical and mechanical methods for controlling weeds and woody thickening	2
Livestock management	
Select animal lines that are resistant to higher temperatures but maintain production	2
Modify timing of mating, weaning and supplementation based on seasonal conditions	2
Provide extra shade using trees and constructed shelters	2

Chapter 4: Climate Change Impacts, Mitigation and Adaptation Options for Broadacre Cropping

Chapter 4: Climate Change Impacts, Mitigation and Adaptation Options for Broadacre Cropping

Key messages

"*Adapting Agriculture To Climate Change : Preparing Australian Agriculture, Forestry And Fisheries For The Future*" published in 2010 by Stokes & Howden, (2010a) provides an excellent reference covering the latest research in all the major agricultural industries and a number of potential options for these industries to adapt to climate change. These key messages are extracted from the three chapters on Grain, Cotton and Rice in this book:

- Agriculture is vulnerable to climatic conditions and climate change impacts are likely to vary between agricultural sectors, with the potential for both positive and negative impacts. A wide range in the magnitude and direction of climate change impacts on crops vary. Effects of climate change include: higher CO_2 concentrations impacts on plants and crops, impacts on the water-use efficiency of dryland and irrigated crop production, and potential effects on biosecurity, production, and quality of product via impacts on endemic and introduced pests and diseases, and tolerance to these challenges. Regional variability plays a key role.
- There is a range of technical adaptations such as changed crop management practices, new varieties, altered rotations and improved water management. However, these practices may need to be modified, enhanced or integrated in different ways to cope with the likely challenges posed by climate change.
- There is also a range of policy adaptations that form the decision environment within which farm and enterprise adaptations take place. These are industry and regional development policies, stewardship programs, infrastructure development, industry capacity development programs and other policies such as those relating to drought support, rural adjustment and trade among many others. Maintaining a flexible research and development base to inform policy adaptations as well as farm-level changes is essential to deliver potential adaptation benefits.
- Maladaptation can occur either through over- or under-adaptation to climate changes or because of misalignment of policy and practice. Effective monitoring of change and adaptation at a range of temporal, spatial and sectoral scales could help reduce the risks of maladaptation by learning from experience and fine-tuning adaptation measures to the unique local conditions. Assessments to ensure that adaptations do not increase net greenhouse gas emissions or have other unintended consequences will become increasingly important.
- The translation of climate change information into adaptation action requires participatory approaches across the agricultural value chain. Such studies will carry the analysis from

climate to biophysical impacts on crops and cropping systems to enterprise level adaptation options to farm financial impacts to regional economic and social impacts (such as via livelihoods analysis) and then through to policy options. Integration and adaptive learning are critical and could occur through social and analytical links between the user communities and researchers.

4.1. Impacts and risks

In Australia, climate plays a significant role in shaping the choice of farming systems and management, productivity, product quality and costs and prices, amongst others. As mentioned in chapter 2, climate also affects natural resource management, particularly with regard to degradation events, restoration opportunities and the longer-term effectiveness of interventions (Howden, Schroeter, & Crimp, 2013). Agriculture will be particularly vulnerable as the sector is heavily reliant on natural resources, which are influenced by climatic conditions. Climate change impacts are likely to vary between agricultural sectors, with the potential for both positive and negative impacts. A wide range in the magnitude and direction of climate change impacts on crops including regional variability has been suggested.

Chapman, Chakraborty, Dreccer & Howden (2012) found a number of associated effects of climate change and higher CO_2 concentrations on plants and crops, including impacts on the water-use efficiency of dryland and irrigated crop production, and potential effects on biosecurity, production, and quality of product via impacts on endemic and introduced pests and diseases, and tolerance to these challenges. Effects of climate variability and change can be mediated within-season by farming practices and by the choice of cultivar (genotype) (Stokes & Howden, 2010a). In addition to biophysical factors, the projected changes are likely to be further influenced by a range of social trends and economic forces (Glover J, Johnson H, Wesley V, P, & C, 2008). Furthermore, there is a substantial uncertainty over the actual changes in climatic factors relevant to Australian agriculture, added by uncertainty as to the impacts of such changes on agricultural systems and the effectiveness of adaptations to those impacts (Howden et al. 2013).

4.1.1. CO_2 concentration

According to the Australian Grains Free Air CO_2 Enrichment (AGFACE)[13], the increase in atmospheric CO_2 concentrations is the most certain trend among all climate change predictions. Apart from the role

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[13] The Australian Grains Free Air CO_2 Enrichment (AGFACE) is a nationally unique facility that enables researchers to investigate crops under atmospheric CO_2 concentrations of 550 parts per million (ppm), an increase of about 40% over current levels

of increasing CO_2 in changing global temperature and rainfall patterns, such a large change in one of the main resources for plant growth will also have a significant impact on all plants and ecosystems. Any envisaged adaptation of crops and cropping systems to future climates can therefore not neglect the direct and interactive effects of increasing atmospheric CO_2 concentrations. The key findings below are extracted from the AGFACE Final Research report "*Adaptation of a range of wheat types to elevated atmospheric CO_2 concentration*" (DAFF, 2011).

- Elevated CO_2 (eCO_2) can increase yields under these environmental conditions by more than 20% and improve leaf level transpiration efficiency of wheat, but at the same time decrease nitrogen and other nutrient concentrations in vegetative biomass, and decrease concentrations of essential micronutrients and protein in grains.
- Despite the general increase in leaf level water use efficiency under elevated CO_2, a cultivar selected for improved transpiration efficiency had a yield advantage under elevated CO_2 which was not evident under current CO_2. This result suggests that selection for transpiration efficiency under elevated CO_2 will provide an even larger gain than under current atmospheric concentrations, making it an important adaptation strategy.
- High tillering varieties of wheat were expected to have increased yields under elevated CO_2, with studies from high rainfall environments showing a positive correlation between tiller numbers and yield. However, AGFACE results show that wheat types with restricted tillering capacity can gain similar yield increases as some freely tillering types if they have sufficient plasticity in other yield components, such as a capacity to increase kernel weights.
- Atmospheric CO_2 rise is likely to result in declines in grain nitrogen, thus protein and flour quality. There is less reduction if N supply to the crop is abundant. However, in many cases, there is a high risk for reductions due to the lack of N.

Results of this project highlighted the need for further research towards strategies for improved nutrient use efficiency of crops for elevated CO_2; adapting crop nutrient management to elevated CO_2 conditions; adapting current strategies to fortify grain micronutrient content; and adapting strategies to improve crop stress tolerance under consideration of elevated CO_2.

Increase in CO_2 concentration will have effects on plant growth under most environmental conditions due to increased photosynthetic rates and increased water use efficiency. Specifically, grain yields may increase by about 21% at CO_2 concentration of 550 ppm; and by 30% at 700 ppm, when compared with

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predicted for 2050. The facility enables the exposure of field grown crops to elevated CO_2 levels under dryland field conditions. AGFACE is jointly run by the Department of Environment and Primary Industries Victoria and the University of Melbourne.

a year 2000 baseline of 370 ppm (Stokes & Howden, 2010a). In CCRP[14] studies where CO_2 has been increased up to 700 ppm, wheat yields have risen by 10–50% and cotton biomass by 35% (DAFF, 2012a). Furthermore, it is likely that the increase on atmospheric CO_2 levels will provide other significant benefits to crop yields (through improved water use efficiency), additional stubble for soil protection and additional opportunity for carbon sequestration (Crimp, Howden, Power, Wang, & De Voil, 2008).

Howden and Jones (2001) carried out assessments in three sites in NSW (including Wagga Wagga) on the combined effects of possible atmospheric CO_2 increases and the associated temperature increases and rainfall changes on the Australian wheat industry for the year 2070. The results of this work predict a likelihood of largely beneficial impacts. Though it is likely that climate change conditions will favour increased wheat yields across NSW, climate change is likely to reduce wheat quality, as the N management for a ‘normal’ season has been insufficient, such that much of the wheat crop was downgraded from premium to feed-quality (Chapman et al. 2012). Other authors also found that whilst increases in atmospheric CO_2 concentrations could lead to an increase in biomass, it could also decrease the nutritional quality of crops and pastures (Glover J et al. 2008). For example the initial findings by AGFACE shows that under elevated CO_2 at Horsham, wheat grain protein declined by 2–7% while the grain zinc and iron content declined almost 10% (PICCC, 2011).

As for cotton, it was shown that increased atmospheric CO_2 concentrations have positive impacts on improvements in growth and yield. Research by Reddy et al. (1996), cited in Bange, Constable, McRae, & Roth (2010) showed that doubling CO_2 concentration in the atmosphere led to increased growth and yield (60% increase in lint yield) in well-watered and even in dry environments. Other field experiments (Pinter et al. 1994; and Mauney et al. 1994 as cited in Bange et al. 2010) growing cotton using free air CO_2 enrichment, where CO_2 was increased to 550 ppm, found that lint yield on average was increased by 43% regardless of irrigation treatment (wet or dry). When CO_2 was increased to 770 ppm in another study by Samarakoon & Gifford (1996), as cited in Bange et al. (2010), substantial increases in growth and leaf area, resulting in water use per plant being 40–50% higher than other crop species, were evident.

There have not been studies on impacts of CO_2 fertilization on rice production in Australia. Some key observations, recorded from studies carried out in Japan, China and the Philippines (Kim et al. 2003; Yang et al. 2007; Ziska et al. 1997 cited in Gaydon, Beecher, Reinke, Crimp & Howden 2010) showed that under elevated CO_2 concentration (200 ppm and 300 ppm greater than the ambient), there is an

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[14] The Australian Government’s Climate Change Research Program (CCRP) was designed to help prepare Australia’s agricultural and fisheries industries for climate change, as a part of the Australia’s Farming Future initiative from 2008 - 2012.

increase in rice grain yield when N was in good supply, but lower responses for low N treatments. Implications of an increase in atmospheric CO_2 for rice production under Australian conditions are not known, though Gaydon et al. (2010) claimed that potential rice yield increases could be similar to those observed in China and Japan. The authors added that uncertainties persist and further research is required.

In conclusion, while elevated CO_2 has potentially had a positive influence on growth, the size of this 'fertilisation' effect will be partially offset by accompanying higher temperature effects over the next 20–30 years, especially in dryland production areas (Howden et al. 2003; Hatfield & Prueger 2011 seen in Chapman et al. 2012).

4.1.2. Temperature and rainfall

Crop yields and quality

Dryland cropping is more vulnerable to climate change since it relies solely on rainfall for the provision of soil moisture, to be grown in areas which experience relatively low rainfall (200–300mm in winter and spring) and high potential evaporation values (Glover J et al. 2008). In general, temperature increases will accelerate plant developmental rates (Stokes & Howden, 2010a). However, the CCRP research comparing present climatic conditions and a range of potential future climate scenarios to determine what stresses wheat and sorghum crops might face from climate change in 2030 and 2050, found that climate change is likely to reduce wheat and sorghum yields through increases in the frequency and intensity of both droughts and high temperatures (DAFF, 2012a). According to the Australian Crop Report 2014, a combination of record high temperatures, below average spring rainfall, gusty winds and severe frosts reduced yields across many canola growing regions in NSW.

It also forecast falls in production for all major summer crops and winter crop production is estimated to have declined by 14% in NSW (ABARES, 2014). More details on impacts of changes in climatic conditions on wheat, barley, cotton and rice production is found in below.

While these are based on unfavourable seasonal conditions, they provide a clear example of the likely effects due to the close alignment of the 2014 season with predicted future climate change.

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A significant decline in summer crop production is expected due to generally unfavourable seasonal conditions during 2013–2014. There have been hot and dry seasonal conditions early 2014 in most summer cropping regions in northern NSW. For the majority of northern NSW forecast median grain sorghum yields were generally extremely low, ranging from lowest on record to the 30th percentile. This pattern reflects the severely deficient rainfall during spring 2013 and 2013–14 summer-to-date in this region.

- Wheat production is estimated to have fallen by 7% in 2013–2014 to around 6.6 million tonnes, reflecting a decrease in the average yield.
- Barley production is estimated to have decreased by 11% in 2013–2014 to just under 1.2 million tonnes.
- Canola production is estimated to have decreased by 48% in 2013–14 to 688,000 tonnes, reflecting declines in the planted area and the average yield. *A combination of record high temperatures, below average spring rainfall, gusty winds and severe frosts reduced yields across many canola growing regions*. The area planted to canola fell by 41% in 2013–2014 to 550,000 hectares, *reflecting low levels of soil moisture at planting time*.
- Cotton area is estimated to have declined by 10% in 2013–2014 to 256,000 hectares. Cotton production is forecast to fall by 8% to 878,000 tonnes of cottonseed and 621,000 tonnes of cotton lint.
- Rice area is forecast to fall by 12% in 2013–2014 to 100,000 hectares. Rice production is forecast to decline by 22% to 900,000 tonnes.

Figure 2: Crop production 2014 outlook, by Australian Bureau of Agricultural and Resource Economics and Science

During 2010 and 2011, in the more northern and eastern regions of Australia, high rainfall associated with La Nina conditions have contributed to high yields for wheat production, and also large accumulations of standing dry matter in the extensive rangelands (Chapman et al. 2012). S. Howden and Crimp (2005) found that wheat yields are generally low due to low rainfall, high evaporative demand and low soil fertility. Average crop yields can vary by as much as 60% in response to climate variability. Increases in heat shock also may reduce grain quality by affecting dough-making qualities (Crimp et al, 2008). Heat waves during the 2008–2009 summer in South Australia and again in 2010 have had impacts on both production and quality of crops (Chapman et al. 2012). Wang et al. (1992)

cited in Howden et al. (2013) found that depending on cultivar, a 3°C increase in temperature could reduce mean wheat yields in Wagga Wagga by up to 50%.

For varieties adapted to existing temperature regimes, higher temperatures will result in reduced yields. Higher temperature may also add to rapid depletion of soil moisture, hence reduce grain number and reduce harvest index. High soil nitrogen may result in major reductions in grain yield (S. Howden, Gifford, & Meinke 2010).

The Garnaut Climate Change Review in 2008 considered 10 study sites to understand the difference in magnitude of impacts on wheat yield in Australia and found that under the no-mitigation case and through adaptive management, much of Australia could experience an increase in wheat production by 2030. However, over time, even with adaptive management, a number of regions would experience substantial declines in wheat yield (as seen in the Table 12). The review stated that under the hot, dry extreme scenario, devastating consequences for the Australian wheat industry are projected, leading to complete abandonment of production for most regions (Garnaut 2008). Scientists are also concerned with the frequency or intensity of El Nino and La Nina events with climate change. This would cause the net impact on wheat to be different from that of the average change in rainfall (Crimp et al, 2008).

According to the Department of Agriculture’s Climate Change Research Program (CCRP) (DAFF, 2013), the future climate change scenarios with an average increase of between 0.6°C and 1.5°C by 2030 together with increasing intensity and incidence of severe weather events over the coming decades will increase production risks for agriculture, such as:

- shifts in the extent and severity of pest and disease outbreaks
- reduced predictability of seasons
- plant and animal heat stress
- crop and livestock losses from flood and drought
- changes in regional suitability of certain production systems

Table 12: Percentage cumulative yield change from 1990 for NSW wheat under four climate cases

	No-mitigation case		**Global mitigation with CO_2-e stabilisation at 550 ppm by 2100**		**Global mitigation with CO_2-e stabilisation at 450 ppm by 2100**		**Hot, dry extreme case (the 'bad-end story')**	
	Cumulative yield change (%)							
	2030	2100	2030	2100	2030	2100	2030	2100
Coolamon, NSW	11.6	1.9	9.9	12.3	8.2	7.4	1.2	-100
Dubbo, NSW	8.1	-5.9	6.1	6.7	4	2.3	-2.4	-100
Moree, NSW	20.6	10.9	17.7	14.1	14.8	10.8	6.4	-79.2

Note: *Moving from left to right, the first three cases are best-estimate cases and use the 50th percentile rainfall and relative humidity, and 50th percentile temperature for Australia. The fourth case is an illustrative 'bad-end story' that uses the 10th percentile rainfall and relative humidity and 90th percentile temperature for Australia (a hot, dry extreme). Data is extracted from Garnaut (2008) for NSW only.*

According to NSW DPI (DPI 2013), climate change (warming and decreases in the number of cold days; however, increase in days above 35°C may be detrimental) may have some benefits for the irrigated rice and cotton industries. It may also permit alternative rice species to be considered. However, fibre quality of both irrigated and dryland cotton is significantly affected by both temperature and water availability.

Rising temperature has two influences on cotton: (i) rates of morphological development and crop growth and (ii) the start and end of a growing season. Warmer temperatures at the start and the end of cotton seasons will increase the length of time cotton has to grow and produce yield. The longer growth period under warmer temperatures, the higher lint yield could be. Furthermore, rising minimum temperatures and reducing the number of cold shocks could improve cotton growth. It is predicted that northern and southern NSW will potentially benefit from this and greater flexibility with planting dates at the start of the season will be available to growers (Bange et al. 2010). However, similar to wheat, large increases in temperature may also reduce the overall yield via limiting the number of fruiting branches, the interval between flowering and boll opening, and shortening the time to maturity. In addition, if water shortage occurs at the same time as temperature increases, the consequences can be worsened (Stockton and Walhood 1960 as cited in Bange et al. 2010).

Although cotton is well adapted to the irregular water supply, compared with other field crops, its growth and development are complex, thus these impacts vary with the time of season and interactions with other variables (Bange et al. 2010). Between 2000/01 and 2004/05 there were significant reductions in the value of irrigated cotton and rice, as a result of reduced water availability. Compared with alternative crops, cotton has one of the highest returns per ML of water used, therefore, it is unlikely that growers will move away from irrigated cotton production in the short term (DPI 2013).

While there is abundant published work from international research on impacts of increased maximum and minimum temperatures, there is limited research on Australian rice varieties (Gaydon et al. 2010). Studies showed that high temperature sterility issues could be a major limiting factor for rice production and the risk of exceeding this temperature threshold more than doubles for flowering rice crops at Griffith by 2070 (Gaydon et al. 2010). While high temperature-related damage may be cumulative, its sensitivity may vary depending on the cultivars (Jagadish, Craufurd, & Wheeler 2007). Gaydon et al. (2010) suggested that a positive yield response to increasing mean temperatures may be possible in Australia in the near future (2030) as long as water is non-limiting. Specifically, under the projected climate scenarios, it is likely that the risk of low temperature occurrence at rice flowering will be reduced by roughly one third.

The largest impact from projected climatic change on Australian rice production is likely to be from reduced supply of irrigation water due to its total dependence on irrigation. Especially for Riverina rice production, the effect of projected climate change on irrigation water supply is the key factor in assessing climate change impacts on rice production (Gaydon et al. 2010). The projected reduction of streamflows in the Murray Darling region, as discussed in chapter 2, is likely to have dramatic implications for irrigation water allocations in the Riverina (Jones & Pittock, 2002). Several studies pointed out that under climate change, increase in irrigation water demand of rice will be likely (as reviewed in Gaydon et al. (2010).

Pest and pathogens

For both crop and pasture, climate change could lead to the plants facing changes in the distribution, abundance and severity of insect pests, pathogens and weeds (Glover et al. 2008). Chapman et al. (2012) showed three main ways where climate change influences pest and pathogens:

1. Change in their geographical range and distribution;
2. Change in their population genetics and biology, including virulence spectrum and rates of evolution;
3. Change the effectiveness of disease resistance genes and gene networks in plants.

The authors noted that these pests and pathogens will migrate with their hosts, as crops shift pole-ward, due to increasing temperature. This situation could create winners and losers (climate change can raise or lower resistance of plants to pests and diseases), depending on how crops respond to additional stress. Invasion of fungal pathogens or increased frequency of outbreaks are other possible impacts due to other extreme events such as hurricanes and warming climates (Chapman et al. 2012).

4.2. Mitigation and adaptation options

This section is substantially based on the findings from "*Adapting Agriculture To Climate Change: Preparing Australian Agriculture, Forestry And Fisheries For The Future*" (Stokes & Howden 2010a). It is important to note that while many adaptation options are extensions or enhancements of existing activities, full evaluation to determine the effectiveness of few adaptation options (e.g. technical feasibility, end user acceptability, costs and benefits), showed that adopting practicable and financially viable adaptations will have very significant benefits in reducing risks of negative climate changes and enhancing opportunities (Stokes & Howden 2010b). Bange et al. (2010) claimed that there has not been explicit investigation of the benefits of implementing adaptation practices for climate change for the cotton industry in Australia, yet the industry is well placed to respond to the challenges of climate change. Rice systems, on the other hand, appear to have a greater range of adaptive response with positive benefits in yield simulated for a warming of up to 5°C (Gaydon et al. 2010). The authors stressed that more systemic change such as moving to intermittently irrigated systems or dryland systems will be needed when negative impacts of climate change on rice production reach a point that they overwhelm all adaptation options.

Studies and modelling across many global adaptation studies including Australia showed that under moderate warming (<2°C) most of the benefits of adapting the existing cropping systems are to be gained but then level off with increasing temperature changes (Howden et al. 2010). The authors stressed the potential options to alter management of grain-cropping to deal with projected climatic changes. These measures if adopted alone or together could have substantial potential for mitigation and adaptation. For example, relatively simple adaptations to future climate change may be worth between $100 million to $500 million per year at the farm gate for the wheat industry alone. If a wider range of adaptation measures are practiced, further benefits may be realized. However these are yet to be evaluated.

Early results of the CCRP studies showed that in NSW, using fallow periods to conserve soil moisture, increasing pasture in the rotation, and retaining crop residues all helped offset potential yield losses resulting from future warmer and drier conditions (DAFF 2013). A report by the Australian Bureau of Rural Sciences in 2008, suggested three main approaches in mitigation and adaptation (i) development of new crop varieties (ii) changing farm management practices, and (iii) using alternative crops or pastures (Glover J et al. 2008).

Howden et al. (2010) outlined various options for adaptation in grain-cropping systems adaptation in two categories of crop/farm management and policy options (for the list of these options, see *Annex 4.1: Priority climate change adaptation options for the grains sector*). The authors concluded that within an existing grains cropping system, under more severe climate changes, effectiveness of adaptation options are going to be limited as compared to the benefits accrued with moderate climate change.

As for cotton, apart from moving to better cultivars, improvements in yield can be attributed to considerable improvements in crop management, including soil management and crop rotation, irrigation scheduling and insect control (Constable et al. 2001 as cited in Bange et al. 2010). Some options combining alternative irrigation and agronomic practices to improve quality of cotton with less irrigation water are provided in *Annex 4.2: Specific adaptation options for the Australian cotton industry*.

The rice industry will need to build on and increase water use efficiency in adapting to climatic change. A wide range of potential farming system changes (new varieties/crops, rotations, water priorities, irrigation methods, farm layouts, use of seasonal climate forecasts in management) need to be considered. There is some scope to adapt existing rice production in an attempt to reduce irrigation demand through reduction in the duration of ponding (Gaydon et al. 2010). The authors suggested adaptive options for rice production under different categories (see *Annex 4.3: Specific adaptation options for the Australian rice industry*). The options under 'Easily implemented' are available now and mainly focus on technologies with demonstrated benefits in all situations. Among the options which are potentially implementable after further R&D, investigations into the potential for aerobic rice in Australian systems is considered a high priority.

The section below discusses some of the options in more detail:

4.2.1. Variety and species change

Howden et al. (2013) suggested that a key adaptation to temperature increase involves selecting varieties with greater thermal time requirements and integrating this with changed planting dates and methods such as dry sowing, which allows earlier sowing than traditional methods (Chapman et al. 2012). Careful evaluation on a site-by-site basis with attention to changes in temperature, rainfall and management needs to be taken into account while adopting the best varietal strategy. However, options to vary planting windows are restricted, reducing flexibility to adapt management. Adaptation options were identified for two regions:

1. **Wet regions or where climate change increases rainfall**: It may be advantageous to breed and adopt slower-maturing cultivars (greater thermal time requirements) that could capitalize

on the earlier date of flowering and potentially longer photosynthetically-active period before seasonal drought forces maturity.

2. **Regions with increases in temperature and reductions in rainfall**: It may be advantageous to either keep varieties with similar or earlier-flowering characteristics than are currently used as this will allow grainfill to occur in the cooler, wetter parts of the year, particularly if planting can occur earlier due to reduced frost risk.

In order to respond to heat shock, the authors stressed the need to develop more heat-tolerant varieties to ensure the capacity to produce high quality wheat. Given the climate projections on drought and increasing number of extreme hot days, the need to improve water use efficiency is very important. There are efforts to genetically alter photosynthetic pathways in cereals (including wheat) and the biggest effort currently concentrates on rice.

While results show that elevated CO_2 alone may increase growth and yield in wheat varieties, it is expected that increased occurrence of high temperature events and seasonal shifts in rainfall will significantly reduce this benefit. CCRP researchers concluded that plant breeders will be able to develop new ‘climate change ready’ varieties. Simulation models were studied to examine how farmers could adjust variety selection and planting dates to avoid high temperatures around flowering and to maximise efficient use of rainfall (DAF, 2013).

Studies on cotton cultivars, well suited to the environmental and climatic conditions, including those specific breeding activities for rain-fed cotton production have already been carried out (Stiller et al. 2005 cited in Bange et al. 2010). Growers are able to select cultivars suitable to their conditions.

It is noted that increased temperatures may allow for summer-growing grain and pulse species such as sorghum in temperate regions where these are not currently used in rotations. Some options which will aid to gradual adjustment of rotations, minimizing risk include: (i) effective monitoring of soil moisture and nutrient levels; (ii) effective decision-support systems; (iii) improved seasonal climate forecasting; and (iv) continuing improvements in crop management.

4.2.2. Planting time variation

Howden &Crimp (2005) showed that varietal change and alteration of planting windows could allow wheat to maintain productivity in Australian environments. The CCRP suggested that decreases in frost risk could enable producers to sow wheat earlier and avoid heat risks around flowering time (DAFF, 2013). A study by Craufurd & Wheeler (2009) on the wheat belt, supported by a more recent study of Zheng et al. (2012) (as reviewed in Chapman et al. 2012), demonstrated how, for a range of crops and environments, flowering time can be manipulated to assist in avoidance of high temperature stress. It was found that changing planting time can provide benefits in maintaining cotton yield, improving fibre quality, reducing the risk of adverse effects of high temperatures and low humidity, and reducing the incidence of seedling diseases early in the season (Bange et al. 2010).

4.2.3. Biotechnology

Research by the Bureau of Rural Sciences in 2008 studied the use of modern biotechnology, including enhanced genetic mapping technologies, such as molecular markers, in plant breeding and in development of genetically modified (GM) varieties in response to climate change impacts. The report found that there are a number of plant traits likely to be important for adapting to climate change including heat tolerance, water-use efficiency, nitrogen-use efficiency, early vigour, waterlogging tolerance, frost resistance, pest and disease resistance, and reduced dependence on low temperatures to trigger flowering or seed germination. Currently, research is being carried out into GM varieties for these traits. The report concluded that biotechnology offers a broad range of options for the development of new crop varieties that are better adapted to a changed climate and plays a key role in reducing greenhouse gas emissions from agriculture and in increasing soil carbon (Glover et al. 2008).

Acknowledging the importance of biotechnology-based breeding technologies, Chapman et al. (2012) however, pointed out that their application requires additional investment in the understanding, genetic characterization, and phenotyping of complex adaptive traits for climate-change conditions. The authors noted that to adapt to climate change, the local farmers will need to have access to the right combination of genes for future climates. Since these processes are complicated and may not have results for many years, growers may need to invest in increasing efficiency.

4.2.4. Crop and water management (spacing, tillage, fallows, rotations, irrigation)

With water becoming more critical, there will be a need for further improvements in water distribution systems, choice of crops to increase returns per litre and irrigation practices such as water application methods, irrigation scheduling and moisture monitoring (Howden et al. 2010).

Some adaptive responses suggested by Clewett (2010) include increasing presence of summer crops in crop rotations, the use of more drought tolerant crop species (e.g. substituting maize with sorghum), using genotypes selected for higher water use efficiency (Hammer 2006 as seen in Clewett 2010) and expansion of summer crops to more southern areas. Adaptive farm practices aiming at higher water use efficiency targets are increasingly important for reducing negative impacts of climate change. These practices include minimum tillage, stubble retention, control traffic systems and precision agriculture to control seeding rates, seed placement, crop nutrition and the maintenance/development of soil fertility and health (Clewett 2010). The author highlighted several management priorities to adapt to climate change impacts, including:

- Structural adjustments to the enterprise such as enterprise mix, machinery selection and adaptation of land use to on-going reviews of land capability particularly for high-risk marginal lands,
- Adjustments in seasonal tactics concerning land preparation and maintaining soil health, crop selection, adoption of new varieties, cropping intensity, planting methods, weed control, livestock management and marketing,
- Development of managerial skill, off-farm investment and other forms of adaptive capacity.

It is important not to assume reasonable access and availability of water for cotton cultivation. Reducing the time to maturity, combining with targeted management towards an economic yield threshold could be an option to cope with limited water availability (Bange et al. 2010). Some options combining alternative irrigation and agronomic practices to improve quality of cotton with less irrigation water are provided in *Annex 4.2: Specific adaptation options for the Australian cotton industry*. A range of measures to improve water use efficiency as adaptation options for rice is substantively outlined in Gaydon et al, (2010).

Figure 3 below shows an example of how the rice industry in the Riverina is responding to water shortages.

In Australia's Riverina, some rice growers have responded to water shortages by reverting to drill sowing in preference to aerial sowing. Aerial sowing has become more common in recent years, but requires that rice bays are flooded from the start in order to maximise establishment. If conventional sowing equipment is available, direct drilling allows the commencement of permanently flooded conditions to be delayed, thereby saving water from both evaporation and deep drainage (Tabbal et al. 2002). Water savings of 10–15% have been reported with negligible yield reductions, however further research is required to understand the process on a range of soils. An ancillary benefit in Australian rice systems is a decreased risk of duck damage to the young crop compared with crops established by aerially sowing into standing water. By the time a permanent flood is established (around panicle initiation), the plants are too large to be significantly damaged by ducks, which prefer to eat the young seedlings. On the downside, delaying permanent ponding may result in increased weed control requirements during the early period. Also, establishing rice in this fashion can present problems in heavy clay sodic soils, such as those in the Murray valley, where drilled rice has difficulty breaking through drying surface layers due to the rice plant's weak emergence capacity. Hence this adaptive measure is geographically limited.

Figure 3: Example of the rice industry responding to water shortages in the Riverina (Gaydon et al. 2010)

Howden et al. (2010) suggested several crop management practices that could be adopted to reduce the risks from changed climate conditions (see Figure 4). The authors noted that these measures are not yet fully analysed for their benefits under climate change. Even where they are studied, the benefits could be site-specific and involve trade-offs.

- Adopting zero-tillage practices;
- Develop more techniques that minimize disturbance (i.e. seed pushing, all-weather traffic lanes that allow planting while raining);
- Using reactive strategies to track climate variation on daily or seasonal time steps (e.g. McKeon et al. 1993);
- Extending fallows to effectively capture and store more soil moisture (suitable mostly with heavy soils); dry sowing, later plantings or staggering planting times depending on the rainfall changes;
- Widening row spacing, skip-row planting or lowering plant populations;
- Developing efficient on-farm irrigation management with effective scheduling, application and transfer systems;
- Reducing losses from irrigation systems during water transfers through improved channel lining, etc.; and
- Monitoring and responding rapidly to emerging pest, disease and weed issues, noting that support of effective research, development and extension would be needed.

Figure 4: Crop management practices (S. Howden et al. 2010)

4.2.5. Nutrient management change

It is suggested that in order to maintain grain nitrogen content, thus grain protein and quality, there may be a need to considerably increase the use of legume-based pastures; increase use of leguminous crops; or increase nitrogen fertiliser application (Howden et al. 2010).

The use of nitrogen fertiliser and water is the key in improving cotton production efficiencies (Bange et al. 2010). Rochester and colleagues (2001 and 2005 cited in Bange et al. 2010), suggested that cotton crops can be grown with nitrogen provided entirely by legumes. These practices have additional benefits including improvements in soil structure and soil health from utilising legumes in the cropping system. It is advised to constantly monitor and adapt fertiliser practices with climate change (Bange et al. 2010).

It is important to note that the adaptations of fertiliser application and change in rotations could also be a source of greenhouse gas emissions. However, farmers can achieve significant reductions in fertiliser input by integrating legumes into cropping operations. Legume–grain crop rotation is a practical way for farmers to reduce emissions associated with commercial nitrogen fertilisers (DAFF, 2013).

CCRP research trials suggested several measures to reduce emissions and adapt to climate change impacts. Farmers can reduce N_2O emissions, and achieve productivity gains, by increasing the efficiency of nitrogen use in cropping systems. Enhanced-efficiency fertilisers can reduce loss of nitrogen, without adverse effects on plant growth while having the potential to provide economic and environmental benefits. Fertiliser management strategies that have shown to reduce N_2O emissions include (i) avoiding high application rates of nitrogen fertiliser before planting, (ii) avoiding application of nitrogen fertiliser before irrigation or high rainfall and (iii) improving fertiliser management to better match soil nitrogen supply to crop nitrogen needs (DAFF 2013).

4.2.6. Management of pests, diseases and weeds

Two key strategies for effective management of pests, diseases and weeds in response to climate change include: (i) integrated pest management and (2) area-wide management (i.e. coordinated responses of growers and policy-makers across an entire region). Within this, an increased understanding of impacts and potential responses of recent climate variability manifestations is the key and strategic element.

Due to the absence of reliable information on the risks to the crop data, especially data on pest numbers to determine high-risk periods for each species, farmers tend to use excessive amounts of chemical. In addition, climate change will reduce the frequency of suitable conditions which ultimately reduce the efficacy and application of these chemicals. (S. Howden et al. 2010) outlined current management practices that respond to, or override, climatic variability, including the following:

- Genetic modification of crop plants to create insect- or disease-resistant and herbicide tolerant varieties (via either conventional plant breeding or genetic modification).
- Importation of exotic natural enemies of pests that were previously introduced without them. Also repeated, mass (inundative) releases of parasitic wasps to control insect pests;
- Isolation and propagation of local natural enemies/diseases (e.g. Metarhizium on locusts, termites);

- Cultural practices such as crop rotations, mixed crops, use of physical barriers to reduce disease transmission;
- Chemical pesticides and increasing bio-pesticides and bio-fumigation of soils using *Brassica sp.* as alternate crops;
- Monitoring and use of predictive models to improve timing of interventions to coincide with high risk periods; and
- Landscape-scale management involving groups of growers cooperating to reduce communal threats, e.g. when growing melons in rotation with soybeans or sugar, or chickpeas mixed with cotton.

4.3. Recommendations and future research[15].

Efforts to enhance resilience is the key since there will be no single solution for all of the challenges raised by climate change and variability. Specifically, an integrated systems-based approach to research and extension is needed to identify management for minimizing economic, social and environmental harm, while maximizing new opportunities.

Further research towards strategies for improved nutrient use efficiency of crops for elevated CO_2; adapting crop nutrient management to maximize elevated CO_2 conditions; adapting current strategies to fortify grain micronutrient content; and adapting strategies to improve crop stress tolerance under consideration of elevated CO_2 is needed.

Research capability, particularly in crop physiology and agronomy, will be needed to fully realize the potentials and opportunities to improve yields or stress tolerance from transgenic technologies for pest management.

A dedicated R&D program involving farmer participation and simulation modelling, which would allow consideration of various scenarios of water availability, climate change, water and commodity prices would be beneficial for the Riverina region. Furthermore, there is a need to consider more systemic changes in resource allocation, including livelihoods diversification. These transformative changes will need integration across scales from farm to region to nation so as to look for synergies and to reduce maladaptive outcomes.

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[15] This is mainly derived from Stokes and Howden (2010a)

Region-specific impacts will need to be assessed thoroughly. This is necessary so that cotton growers can improve their capacity to assess likely impacts at their business level. Detailed integrative research is required in the area of water stress and higher temperature scenarios, influences of elevated CO_2 on cotton growth and insect pests, and to determine how these changes affect yield and quality. This includes the development of cultivars tolerant to abiotic stress (especially for more frequent hot and water-deficit situations). Some consideration or allowance will be needed in these studies for both cotton cultivars and insect pests that have been naturally selected in rising CO_2 environments. It will also be important to understand and consider global changes in cotton markets as part of adaptation strategies.

There have been few studies on impact of increased temperatures and CO_2 on rice. Therefore, research into regional impacts, novel rice production systems and its viability is urgently needed to allow for future farm planning.

Some key questions specific to the Riverina rice industry in the context of reduced water availability for irrigation and climate change include:

- What do optimal irrigation water priorities look like if my farm is no longer to be a fully irrigated enterprise?
- Is it better to partially irrigate everything or plan to intensively irrigate a small portion of the farm with the remainder dryland?
- How does a small intensively irrigated area of vegetables, maybe under a sub-surface drip irrigation system, compare with conventional rice production?
- How would aerobic rice (if found to be viable) affect water priorities on farm, and impact on other crops, rotations, weed control, diseases, etc.?
- Is water better diverted to winter crops as a first priority, due to their need for supplemental irrigation only, and should rice be considered an option only in years with high allocation?

Annex 4.1: Priority climate change adaptation options for the grains sector

Table 13: Priority climate change adaptation options for the grains sector (Howden et al. 2003). Priority 1 (high), 2 (medium) and 3 (low) (S. Howden et al. 2010)

Adaptation option	Priority
Adaptation to climate change – crop and farm management	
Develop participatory research approaches to assist proactive adaptations on-farm and across the value chain	1
Develop further risk amelioration approaches (e.g. zero tillage and other minimum disturbance techniques, retaining residue, extending fallows, row spacing, planting density, staggering planting times, erosion control infrastructure, controlled traffic)	1
Alter planting rules to be more opportunistic depending on environmental conditions (e.g. soil moisture), climate (e.g. frost risk) and markets	1
Select varieties from the global gene pool with high levels of CO_2 responsiveness, appropriate thermal time and vernalisation requirements, heat shock resistance, drought tolerance (i.e. Staygreen), high protein levels, resistance to new pest and diseases and perhaps that set flowers in hot/windy conditions	1
Maximise utility of seasonal climate forecasts by research, develop and extension that combines them with on-ground measurements (i.e. soil moisture, nitrogen), market information and systems modelling	2
Research and revise soil fertility management (fertiliser application, type and timing, increase legume phase in rotations) on an ongoing basis including implications for off-farm impacts (e.g. greenhouse gas emissions)	3
Policy-related and other adaptations	
Continue training to enhance self-reliance via improved climate risk management, and to provide knowledge base for adapting	1
Provide public sector support for a vigorous agricultural research and breeding effort including undertaking further adaptation studies which include costs/benefits, adoption paths and maladaptations	2
Explore transformation options in the cropping zones that can provide positive production, environmental and social outcomes from these major changes	2
Establish an effective adaptation monitoring program to learn what works, what does not and why	2
Further improve water distribution systems (to reduce leakage and evaporation), irrigation practices such as water application methods, irrigation scheduling and moisture monitoring to increase efficiency of use	2
Further develop Area-wide Management operations, integrated Pest Management and other innovative pest, disease and weed adaptations	3

Annex 4.2: Specific adaptation options for the Australian cotton industry

Table 14: Specific adaptation options for the Australian cotton industry. Some feedback and prioritisation was assessed from the survey published by McRae et al. (2007) cited in (Bange et al. 2010). Priority 1 (high), 2 (medium) and 3 (low).

Adaptation options	Priority
Policy/industry	
Policy settings that encourage development of effective water-trading systems that allow for climate variability and support development of related information networks	1
Public sector support for vigorous agricultural research for adaptation studies and breeding efforts with access to global gene pools	1
Encouragement of diversification of farm enterprises (other crops and livestock)	1
Introduction of climate change adaptation (including minimising industry's greenhouse carbon footprint) into environmental management systems	1
Investigation of trends and extremes resulting from climate change both regionally and globally for production and exploration of implications for our markets and impact on competitors	2
Expansion of industry to other regions (including northern Australia)	2
Crop and farm management	
Improvement of nitrogen use efficiency of cotton crops through changes in fertiliser application, type and timing and increase use of legume phase in crop rotations	1
Improved management options in limited water situations (alternative irrigation systems; row configurations, irrigation scheduling strategies) to maximise water use efficiency	1
Selection of cultivars with appropriate heat-stress resistance, drought tolerance, higher agronomic water use efficiency, improved fibre quality, resistance to new pest and diseases (including introgression of new transgenic traits)	1
Ongoing evaluation of cultivar/management/climate relationships on both yield and quality with higher CO_2, increased temperature, and lower vapour pressure deficits)	1
Development of practices to take advantage of increased temperatures especially at the start and end of the growing season to raise yields	2
Linkage of on-farm adaptation with catchments impacts	2
Alteration of planting rules to improve yield and quality	3
Development of future cotton systems that are earlier maturing, use less water and allow more crops to be grown in rotation	3
Climate information and use	
Provision of information on the likely impacts at business level (downscaling climate change predictions to regional scales)	2
Tools and extension to enable farmers to access climate data and interpret the data in relation to their crop records and analyse alternative management options	2
Warnings of the likelihood of very hot days and heavy rain which may result in high erosion potential	3
Managing pests, disease and weeds	

Avoiding resistance of pests (both insects and weeds) through appropriate integrated pest and weed management systems to maintain transgenic technologies	1
Improvement in pest (weeds, invertebrate and diseases) predictive tools and indicators	2
Further development of integrated pest, weed and disease management including area-wide management operations	2

Annex 4.3: Specific adaptation options for the Australian rice industry

Table 15: Summary of adaptation options for the rice industry. Priority 1 (high), 2 (medium) and 3 (low) (Gaydon et al. 2010)

Adaptation option	Priority
Easily implemented	
Combine and sodsowing of rice	1
Alternate wet-and-dry rice culture	1
Better definition of rice-suitable soils	1
Irrigation scheduling	2
Potentially implementable after further R&D	
Aerobic rice evaluation	1
New available water determination water management practices	1
Seasonal climate forecasts	1
Consideration of new crops, rotations, priorities for water	1
Conventional breeding for shorter season varieties, increased yields	2
Requiring major investment	
Investment in more efficient irrigation technology	2
Whole farm planning	2
Piping water on farm	3
Piping water in district	3
Raised beds in bays	2

Chapter 5: Climate Change Impacts, Mitigation and Adaptation Options for Intensive Livestock

Chapter 5: Climate Change Impacts, Mitigation and Adaptation Options for Intensive Livestock

Key messages[16]:

- Climate change, including changes in the intensity and frequency of extreme events, will present challenges to traditional intensive livestock farming systems.
- Warmer and drier conditions are projected for most intensive livestock-producing regions, raising the likelihood and incidence of heat stress in stock. Traditional high energy and water use options for improving the environment of livestock under heat stress conditions are likely to be maladaptive. Low energy and low emission options should be identified and evaluated.
- Regional differences in dairy production will arise from the relative magnitudes of regional climate change effects. These effects influence the relative competitive advantage of different regions, with respect to both the supply of dairy output and purchases of inputs, such as supplementary feed.
- Suppliers and consumers in global commodity markets will be affected by climate change and associated issues such as international food security, and governmental policy responses. The costs of inputs required to maintain productivity are likely to increase. Farmers and producers need to have a greater awareness of environmental, economic and social conditions beyond their farm gates than ever before.
- Livestock enterprises must have the flexibility to rapidly change management systems in response to dynamic environmental, economic and social conditions. Proactive adaptation is about risk management and creating opportunities for prosperity under dynamic and challenging conditions.
- Mitigation options for intensive livestock is either: (i) captured in the livestock section or (ii) manure management for feedlots, pigs and poultry. This can include methane generation from effluent systems, but should also include management of solid waste from feedlots to reduce nitrogen losses and the best practice spreading of these back on agricultural land.

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[16] These key messages are mainly extracted from the chapter by Miller, Howden, and Jones (2010), which cites more than 65 references

Chapter 5: Climate Change Impacts, Mitigation and Adaptation Options for Intensive Livestock

Climatic conditions in intensive livestock-producing areas will be warmer and drier, resulting in increased evaporation and reduced runoff in 2030 (Hennessy, 2007). Increased climatic variability, the increased frequency and intensity of extreme events are likely to have significant impacts on intensive livestock farming. The effects of higher temperature on livestock and their forage base are most certain and significant while effects of rainfall would be more speculative. Livestock production will be affected by changes in temperature and water availability through impacts on pasture and forage crop quantity and quality, feed-grain production and price, and disease and pest distributions (Henry, Charmley, Eckard, Gaughan, & Hegarty, 2012). Warmer and drier climates in south eastern Australia will adversely affect pasture-based dairy systems. The potential rise in water requirements and projected reduction in water availability decreases will exacerbate the impacts (Cullen, Eckard, & Rawnsley, 2012). A recent study by Hanslow et al. (2014) examining economic implications for the pasture-based dairy sector in Australia, indicated that by 2050, the loss in dairy output will be six times larger in the severe climate change scenario[17] than it would be in the moderate one[18]. According to the "Dairy Situation and Outlook Price - May 2014" (Dairy Australia, 2014), price and input costs are still considered to be the greatest challenges likely to be faced, but there is increasing concern over climate factors and impacts on livestock.

5.1. Impacts of heat stress, pests and diseases in livestock

Heat stress

A study using spatio-temporal modelling of heat stress and assessing climate change implications for the Murray dairy region, indicated an increase in 'high' consecutive heat stress days for 2025 but a substantial increase in 'severe' consecutive heat stress days for 2050. These projected increases in heat stress days are likely to cause significant heat load impacts on dairy cattle, production losses, and additional management costs for dairy producers (Nidumolu et al. 2013). According to the Department of Agriculture, climate change is expected to increase the number of days each year that livestock experience heat stress. Animals with heat stress have a reduced appetite and are less likely to breed, resulting in possible productivity losses for the $19 billion livestock industry[19]. The impacts of increased heat stress in cattle include reduced grazing time, reduced feed intake, increased body

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[17] IPCC A1FI scenario

[18] IPCC A1B scenario

[19] Daff.gov.au,. (2014). Adapting to a changing climate - Department of Agriculture. Retrieved 22 June 2014, from http://www.daff.gov.au/climatechange/australias-farming-future/adapting-to-a-changing-climate

temperature, increased respiration rate, and weight loss. CCRP researchers studied the relationship between heat stress and ryegrass toxicity. Early findings show that high temperatures can increase the impact of perennial ryegrass toxicity in sheep, causing them to drink and eat less, and respire more (DAFF, 2013). In dairy cows, heat stress reduces milk yield, reduces milk fat and protein content, and decreases reproduction rates (R. Jones & Hennessy, 2000).

High-producing dairy cows are the most susceptible to increases in the Temperature Humidity Index THI. Heat stress days with THI > 80 lead to a substantial effect on reproduction of dairy cows. When assessing the impact of climate change on THI, it is important to assess, not just the change in the mean, but also the change in the number of extreme days (S. Howden, Hall, & Bruget, 1999). These effects could potentially result in changes in the types of animals and genotypes that are used, changes in facilities and housing utilised for care and management of livestock, and eventually a potential redistribution of livestock and livestock species in a region (Henry et al. 2012). Nidumolu et al. (2013) reviewed a number of quantitative studies measuring the impact of THI on milk production, studying factors such as level of milk production, breed, coat colour, stage of lactation and health status. It is important to understand the frequency and occurrence of high THI to be able to develop heat stress management strategies (Nidumolu et al. 2013). However, this type of quantification is limited for the dairy regions in Australia (Mayer et al. 1999). Dairy Australia provide information on managing heat stress through their Cool Cows web site[20], including weather forecasting, infrastructure options and other tools. This initiative has led to a significant increase in shade provision for cows in the Riverina.

Other intensive animal industries, such as poultry and pigs, are also vulnerable to increases in temperature and the resultant heat stress on animals. As reviewed in Miller et al. (2010), apart from reduced productivity, heat stress also reduces the reproductive success of livestock including cattle, pigs and poultry.

Pests/Diseases

Climate change is likely to trigger the increase of pests/deceases due to the changes in the abundance and distribution of insects. This is likely to adversely affect animals' health. Under projected warming climate conditions and increased summer rainfall, southward expansion of insect vector to permanently establish in entire NSW coast, South Australia and Western Australia is anticipated (Sutherst 2001 cited in S. M. Howden et al. (2008).

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[20] Coolcows.com.au,. (2014). *Cool Cows - Cow heat stress - Cooling dairy cattle*. Retrieved 3 September 2014, from http://www.coolcows.com.au

An additional risk from climate change to livestock industries, is the potential for changing patterns of parasite risk to animals; for example, the potential for the 'tick line' (the cattle tick boundary) to move further south (IPCC, 2007). This tick is estimated to cost $146 million in lost productivity each year, by reducing cattle productivity and spreading tick fever that can sicken and kill non-immune cattle (Steffen, 2012). As reviewed in Howden et al. (2008), it was suggested that under the scenario of 1.6^{o}C increase in seasonal maximum temperature, approximately 5.6-fold increase in tick numbers, equivalent to losses in liveweight gain of 21,600 tonnes per year by 2100, compared with present estimated losses of 6,600 tonnes per year, may occur.

5.2. Pasture productivity/quality and water availability:

A recent study by Nidumolu et al. (2013) found that apart from the impacts of increasing heat stress days, the warming and drying trend poses additional challenges to water availability (which ultimately affects adaptation options such as spraying) and significantly impacts on pasture productivity, as result of reduced rainfall. (Harle et al. 2007) indicated that climate change is likely to have impacts on pasture growth and quality and greater inter-annual variability in pasture production. CCRP results showed that southern pasture growth is reduced under temperature changes beyond a 1°C increase and 10% lower rainfall. Livestock production, may thus be reduced by 15-20% in some areas of this region (DAFF, 2013).

Pasture growth and herbage quality is reduced due to heat stress and moisture deficits during summer conditions (Waller and Sale 2001 cited in Miller et al. 2010). The key issue with pasture persistence is that most of the majority of ryegrass cultivars are not suitable for hot dry summers. New heat-tolerant cultivars were developed but not yet widely used (Miller et al. 2010).

In the case of projected temperature increase in southern Australia, farmers may benefit from enhanced pasture growth during autumn or winter, provided that water is available. The effects on pasture due to elevated CO_2 is discussed in Chapter 3 on Grazing, noting that a composition change favouring C3 grasses may also provide positive benefits to dairy farmers. However, effects of CO_2 fertilization and reduced rainfall on pasture composition is not well understood under Australian conditions (Harle et al. 2007).

Water is essential for intensive livestock production. Perennial pasture requires the equivalent of 1200–1300 mm of water in the Murray Dairy region (Austin 1998). In addition, when evaporation exceeds rainfall, pasture production will sustain only with irrigation water (Bethune and Armstrong, 2004 cited in Miller et al. 2010). As discussed in Chapter 3, it is projected that climate change is likely to reduce the reliability of available water which will in turn reduce the ability of rain-fed pasture to support dairy herds (Hanslow et al, 2014).

As temperatures rise, water demand by livestock is likely to increase in the future. Under projected reduced rainfall for most of southern Australia, there will be impacts on rain-fed pasture growth and crops used for supplementary feed, runoff into rivers and storages, and aquifer recharge, thus water availability for irrigation, stock drinking and evaporative cooling (Howden and Turnpenny 1997 cited in Miller et al. 2010). For example, approximately 13% increase in stock water is required under the scenario of temperature rise of 2.7^{0}C. Other effects include soil degradation near watering points and depletion of small water storages (Howden et al. 2008).

5.3. Mitigation and adaptation

Mitigation options are extensively discussed in Chapter 3: Climate Change Impacts, Mitigation and Adaptation Options for Grazing. Methane capture from waste management systems is the main mitigation option available for intensive feedlot, piggery and poultry waste. This methane can either be flared, or used to generate heat and/or electricity to offset electricity use. In general these systems are only financially viable for larger operations. Figure 5 shows an example of how captured methane from intensive livestock operations could be used for heating in the piggery.

A study at a piggery in Grantham, Queensland, demonstrated the use of a floating cover over the animal waste pond. The cover captured more than half of the site's methane emissions, with a more than 50% reduction in waste pond emissions following flaring. The study also demonstrated that the captured methane could be used as an energy source for heating in the piggery. This study was used as the basis for one of the first Carbon Farming Initiative methodologies. The potential to generate heat or electricity from waste methane offers the meat processing and intensive livestock sectors further incentives to adopt methane capture and combustion technologies.

Figure 5: Capturing and using methane from intensive livestock operations (DAFF, 2013)

This section will discuss adaptation options specific to intensive livestock production. In common with broadacre grazing, potential adaptation options are available for intensive livestock industries for moderate climate changes, including variations of existing climate risk management strategies (Howden et al. 2008). Miller et al. (2010) claimed that there is a wide range of adaptation options, given the regional differences. Some of these options are outlined in *Annex 5.2: Farm level adaptations*.

Chapter 5: Climate Change Impacts, Mitigation and Adaptation Options for Intensive Livestock

Successful adaptation for intensive livestock production to climate change requires actions at three levels: farm, industry and government. At farm level, adaptation has been taking place in two forms: tactical and strategic. While tactical measures are more reactive and may stop, strategic measures tend to enhance resilience and preparedness towards projected conditions (Miller et al. 2010). McKeon et al. (2009) suggested that altering livestock system management according to seasonal climate forecasts may be an effective adaptation strategy. An alternative transformational adaptation strategy is to relocate to a more favourable climatic region. This option will have flow-on effects to local communities, such as changed employment options (DPI, 2013).

Figure 6 below features adaptation options adopted at two farms in the Riverina.

Rob and Gai Singleton's farm provided an example of improving efficiency and responding to climate variability by moving away from an entirely pasture-based system. The Singletons now use a hybrid system of feeding their 755-strong herd where pasture is grazed from April to November and a total mixed ration is provided on a feed pad for the balance of the year. The operation has a strong focus on cow comfort, based on the premise that when cows are comfortable they eat more feed and produce more milk. Infrastructure installed to improve cow comfort includes sprinklers in the dairy and shade in the drylot to reduce heat stress. These strategies have improved feeding efficiency through reduced wastage and increased dry matter intake.

Neville and Ruth Kydd have expanded their herd five times over the past 30 years, but have also been willing to sell cows to reduce grazing pressure in times of drought. This approach to the variable climate means the Kydds have avoided investing in infrastructure and equipment needed to shift to a more intensive feeding system. By selling cows to reduce the stocking rate during dry times they reduced the wear and tear on machinery that would have been necessary if they fed more conserved forage. This also reduced the pressure on the people working in the business at the time. To increase the flexibility of their system, without the need for further labour and equipment, the Kydds fed more grain through the dairy, believing that buying grain was cheaper and more effective than buying forage.

Figure 6: Two examples of dairy farmers in the Riverina responding to climate variability[21]

CCRP researchers (DAFF, 2013) examined practices that can limit climate change impacts on livestock production. Through on–farm demonstration researchers investigated the best combinations of these management options to build resilience through increased productivity and reduce the vulnerability of

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[21] DairySA. (2012). DairySA Newsletter June 2012. Retrieved 22 June 2014, from http://frds.dairyaustralia.com.au/wp-content/uploads/2012/07/DASA_newsletter_0612_lr.pdf

the livestock industry to climate change. These options are included in *Annex 5.3: Adaptation options proposed by CCRP researchers*.

The book "*Adapting agriculture to climate change: preparing Australian agriculture, forestry and fisheries for the future*" outlined and ranked a range of adaptation options under four categories of feedbase management; livestock management; farm management and infrastructure and energy (see *Annex 5.1: Potential climate change adaptation options for the intensive livestock industry*). The section below discusses some priority options in detail.

Protecting stock from sun and heat

Renaudeau et al. (2010) suggested three approaches to minimize effects of high heat load, including (i) adjusting the environment, (ii) nutritional manipulation, and (iii) selection for thermal tolerance. Henry et al. (2012) advised two main strategies to improve heat exchange between an animal and its environment: (i) ameliorate thermal heat load, e.g. by the use of shade, misters, foggers, or pad cooling; and (ii) improve the ability of the animal to dissipate body heat by increasing sensible heat or increasing evaporative heat loss, e.g. using sprinklers to wet animals. A number of authors (reviewed in Nidumolu et al. (2013) suggested methods to mitigate the impacts of heat stress on livestock, including the practice of feeding low fibre rations and more concentrate during days of high heat stress and changes of feeding time (e.g. at night for high yielding cows); managing calving periods; and a range of artificial cooling systems.

Availability of shade for cattle and sprinkler cooling system can significantly reduce their heat load. This cooling strategy is a key factor in minimising the impacts of increased THI for both dairy and beef cattle. The THI threshold at which a cow will generally start to be impacted by heat when no shade is provided is ~72. This can be increased to 76 by providing shade in feeding areas, and to 78 through the provision of shade and sprinklers[22] (Jones & Hennessy 2000). However, using sprinkler systems to reduce heat stress in dairy cows can also increase the risk of mastitis, because udders can become wet and dirty, creating ideal conditions for the growth of bacteria (Miller et al. 2010).

Under a rising temperature scenario, housing dairy cattle indoors with a controlled climate during summer, may become necessary in some areas when it becomes unprofitable to run dairy cows on pasture, or to free-range pigs or poultry, particularly during summer. New sheds could be designed and built with passive cooling and heating, powered by energy generated onsite (Miller et al. 2010).

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[22] The significant stress is experienced at a THI of 80. When the THI rises above 82, very significant losses in milk production are likely, cows show signs of severe stress and may ultimately die. Retrieved from http://www.coolcows.com.au/go-on-alert/thi.htm in June 2014.

However, the authors noted that a comprehensive cost–benefit analysis on a case-by-case basis needs to be carried out since this model is not necessarily desirable.

Other authors noted adaptation to increased heat stress could involve cross-breeding (Henry et al. 2012). CCRP researchers at the University of Melbourne have found that low doses of the amino acid betaine[23] can reduce the impact of heat stress on sheep[24].

In terms of practical tools, Dairy Australia has a designated website: http://www.coolcows.com.au/ with information and tools to deal with heat stress in dairy herds. An early warning system for notifying dairy farmers of impending heat stress conditions was also developed.

Feedbase management

Nutrition management plays a significant role in managing dairy productivity. Manipulating the diet and feeding times of livestock can help in reducing heat stress during hot conditions (Miller et al. 2010). A study on annual and seasonal pasture production to climatic changes at six sites in south-eastern Australia, pointed to the need to explore changes to the feed base to build a higher level of resistance to warmer and drier climates (Cullen et al. 2009). One of the suggested options is to develop new pasture or fodder crop varieties that are tolerant of climate variability. Some ryegrass ecotypes, adapted to more Mediterranean conditions, will become more available to farmers. However, scientists also noted that there needs to be cultivars that are robust to a variable climate, not just to prevailing or idealised climatic conditions (Smit and Skinner 2002 cited in (Miller et al. 2010)). There is also a possibility of genetically engineered C3 pasture grasses with C4 metabolic traits of better heat tolerance and water efficiency (Miller et al, 2010).

Water management

Improving water use efficiency of irrigation is identified as one of the top-priority adaptation options at farm level as seen in *Annex 5.2: Farm level adaptations*. Meat and Livestock Australia[25] (MLA) advised that management can increase effective annual 'rainfall' by up to 20%, by utilising rainfall more efficiently and effectively, increasing pasture production and potential productivity by up to 40%. By adopting these practices, farmers will simultaneously achieve substantial increases in productivity, but also enhance and improve the environment, through less nutrient and fertilizer loss, reduced risk of

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[23] Betaine is a naturally occurring amino–acid found in plants and invertebrates

[24] Daff.gov.au,. (2014). Adapting to a changing climate - Department of Agriculture. Retrieved 22 June 2014, from http://www.daff.gov.au/climatechange/australias-farming-future/adapting-to-a-changing-climate

[25] Mla.com.au,. (2014). Climate variability - using water wisely | Meat & Livestock Australia. Retrieved 22 June 2014, from http://www.mla.com.au/Livestock-production/Environmental-management/Sustainable-grazing-a-producer-resource/Climate-variability-using-water-wisely

soil erosion, soil acidity and dryland salinity. The MLA outlined several ways (with specific guidelines) for effective use of water:

- Optimising the amount of rainfall that enters and is stored in the soil for maximised pasture use
- Minimising the amount of rainfall that is lost from evaporation
- Managing surface run-off at the soil surface by maintaining ground cover
- Moderating the losses to deep drainage with deep-rooted perennials

5.4. Recommendations and future research

As mentioned in other sections, in order for adaptations to be successful, the options reviewed here will need to be investigated and integrated in a broader decision context of livestock enterprise managers, taking into account social, economic and institutional pressures (Howden et al. 2008).

The lack of experimentation and simulation of livestock physiology and adaptation to climate change makes it difficult to predict impacts or develop adaptation strategies (Hoffmann, 2010). Further selection for livestock lines with effective thermoregulatory control will be needed (S. M. Howden et al. 2008).

For the Murray Darling region, significant future challenges for the industry are posed due to the combination of increased heat stress and additional costs in its management, projected lower water availability for irrigated pastures as well as ongoing price pressures. Nidumolu et al. (2013) suggested that more systemic changes in farming operations may need to be considered, such as targeted diversification of production systems and livelihoods.

Furthermore, there is a serious need to improve the understanding of how combinations of various factors such as CO_2, temperature and rainfall, pests and diseases affect livestock systems (Tubiello et al. 2007 cited in Howden et al. (2008)) and how management responses will interact with these (Howden et al. 2008). Most importantly, policy analysis at a whole system level is necessary to reduce the risks of maladaptation or counteracting policy and regulation inherent in portfolios with different objectives (Miller et al. 2010).

It is important for industries to realize their roles in ensuring water and energy efficiency in designs/retrofitting livestock production buildings; specifically in developing guidelines, exploring and incorporating options for energy generation and passive or environmental air conditioning. At farm level, it is important for farmers to extend their knowledge beyond their farm gates to gain and be able to incorporate broader understanding on issues such as seasonal and out-year forecasts, the dynamics of global commodity and financial markets, and consumer demands (Miller et al. 2010).

There needs to be a coherent framework to enable industry managers to more effectively consider climate impacts and options for adaptations in their decision-making processes (Howden et al. 2008). Crimp, Ash, Gifford, Howden, (2003) outlined a systematic approach for the grazing industry with broader application to other industries. This tool could be used to serve this purpose. It is recommended that industries may want to consider adoption of such (or similar) tools in their decision-making.

Enhancing capacity to manage climate risks is the key in adaptation to climate change. Within this domain, mapping out adaptive capacity will not only serve the purpose of better target capacity-development programs, but also as an awareness raising exercise for policy makers (Howden et al. 2008).

Annex 5.1: Potential climate change adaptation options for the intensive livestock industry

The options identified here are not comprehensive and those chosen will depend on individual circumstances. Priority 1 (high) and 2 (medium) (Miller et al. 2010)

Adaptation options	**Priority**
Feedbase management	
Selection of drought-tolerant pasture species	1
Use of perennial and annual pasture species	1
Fodder conservation and conserved fodder use strategies	1
Forward contracting supply of supplementary feedstock	1
Livestock management	
Selection for thermotolerance and thermoregulation capacity	2
Provision of shade and shelter through infrastructure or tree planting and protection	1
Feeding of feedlot-grown stock in cool periods of the day	1
Agist stock during unsuitable conditions	1
Farm management	
Improve water use efficiency of irrigation	1
Increase groundwater recharge and soil moisture maintenance through revegetation and soil organic carbon management	2
Use decision-support tools with seasonal climate forecasts to make proactive decisions	1
Infrastructure and energy	
Climate control in buildings through natural air conditioning	2
On-site power generation	2
Use alternative energy sources such as biodiesel	2

Annex 5.2: Farm level adaptations

This is a small subset of those available (S. M. Howden et al. 2008)

Adaptation to climate change: managing pasture productivity and grazing pressure

- Selection of sown pastures and forage crops better adapted to higher temperatures and water constraints
- Revision of fertiliser management through sown legumes and phosphate fertilisation where appropriate
- Provision of urea and phosphates directly to stock via reticulation, effective supplementary feeding strategies
- Greater use of strategic spelling and attention to fire management especially for woody weed control
- Use responsive stocking rate and rotation strategies based on seasonal climate forecasting, alter crop/livestock mix
- Development of regional safe carrying capacities i.e. constant conservative stocking rate
- Where appropriate, development of software to assist pro-active decision making at the on-farm scale
- Improved management of water, particularly for pasture irrigation

Adaptation to climate change:- managing pests, disease and weeds

- Improve pest predictive tools and indicators
- Improve quantitative modelling of individual pests to identify most appropriate time to introduce controls
- Increased (but cautious) use of biological and other controls
- Increased use of insect traps for sentinel monitoring and for population control
- Incorporation of alternative chemical and mechanical methods for reducing woody weeds

Adaptation to climate change: animal husbandry and managing health

- Selection of animal lines that are resistant to higher temperatures but maintain production
- Modify timing of mating based on seasonal conditions
- Modify timing of supplementation and weaning
- Construction of shading and spraying facilities
- Increase use of trees as shading and reducing wind erosion

Annex 5.3: Adaptation options proposed by CCRP researchers

- changing stocking rates
- rotational grazing methods
- improving pastures
- planting forage crops and pasture legumes
- improving breeder herd efficiency
- improving soil carbon and soil health
- placing livestock in drought lots
- altering the proportion of cropping and livestock in mixed enterprises
- improving water use efficiency
- sowing improved pastures
- managing animal nutrition
- developing infrastructure (e.g. watering points, fencing)
- resting pasture during the growing season in northern Australia (wet season spelling)
- controlling woody weeds

Chapter 6: Climate Change Impacts, Mitigation and Adaptation Options for Horticulture

Chapter 6: Climate Change Impacts, Mitigation and Adaptation Options for Horticulture

Key messages for horticulture

These key messages are extracted from the Horticulture Chapter (L. Webb & Whetton, 2010) in the book “*Adapting agriculture to climate change: preparing Australian agriculture, forestry and fisheries for the future*” (Stokes & Howden 2010a).

- Site suitability may change for some horticultural crops as a result of climate change. In particular, there may be a reduction in areas suitable for growing stone- and pome-fruit varieties that require chilling, and an expansion in areas suitable for growing subtropical crops.
- Changes in rainfall and evaporation are likely to reduce soil moisture and runoff. Increased crop water demand combined with reduced water supply poses significant challenges. Efficient water use will become paramount. Lower winter and spring rainfall may indirectly cause increased frost risk.
- Increased temperatures will advance phenology (timing of crop developmental stages) with likely effects on flowering, pollination and harvest dates. Warmer temperatures may also increase sunburn incidence and reduce colour development. Also of concern for vegetable growers is a potential increase in premature flowering (bolting).
- For some perennial horticultural crops increased night-time temperatures will lead to increased respiration and thus affect the distribution of assimilates to reproductive sinks. It may be more difficult to obtain desired fruit size classes.
- Varietal selection can be used to match crops to new climate regimes. Utilising existing varieties or breeding new varieties can facilitate adaptation. For example, drought-tolerant plants for amenity horticulture (parks and gardens) will be favoured in a drier climate.
- The net effect of increasing atmospheric carbon dioxide concentrations is crop-specific. Elevated concentrations can enhance photosynthesis and water use efficiency in some plants. There are likely to be changes in the nitrogen status of horticultural crops as CO_2 levels increase, affecting crop management and quality.
- Decreasing rainfall and humidity may reduce fungal pressure in some regions. In other regions increased summer rain may favour fungal growth as will increases in extreme rainfall. Cold season suppression of some pest species may be reduced. Efficacy of parasites and beneficial organisms may change in a future climate.

- Consumers may require assistance in accepting some changes in the availability, cost and quality of produce. For example, the cost of some produce tends to rise during droughts, which are likely to occur more often.

Key message for winegrapes

These key messages are extracted from the Winegrapes Chapter (Webb, Dunn, & Barlow 2010) in the book "*Adapting agriculture to climate change : preparing Australian agriculture, forestry and fisheries for the future*" (Stokes & Howden 2010a)

- A warmer climate will hasten the progression of phenological stages of the vine (e.g. budburst, flowering and veraison) so that ripening will occur earlier in the season.
- In most cases, quality of existing mainstream winegrape varieties will be reduced if no adaptation measures are implemented.
- Water requirements for grapevines are likely to increase while at the same time rainfall and associated runoff to water storages is likely to decrease.
- Vintage, the period when grapes are harvested and processed in wineries, is likely to become more compressed requiring possible changes to winery infrastructure and vintage staffing levels.
- Yield can affect wine quality, so effects of elevated CO_2 and increased temperature on yield and its components will need to be closely monitored and, if necessary, managed.
- Budburst in some of the more maritime climates may become uneven due to less chilling during the winter dormancy period.
- Shifting to cooler sites will alleviate some warming impacts. As vineyard blocks have an average life of 30+ years, this option will need to be considered with some urgency.
- Within regions, existing varieties can be replaced with 'later season' varieties to compensate for the warmer temperatures and compressed phenology.
- Consumer education relating to new wine styles and varieties will be important, e.g. the typical style for any given region is likely to change.

Chapter 6: Climate Change Impacts, Mitigation and Adaptation Options for Horticulture

6.1. Impacts

According to the IPCC AR5 (IPCC, 2014), climate change will lead to earlier budburst, ripening and harvest for most regions and scenarios (Grace et al. 2009; Sadras and Petrie, 2011 cited in IPCC, 2014), (L. B. Webb et al. 2012). It is predicted with high confidence that without adaptation, crop quality will be reduced in all Australian regions (Webb et al. 2008 cited in IPCC 2014).

6.1.1. Impact of temperature on plant growth, yield and crop quality

Higher temperatures tend to shorten the period of growth of individual crops. The opportunity to plant earlier in the season, or harvest later, will effectively extend the potential length of the growing season for annual crops (Webb & Whetton 2010). The impact of higher temperature on development time is not limited to crops. If climate change has different effects on the timing of flowering of the different cultivars this may lead to problems with fertilisation and hence fruit production (Webb and Whetton 2010). Model simulations of crop yields of almonds, table grapes, oranges, walnuts and avocados suggest reductions in future yields due to climate change (Lobell et al. 2006 cited in Webb & Whetton 2010).

Winegrapes

Earlier maturity (onset of ripening) of grapes in south eastern Australia has been observed in the last 15 years (Sadras and Petrie 2011 cited in Chapman et al. 2012, and Webb et al. 2012). This has both negative and positive impacts on the wine industry depending on climate regimes.

A study by Webb et al. (2012) detecting trends in wine grape maturity in ten sites across Australia and over various observation periods since 1976, concluded that wine grapes have been ripening earlier in Australia in recent years, often with undesirable impacts. Attribution analysis of detected trends in winegrapes maturity, using time series of up to 64 years in duration, indicates that two climate variables—warming and declines in soil water content—are driving a major portion of this ripening trend. Crop-yield reductions and evolving management practices are likely to have also contributed to earlier ripening. An earlier study by Webb (2006) on the impact of climate change on vineyards suggests that season duration in all grape growing areas will be compressed, with harvest usually occurring earlier. Grape flavour compounds including sugar, acid aroma, and its colour are also affected due to rising temperature. The author also projected negative impacts on grape quality if no adaptation strategies are implemented. Webb's (2006) modelling also showed a shift towards the south and coastal areas of suitable conditions for many varieties. It is expected that there will be a severe reduction in the potential area available in Australia for growing varieties and making wine styles suited to cooler regions. Figure 7 below shows the expected changes in the Riverina grape quality in warming scenarios.

The coping range of each of the horticultural crops is determined by the climate in which it has developed. For example, conditions outside the range of ideal temperature will result in a loss of production as seen in citrus production with temperatures over 37°C. Therefore, Pittock (2003 cited in DPI 2013) pointed out that is it particularly important to determine the effect of temperatures outside those normally encountered, coupled with increased carbon dioxide for horticultural regions in NSW. According to NSW DPI, there has been little work done on documenting the adaptation strategies required to extend the coping range of each of these industries in the face of climate change (DPI, 2013).

In the Riverina, a 16% decline in grape quality is projected for the minimum warming scenario, and a maximum decline in quality of 52% by 2030 for the maximum warming scenario. Projections for 2070, using the maximum warming scenario, suggest that vineyards will become economically unviable in the Riverina. Leanne Beryl Webb (2006)'s modelling also showed a shift towards the south and coastal areas of suitable conditions for many varieties. However, reductions in grape quality may be offset by increases in yields. For example, modelling for the Canberra region indicates increases in gross economic returns of up to 35%. However, this is not true for the Riverina, where increases in yields are not sufficient to offset the economic impacts of reduced grape quality. As a consequence, gross returns for the Riverina could be reduced by 12–46% by 2030, depending on the level of warming.

Figure 7: Riverina grapes quality in projected climate change (DPI, 2013)

Fruits

Climate and weather are key determinants of successful production of deciduous fruit. Plant responses to climate trigger different phases throughout the annual cycle. One important phase in this cycle is winter dormancy. Deciduous fruit trees enter this dormant stage to survive winter conditions and avoid cold weather damage (Saure 1985 cited in Darbyshire, Webb, Goodwin, & Barlow 2011). The warming trend will increase the likelihood of inadequate chill exposure and this has already taken place in Australia. However, there have not been quantitative analyses (Darbyshire et al. 2011). In this study, chill was calculated at 13 locations of horticultural importance in Australia, including NSW. Using four different chill models for 1911–2009, it was found that impacts are likely to be regionally dependent as there was no consistent trend in chill across the studied areas.

For citrus fruit, winter temperatures between 0 and 14°C are required during the 'resting period' for optimum production, so some warmer sites may lose suitability. As reviewed in Webb & Whetton (2010), a number of impacts from excessive temperature rise include premature fruit fall in citrus fruit and falling off flower buds, hence reduced productivities in capsicum; adverse effects on pollination of avocado and some varieties of tomatoes; increasing sunburn damage in apples; negative impacts on fruit (citrus, strawberry and melon) quality (reduced level of Vitamin C) and colour.

Vegetable

Rising temperature negatively impacts yield and quality of leafy crops such as lettuce and spinach (Titley 2000 cited in L. Webb & Whetton 2010). Apart from this, rising temperature also negatively affects the self-life and storage of produce, thus the costs and benefits of shifting harvest time to a cooler part of the day, or increasing refrigeration, will need to be assessed. Figure 8 below depicts the potential impacts on vegetables in Hay. Specific information on impacts on vegetable crops in response to daily average temperature increases up to 4°C in Hay are included in *Annex 6.3: Impacts on vegetable crops in response to daily average temperature increases up to 4°C in Hay*. *Annex 6.4: Impacts of frost and high temperature for a range of vegetable crops* contains information on impacts of frost and high temperature for a range of vegetable crops.

- **The Hay region** has already seen a transformation in production with a shift from vegetable cropping to other summer crops such as cotton. Such transformations are driven by a number of factors such as markets, labour and water availability. Changes in climate are just one of the factors in such transformations of a region.
- Looking forward to 2035 the Hay region is projected to see an increase in summer extremes that will make producing quality summer crops such as cucurbits difficult. Providing water is available such high temperatures may have minimal effect on yield.
- May adversely affect fruit quality in melons and may also adversely affect kernel fill in sweet corn.
- The potential increase in the frost window may have significant implications for the Hay region. The consequence will vary for crops and their sensitivity to frosts. But the potential for crop damage to increase is likely as generally warmer conditions allow for new growth, which is then susceptible to late and early "out of season" frosts.

Figure 8: Potential impacts on vegetable production in Hay (HAL, 2013)

6.1.2. Impact of water balance changes

Since rainfall is projected to decline as discussed in chapter 2, less water will be available for irrigation. Overall vulnerability to water shortages is greater for perennial crops than for annual crops (Webb & Whetton 2010). It was found that grape yields can decline without water (Jackson et al. 2008) while vines can suffer from long-term damage (Hardie & Considine 1976 as cited in Webb & Whetton 2010).

6.1.3. Extremes: extreme rainfall, hail, frost, drought, cyclones

Hail damage could cause losses in perennial tree crops such as apples and cherries. However, frost, the major threat to horticultural production, is expected to decline in the future. Earlier planning and expansion for annual crops including broccoli and pineapple (Deuter 1995 & Scott 1995 cited in L. Webb and Whetton (2010) could be possible. However, Webb & Whetton (2010) pointed out that reduction in rainfall may counteract some of the warming trend with regard to risk of frost in the future. Impacts from drought on horticulture were evident threatening survival of perennial vine and tree crops in the Murray–Darling Basin. Cyclones have caused tremendous crop loss, as seen in the Severe Tropical Cyclone Larry in 2006 (Webb & Whetton, 2010).

6.1.4. Pests, diseases and weeds

These impacts are already discussed in detail in chapters 4 and 5. While rising temperatures may result in increased pest and disease incidence and severity due to increased populations of pests and pathogens (Aurambout et al. 2006 cited in (Webb & Whetton 2010)), reductions in rainfall and humidity may reduce disease pressure (Coakley et al. 1999 cited in (Webb & Whetton 2010)). The life cycles of some of the indigenous insect pests affecting viticulture are strongly influenced by climate. Specifically, there is an increased risk of downy mildew and related diseases due to the trends of increased night-time temperatures (Webb & Whetton 2010).

As the result of temperature rise, altered wind patterns or flooding may allow tropical and frost-tolerant weed species to move further south which ultimately change the competiveness among weed species and crops. Many agricultural pesticides and herbicides cannot be used in very hot conditions (McFadyen 2008 cited Webb and Whetton 2010).

6.1.5. Carbon dioxide enrichment effects

It is worth noting that horticulture responses to these effects vary. For example, it was found that tree crops respond more than herbaceous crops in a CO_2-enriched environment (Ainsworth and Long 2005 cited in Webb and Whetton 2010).

Similar to the discussion in the previous chapters, limited direct CO_2 effects on plants are also observed for vegetables. For example, for lettuce, while increasing CO_2 should increase yield, this will be partially offset by warmer temperatures (Pearson, Wheeler, Hadley, & Wheldon 1997). While for potatoes, crop growth counteracted the negative effects of warmer temperatures depending on the initial temperature regime (Miglietta et al. 2000). Furthermore, these effects are found to alter plant physiology, canopy size (could shade out winegrapes, thus causing a reduction in fruitfulness (May et al. 1976 as cited in Webb and Whetton 2010) and composition, which may be associated with changes in the geographical range of native and cultivated host plant species (Aurambout et al. 2006 cited in Webb and Whetton 2010) and reduce nutritional values of the crops.

6.2. Mitigation

The Australian vegetable industry is a relatively small emitter of greenhouse gases due to its small total area of cultivation (about 110,000 ha) (HAL 2013). The greenhouse gas emissions from the vegetable sector have been estimated at 1.188 MT CO_2-e/year from direct and indirect emissions (Maraseni, Cockfield, Maroulis, & Chen 2010). Direct soil emissions from vegetables (as nitrous oxide) are high compared to wheat (Scheer, Grace, Rowlings, & Payero 2012). HAL's "Vegetable Industry Carbon Footprinting Scoping Study" found that the major sources of greenhouse gas emission are (i) electricity for pumping irrigation water (66% of the total emissions from the vegetable industry) and (ii) N_2O emissions from soils (19%). HAL (2013) listed three main ways that greenhouse gas emissions can be reduced from vegetable farming operations:

1. Reduce electricity use for pumping and refrigeration, or generate power on farms from renewable energy sources. Indirect CO_2 emissions could be reduced by reducing farm electricity consumption, which is used mainly for pumping irrigation water and running cool rooms (refrigeration). This can be achieved by either improving the efficiency of pumps and refrigeration, or by on farm power generation using renewable energy sources.
2. Reduce N_2O emissions from soil: Reducing N_2O loss through chemical routes, to increase the rate of denitrification–nitrification inhibitors.

- Cost-effective, slow-release nitrogen fertiliser products, which reduce gaseous nitrogen emissions in synergy with increased productivity and profitability.
- Managing the relationship between soil carbon and nitrogen (e.g. potential increases in N_2O emissions as soil carbon is increased).
- Improved nitrogen management.
- Improved irrigation management, especially sub-surface drip irrigation.

1. Sequester carbon in soils: Sequestering carbon in soils for the long term (100 years) can be an effective way of taking CO_2 out of the atmosphere. However, there is a need for improved understanding of management practice on soil-carbon change before these options can be properly assessed. Some methods that have potential for achieving this in the vegetable industry include:

- Biochar
- No-till and controlled traffic
- Cover crops and incorporation of organic matter
- Manures

6.3. Adaptation measures

Webb & Whetton (2010) outlined key adaptation measures for horticulture, but highlighted that the overall vulnerability will be crop and site specific. The authors suggested that adapting to a changing climate may occur autonomously. A report by Horticulture Australia in collaboration with CSIRO in 2009 claimed that the simplest adaptation measures will be and are adopted by growers. The authors put an emphasis on flexibility as the key to adaptation in horticulture to date and that it will continue to be an important component of adaptation strategies (HAL 2009).

Several management options are available for locations at risk. The Darbyshire et al. (2011) study in chill trends emphasized that further declines in chill exposure may significantly affect commercial fruit production and suggested that replanting with varieties that require less chill may be necessary. In other locations, larger transformational change may be necessary, such as converting to different horticultural crops or production systems. It is important to consider other dependent factors such as trends in other climate variables, market and social drivers. The authors suggested that to inform growers, a similar analysis should be carried out under climate change conditions.

The adaptive capacity of the horticulture industries will be as varied as the industries themselves, and will depend on the investment cycle of the particular industry; for example, vineyards have a life of 30 years or more, posing a major challenge for adaptation (Pittock 2003). According to Horticulture Australia, in comparison with R&D investment in broad acre agriculture and the grazing industries, the investment by horticulture is smaller and mainly involves more recent investments as a result of drought[26].

Information on good practices is available. For example, NSW DPI published a practical manual for preventing sunburn on fruit (DPI 2011). The government of South Australia produced a booklet, presenting probable impacts of climate change on South Australia's main farming sectors and adaptation options. This document contains a whole section on horticulture, which is presented in *Annex 6.6: Horticulture and viticulture*. Adaptation options are also listed by Webb & Whetton (2010) in *Annex 6.2: Adaptation options for the Australian horticulture industry*, with the most urgent options being given the highest priority ranking. Adaptation measures for winegrapes by Webb et al. (2010) are listed in *Annex 6.1: Adaptation options for the Australian viticulture industry*. Some of these measures are discussed in more detail below.

6.3.1. Site selection

The recent IPCC report claims that change in cultivar suitability in specific regions is expected (Clothier et al. 2012 cited in IPCC 2014), with potential for development of cooler or more elevated sites within some regions (Tait 2008; Hall & Jones 2009 cited in IPCC 2014) and/or expansion to new regions, with some growers in Australia already relocating (e.g. to Tasmania; Smart 2010 cited in IPCC 2014).

Webb et al. (2010) suggested that in the context of climate change, while the practice of carefully selecting appropriate sites for different annual crops may not change, it is challenging and urgent to select sites for perennial varieties. Identifying suitable areas for planting could be mapped out based on careful analysis incorporating phenological information, analysis of threshold temperatures and other relevant aspects of the climate for a range of future climate regimes.

Due to the smaller number of growers involved in horticultural species (vegetables, fruits, and grapes), one rational industry response to climate change is to shift the industry geographically, rather than to breed new varieties. This shift has already begun in several industries, most notably in grape production, where several wine producers have bought properties in cooler regions (Chapman et al, 2012). However, the set up/infrastructure and nature of the vineyards together with tourism make it

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[26] Horticulture.com.au,. (2014). Horticulture Australia - Responding to Climate Change. Retrieved 22 June 2014, from http://www.horticulture.com.au/areas_of_Investment/Environment/Climate/responding_climate_change.asp

impossible to move on a year-to-year basis, thus decisions to select new regions/sites will have long-term implications. Adaptation to temperature increases through winemaking and winery infrastructure changes are currently under investigation (Webb et al, 2010)

6.3.2. Crop management

For annual crops, the timing of planting may be changed. Therefore, considerations of day length requirements will need to be taken into account while planning change in sowing needs. As for perennial crops, adaptation will be required to manage the variability and protracted full bloom of pome- and stone-fruit and nut trees, if bud dormancy is affected in a way that leads to non-uniform budburst (Saure 1985 cited in Webb et al. 2010).

Olesen & Grevsen (1993) suggested that to compensate for the reduced yield, sowing annual crops should take place earlier. Also to cope with other external factors such as market fluctuations when crops mature rapidly, it may be necessary to plant smaller areas of crop more frequently. Grant et al. (2004) drew attention to the useful trait of natural self-shading ability and the need to consider breeding programs aimed at sunburn.

Webb et al. (2010) recommended that in order to maintain consistency in wine styles, the industry will need to consider altering the balance of varieties growing in different areas to better match varieties to growing season conditions. The authors also emphasized the importance of monitoring the effects of climate change on yield, particularly when water availability is uncertain.

6.3.3. Varietal selection, pest and water management

Other measures include varietal selection where breeding of varieties suited for new climatic regimes could assist in avoiding the impacts discussed. Moving to new varieties for winegrapes may be difficult as markets are often based on traditional grape varieties and it takes 20–30 years to introduce new varieties (Rose 2007 cited in Webb et al. (2010)).

With regards to pest management, quantitative understanding of the ecology of each pest can contribute to quality decision support systems for adaptation. As for winegrapes, better targeted application methods for pesticides and increased knowledge of vine and pest dynamics and the CO_2 effects on disease and hosts is the key.

Webb et al. (2010) put an emphasis on water management, especially at the farm level. Methods for conserving water once it reaches the farm will become critical. As reviewed in Webb et al. (2010), some of the techniques to increase irrigation efficiency and suitable water saving techniques (also applicable for winegrapes) include: partial rootzone drying; mulching the soil surface with organic matter to reduce water evaporation; kaolin clay applied to plants to reduce the effects of water and heat stress; and night time watering. Specifically for winegrapes, coordinated adjustment of irrigation scheduling and leaf area may be needed in response to CO_2 changes. The use of this recycled water on grapevines proved no negative impact on yield or quality of the resulting wine, and some improvements, compared to vines watered with mains water, were noted (Rawnsley 2007 cited in Webb et al. 2010).

Some of the barriers to reclaiming water for horticulture are found to be (i) insufficient knowledge of impacts on market acceptance, (ii) insufficient knowledge of food safety issues, (iii) inadequate understanding of consumer perceptions, and (iv) uncertainty about pricing of reclaimed water. These issues need to be tackled.

6.4. Recommendations and Future Research

Information on regional impacts of projected climate change and relevant, crop-specific, climatic thresholds will assist in estimating whether climate change will increase or decrease the risks of growing crops in particular geographic locations. It is particularly important to determine the effect of temperatures outside those normally encountered, coupled with increased carbon dioxide for horticultural regions in NSW.

There are both positive and negative effects from climate change on crops. It is important to consider other dependent factors such as market and social drivers.

More investment in R&D in horticulture is recommended. Some areas of studies may include quantitative studies on warming trend effects on inadequate chill exposure; identifying and quantifying the responses of winegrape vines to climate, assessment of regional exposure (both climatically and socially); and documenting adaptation strategies required to extend the coping range of each of these industries in the face of climate change.

It is important to understand the future risks in the existing wine regions which will inform the evaluation to select potential new regions. New management techniques need to be further explored and shared across the industry. Water recycling usage with its great potential for water security are not yet fully realised.

Other recommendations for further research on quantifying potential future water availability in Chapter 3, 4 and 5 are also critical here. Key barriers to reclaiming water for horticulture as outlined above need to be considered and tackled.

Annex 6.1: Adaptation options for the Australian viticulture industry

The most urgent options are given the highest priority ranking (1) (L. Webb & Whetton, 2010)

Adaptation options	**Priority**
Temperature increase	
Assess new and existing sites for future climate-related risks	1
Vineyard design strategies to ameliorate climate impacts	1
Harvest logistics: infrastructure capacity modelling	1
Evaluate varieties to best match changing climate	1
Determine extent of consumer and product flexibility	2
CO_2 enrichment	
Determine the effect of CO_2/temperature on vine–water interactions	1
Determine changes in viticultural management required to deal with possible increased growth	2
Economic and legal adaptations to manage the risk of yield variation	2
Manage vine nutrition to address possible imbalance in C:N ratios	3
Rainfall changes	
Water demand and supply predictions: vineyard and regional scale	1
Irrigation management to increase efficiency	1
Alternative sources of water e.g. water recycling	1
Irrigation and other viticultural management strategies (e.g. rootstock selection) to address salinity	1

Annex 6.2: Adaptation options for the Australian horticulture industry

The most urgent options being given the highest priority ranking (1) (L. Webb & Whetton, 2010)

Adaptation options	**Priority**
Temperature increase	
Determine climatic thresholds to plant growth and product quality	**1**
Re-assess location in regional terms to optimise reduction of climatic risk	1
Invest in conventional breeding and biotechnology to address future adaptation capacity	1
Tailor seasonal climate forecasts to horticultural requirements	2
Develop and modify markets for new crops and crop schedules	3
Change crop production schedules to align with new climate projections	3
CO_2	
Ascertain the crop-specific interactive effect of increased CO_2, temperature and water use	1
Determine the effect of CO_2 on pests, diseases and weed species	1
Rainfall	
Integrate catchment management and climate change projections to assess future water availability	1
Constantly benchmark irrigation management to increase efficiency	1
Pests and diseases	
Geographically sensitive pest and disease risk assessments using projected climate data	2

Annex 6.3: Impacts on vegetable crops in response to daily average temperature increases up to 4°C in Hay

Crops	**+1°C average**	**+2°C average**	**+ 3°C average temp**	**+ 4°C average temp**	**5 days over 35°C**
Lettuce Traditionally May-October harvest using winter varieties	Days to harvest quicker by 3-4 days	Days to harvest quicker 5-7 days, change varieties	Days to harvest quicker 8-10 days, change varieties in mid-winter	Commence season later, improved quality in id winter as less frosts, change varieties	Unlikely during winter harvest period
Baby leaf lettuce, spinach, rocket Not a traditional area for winter grown baby leaf	Days to harvest quicker by 3-4 days	Days to harvest quicker 5-7 days, change varieties	Days to harvest quicker 8-10 days, change varieties in mid-winter	Commence season later, improved quality in id winter as less frosts, change varieties	Unlikely during winter harvest period
Broccoli & cauliflower Traditional harvest window May-Nov	Earlier maturity	Change in variety mix	Less cold season varieties	Harvest window reduced to June-Oct	Quality & yield decreases

Source: (HAL, 2013)

Annex 6.4: Impacts of frost and high temperature for a range of vegetable crops

Crop	Frost sensitivity	Specific frost-sensitive stage	High temperature sensitivity	Effects of prolonged hot weather
Broccoli	Tolerant	Emergence to 8 weeks	Very sensitive	Very poor quality heads, hollow stem, leafy heads, no heads, bracting.
Brussels sprouts	Tolerant	Emergence	Very sensitive	Cool season crop only
Cauliflower	Moderate tolerance	Emergence to 8 weeks	Very sensitive	Very poor quality curd, hollow stem, leafy heads, no heads, bracting.
Beans	Very sensitive	All stages affected by cool temperatures	Sensitive	Pollination problems, high fibre in pods
Carrots	Tolerant	Emergence to 8 weeks	Sensitive	Reduced yields & low beta carotene content (poor colour). Temperatures < 10°C or > 20°C
Celery	Moderate tolerance	Emergence to 8 weeks	Sensitive	Poor quality stems
Lettuce	Low tolerance	All stages	Sensitive	Bolting & small light heads, tipburn, bolting, loose, puffy heads. >24°C day and 15°C night, poor shelf life.
Babyleaf general: chard, Asian greens	Moderate tolerance	All stages	Sensitive	Low yield
Garlic	Tolerant	Emergence to 8 weeks	Sensitive	Cool season crop only
Kohlrabi	Tolerant	Emergence	Sensitive	Poor root quality
Leek	Tolerant	Emergence to 10 weeks	Sensitive	Cool season crop only
Parsnip	Tolerant	Emergence	Sensitive	Poor root quality
Peas	Tolerant	Flowering	Sensitive	Poor pollination
Babyleaf spinach	Moderate tolerance	All stages	Moderate	Low yield
Babyleaf rocket	Moderate tolerance	All stages	Moderate	Low yield

Turnip	Very tolerant	Emergence	Moderate	Poor root quality
Tomato	Very sensitive	All stages affected by cool temperatures.	Moderate	Fruit cracking, sunscald, poor fruit set above 27°C. Blossom-end rot when combined with water stress.
Beetroot	Tolerant	Emergence	Moderate	Poor root quality
Cabbage	Moderate tolerance	Emergence to 8 weeks	Moderate	Loose, light heads
Chinese cabbage	Moderate tolerance	Emergence to 8 weeks	Moderate	Loose, light heads
Onion	Tolerant	Emergence to 10 weeks	Moderate	Bulb splitting
Snow peas	Moderate tolerance	Emergence to 6 weeks and flowering	Moderate	Reduced growth, fruit set
Asparagus	Very tolerant	Dormant in winter	Tolerant	High fibre in stalks, feathering and lateral branch growth. Temperatures > 32°C, if picking frequency is not increased.
Capsicum	Very sensitive	All stages affected by cool temperatures	Tolerant	Reduced pollination and yield, sunburn on fruit.
Parsley	Moderate tolerance	All stages affected by cool temperatures	Tolerant	Tolerant
Potatoes	Low tolerance	Emergence to 8 weeks	Tolerant	Poor tuber set, secondary growth and heat sprouting.
Pumpkins	Very sensitive	All stages affected by cool temperatures	Tolerant	Poor fruit set
Radish	Tolerant	Emergence	Tolerant	Poor root quality
Rockmelon	Very sensitive	All stages affected by cool temperatures	Tolerant	Sunburn
Shallot	Tolerant	Emergence to 10 weeks	Tolerant	Tolerant
Silverbeet	Moderate tolerance	Emergence to 8 weeks	Tolerant	Tolerant
Sweet potatoes	Sensitive	All stages affected by cool temperatures	Tolerant	Tolerant

Cucumber	Very sensitive	All stages affected by cool temperatures	Tolerant	Lack of pollination
Eggfruit	Very sensitive	All stages affected by cool temperatures	Tolerant	Sunburn on fruit
Watermelon	Very sensitive	All stages affected by cool temperatures	Tolerant	Sunburn
Zucchini & button squash	Very sensitive	All stages affected by cool temperatures	Tolerant	Poor pollination
Sweet corn	Very sensitive	All stages affected by cool temperatures	Tolerant, affected >35°C	Pollination problems, poor kernel development, poor husk cover, tasselate ear.

Source: Understanding and managing impacts of climate change and variability on vegetable industry productivity and profit by HAL (2013)

Annex 6.5: Impacts from climate change on Horticulture by Horticulture Australia

- Changes in the suitability and adaptability of current cultivars as temperatures change, together with changes in the optimum growing periods and locations for horticultural crops
- Changes in the distribution of existing pests, diseases and weeds, and an increased threat of new incursions
- Increased incidence of disorders such as tip burn and blossom end rot
- Greater potential for loss of product quality e.g. because of increased incidence of sunburn
- Increases in pollination failures if heat stress days occur during flowering
- Increased risk of spread and proliferation of soil borne diseases as a result of more intense rainfall events (coupled with warmer temperatures)
- Increased irrigation demand especially during dry periods
- Increased atmospheric CO_2 concentrations will benefit productivity of most horticultural crops, although the extent of this benefit is unknown
- Increased risk of soil erosion and off-farm effects of nutrients and pesticides, from extreme rainfall events

Source: (HAL, 2009)

Annex 6.6: Horticulture and viticulture

IRRIGATION WATER

Water is expected to become scarcer under climate change, with reduced rainfall and increased demand for irrigation water. This has implications for horticulture, as a major water user.

Impacts

- Variable water supplies and reduced river flows may lead to increases in irrigation salinity, reducing water quality and affecting plant growth and soil health. Water quality can have significant impact on horticulture management practices.
- Increased demand, increasingly variable water supplies and rationalisation are expected, especially during hot and dry periods, as is reduced water availability in some locations and in some seasons.
- Critical water allocations along the River Murray corridor will require irrigators to manage plantings with reduced allocations at different times in the season.
- Increased incidence of severe weather conditions may require the types of irrigation systems used and timing of irrigations to be modified.

Adaptation options

- Prioritise the use of scarce irrigation water resources away from low-value crops.
- Assess crop and water management practices to reduce variability in yield and quality. For each crop, assess modified growth and changed water requirements under new climatic conditions.
- Increase irrigation efficiency, through:
    - enhanced monitoring of soil water conditions to improve timeliness and quantity of irrigation; and
    - effective and efficient use of water management technologies, i.e. upgrading to efficient irrigation systems and enhanced use of monitoring and timing equipment.
- Use computer-controlled irrigation scheduling and soil moisture probes to help regulate irrigation frequency and to manage salt levels.
- Increase water storage capacity to better meet irrigation requirements.
- Reassess the types of ground cover crops used to preserve moisture in the soil.

RAINFALL

The amount of overall rainfall in Southern Australia is expected to drop, though there may be more heavy falls, and the timing of rain events will shift.

Impacts

- For most horticultural crops, the timing of rainfall is important. For viticulture, the biggest risk is late summer rainfall which can lead to splitting, ringing, disease exposure and rot. Such conditions could also increase fungus and bacterial infections.
- Heavier falls of rain may provide increased opportunities for water harvesting, but may also cause flooding and run-off damage.
- Warmer conditions and reduced rainfall will increase water requirements while also increasing evaporative losses, putting pressures on water availability for irrigation.
- A possibly more humid late summer may lead to modifying variety selection. For example, possible use of grape varieties with looser bunching.

Adaptation options

- Careful management of the soil moisture profile will help horticulture producers cope with drier conditions. Techniques that make best use of available soil moisture will be useful for responding to changing risks across most horticultural industries.
- While uncertainty continues, increasing atmospheric CO_2 concentration may provide benefits by increasing water use efficiency and allowing the same yield from less water.
- Landscaping may assist in directing heavy falls of rain into water storage areas such as dams and may be useful in limiting erosion damage.

TEMPERATURE

Expected higher temperatures may reduce the extent of land that is available for cool climate horticulture. There are maximum temperature limits for some crop varieties, which may modify land-use capability.

Chapter 6: Climate Change Impacts, Mitigation and Adaptation Options for Horticulture

Impacts

- With warmer, drier conditions, particularly in winter and spring, more rapid phenological progression is expected in horticulture crops, with earlier ripening and possible reductions in quality and yields.
- Some common cultivars of pome fruit have shown an adverse reaction to excessively warm conditions, with problems such as sunburn, water-core and lack of colour. Expected increased potential for downgrading product quality due to sunburn and other negative temperature impacts.
- Warmer temperatures may increase the frequency of bolting[27] in some vegetables, such as lettuce, parsley, spinach and silverbeet.
- Some crops are very sensitive to temperature change. For example with wine grapes, an increase in average temperature by just 2-3°C will significantly change grape quality and wine style.
- The expected continued rise in winter temperatures will affect the required chilling hours for many fruit varieties, particularly stone and pome fruit, and nuts, which have very specific winter-chilling requirements.
- With rising minimum temperatures, the incidence of frost may decrease. However, rising minimums are likely to be accompanied by greater variability, resulting in an increased risk of unexpected frost at critical times.
- Higher night temperatures can be a problem for some late-harvested varieties of fruit and grape varieties that need to be harvested and handled in the cooler temperatures.

Adaptation options

- With little scope for adapting through relocation, at least in the short term, the main adaptive strategy available to the fruit industry may be moving to varieties that have a lower chilling requirement.
- Undertake risk assessment to assess sustainability in more marginal areas (e.g. chilling requirements, increased frost risk, increased quality problems).
- Develop apple and pear cultivars (either new or existing) with lower chilling hour requirements and greater pest and disease resistance.
- Use chemical dormancy breakers to help counteract the lack of suitable chilling hours.

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[27] Bolting is the premature formation of seed heads or flowers.

- Implement localised microclimate assessment systems.
- Consider evaporative cooling as a technique for reducing sunburn, along with shade nets and some commercial kaolin[28]-based coatings that often repel pests as well. Shade nets have the added benefit of preventing hail damage.

Opportunities

- Warmer night temperatures and a reduction in frost frequency may allow planting of earlier bearing viticultural and other horticultural varieties, though the unpredictable nature of frosts remains a risk.
- Higher temperatures tend to shorten the period of growth of individual crops. The opportunity to plant earlier in the season or harvest later, may extend the growing season for crops such as lettuce, french beans and tomatoes.
- With shorter phenological cycles, double cropping may become possible, e.g. lettuce.
- Warming may allow new varieties to be grown in cooler climate production areas.

SOILS

Adopting management practices that improve the efficiency of nitrogen use can generate benefits for farm profitability, while also reducing greenhouse impacts and improving environmental sustainability.

Impacts

- Inappropriate nitrogen use for the soil type or rainfall factors, and management practices such as fertiliser placement, can lead to additional losses of nitrogen through ammonia volatilisation and nitrate leaching and run-off.
- Heavier rainfall scenarios may see changes in soil quality through increased erosion and leaching of nutrients.
- Soil compaction or waterlogging can cause anaerobic soil conditions favouring denitrification[29].

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[28] Kaolin is used in some horticulture products to repel pests in the horticulture industry. Kaolin is a non-toxic particle film that places a barrier between the pest and its host plant. The active ingredient is kaolin clay, an edible mineral long used as an anti-caking agent in processed foods and in such products as toothpaste.

[29] Denitrification is the conversion of nitrate to nitrous oxide and nitrogen gas forms, which are unavailable to plants and are lost to the atmosphere.

- Increased erosion and leaching of soil nutrients is also possible under drier summer conditions and more extreme weather events.
- Increases in soil acidification due to increased carbon dioxide concentrations are possible.

Adaptation options

- Use soil or plant testing to assess available nitrogen supply prior to fertiliser application; apply nitrogen fertiliser based on a calculation of target yield and crop nitrogen requirement over the growing season; and use split applications, rather than a single large application, to ensure maximum plant uptake and minimum nitrogen losses.
- Ensure soils are well drained to minimise waterlogging. Avoid application of fertilisers (especially nitrate) to very wet soils and before heavy rainfall events. Place fertiliser below the soil surface where possible to limit ammonia volatilisation; and time fertiliser application to minimise loss via denitrification or volatilisation (if top dressing urea, apply prior to rainfall or irrigation events). Consider foliar application when supplementary nitrogen is required.
- Ensure continuous plant cover (between growing seasons and between row crops) to avoid losses of nitrogen by leaching or denitrification. Retain prunings and stubbles after harvest.
- Aim to build organic matter in soils through pasture rotations or by adding composted material. Use gypsum to improve soil structure and help avoid anaerobic conditions. Consider the production and application of ‘compost tea’ or ‘biochar’ to improve soil quality, carbon retention and productivity.

Opportunities

- Adopting management practices that improve the efficiency of fertiliser use can generate benefits for farm profitability, while also reducing greenhouse impacts and improving environmental sustainability.
- With an increased interest in soil conditioners such as worm castings, compost tea and biochar, there may be commercial opportunities in the production of these products.

PLANT PRODUCTION CYCLES

Expected greater seasonal variability will affect quality and yields.

Chapter 6: Climate Change Impacts, Mitigation and Adaptation Options for Horticulture

Impacts

- Changing conditions are expected to affect flowering, pollination and fruit set.
- Changes in time to harvest for some crops and locations can be expected and may require revised crop scheduling and marketing responses.
- Hot dry spells and fewer chilling periods will affect plant production and yield of perennial fruit crops. Changes in the suitability of cultivars for current and future production locations are expected.
- Higher CO_2 concentrations may lead to more canopy growth and shading, leading to potential decreases in fruitfulness. Due to changing levels of CO_2, additional fertiliser applications may be required to maintain product quality, though this may have other impacts as well. The real effects of increased atmospheric CO_2 are not yet fully understood.
- It is expected the winegrape cropping calendar will change. Phenological shifts in winegrape vines may result in ripening in a warmer part of the season. With earlier harvest in a warmer climate, the temperature of the ripening period in some regions will become too high to produce balanced wines from some or maybe all grape varieties growing there now.

Adaptation options

- Make changes to varietal choices and site management:
- source new ‘longer season’ varieties; and
- undertake research on altering management practices to change bud burst, canopy density, etc.
- Change cultivars or develop new, more phenologically suitable cultivars for projected climate conditions. For example, crops with extended flowering periods such as peas and pumpkin, are generally less sensitive to heat stress, compared with those with tighter flowering times such as cauliflower and broccoli.
- Increase the use of environmental netting structures to protect crops, enhance fruit quality and improve water use efficiency.
- For many perennial crops, plan for earlier harvest times and address marketing issues such as access and timing.
- Assess the potential for new sites, considering varietal performance and chilling requirements.
- A shorter grape growing season and earlier ripening will compress harvest dates, with subsequent pressure on picking, crushing, transport and winemaking resources.

- There may be changes in wine flavours and styles for key regions that have reputations and secure markets based on their current styles.

Opportunities

- Increased atmospheric CO_2 concentrations may benefit productivity of most horticultural crops, although the extent of this benefit is not fully understood at this stage, and may depend on the availability of nitrogen and water.
- Opportunities to grow previously unsuitable grape varieties in different wine growing regions may be realised as average temperatures rise with climate change.

EXTREME EVENTS

Hail storms, heat stress, high winds, heavy rains and frosts are major climatic risks causing potential damage to horticulture crops, productivity and infrastructure.

Impacts

- Horticulture producers in flood-prone areas face an increased risk of flood damage.
- Extreme rainfall events and flooding may affect soils and crops via soil erosion, salinity and sedimentation of waterways, as well as damage to farm infrastructure.
- With the possible increase of dust storms, layers of dust over greenhouse coverings can reduce the transmission of thermal radiation.
- Some wine-growing regions in or near high-risk fire areas not only face the direct risk from an expected increase in fire events, but also the indirect damage to wine caused by smoke taint. In recent years, smoke damage has been reported many hundreds of kilometres away from the source of the fire.

Adaptation Options

- Improve medium and long-term forecasting of seasonal conditions.
- Develop strategies to hedge production risks and manage climate variability, for example, specific cultivars or protected cropping for high-value crops.
- Modify the management of the inter-row environment to take into account potential frost risk and the impacts of high rainfall events such as erosion and salinity.
- Consider canopy protection using netting in fruit orchards to increase protection from heat stress, frosts and hail.

Opportunities

- Many believe ‘controlled-environment horticulture’, a combination of greenhouse and hydroponic production systems, presents a substantial opportunity in the future, with the ability to control the climate, maximise water use efficiency and continue high-quality, high-volume production of food.
- Southern Australia already has significant greenhouse infrastructure and so is well equipped to expand controlled-environment horticulture opportunities.
- New enterprises and forms of enterprise present alternative opportunities, such as processing, energy generation and supply, and bio-sequestration.

PESTS AND DISEASES

Higher average temperatures may encourage an earlier pest presence and affect the usual windows of opportunity for control. It may also increase the number of certain pests and diseases and boost the possibility of a shift in their distribution to more southern regions. Other pests and diseases might disappear from certain areas. Many pests such as Heliothis moths, armyworms, sucking bugs and locusts respond strongly to climate signals.

Impacts

- A changing environment will modify pest and disease life-cycles, alter current relationships, and require adjustments to existing integrated pest management practices and monitoring systems. Climate change may activate ‘sleeper’ pests and pathogens and entirely new strains might develop. The range of diseases and pests such as fruit fly, which are now limited by temperature, may expand.
- Milder winters may decrease the amount of plant pathogens killed annually, and increase the spread of disease, and may present more favourable conditions for some pests. For example, the Diamondback moth is a significant pest to brassicas, but does not usually survive cold winters.
- Unpredictable frost may also restrict opportunities to destroy temperature-dependent fungi.
- Increased incidence of downy mildew, powdery mildew, botrytis, and parasitic nematodes may also occur.

- Increased hail and storm damage may leave produce vulnerable to pest and disease invasions.
- Variable climatic conditions may lead to an increase in disorders such as tip burn and blossom-end rot.
- The effect of increased temperature and CO_2 enrichment may change disease dynamics from the pest's perspective. Host-pathogen interactions have been found to change, and herbivory[30] may increase, in high CO_2 environments.
- Increased risk of spread and proliferation of soil-borne diseases as a result of more intense rainfall and wind events (coupled with warmer temperatures).

Adaptation options

- Undertake closer monitoring and more responsive management of diseases and insect pests and predators to avoid surprise outbreaks. Modify pest management practices and change timing and methods of pest management and control strategies.
- Maintain host free zones around commercial producers. For example, eliminate hawthorne and other host species for cherry slug and codling moth within 600 metres of commercial orchards.
- Promote better on-property hygiene.
- Increase the use of weather recording stations within horticultural growing regions for better predictive modelling for pests and diseases.
- Integrate more 'biocontrol' techniques to reduce increased use of pesticides. For example, Montdorensis is a predatory mite that feeds on the larvae of western flower thrips, tomato thrips, onion thrips, broad mites and tomato russet mite. Montdorensis prefers warmer, greenhouse situations.

Opportunities

- For perennial horticulture and vines, located in the cooler temperate part of southern SA, disease incidence may reduce with lower rainfall in spring.

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[30] A herbivore is an animal that eats plants, so herbivory is the act of eating plants. Herbivory can have substantial impacts on habitat health, the structure and diversity of plant and soil invertebrate communities and the productivity of economically important crops.

- Producers may be able to take advantage of the stress conditions that traditional pest species will face, by reducing population numbers and host species whenever economically feasible, and encouraging the adaptation of more desirable species.
- Pests such as rabbits may struggle with the longer periods of dry feed, higher temperatures, and expected increased effectiveness of calicivirus under drier conditions.

WEEDS

Higher temperatures could increase the likelihood of a shift in weed distribution to more southerly regions. Increased carbon dioxide levels are expected to enhance weed growth, although this will be specific to the weed species and the environment in which it grows.

Impacts

- Increased weed distribution can provide a habitat for pests and diseases. If herbicides are used in greater volumes, there is the risk of increasing resistance as well as the cost of control measures. There is the potential for increased herbicide residues on crops to exceed defined maximum limits, which may affect both domestic and export market potential.
- The increased extremes expected with climate change, such as long dry or drought periods interspersed with occasional very wet years, may worsen weed invasion because established vegetation (both native and crop) will be weakened, leaving areas for invasion. Weeds with efficient seed dispersal mechanisms, such as water or wind, may be better able to take advantage of the expected floods and dust storms.
- Disturbed habitats may be more easily colonised by pest animals and weeds, for example, after a drought.
- Drought-stressed weeds are more difficult to control with post-emergent herbicides than plants that are actively growing. For example, systemic herbicides that are translocated within the weed need active plant growth to be effective. Pre-emergent herbicides or herbicides absorbed by plant roots need soil moisture and actively growing roots to reach their target species. Drying winter and spring rainfall trends have the potential to reduce the effectiveness of pre-emergent herbicides such as triazines or atrazine.
- There is the chance that climate change will favour some native plants to the extent that they will become weeds.

Adaptation options

- Undertake closer monitoring and more responsive, integrated management of weeds. Use weed risk assessment modelling to identify current and potential weeds posing the greatest threats to horticultural crops.
- Practise integrated weed management to reduce the reliance upon herbicides for weed control and minimise risks of herbicide resistance. Options might include combining various techniques for weed control such as crop competition, cultivation in combination with strategic herbicide use and biocontrols.
- Identify weed species that host pests and diseases and maintain active control programs on these particular weed species.

Opportunities

- Increased ground cover may reduce soil erosion and increase moisture retention.
- Increased weed numbers will increase the amount of organic material available for conversion to supplement soils.

Chapter 7: Climate Change Impacts, Mitigation and Adaptation Options for Non-Agriculture Land-use

Chapter 7: Climate Change Impacts, Mitigation and Adaptation Options for Non-Agriculture Land-use

Key messages for non-agriculture land-use

7.1. Impacts

Australia's biodiversity is already subject to multiple threats, and rapid anthropogenic climate change will add to and interact with these existing stresses. Therefore, the challenges for predicting the future of Australia's terrestrial plants and animals are immense, given the insufficient understanding of multiple factors determining the distribution and dynamics of species, communities and ecosystems (Hughes, 2013).

The IPCC AR5 indicated that assessments of the impacts of climate change on the provision of ecosystem services via impacts on terrestrial and freshwater ecosystems in Australia are generally lacking. Furthermore, the concept of ecosystem-based adaptation, the role of healthy, well-functioning ecosystems in increasing the resilience of human sectors to the impacts of climate change, is relatively unexplored. Therefore, uncertainty remains, regarding the role of non-climatic drivers, including changes in atmospheric CO_2, fire management, grazing and land-use (IPCC 2014).

7.1.1. Aquatic biodiversity, river health and function

The IPCC AR5 stated that freshwater resources in far south eastern and far south west Australia will decline (*high confidence*; by 0-40% and 20-70%, respectively, for 2°C warming). This decline can be further accentuated by the unprecedented declines in flow in far south eastern Australia in the 1997–2009; higher temperatures and associated evaporation, tree re-growth following more frequent bushfires; interceptions from farm dams and reduced surface-groundwater connectivity in long dry spells (IPCC 2014).

Climate and hydrologic regimes have long been recognized as important environmental filters operating on aquatic ecosystems (Bond, Thomson, Reich, & Stein 2011). Australia's aquatic ecosystems are unique, supporting a high diversity of species and high levels of endemism (Pratchett et al. 2011). Back in 1990, (Pollard, Ingram, Harris, & Reynolds, 1990) suggested that 34% (65 of 192 species) of

Australia’s freshwater fishes were already threatened by habitat loss, invasive species or overfishing. Australia’s aquatic ecosystems are extremely vulnerable to climate change (Pratchett et al. 2011).

The IPCC AR5 (IPCC 2014) found that despite its limitations, Species Distribution Modelling (SDM) when used in combination with other biophysical and demographic models, consistently indicates future range contractions for Australia’s native fauna and flora species. Bond et al, 2011 identified a serious data gap in spatially distributed information on both current and potential future hydrologic characteristics of rivers, hampering abilities to refine predictions of ecological change in response to shifting environmental conditions. As reviewed in Hughes (2013), some changes to biodiversity and ecosystems could be incremental, while others could be abrupt and transformative. It was found that empirical research on identifying early warning signals as systems approach the tipping points at or below 2°C global warming in freshwater lakes and rangelands is emerging, but little has been done in Australia. Pratchett et al. (2011) claimed that research on the effects of climate change in aquatic ecosystems lags behind that of terrestrial ecosystems.

There is *high confidence* that inland freshwater and groundwater systems will be subject to drought, over allocation and altered timing of floods (IPCC 2014; Jenkins et al. 2011; Pratchett et al. 2011). With a lower average annual runoff, droughts may be more intense and floods less frequent by 2030. Projections out to 2050 and 2070 show more profound changes to average runoff, with the prospect that the average runoff could be similar to that experienced in the decade of the millennium drought (CSIRO 2011).

By 2030, average river flows in some regions of southern Australia will be reduced by 10%-25% due to climate change (Chiew & Prosser 2011). In the Murray-Darling Basin (MDB), a 15% reduction of inflows has been observed for a 1^{o}C rise in average temperature (Cai & Cowan 2008). On the basis of projected declines in total rainfall over the next 20–50 years (especially in the south-eastern section of the MDB), river flows in the MDB are expected to further decline by 5–15% (Van Dijk et al. 2006 cited in Pratchett et al. 2011). The unprecedented decline in river flows during the 1997-2009 ‘Millennium’ drought in south-eastern Australia resulted in a number of major environmental impacts (Chiew & Prosser 2011).

Apart from reduced rainfall, increasing atmospheric temperatures will reduce inflows to freshwater environments because of increasing evaporative water loss (Cai & Cowan 2008). These changes will negatively affect existing freshwater ecosystems, especially in the southern MDB (CSIRO 2008b; Dunlop & Brown 2008). Climate change will also affect the distributions and abundance of invasive species, with flow on effects to native communities (O'Donnell et al. 2012). While reviewing a number of major threats to the freshwater habitats and fishes in the MDB, Pratchett et al. (2011) found that regulation of water flows will have significant effects across a wide range of species and major impacts on the functioning and resilience of freshwater habitats.

In some studies, complete loss of climatically suitable habitat is projected for some species within a few decades, and therefore increased risk of local and, perhaps, global extinction (*medium confidence*) (IPCC 2014). Specifically, extreme heat and reduced water availability, will be significant drivers of future population losses and will increase the risk of local species extinctions (e.g. McKechnie & Wolf, 2010; cited in IPCC 2014). For example, recent drought-related mortality has been observed for amphibians in south east Australia (Mac Nally et al. 2009). Bond and his colleagues (Bond et al. 2011) examined the impacts of three climate-change scenarios on 43 freshwater fish species (including three native species) in south-eastern Australia. The study predicted potentially severe impacts of climate change for some species, including potential losses of populations from entire catchments. As reviewed by Pratchett et al. (2011), major impacts of climate change on aquatic ecosystems in Australia include declines in biodiversity and productivity changes in taxonomic composition and community dynamics and shifts in the geographic ranges, distribution and abundance of species.

In the lowland reaches of the Murray–Darling river system, declines in surface water availability and riverine flow, have already been shown to affect native fishes (Pratchett et al. 2011). Reductions in the quantity and quality of river flows in the MDB will have severe impacts on breeding habitat for birds (Pittock & Finlayson 2011). It is anticipated that current and substantial losses of freshwater biodiversity will be exacerbated in the MDB. Additional declines in water quantity and quality and modified riverine thermal regimes will have an adverse impact on ecological processes what support freshwater biodiversity (Pittock & Finlayson 2011).

According to CSIRO (2008a), many of the major wetlands in the MDB are threatened and climate change is expected to decrease flood frequency for major wetlands, further threatening waterbirds. Major ecosystem changes are also taking place. For example, tens of thousands of hectares of floodplain forests are in transition to more terrestrial ecosystems (NRC 2009).

Apart from changes in water quality due to the reduced inflows, increased temperatures and soil erosion from more frequent extreme rainfall events, other authors[31] reviewed in Pittock & Finlayson

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[31] Bowling and Baker 1996; Davis and Koop 2006; Hall et al. 2006; Baldwin and Fraser 2009; Kingsford et al. 2011; Jolly et al. 2001; Bailey et al. 2006; Phillips and Muller 2006

(2011) found other impacts from climate change to river health such as acidification, increasing salinity and changes in ecological character, toxic blooms and sulfidic sediments in the wetlands.

Other non-climatic factors including ongoing competition for water from agriculture and urban areas will exacerbate these threats (Hughes 2013). However, in many freshwater systems, direct climate impacts are difficult to detect above the strong signal of over allocation, pollution, sedimentation, exotic invasions and natural climate variability (Jenkins et al. 2011).

7.1.2. Groundwater

Climate change is a threat to global water resources that has not had adequate investigation in the past. The issues of scale and consistency are still of concern in impact studies because most studies are of a local scale and no two studies have used an identical methodology (Crosbie et al. 2013).

Climate change will affect groundwater through changes in recharge rates and the relationship between surface waters and aquifers. Dryland diffuse recharge in southern Australia is projected to decrease because of the decline in precipitation (Crosbie et al. 2013). Over the longer term, projected changes in rainfall due to climate change are expected to create risks for water availability (IPCC 2014).

The Sustainable Yields Assessment Project for the Murray–Darling Basin (CSIRO, 2008a) identified that the current and probable future levels of groundwater extraction will have a greater impact on inland aquifer systems than a likely reduction in recharge from rainfall and river systems due to climate change.

Sustainable development of groundwater in the context of climate change remains challenging and contentious. In general, governance systems, resource policies, innovation incentives, data collection and information provision need to relate to a wide range of scales, with different adaptive management approaches in rural and urban environments (Green et al. 2011). The author suggested that under conditions of climate change, the typical emergency response of abstracting groundwater resources of in times of surface-water shortages during droughts, especially in the areas with prolonged period and high frequency of droughts, is likely to be unsustainable.

7.1.3. Terrestrial biodiversity and native vegetation management (including native grasslands)

Nearly 50% of the world's known mammal extinctions have occurred in Australia in the last 200 years (Johnson 2006). Twenty-eight threatened species from the Riverina Bioregion are listed in the schedules of the *Threatened Species Act* (NSW NPWS 2001). Twelve of these are listed as endangered, 15 are listed as vulnerable and one species *Tetratheca pilosa ssp. pilosa*, is considered extinct in the bioregion.

Australia's Biodiversity Conservation Strategy (2010–30) listed: habitat loss, degradation and fragmentation, invasive species; unsustainable use of natural resources, changes to aquatic environments and flows, changing fire regimes; and climate change as major stresses on biodiversity. As many Australian species are adapted to highly variable climates, they are likely to have some capacity to cope with expected changes in climate. However, their resilience may have been eroded by those stresses. Climate change represents an additional stress, one that will add to, and interact with, existing pressures (Hughes 2011; Steffen, 2009).

Impacts are likely to accrue in two non-mutually exclusive ways. Changes in rainfall and temperature could alter the distribution of pests and weeds and create new opportunities for the establishment of some species (Hughes 2012). Some change may be incremental. For example, gradual increases in mean temperatures or rainfall could result in gradual changes in ecotonal boundaries between ecosystems, such as those observed between rainforests and savannahs over the past few decades in northern Australia, thought to be mediated via changes in rainfall and fire (Fensham et al. 2003 cited in Hughes 2013). But other changes could be abrupt and transformative.

The Riverina region

Climate change impacts on ecosystems in the Riverina region are found in *Annex 7.2: Climate change Impacts on land and natural ecosystems in Riverina region* (DECCW, 2010). Key changes in this region are summarized below:

- Higher temperatures and drier conditions are likely to cause major changes in ecosystems. Climate change is likely to increase stress on fragmented and degraded ecosystems and on threatened species.

- Riverine, floodplain and wetland ecosystems are highly vulnerable. Wetland-dependent colonial birds are likely to be reduced in numbers. The decline of wetland ecosystems in the Riverina is likely to affect ecosystem services.
- Productivity and nutrient cycling are likely to be affected.
- Climate change is likely to alter the size and frequency of plague locust outbreaks.
- More mobile habitat generalists, including some pests and weeds, are likely to persist while species that are sedentary or specialists or have complex life cycles are at greatest risk of decline.
- Fire and drought are likely to reduce seed and nectar production and affect granivores and nectarivores, including pollinators.
- Change is likely even in biological communities that are adapted to aridity.

In 2008, the NSW government undertook an assessment of regional impacts of climate change, which served as a first step in providing information for government planning and decision-making. Assessments of impacts on each of the ecosystems in the South Western NSW (largely corresponds to the Riverina NSW State Plan region) are provided in *Annex 7.1: Assessment of Impacts on Biodiversity in the South Western Region of New South Wales.*. This assessment contains detailed information covering forests, woodlands, grasslands and wetland ecosystems. Table 16 below gives a summary of impacts by ecosystem in the south western/Riverina region of NSW.

Ecosystem	Community	Main reasons
Grassy woodlands	south western region	Vulnerable to increasing levels of human disturbance and increased frequency of storms and fire.
Dry sclerophyll forest	south western region	Patchy declines in viability and changes in community structure are likely.
Semi-arid woodlands	south western region	Major changes in structure and composition are predicted with reduction in water availability compounding the situation.
Semi-arid woodlands	western peneplain and inland rocky hill woodlands	Increasing aridity will play a major role in determining changes in species composition and structure.
	semi-arid sand plains	Expected to experience continual decline in geographic extent and condition.
	sand plain mallee woodlands	Loss of grassy understorey and associated fauna is predicted to occur with decreased seasonal rainfall.
	dune mallee woodlands	Hotter conditions are likely to amplify the effects of grazing.
	Riverine sandhill woodlands	Unlikely to persist as they are currently known with severe degradation expected.
	subtropical semi-arid woodlands	May be somewhat resilient to changing climatic conditions.
Grasslands	south western region	A large proportion of the species composition and community structure is likely to be affected.
Forested wetlands	southern-sourced rivers	Likely to suffer from moisture stress while responses to climate change will differ among wetland types.
Freshwater wetlands	south western region	Impacts dependent on factors such as changes to river regulation levels and evaporation rates.
Saline wetlands		Some possible changes in geographic extent.
Arid shrublands	south western region	Marked changes in species composition and community structure are expected.

Table 16: Summary of impacts by ecosystem: South Western regions (OEH NSW 2011)

7.1.4. Soil health and carbon storage capacity

Climate change is projected to lead to variations in precipitation and temperature, both of which will affect soil water content. Changes in soil water content could modify soil structure through the physical process of shrink-swell (IPCC, 2007). In general, the primary impacts of climate change in each region will be to change the current natural relationship between soil hydrology, soil water balance, soil biodegrader activity and vegetation growth. In addition, changes in soils can leave it more vulnerable to damage by erosion (NSW, 2011).

According to the former NSW Department of Environment, Climate Change and Water (DECCW, 2010), in the Riverina reduced vegetation cover, caused by a reversal of seasonal rainfall patterns and overall drier conditions, is likely to leave many soils vulnerable to increased erosion. This risk is likely to be exacerbated by increased summer rain with more intense storms. Vulnerable areas include the alluvial plains of the Riverina and susceptible gullies on the south-west slopes and plains. Acidification hazards are likely to be reduced for the slopes. Salinity hazards are likely to change but the risk cannot yet be quantified (DECCW, 2010).

Key climate change impacts on land (including soil) in the Riverina Region include the following (DECCW, 2010) (Information specific for the Riverina is found in *Annex 7.2: Climate change Impacts on land and natural ecosystems in Riverina region*):

- poorer conditions for plant growth are very likely to increase erosion hazards
- sheet and rill erosion are very likely to increase
- gully erosion is likely to become worse on the slopes and plains
- wind erosion is likely to increase
- sodic surface soils are particularly at risk
- acidification hazards are likely to ease
- potential changes in salinity are difficult to predict

7.1.5 Social community networks and interactions and indigenous peoples

According to the IPCC AR5 (*medium confidence*), Indigenous peoples in Australia have higher than average exposure to climate change due to a heavy reliance on climate-sensitive primary industries and strong social connections to the natural environment, and face particular constraints to adaptation (IPCC, 2014). Social status and representation, health, infrastructure and economic issues, and engagement with natural resource industries could potentially constrain adaptation and are only partly offset by intrinsic adaptive capacity (*high confidence*).

Increased temperatures and changes to rainfall and run-off are likely to affect Aboriginal cultural heritage values in the Riverina. The region includes a variety of sites, places and objects that are culturally significant to Aboriginal people, including burial sites, earth mounds, hearths and scarred trees. Higher temperatures, decreased rainfall, decreased run-off and increased erosion are likely to result in the loss of culturally significant trees. Flooding and erosion are likely to result in damage to burial sites (DECCW 2010).

Bardsley & Wiseman (2012) found that in the Anangu Pitjantjatjara Yankunytjatjara lands in South Australia, the Indigenous communities in many ways already have considerable capacities to manage the challenging present and uncertain future. However, current and past knowledge of systems is going to be insufficient to learn to adapt. It is recommended that traditional ecological knowledge will need to be integrated with other knowledge, including new scientific knowledge, to facilitate future planning and management. In order to embark on effective adaptation to climate change impacts, Anangu communities will need to own the issue of climate change, make decisions about the best ways forward for themselves, and be supported to make autonomous adaptation to change an integral part of local management. To enable this, integrated assessments of how socio-ecological vulnerability will be influenced, not only by climate change, but also other socio-ecological risks including constraints such as rising energy, fuel and food costs should be carried out. Other factors such as access to information, education, wealth and the broader social capital of networks are also fundamental. If undertaken effectively, climate change adaptation can offer a new opportunity to deal with some of the risks of social marginalisation by creating institutions and frameworks for natural resource management (NRM) to support livelihoods of many people within remote, Indigenous communities. These lessons may be useful and applicable for the Riverina region.

Little adaptation of Indigenous communities to climate change is apparent to date. Plans and policies that are imposed on Indigenous communities can constrain their adaptive capacity if they are developed and imposed in a top-down manner (Ellemor, 2005; Petheram et al. 2010; Veland et al. 2010; Langton et al, 2012). At the same time, the preferable approach of participatory development of adaptation strategies is difficult to achieve and may be made more difficult by the uncertainties and stress introduced by climate change (Leonard et al. 2013b; Nursey-Bray et al. 2013). Extensive land ownership in northern and inland Australia and land management traditions mean that Indigenous people are well situated to provide greenhouse gas abatement and carbon sequestration services that may also support their livelihood aspirations and increase their adaptive capacity (Whitehead et al, 2009; Heckbert et al. 2012).

Griggs et al. (2014) consider that the Indigenous communities of Australia hold valuable knowledge that has not generally been used effectively or equitably in environmental decision making. Indigenous people have not been empowered to participate in decision making processes due, in part, to lack of mutual understanding of western science and Indigenous knowledge systems and lack of capacity to capture, manage and present traditional knowledge in Indigenous communities. In a project supported by the Victorian Centre of Climate Change Adaptation Research, a community mapping process was used to collect Yorta Yorta knowledge and combine it in a geographical information system (GIS) with conventional environmental and other data. In this way, Indigenous knowledge could be used to producing integrated maps and analyses to support decision-making in the Barmah-Millewa region.

Putting all this data in the same GIS framework and exploring it with simple data layering provided significant and powerful new insights about the region for the Yorta Yorta. Two examples for further development were analysis of regional climate variability and a study to determine cultural flows. For the Yorta Yorta, having an archive of their knowledge and access to other regional data means that they are much better informed and confident in participating in policy and regional management discussions.

7.2. Mitigation and Adaptation

Mitigation

Ironically, strategies to mitigate the effects of climate change may exacerbate some impacts on freshwater systems. Tree plantations established to sequester CO_2 emissions will reduce runoff from forested catchments and have the potential to further reduce stream flows (Macinnis-Ng & Eamus, 2009)

An 8,500 hectare section of native forest in western NSW has been deemed eligible under the Carbon Farming Initiative (CFI) by the federal government[32]. According to a CFI case study in NSW, unless planted on unproductive land, establishing an environmental plantings project will probably require the removal of some land from other types of farm production, such as growing crops or grazing

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[32] Thesustainabilityreport.com.au, (2014). NSW leasehold approved for Carbon Farming Initiative | The Sustainability Report - Part 4594. [online] Available at: http://www.thesustainabilityreport.com.au/nsw-leasehold-approved-for-carbon-farming-initiative/4594/ [Accessed 23 Jun. 2014].

livestock. A decision to permanently remove some land from normal farm production will require careful consideration (DAFF 2013).

In Australia, high rates of habitat loss and species extinctions since European settlement, together with additional stresses including erosion, changes in nutrients and fire regimes, mining, invasive species, grazing and salinity, increase vulnerability to rapid climate change and provide challenges for both autonomous and managed adaptation in Australia (Steffen, 2009).

Hughes (2013) suggested three main options available to species to adapt to the rapidly changing environment:

1. To shift their distribution and thus evade the change by moving elsewhere to more suitable conditions. However, most estimates of range shifts in species are dominant by terrestrial species in the Northern Hemisphere and it remains unclear if species in Australia are able to disperse that rapidly (Hughes 2013). Steffen (2009) found that the distributional shifts to more climatically suitable areas for many species in Australia are limited.
2. To undergo genetic change.
3. To stay put and adapt *in situ:* Anticipated rates of climate change, together with fragmentation of remaining habitat and limited migration options in many regions (Steffen 2009) will limit in situ adaptive capacity.

Management approach

The overall effects of climate change on the MDB will largely depend on other activities being undertaken to reduce water use (Pratchett et al. 2011). The authors highlighted both non-spatial and spatial aquatic ecosystems management options in the context of climate change. Four types of spatial management, promoting adaptation of aquatic ecosystems and species to climate change, were identified and suggested to use in combination with and support of policy, regulations and other non-spatial management measures. The non-spatial management approaches include (i) regulation for sustainable harvest of species; (ii) reduced by-catch; (iii) quarantine arrangements to prevent the arrival of invasive species; (iv) environmental water allocations, and (v) strategies to reduce water extraction from streams and wetlands for agricultural and urban uses. It is particularly important for freshwater ecosystems to aim for a complementary management approach, considering requirements of species with life histories that involve moving among ecosystems. Under the context of climate change, to achieve this management approach, apart from the knowledge of the complementary nature of particular ecosystems and appropriate conservation actions in each, it will also require some understanding of how each of the ecosystems, and the biological connections between them, might change. It is also important to address the impacts on aquatic ecosystems from afar, by increasing the level of understanding of the influence of climate change on land use and runoff (Pratchett et al. 2011).

Past adaptation and sectoral policy measures in the MDB have not adequately considered the whole system, reducing river inflows, and further representing maladaptation (Barnett & O'Neill 2010).

Adaptation for biodiversity and catchment management

Climate change is likely to profoundly affect the region's catchments and is likely to impact on all aspects of NRM (Campbell 2008). For example, the 2012 Victorian Catchment Condition and Management Report (VCMC 2012) mentions climate variability and change as the most challenging of current pressures on Victorian land and water resources. The most severe physical impacts of climate change on catchments were anticipated to be reduced runoff to waterways of 5-45% by 2030 and 50% by 2070, changes in the distribution and frequency of extreme weather events and the increases in the extent and frequency of droughts. The report also highlighted the following:

- Risks to small and fragmented populations of native flora and fauna and those at limits of their range
- Intensifying competition between consumptive and environmental uses of scarce water resources

While the Australian climate has always been extremely variable, anthropogenic climate change and exacerbated climate variability will significantly affect overall catchment and waterway health. More severe and long-lived impacts may result from the occurrence of multiple extreme weather events within short periods. For example, bushfires followed by heavy rain and flooding, as experienced between 2009 and 2010-11, in many parts of Victoria can lead to greater impacts than for either event alone. In 2006, bushfires at Mt Lubra in the Grampians destroyed large tracts of the catchment, but the critical impact on water resources was avoided until the major floods of January 2011 washed large amounts of ash and debris into Lake Bellfield: the principal source of town water for Horsham in the Wimmera. Water quality in the region is still adversely impacted in the Wimmera Mallee region.

Adaptation is challenging because it requires making complex decisions under conditions of uncertainty beyond 'typical' realms of uncertainty in policy-making, and it challenges the status-quo and the value-basis of our decisions. Acknowledging uncertainty and finding ways for making robust decisions that can allow for these uncertainties are important strategies for building the adaptive capacity of the NRM sector (Wallis, Ison & Samson 2013).

While uncertainty regarding the projected impacts of climate change is a challenge for natural resource managers and may inhibit adaptation action (Bardsley & Sweeney 2010; Cross, McCarthy, Garfin, Gori, & Enquist 2013) it is argued that it would be a mistake to postpone adaptive actions until impacts are better understood (Fankhauser Smith & Tol 1999).

Consequently, effectively integrating climate change projections into regional NRM planning processes is challenging (Bardsley & Sweeney 2010) as it is often not possible to apply standard probability-based approaches to water infrastructure planning or other decisions (Clarke et al. 2014). Research on risk within NRM systems has often been reductionist in nature – attempting to better understand sectoral impacts or components of systems by analysing their respective parts (Bardsley & Rogers 2010). Climate change can render traditional decision-making processes based on the predict-then-act approach impossible, because adaptation involves not only one but many different policy problems, a range of actors, and diverse decision-contexts, geographic scales, and time scales (Dessai, Hulme, Lempert et al. 2009; Lempert et al. 2004)

Concepts such as Integrated Catchment Management (ICM) and Integrated Water Resources Management (IWRM) appear to embrace a more holistic approach. Many NRM bodies continue to view adaptation as 'fitting into' an existing situation, relying on linear, one-way concepts of designing and implementing policies and practices that lead to a situation (or an organisation) being better adapted (Ison et al. 2011). In the UK, (Collins et al. 2007) concluded that catchment management remains largely based on a relatively narrow evidence base where catchment modelling science is used to inform policy but there is often a need to consider a wider range of factors.

Biodiversity management also generally still operates within a static framing of biodiversity and landscapes (Dunlop et al. 2012) but we know that species and ecosystems will be more dynamic in future.

(Dunlop et al. 2012) put forward three propositions for managing biodiversity under a changing climate:

- Conservation strategies need to accommodate large amounts of ecological change and the likelihood of significant climate change–induced loss in biodiversity.

- Strategies need to remain relevant and feasible under a range of possible future trajectories of ecological change.
- Strategies should seek to conserve the multiple different dimensions of biodiversity that are experienced and valued by society.

Climate change may make maintaining vegetation community types in their current locations increasingly difficult. Moving toward objectives and actions that accommodate large amounts of change, including potential losses and that remain relevant and feasible under a range of possible future trajectories of change might provide a better basis for conserving the multiple different values inherent in our natural resources.

Such concepts might be expanded within an NRM context (Wallis et al. 2013). For example, Matthews & Wickel, (2009), suggested that a 'natural history approach' involving a shift from 'impacts thinking' guided by climate models from which uncertainty can never be eliminated, towards 'adaptation thinking' that acknowledges dynamic processes is a better model for adaptation action. Such a shift could lead to successfully understanding the qualities that enable ecosystems to adapt and be resilient to climate impacts and how NRM institutions can facilitate these processes. This requires development of capacity at the institutional level to anticipate and detect climate change and to implement responses.

Regional adaptation efforts should therefore focus on empowering of stakeholders in a way that increases resilience of the landscape system that involves people and natural systems. Transfer of information needs to be supported by acceptance and ownership of the concept of change. This can be used as a platform to apply tools such as participatory GIS modelling environmental risk analysis, and participatory action learning (Bardsley & Sweeney 2010).

For example, in the Goulburn-Broken catchment in NE Victoria, the current state of the system is a consequence of changes in resource use. Crossing of identified biophysical, economic and social thresholds operating at different scales, may result in irreversible changes in goods and services generated by the region. It was suggested that managing in a way that supports resilience is constrained by current governance but that maintaining the region in its current state may not be either feasible or desirable. Transformation could be achieved through:

- clear evidence that transformation is needed
- acceptance that change is necessary

- leadership, strong social networks and trust
- a negotiation process
- strategic disinvestment in infrastructure, subsidies, or incentives that maintain the current regime
- support for those who will lose from the transformation
- political ability to implement structural changes
- strategic new investments in social and human capital, infrastructure, and technology

More knowledge is therefore often not the answer. Measham, (2009) reflected that stakeholders commonly thought knowledge about managing complex problems like salinity will never be sufficient but learning can occur through the process of gathering knowledge. Building shared understanding through knowledge gathering can support more effective adaptation because it often requires making complex and often unpopular decisions that, if they are not co-owned and supported by all key stakeholders, may not get implemented.

Limited attention has been given to these psycho-social aspects of adaptation in NRM planning. Beliefs and perceptions that underpin the acceptability of particular measures can often be the deciding factor (Dunlop et al. 2013). It is important to better understand individual and collective perceptions, as well as the individual psychological and organisational processes that lead to the acceptance or rejection of new ideas (Wallis et al. 2013)

Generally, only a few academic studies of adaptation contain information relevant and directly useable for natural resource managers at an operational level (Peterson et al. 2011). Adaptation is possibly best considered as a pathway that starts by implementing small-scale, ‘no and low regrets’ measures to respond to known vulnerabilities, which can be scaled up at a later stage (Bardsley & Rogers, 2010). However, there is a risk that in focusing too much on the ‘low hanging fruit’ of well-supported adaptation issues and incremental adaptation, more innovative adaptation measures may never be fully explored, leaving organisations with only applying simple solutions to increasingly complex problems.

Adaptation will require participatory planning and decision-making processes that enable organisational and social learning. However, it can be difficult to implement the experimentation in management practices required because institutional or cultural constraints “force projects back into the mainstream” (Wallis et al. 2013). Existing hierarchies of power and the need to devise and adhere to preconceived project management milestones, as well as existing cultural norms (politeness, preference for expected behaviours, role understanding, ideas regarding what constitutes knowledge) and pragmatic issues, such as tight timeframes and working with the willing and those available can impact on the capacity to experiment and observe the outcomes of different approaches (Ostrom 2005).

Social learning, based on joint exploration of ideas, power sharing and experimentation fundamentally clashes, philosophically, with the technology transfer paradigm. For example, in a study evaluating soil management and soil health conducted by the Murray Catchment Management Authority, it was found that, despite a perceived ‘participatory turn’ in agricultural extension and NRM, traditional practices, grounded in the paradigm of technology transfer, continue to prevail (Allan & Wilson 2009).

Consequently, social learning or participatory processes require a different type of institutional environment and strong leadership and commitment to overcome situations where hierarchies of power may limit the agency of staff, where time allocations to participate are insufficient or where expectations about outcomes differ. These constraints do not constitute a good reason for avoiding participatory learning approaches, but should be carefully considered when designing projects that deviate from organisational and cultural norms (Allan & Wilson 2009)

Research – policy – practice collaboration

Collaboration between researchers, policy makers and NRM managers is a key to effective adaptation (Wallis et al. 2013). For example, a collaborative adaptation planning framework specifically designed for NRM, Adaptation for Conservation Targets, was used in the south west of the United States to facilitate collaborative climate change adaptation planning. It provided a workshop-based process for identifying adaptation actions with regard to conservation features such as species, whole ecosystems, or ecological functions (Cross et al. 2013).

Workshops promoting two-way learning between scientists and forestry resource managers that included highly interactive components such as the joint production of a short course video embedded in facilitated discussions about adaptation options was another successful partnership model (Peterson et al. 2011)

In a survey of NRM managers in Victoria, (Wallis et al, 2013) found that the prolonged drought, from 1997-2009 was a focus for concern about climate change. This drought had many adverse impacts, including a reduction in water resource allocation in the Goulburn-Murray Irrigation District in northern Victoria, and flow-on effects in the form of large-scale bushfires (in 2002/03, 2006/07 and 2009) and reduced breeding of fauna. There were some reported beneficial aspects, with the drought reducing weed cover and improving quality of native habitat. The drought also caused water tables to fall and reduced salinity.

(Wallis et al. 2013) identified two potential areas of focus for NRM organisations to support adaptation:

- fostering innovation in regional governance
- supporting regional facilitators

In preparing Regional Catchment Strategies, NRM organisations need to consider future climate impacts and the possibility of carbon markets to support re-vegetation. Funding for NRM planning and development of information and capacity provides the opportunity for NRM bodies to show initiative and incorporate adaptation thinking into their planning and operational processes and to extend this into the wider community for impacted sectors such as health, community services or emergency management. Natural resource management bodies are often custodians of accurate, reliable and trustworthy information, but do not always make use of it in informing wider decisions in their catchment areas. Acting as facilitators or 'knowledge brokers' would provide a stronger role and support for NRM bodies. While adaptation is not a simple 'knowledge deficit' problem, there is a need to translate understandings from one community of expertise to another. In the academic literature, this concept is called 'boundary work' (Clark et al. 2011). In a similar role, Regional Landcare Facilitators (RLF) have emerged as key actors, by connecting stakeholders and acting as 'conduits' for information (Clear Horizon 2012).

Organisations and individuals in the NRM sector deal with climate change adaptation in different ways: as a discrete and separate threat to be identified and managed, as a systemic issue that is connected to all other management issues, or not at all. Climate change does affect all aspects of NRM and adaptation is best considered a cross-cutting, systemic issue. By applying an adaptation lens across all issues, current measures of performance (eg. biodiversity targets) could continue, with investment prioritised to activities that address key risks to biodiversity assets.

Finally, NRM bodies will need to act on the best available information. There is a growing body of documented adaptation measures that use strategies such as supporting autonomous adaptation, enhancing organisational adaptive capacity, applying adaptive management techniques, and adopting principles of adaptive governance. Considering adaptation as an ongoing process of learning and organisational change, and documenting and sharing progress and setbacks across the sector will be an important overall strategy for addressing climate change in NRM bodies.

Annex 7.1: Assessment of Impacts on Biodiversity in the South Western Region of New South Wales.

Information for this Annex is extracted for South Western Region[33] from the Technical Report "*New South Wales Climate Impact Profile - Technical Report: Potential impacts of climate change on biodiversity*", by NSW Department of Environment and Climate Change with the support of the NSW Department of Water and Energy (OEH NSW, 2011).

Annex 7.1.1. Grassy woodlands – south western region

The impacts of climate change are likely to be displayed much sooner and to a much greater extent in the grassy woodlands of the south western region than in those of the north western region, because the former has lower overall annual moisture availability and is projected to have substantially less precipitation over spring, autumn and winter months. (The north west woodlands should gain some reprieve because of an expected large increase in summer rainfall.) The south western community is already less resilient owing to greater levels of fragmentation over longer periods of time, resulting in more depauperate seedbanks and ensuing low levels of recruitment. This will be compounded by the effects of climate change, with significant changes in species composition and decreasing condition of the community, as well as eventual severe decreases in geographic extent. These effects may not necessarily be evident by 2050, but they will develop much faster than those in the grassy woodlands of the north western panel region. The distribution of this ecosystem is currently limited to the west by low rainfall levels, implying a potential shift to the east and south given the ability to do so (if not isolated because of fragmentation). The lower resilience levels of this community in the south western region leave the community vulnerable to increasing levels of human disturbance as well as natural disturbances such as increased frequency and intensity of storms and fire, with the potential to push species, and perhaps entire communities, over the edge. Degradation of the condition of these ecosystems will also lower their value as refugia for western species during harder times, with negative impacts on more western species.

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[33] Covering most of the large floodplains of the Murray, Murrumbidgee and Lachlan valleys. The south western region largely corresponds to the Riverina NSW State Plan region.

Chapter 7: Climate Change Impacts, Mitigation and Adaptation Options for Non-Agriculture Land-use

Major impacts

Major **decrease** in winter rainfall and change in seasonality:

- changes in species composition—fewer winter-growing species:
    - increase in abundance of annual species and decrease in perennial species
    - increase in abundance of the more arid-adapted species
    - fewer winter weeds, e.g. ryegrass *(Lolium spp.)* and capeweed *(Arctotheca calendula)*
- changes in agriculture from cropping to grazing:
    - increase in abundance of non-palatable species through overgrazing and summer grazing patterns
    - increased competition between native herbivores and stock
    - decreased eucalypt recruitment; die-off of canopy species
    - direct impacts on arboreal fauna habitat and food resources
- changes in flowering regime:
    - Earlier flowering has potential to favour timing of swift parrot migration – change from winter-flowering to autumn
- potential for increased dieback:
    - increased patch deaths from insect attack on eucalypts because of increased stress from lack of moisture
    - increased levels of mistletoe infestation on stressed trees

Increased temperatures:

- invasion of areas by species currently limited by lower temperatures, e.g. Indian myna (*Acridotheres tristis*).

The change in seasonality of moisture availability will have wide-ranging impacts throughout the ecosystem, with impacts on plant species composition and resulting impacts on resource availability for fauna species. Summer-growing plants will be favoured over winter-growing plants because of increased summer rainfall, with corresponding reductions in the abundance of winter species, including winter grasses, which make up a large proportion of the ground cover, as well as forbs and herbs, which are adapted to the current winter rainfall regime. Species that are tolerant of drier conditions will be advantaged over those that depend on higher moisture levels. These changes in plant species composition will result in decreased productivity of these woodlands, with implications for resource availability for fauna.

Decreased winter rainfall will lower the viability of cropping in the region, with a potential change in agricultural management from cropping to grazing and the prospect of increased degradation of these ecosystems because of elevated grazing levels. An increase in summer rainfall and the resulting increased grazing levels when plants are flowering will disadvantage palatable species that recruit from seasonal seed production, including eucalypts, whereas the less palatable species will proliferate. At present, grazing regimes allow for only sporadic recruitment of canopy species in these ecosystems; an increased level of grazing will result in decreased tree recruitment and may ultimately result in the die-off of the overstorey, with resulting impacts on all faunas in the system. There will be a direct impact on arboreal species such as squirrel gliders (*Petaurus norfolcensis*), because of a decrease in nesting habitat and food resource availability. This will result in the reduction of these productive (though degraded) ecosystems, first into highly modified, poor, grassy woodlands with an abundance of weedy species, and eventually into secondary grasslands of poor condition and low productivity. Grazing-tolerant perennials will potentially be favoured in the east of the region (areas of higher moisture availability). With increased stocking levels, transport and dispersal potential will be elevated for weeds such as spiny burrgrass (*Cenchrus incertus*). An invasive environmental weed, this species has the potential to displace native species already present. With a lack of grazing pressure, these ecosystems may be regenerated to woodlands with dry-tolerant species, though they may not necessarily be species-rich.

Changes in rainfall and temperature will influence the flowering of eucalypts, with the potential for asynchrony with the breeding patterns of fauna that utilise these resources—in particular, nomadic species such as the regent honeyeater and swift parrot. Of particular impact will be changes in the timing of flowering of currently winter-flowering eucalypts, which provide essential resources to many fauna species during periods of low resource availability.

Because of fuel reduction, high levels of habitat fragmentation and small remnant sizes, fire is not as much of an issue in the areas affected by grazing, but it could have an impact in reserves, which are larger areas without the ongoing effects of heavy grazing. This will be contingent upon potential increases in rates of macropod grazing in these larger remnants, and on whether these increases will serve to reduce fuel loads in these woodlands. Any changes in fire regime will have an effect on hollow formation, a process that provides an important source of habitat in woodland ecosystems, as will changes in storm intensity and frequency.

Species that are currently limited by cold temperatures will be able to expand their range with increased minimum temperatures. The Indian myna is a predominantly subtropical species and as such will be suited to warmer temperatures. Although the species prefers wetter climates, it has been able to expand its range during drought periods and so will not necessarily be limited by lower rainfall levels. An increase in abundance of this highly competitive species will have serious implications for native hollow-nesting species such as parrots and arboreal mammals. This will be more of an issue in smaller remnants than larger ones.

Annex 7.1.2. Dry sclerophyll forest (grassy and shrub–grass subformations combined)

The geographical extent of these forests is unlikely to decrease to a large degree in the next 40 years, but will potentially experience range retractions post-2050. Already fairly fragmented because of their topographical location and through clearing for pastoral development, the dry sclerophyll forests of the south western region—namely the Western Slopes and Upper Riverina dry sclerophyll forests—will not experience nearly as much decline as the grassy woodlands, but small-scale extinctions of the community may occur. This ecosystem is highly likely to experience patchy, in situ declines in viability as climatic conditions change. Changes to community structure and function and to species composition resulting from decreases in annual rainfall and changes in the seasonality of moisture availability are likely to cause an overall decline in species diversity.

Major impacts

Increased summer rainfall and much lower winter rainfall (change in seasonality):

- overall decrease in moisture availability:
    - level of resources will decline, leading to decreased productivity
    - there may be problems of latent degradation in this community
    - species that are more dry-tolerant will be favoured, as will summer-flowering plants
    - decreased shrubbiness of understorey may cause a change in habitat resources for fauna species
    - may favour noisy miners *(Manorina melanocephala)* and brown treecreepers *(Climacteris picumnus)*
- change in seasonality of resource availability:
    - effects on timing of migration of nomadic fauna

This ecosystem occupies high topographic levels throughout the landscape of the South Western region and is therefore under less pressure from agriculture than are other ecosystems such as the grassy woodlands. However, the dry sclerophyll forests of the south western region are much more highly fragmented than those of the north western region and therefore have a reduced dispersal capacity. The higher topography also brings added pressure of lower moisture availability, a factor that will be compounded by reduced annual rainfall, resulting in a decline in productivity throughout the community and reduced importance of these areas as refuge for arid/semi-arid species.

The community is at risk from a lack of recognition of degradation. The effects of disturbance are latent throughout the ecosystem: e.g. conspicuous features of the community include stringybarks, which produce copious amounts of seed, providing food resources for species such as gang-gang cockatoos (*Callocephalon fimbriatum*). Low-intensity fire can decrease seed production of brown stringybark (*Eucalyptus baxteri*) for up to 10 years, with flow-on effects of reduced resource availability to fauna species. So while the community can look healthy and intact, with the trees appearing to be in good physical shape, the community's ecological functions can, in fact, be disrupted.

Dry sclerophyll forests are stepping stones in the landscape with respect to the movement of nomadic fauna species—especially those with north–south migrations.

Mugga ironbark (*Eucalyptus sideroxylon*) is known for its profuse flowering, which is relied upon by nomadic/migratory nectivorous species such as the swift parrot (*Lathamus discolor*). This ironbark is likely to be adversely affected by lower moisture availability, as well as by changes in seasonality. The potential also exists for synchronised failed flowering events in this ecosystem over different regions of NSW with changing seasonality (e.g. in the mugga forest in the south-west and the swamp mahogany on the coast), with possible decreases in the abundance of mobile nectivores [e.g. swift parrots and little red flying-foxes (*Pteropus scapulatus*)] and eventual patch deaths of trees. Extended bottlenecks of resource availability are also likely to affect sedentary nectivores/insectivores, with generalist, dry-tolerant (semi-arid) fauna species favoured.

Levels of resources within these forests are likely to decline with higher levels of moisture stress, resulting in decreased productivity (lower levels of biomass) throughout the ecosystem. Decreased water availability will result in the loss of some *Acacia* species because of moisture stress, with consequential changes to understorey structure and function and fauna habitat. The opening of shrubby forests will serve to increase suitable habitat for the noisy miner, a competitive native honeyeater species. Other species, such as the brown treecreeper, prefer heterogeneous ground habitat and as such may also benefit from an opening of the understorey, provided that the current impacts of fragmentation are not too great. In general, however, the more aggressive, generalist species such as wattlebirds and friarbirds will be favoured over species that utilise more specialised resources.

The higher levels of fragmentation in these forests mean that fire is not as much of an issue as in the forests in the north western region. Moreover, in the south western region, fire management by private landholders has reduced the levels of biomass accumulation, and hazard reduction burns are more common.

Annex 7.1.3. Semi-arid woodlands (grassy subformation)

Climate change is likely to exacerbate the current degradation and decline of this ecosystem in the south western region, especially during times of high stress. The inland floodplain (black box) woodlands are already under significant levels of moisture stress, with little water availability from local rain, stream flow and farm runoff and increasing pressure of groundwater extraction and water harvesting. These changes have already contributed to the extinction of southern bell frog (*Litoria raniformis*) populations in the region (e.g. in barren box swamp). The regeneration of black box and riverine plain (boree) woodlands is also suppressed by the current grazing regimes, with these impacts predicted to continue or increase with lower levels of annual rainfall throughout the region. Major changes in these ecosystems are predicted, as upper level floodplain woodlands are likely to be lost entirely without active management to provide environmental water flows into their depressions. Most of the overall structure and composition of these woodlands is predicted to change with the modelled changes in climate, with large reductions in water availability compounding the already degraded state of these woodlands. Large losses of biodiversity and geographic extent are expected.

Major impacts

Reduced water availability (overall decrease in annual rainfall):

- increased pressure for water harvesting for agricultural and urban use
- general decrease in ecosystem condition and species diversity:
    - reduced germination rates and fewer flowering events
    - decreased abundance of winter-growing plants
    - change in species composition towards shrubbier, summer-growing, better arid-adapted plant species
    - decreased resources for fauna
- increased requirement for drought fodder in boree woodlands:
    - continued or increased grazing suppression of regeneration
    - decreased food resources for painted honeyeaters and superb parrots *(Polytelis swainsonii)*.

The regeneration opportunities of the floodplain woodlands have been significantly decreased by existing water stress caused by reduced local rainfall levels and decreases in river flows as a result of water extraction for agricultural purposes. Water table levels have also been lowered because of increased groundwater extraction. As moisture availability in this region decreases with the effects of climate change, the pressures on water harvesting are only likely to increase, further increasing moisture stress on these woodlands and resulting in considerable reductions in ecosystem condition and species diversity. The Darling River may have flooding potential with increased rainfall to the north, and woodlands along this river may therefore not be under as much pressure as those along the southern rivers, provided that management ensures that sufficient environmental water flows reach these communities.

A general decrease in species diversity is predicted, with decreased levels of winter rainfall reducing the amounts of resources available overall throughout the ecosystem. This is likely to be manifested through reduced spring germination rates of palatable annual plants, as well as lowered levels of foliar nutrients and decreased tree flowering events. Perennial forbs are also winter growing and will be greatly affected by the lack of rain, as will winter-growing weeds [e.g. rye grass *(Lolium spp.)* and barley grass *(Hordeum leporinum)*]. Geophytic species such as lilies, irises and orchids (e.g. *Pterostylis* species) will be heavily disadvantaged, requiring winter rains for shooting; although they possess underground storage organs there is a limit to the length of time they can survive without rain. Summer-growing grasses and weeds [e.g. African boxthorn *(Lycium ferocissimum)*] may be advantaged in wetter years. A general shift in species composition towards opportunistic, less-palatable species (e.g. saltbush, cotton bush) is expected, with these plants able to tolerate tougher growing conditions, including drier winters. All of these changes in vegetation will have wide-ranging consequences on resource availability for fauna.

Structurally, black box *(Eucalyptus largiflorens)* and river red gum *(Eucalyptus camaldulensis)* populations are currently senescing at an increased rate, showing signs of dieback from increased water stress and resultant insect and mistletoe infestations, as well as being affected by salinity issues, firewood collection and potential problems with acid-sulfate soils. It is highly likely that these woodlands, under additional climate change stresses, will undergo major structural changes due to a loss of canopy trees, with ensuing loss of habitat resources for hollow-nesting species (e.g. bats, gliders, cockatoos, owls) and loss of food resources for nectivores and insectivores (e.g. swift parrot, superb parrot, painted honeyeater). These changes in habitat will also have major consequences for fauna species composition in this community, with a predicted shift towards more arid-adapted species [e.g. the saltbush morethia skink *(Morethia adelaidensis)* would be favoured over the south eastern morethia skink *(Morethia boulengeri)*] or species preferring more open habitats (e.g. *Mormopterus* species bats over *Vespadelus* species).

Moisture-dependent fauna such as frogs will be significantly affected, with species such as burrowing frogs e.g. the giant banjo frog, (*Limnodynastes interioris)* requiring significant rainfall events for breeding to occur. Some burrowing frog species are tolerant to dry periods and are opportunistic breeders; these are less likely to be sensitive to the shift to summer rainfall. However, other species, such as the painted burrowing frog *(Neobatrachus sudelli)*, are winter breeders and may experience reduced breeding opportunities and undergo local extinctions. Although rates of metamorphosis are faster in summer because of higher temperatures, high evaporation rates may reduce the hydroperiods of rain-fed wetlands to an extent where mass mortalities of tadpoles are more common. Reductions in flooding frequency as a result of flow regulation have already contributed to reduced diversity of frog communities and local extinctions of flooding-dependent species such as the southern bell frog and the green tree frog *(Litoria caerulea)*. The predicted decreases in flooding frequency owing to the effects of climate change are likely to compound these declines.

A number of threatened flora species [e.g. slender Darling pea (*Swainsona murrayana*)] are supported by these woodlands in the south estern region. These species are likely to be significantly disadvantaged by decreases in resource abundance throughout the community and by increased pressure from grazing. Other non-threatened species, such as ruby saltbush (*Enchylaena tomentosa*), will also be negatively affected. Relying on perching birds for seed dispersal, this species is likely to decline with predicted changes in bird species composition owing to overall reductions in resource abundance. The boree woodlands are likely to experience an increase in pressure for drought fodder for livestock with reductions in rainfall; this will reduce the abundance of food resources available to threatened fauna species such as painted honeyeaters and superb parrots.

These semi-arid woodlands may gradually shift their range to the east, potentially replacing grasslands. The riverine plain (boree) woodlands are likely to contract from the west because of increased levels of moisture stress, but they are restricted in geographic range by edaphic factors. Decreases in the geographic extent of this system may be offset by increases in the distribution of shrubby semi-arid woodlands; the winter grasses disadvantaged by changing seasonality will be replaced by arid-adapted species such as dillon bush *(Nitraria billardierei)*, cotton bush *(Maireana aphylla)* and copperburrs *(Sclerolaena spp.)*. These woodlands are eventually expected to be replaced by highly degraded, species-poor chenopod shrublands, with shrubbier areas and loss of ground debris detrimental to specialist species such as the bush stone-curlew *(Burhinus grallarius)*. Remnant sites are likely to remain, perhaps more so in the far east of the geographic range.

Annex 7.1.4. Semi-arid woodlands (shrubby subformation)

This formation was broken down into its component vegetation classes as ecological boundaries for discussion, as it was decided that the landscape, vegetation, and fauna were too disparate to allow for accurate comparison across the entire formation. Different classes were anticipated to experience different impacts and were therefore discussed at the class level, with some not separated by regional boundaries, as the impacts were predicted to be primarily the same between the North Western and South Western regions. Desert woodlands have been discussed with the mulga shrublands as part of the *Arid shrublands* (*Acacia* subformation). An overview of each class considered within this formation is provided below, followed by a synthesis of the major impacts across the entire formation and a subsequent breakdown of the details that these impacts will have on each of the classes.

The **western peneplain and inland rocky hill woodlands** have suffered heavy clearing in the past for agricultural purposes. The combination of overgrazing and partial land clearing for cropping has already led to increased incidences of erosion and scalding throughout this community, as well as the proliferation of unpalatable shrubs ('woody weeds'). In addition to this, these woodlands are currently being further degraded by continuing drought conditions, with loss of tree species occurring throughout the region. Increasing aridity, especially in the southern parts of the distribution of these woodlands, will play a major role in both species composition and structure, with decreased moisture levels predicted to open the canopy, providing less shelter, with potential conversion to shrublands in some areas. Ultimately, however, the severity of predicted climate change impacts will depend upon changes in the interplay between fire regime and changing land use practices, which are unable to be predicted at this time. These communities are defined primarily by edaphic factors, with the woodlands inhabiting these areas more likely to undergo in situ changes in response to climate change, rather than shifts in distribution.

The **semi-arid sand plains (belah–rosewood) woodlands** are unlikely to persist as they are currently known, existing primarily in large remnants of senescent, poor-quality woodland. This ecosystem is already heavily degraded by the impacts of overgrazing and extended drought conditions, and with recruitment and regeneration heavily suppressed, the effects of climate change—notably decreased winter rainfall—will lead to further losses of productivity. This community is unlikely to shift in geographic range owing to edaphic restrictions on its constituent vegetation; it is expected to experience continual decline in geographic extent and in general condition—perhaps not to extinction level within the 2050 time frame, but potentially beyond it. The persistence of these woodlands depends entirely on the removal of grazing to give them the potential to remain in remnants.

The **sand plain mallee woodlands** are currently highly fragmented and degraded because of extensive land clearing and grazing. Loss of the grassy understorey and associated fauna is predicted to occur with decreased winter rainfall, with a consequential trend towards lower productivity and extensive simplification of the ecosystem. This will also result in changes in fire regime, with changes in structure and function evident throughout the ecosystem and resulting small losses in geographical extent.

The **dune mallee woodlands** are already heavily affected by grazing throughout their distribution, with ongoing grazing by goats affecting the structure and composition of this ecosystem by the suppression of mallee regeneration and the increased prevalence of unpalatable plants. Hotter, drier conditions and increased fire risk are likely to amplify these sources of disturbance; additional reductions in productivity and simplification of overall diversity will cause changes to a large proportion of the structure and composition of this ecosystem, with ensuing losses of geographic extent predicted to occur. High levels of fragmentation of remaining woodlands are likely to exacerbate these impacts. Increases in pressure from agricultural practices, similar to those in other mallee communities, are likely to be experienced, with changes in land use practices (in conjunction with changes in fire regime) having the potential to influence the eventual condition of these woodlands.

The **riverine sandhill woodlands** have experienced previous heavy clearing to supply wood for farm infrastructure and for wheat cropping areas. Regeneration opportunities for this community are highly limited because of the effects of current grazing by domestic livestock and rabbits. The increased drought severity due to climate change and continued effects of grazing are likely to exacerbate the decline in quality of these woodlands, with conditions unlikely to allow the community to regenerate. As a consequence, these ecosystems are unlikely to persist as they are currently known; instead, they are likely to be replaced by species-poor, weedy grasslands, or alternatively reduced to nothing more than the sandhills they currently occupy. A great deal of intervention, including the removal of grazing, is required for the continued survival of this community by allowing potential recruitment in the overstorey given the opportunity for resource (water) availability.

The **subtropical semi-arid woodlands** in the North Western region are unlikely to experience the severity of climate-change related impacts that will be suffered by other classes within this formation, as they are at the southern extremity of their distribution in this region and may actually persist where the northern woodlands retract. Because of the infertility of the soils, increased summer rainfall is unlikely to influence grazing practices in a major way. Because the woodlands are already well adapted to fire, it is doubtful whether increases in fire frequency will have any major impacts on their species composition or structure.

The naturally restricted range of the **north west alluvial sand woodlands** has been greatly reduced by land clearing, most of it occurring relatively recently. Predicted changes in climate will serve to increase pressure on this ecosystem in the future, with higher pressure from agriculture and river regulation having direct impacts on vegetation structure and species composition. Some changes in structure and composition are expected with the projected effects of climate change. However, human land management of these woodlands (notably grazing and water regulation/dam expansion) is the most important factor influencing the potential increase or decrease in condition of this community.

Major impacts – formation-wide

Change in moisture availability and seasonality (increased summer rainfall; decreased winter rainfall), with an overall increase in annual rainfall in northern regions and an overall slight decrease in annual rainfall in southern regions:

- potential for summer-growing species to be favoured over winter-growing species
- change in agricultural pressure, with increased pressure from grazing (most areas) and cropping (some areas):
    - change in understorey structure (increased shrubbiness)
    - problems with woody weeds
- combined with higher temperatures, the moisture changes will increase the severity of drought (unsure of frequency):
    - lack of recruitment of species requiring good rainfall
- increased productivity in northern areas
- decreased productivity in southern areas
- increased fire frequency and intensity (depending on grazing practices)
- decreased photosynthetic capability of lichens in soil crusts as a result of increased temperatures:
    - reduced nitrogen fixation
- wetter summers, increasing the frequency of locust plagues in grassy areas

Higher temperatures:

- herpetofauna potentially favoured
- physiological limits may be reached (e.g. for cockatoos, or for flowering and seeding of eucalypts)
- potential for frost-sensitive species to increase in abundance
- increase as refugia for more northerly distributed species
- survivorship of species that germinate after summer rain may be reduced because of higher summer temperatures

Increased CO_2 levels:

- C4 are grasses quite sensitive to grazing; also threatened herb species.

Annex 7.1.5. Semi-arid sand plain woodlands (north western and south western regions)

The Belah–Rosewood woodlands have already been heavily degraded by the impact of overgrazing and extended drought conditions. Both of these sources of disturbance have prevented sufficient regeneration of this community, which is unlikely to shift in geographic range owing to the edaphic restrictions on its constituent vegetation. This ecosystem is unlikely to persist as it is currently known, existing primarily in large remnants of senescent, poor-quality woodland. Die-offs of mature rosewood (*Alectryon oleifolius*) shrubs have already been observed, and with the recruitment of both this and belah (*Casuarina pauper*) suppressed by grazing by sheep and goats, these woodlands are likely to be replaced by chenopod shrublands containing unpalatable plants such as cannonball burr (*Dissocarpus paradoxus*), cassias (*Senna* spp.) and hop-bushes (*Dodonaea* spp.), and other hardy shrubs. This will likely decrease the abundance of ground litter, with predicted increases in cryptogamic ground cover in its place. This is a disadvantage to threatened fauna species, such as the narrow-banded shovel-nosed snake (*Simoselaps fasciolatus*) and yellow-tailed plains slider (*Lerista xanthura*), that rely on litter for cover and food. These changes in the structure and species composition of this community will have marked impacts on the resident fauna utilising the resources of these woodlands. Species such as pink cockatoos nest in hollows in belah, whereas white-browed treecreepers (*Climacteris affinis*) are virtually restricted to this community in the west. Decreases in winter rainfall due to climate change are likely to cause further decreases in productivity of the ground cover. The reduced abundance of winter-growing grasses and forbs will reduce the availability of resources for herbivorous and granivorous species and will affect insect abundance and species composition. A loss of termites would have marked impacts on insectivorous fauna, as well as on decomposition and nutrient cycling throughout the ecosystem. As such, it seems that the effects of climate change will serve to exacerbate the current decline in condition of the belah–rosewood woodlands.

Annex 7.1.6. Sand plain mallee woodlands

Decreased winter rainfall will disadvantage winter-growing plants, including grasses such as speargrasses (*Aristida* spp.), forbs and subshrubs, as well as weeds [e.g. Ward's weed (*Carrichtera annua*)]. The more resilient perennial species are likely to be favoured, with species such as saltbushes (*Rhagodia* spp.*)*, daisy-bushes (*Olearia* spp.), cassias and cannonball burr likely to replace annuals, creating major changes in the species composition and structure of these woodlands. This will serve to decrease the species diversity of the community, with increased shrubbiness and decreased abundance of grasses in the understorey. This sparse ground cover is also less likely to carry fire, which would generally stimulate the emergence of a more diverse understorey. Some introduced species will be advantaged by a change in seasonality, with increased summer rainfall favouring some such as vervain (*Salvia verbenaca*), whereas others (e.g. medics, *Medicago* spp.) will be disadvantaged by the decrease in winter rainfall.

With this community already highly fragmented and degraded because of extensive landclearing and grazing, a trend towards lower productivity is predicted due to the loss of the grassy understorey and associated fauna, thus greatly simplifying the ecosystem. Tree and shrub cover will remain, but the changes in ground cover will have major impacts on reptile diversity because of changes in soil structure and resource availability. These latter factors will decrease the prevalence of termites, which are a major food resource for herpetofauna, including sand monitors (*Varanus gouldii*), geckos (e.g. *Diplodactylus* spp.) and skinks (e.g. *Ctenotus* spp., *Lerista* spp.), and other ground insectivores (and their associated predators). They will also affect decomposition and nutrient cycling throughout the ecosystem.

The endangered malleefowl will also be negatively affected by climate change, with the effects of lower levels of winter rainfall and moisture content on recruitment persisting for years beyond any good rainfall years. Certain moisture levels are required for the decomposition of leaf litter in mounds created by this species for heat production and egg incubation. Egg development may also be affected by increased ambient temperatures, with birds potentially spending less time tending their mounds because of the higher temperatures.

Annex 7.1.7. Dune mallee woodlands

Hotter and drier conditions throughout the distribution of these spinifex-dominated woodlands, as well as increased storm frequency in summer, will increase fire risk throughout this community. This is likely to result in increased frequency of wildfires or hazard reduction burns, the latter being common land management tools for preventing large wildfires. In years of good rainfall, early successional species should be favoured by the increased frequency of fires. However, species requiring fairly long periods between fires will be at a significant disadvantage. This covers a large range of threatened fauna, including bats (e.g. greater long-eared bat), birds [e.g. southern scrub-robin (*Drymodes brunneopygia*), black-eared miner (*Manorina melanotis*), malleefowl], reptiles [e.g. jewelled gecko (*Strophurus elderi*), mallee blue- tongue lizard (*Cyclodomorphus melanops elongates*)] and mammals [e.g. southern ningaui (*Ningaui yvonnae*)]. This community is generally quite resilient to fire, as it is already a major driver of ecosystem processes and contains quite a few threatened plant species that require fire to regenerate [e.g. yellow swainson-pea (*Swainsona pyrophila*), harrow wattle (*Acacia acanthoclada*)]. Although short inter-fire intervals may advantage fire-ephemeral species such as spinifex (*Triodia* spp.), toothed raspwort (*Haloragis odontocarpa*), rough halgania (*Halgania cyanea*) and native poplar (*Codonocarpus cotinifolius*), they may cause extensive death of mallees, which regenerate from lignotubers, and cypress trees, which take a long time to accumulate their seed banks. The lignotubers, or underground storage organs, of mallee species are likely to be under increased stress from lower moisture levels. This, coupled with a number of fires in quick succession, will mean that these trees will have a decreased ability to regenerate, given insufficient time to restock their resources. Fire frequency will thus affect the structure and composition of this community, with species adapted to early succession favoured over secondary and longer successional species.

Decreases in overall annual rainfall throughout the areas occupied by these woodlands will see a loss of productivity in this community, with decreased ground cover of ephemeral tussock grasses and herbs, less flowering and seeding of spinifex, eucalypts and shrubs, and replacement of winter-breeding annuals with hardier, summer-growing perennial plants. This will have flow-on effects on resource availability for fauna species. The reduction in the abundance of flowering events will reduce nectar availability to insects and nectivorous bird species such as purple lorikeets (*Glossopsitta porphyrocephala*), and yellow-plumed (*Lichenostomus ornatus*), white-fronted (*Phylidonyris albifrons*) and grey-fronted (*Lichenostomus plumulus*) honeyeaters.

Increases in pressure from agricultural practices, similar to those pressures on other mallee communities, are likely to be experienced, with changes in land use practices (in conjunction with changes in fire regime) having the potential to influence the eventual condition of these woodlands. Much of the mallee is grazed by goats, sheep and rabbits, affecting the flora by the preferential removal of palatable grasses and seedlings of perennial plants, encouraging the growth of less-palatable species. The changes elicited by climate change will serve to compound the effects of these sources of disturbance.

Annex 7.1.8. Riverine sandhill woodlands

This community has experienced previous heavy clearing to supply wood for farm infrastructure and for wheat cropping areas. This clearing, combined with the effects of current grazing by domestic livestock and rabbits, means that regeneration opportunities for this community are highly limited. Regeneration of white cypress pine (*Callitris glaucophylla*) in the overstorey generally occurs during wet years in association with La Niñã periods, the occurrence of which have been limited recently. The effects of grazing, as well as competition with Mediterranean weeds such as barley grass and Paterson’s curse, have meant that this ecosystem has become highly degraded. It has therefore been listed as an Endangered Ecological Community. Few resources remain for native species. In the past such resources would have represented quality habitat for woodlands birds such as the speckled warblers (*Pyrrholaemus saggitatus*), but they have now been invaded and taken over by unpalatable, weedy species such as African boxthorn.

The effects of climate change are likely to exacerbate the decline in quality of these woodlands, particularly if the interval between La Niñã periods increases (although there is a large degree of uncertainty surrounding El Nino-Southern Oscillation patterns), along with the severity of drought, because of increases in temperature. Continued grazing is unlikely to allow the community to regenerate. As a consequence, these ecosystems are unlikely to persist as they are currently known. Instead, they are likely to be replaced by species-poor, weedy grasslands, or alternatively reduced to nothing more than the sandhills the woodlands currently occupy. Decreased vegetative cover is likely to result in the erosion of these sandhills, which may fill nearby depressions. Examples of these woodlands used to occur around the Broken Hill district, but because of timber removal and subsequent grazing of the sites no evidence of them remains on the ground. These sandhills also have high cultural heritage value, historically having been used by Indigenous people as burial sites. This community is already severely degraded, and the effects of climate change will further intensify its degradation. With maximum intervention it is likely to persist only in small areas.

Annex 7.1.9. Grasslands

Stocking rates on the riverine plain grasslands in the south western panel region have already begun to decline over the past 15 years owing to increased periods of drought. Further decreases in rainfall predicted to occur with climate change will increase pressure from agriculture on these grasslands until pastoral practices become entirely unviable throughout the region. Major changes are predicted for this ecosystem, with particularly dire consequences because of the ecosystem's high degree of endemism and biodiversity. A large proportion of the species composition and structure of this community is likely to be affected, with its entire geographic extent predicted to be affected past the point of no return.

Major impacts

Decreased moisture levels:

- increased pressure from grazing practices; areas of high species diversity are more likely to be targeted:
  - decrease in abundance of palatable species
  - species-diverse grasslands on lighter soils take longer to regenerate than those on heavier soils, even after de-stocking
- loss of lichen-dominant biological soil crusts:
  - increased soil erosion and changes in soil chemistry
- change in plant species composition and structure:
  - decrease in species diversity, with loss of winter-reproducing species
  - increased abundance of the more arid-adapted, shrubby species and summer weeds
  - loss of endemic plant species
- changes in resource availability for fauna species:
  - changes in fauna species composition
  - effects on plains-wanderer (*Pedionomus torquatus*).

Increased levels of moisture stress will result in increased concentration of grazing patterns on areas of grasslands with high species diversity, owing to their higher content of palatable plants. These higher diversity grasslands are supported by lighter soils and take longer to regenerate after disturbance than the species-poor grasslands on heavier soils, owing to higher rates of erosion after disturbance. The structural nature of these soils also makes them more susceptible to invasion by weeds and rabbits, with lighter soils much easier to colonise and burrow in.

Extended periods of drought and higher grazing pressure on these grasslands will lead to decreased soil cover by forbs and lichen crusts, serving to exacerbate wind erosion and loss of topsoil and resulting in increased rates of scalding, in particular on lighter soils. The loss of well-developed lichen crusts through intense grazing will also lead to decreased levels of nitrogen fixation in the soil, with unknown but potentially dramatic effects on soil food webs, further degrading these communities. The loss of biological soil crusts will also potentially destabilise the soil and increase rates of erosion, as well as affecting the habitat of burrowing fauna such as dunnarts, lizards, frogs and termites.

The species composition of the grasslands of the south western region are predicted to be altered significantly by reduced annual rainfall (in particular, the large reduction in winter rainfall). A large proportion of the plant species present throughout this system are winter-reproducing, including grasses [e.g. wallaby grasses (*Austrodanthonia* spp.)] and annual forb species, which are likely to be lost altogether, with ensuing decreases in species diversity throughout the community. Winter weeds (e.g. ryegrass), will also be disadvantaged by decreased levels of winter rainfall. A decline in the abundance of geophytic species such as lilies, irises and orchids (e.g. *Pterostylis* spp.) has already been observed, with drought conditions removing the winter rains required for shooting. Although these species possess underground storage organs, there is a limit to the length of time for which they can survive without rain. A drastic simplification in plant species diversity is likely to be observed in these grasslands, with anticipated invasion by the more woody, arid-adapted species such as boree and saltbush, as well as by unpalatable chenopods (e.g. dillon bush) and weeds such as Paterson’s curse, crowfoot (*Erodium* spp.) and thistles, with resulting disastrous losses of endemic grassland plant species. This ecosystem has many more endemic plant species, such as peas (e.g. *Swainsona* spp.) and daisies (e.g. *Brachyscome and Leptorhynchos* spp.) than comparable areas of other ecosystems in the western half of the State. It therefore has a lot more to lose.

Increased levels of moisture stress, changes in plant species composition and increased grazing pressure will also have major flow-on effects on resource availability for fauna species. Extended drought periods will result in fewer seeds and fruits being produced, as well as reduced numbers of invertebrates. These ecosystems support a range of endemic grassland fauna species, such as curl snakes (*Suta suta*), which are likely to be adversely affected by losses in productivity, with the potential exclusion of these species and others such as Australian pipits (*Anthus australis*) and brown song larks (*Cincloramphus cruralis*) from these grasslands. Seasonal habitat users such as quail are also unlikely to make use of these ecosystems with changes in productivity and weather conditions. Instead, species such as banded lapwings (*Vanellus tricolor*), inland dotterels (*Peltohyas australis*) and Australian pratincoles (*Stiltia isabella*) may be favoured by drier, hotter weather conditions and a sparser vegetation structure.

The endangered plains-wanderer is currently under severe pressure of extinction from agriculture and feral predators, and the effects of climate change will compound the threatening processes this bird already faces. A grassland specialist, this species inhabits species-diverse grasslands on lighter soils. The habitat suitable for this species is predicted to decline because of increased grazing pressure under the predicted impacts of climate change. This species is already heavily affected by continuing drought, with breeding events occurring in response to rainfall. During favourable conditions, breeding can be year-round, but in the last six or seven years only one or two years have been wet enough to facilitate recruitment. Consequently, numbers have decreased by 90% in this time. Plains-wanderers require vegetation cover to a height of 30 cm (but no higher) to allow for both protection and predator detection. Increased grazing pressure, changes in grasslands species composition, and predicted increases in storm frequency and severity may change the habitat structure significantly enough to reduce the amount of suitable habitat available to this highly threatened species.

Annex 7.1.10. Forested wetlands

The forested wetlands were divided up by the origin of their water sources (northern-fed rivers or southern/centrally-sourced rivers), rather than by north western and south western panel regions, as the effect of climate change on river flow regimes was deemed to be the most important factor influencing the persistence and potential changes in the inland riverine forests.

Moisture stress from the combined effects of river regulation and drought, coupled with increasing rates of salinity, have seen the loss of more large, old-growth trees in this ecosystem in the last 10 years than in any other ecosystem in NSW. Without serious intervention to provide these forests with sufficient environmental flows, there is little chance of regeneration. The effects of climate change will exacerbate the stresses already in place in this system, particularly as a reduction in rainfall throughout the southern parts of the region increases the need for water by irrigators. Significant effects on forest structure and composition are predicted, with considerable changes likely to occur throughout the ecosystem, and forests expected to retract right to the water's edge. A continuing exponential decline in geographic extent and condition is projected from the extent of decline that has occurred in the past 10 years, with significant losses of this ecosystem by 2050. These forests may persist in remnants, especially in places with slightly higher rainfall. The predicted scale of biodiversity loss will be much bigger in forests fed by central- and southern-sourced rivers than in the north. The south western area has much larger stands of forest under more intense pressure of degradation by human land-use practices such as forestry, irrigation and grazing. The northern-fed rivers have the potential to be advantaged by increased water flows; this will ultimately depend on levels of river regulation.

Major impacts

Changes in rainfall patterns:

- increased rainfall in northern-fed rivers; decreased rainfall in central- and southern-sourced rivers:
    - increased potential for water regulation for agriculture in northern systems; the net result will be to decrease water flow through rivers,
    - large amount of water required to restore subsoil water levels,
    - increased water stress in all rivers, with alteration of hydrological regimes due to regulation (in turn affecting the reproduction and recruitment of ephemeral species); loss of resources for fauna; changes in the structure and composition of vegetation to the

better dryness-adapted species; increased rates of erosion; and potential for saline groundwater issues,

- increase in extent of acid-sulfate soils,
- degradation of the cultural heritage values of river red-gum communities,

Increased temperatures:

- potential to exceed the physiological thermal limits of fauna and flora,
- combined with decreased flows, will lead to increased occurrence of algal blooms,
- decreased numbers of feral pigs and carp.

Annex 7.1.11. Central- and southern-sourced rivers (Murray, Murrumbidgee, Lachlan)

Already highly regulated and stressed through lack of moisture, these forests will be further affected by the increased moisture stress and temperatures expected with climate change. Southern-sourced rivers will experience much less rainfall than centrally-sourced rivers, which in turn will experience much less rainfall than the northern-fed river systems. The forests supplied by these rivers will not experience the lack of water flows due to increased water regulation that will be experienced in the north; instead, they will experience reduced water flows due to reduced rainfall levels—in particular, reduced spring floods. The predicted scale of biodiversity loss will be much bigger in forests fed by the central- and southern-sourced rivers than in the north, with much larger stands of forest under more intense pressure of degradation by human land use practices such as forestry, irrigation, and grazing and resulting increases in salinity. The worst affected areas will be the Lower Murray and the Lowbidgee floodplain.

These forests are likely to experience the same effects of moisture stress as in the forests fed by northern-sourced rivers, including loss of riparian vegetation and the resulting decreases in resource availability for fauna. There are large numbers of already threatened fauna that rely on resources supplied by river red gum habitat, including the regent (*Polytelis anthopeplis*) and superb parrots, squirrel gliders, large-footed myotis (*Myotis macropus*) and powerful and barking owls. Reductions in flow will reduce the numbers of breeding events of colonial nesting birds, thus reducing the numbers of rookeries constructed by species such as egrets, herons, ibis and spoonbills and reducing the availability of habitat for other taxonomic groups such as fish, crayfish, and frogs, including the endangered southern bell frog. Populations of fish will decline as water quality decreases, with flow-on effects on food resource availability for birds. Loss of nocturnal insectivores such as bats and other insectivorous fauna such as birds because of habitat loss will result in increased potential for mosquito populations to flourish, especially with more pooling of water due to lack of significant flow in rivers; this will result in increased potential for the spread of diseases such as Murray River encephalitis and Ross River fever.

Increased pooling and temperatures may lead to higher tadpole mortality rates, with consequential effects on recruitment to amphibian populations. Responses may differ among different wetland types, with river red gum forests responding better to summer flows than freshwater (black box–lignum) wetlands. However, studies comparing primary productivities on river red gum wetlands flooded at different times of year found that spring flooding produced higher diversity and productivity than summer flooding (Robertson et al. 2001). Amphibian populations—particularly those of the southern bell frog—are at high risk of extinction owing to their high level of sensitivity to reduced frequency of flooding and extended dry periods. Local extinctions of southern bell frog populations have already been recorded as a result of reduced flooding frequency. The change in seasonality of water availability because of climate change will have an enormous impact on these wetlands.

The threatened flora in this community also requires flooding, and decreases in the intensity, duration and frequency of flooding events will have negative impacts on the growing conditions of species such as the small scurf-pea (*Cullen parvum*) and river swamp wallaby-grass (*Amphibromus fluitans*), as well as decreasing their capacity for dispersal and recruitment. Species that require regular flooding will be replaced by the more arid-adapted species and salt-tolerant plants, such as chenopods and samphire (*Halosarcia* spp.), as well as by introduced weeds and grasses, further reducing the quality of this habitat.

Decreased river flows have already resulted in higher prevalence of acid-sulfate soils throughout these river systems, most notably in tributaries of the Murray River. Once exposed to air, these soils release sulfuric acid into the ground water and surface water. Acidic water can dramatically alter the ecological character of wetlands and estuaries, cause fish kills, reduce farm productivity, release heavy metals from contaminated sediments, pollute water, affect human and animal health, and damage infrastructure such as bridges.

Annex 7.1.12. Freshwater wetlands

The impacts of climate change on freshwater wetlands in the South Western panel region are similar to those in the North Western region and will be heavily influenced by any changes in evaporation rates affecting the duration of flooding events. The wetlands in this system, however, are likely to experience much lower levels of rainfall than those in the north. The wetlands in this region are already reliant on human intervention to receive water flows because of the high level of regulation of the river systems; with further predicted decreases in rainfall, the opportunities for environmental flows throughout this system will be significantly reduced. For ecosystems that are already struggling to survive, the effects of climate change are likely to have significant negative impacts.

The impacts of predicted climate change on these freshwater wetlands will depend ultimately on a number of factors, including changes to river regulation levels and potential changes in evaporation rates. Wetlands located in this region will experience much less rainfall and are likely to be reduced in condition considerably. Changes in most of the species composition and structure are predicted to occur, with the loss of the entire geographic extent possible. The wetlands of the South Western panel region were deemed to be at a higher level of risk than those in the North Western panel region.

Increased moisture stress during winter, spring and autumn:

- all wetlands likely to have reduced periods of inundation
- changes in seasonality of flooding events
- lower water volumes entering system, thus decreasing the hydroperiod of the wetlands
- increased pressures from agriculture because of decreased viability in other areas, possibly leading to the draining of wetlands and the cropping of highly fertile lake beds
- changes in the species composition of vegetation (especially decreased lignum survival):
    - impacts on resource availability for fauna (especially fauna relying on lignum)
    - decreased frequency of large breeding events, with population dynamics issues for affected species
    - loss of water-dependent species (e.g. non-burrowing frogs and fish and invertebrates)
    - change to the better dryness-adapted plant species
- fewer recreational visitors; human impact and disturbance will be reduced, but the system will be degraded anyway.

There are three key issues that need to be emphasised in relation to wetland hydrology: seasonality, frequency and hydroperiod. A shift in the timing of inundation of seasonally flooded and ephemeral wetlands is likely to significantly alter recruitment success of waterbirds and amphibians, particularly within black box–lignum systems. These water bodies traditionally flood in early spring through a combination of snow melt and tributary inflows higher in the Murray-Darling Basin. During the environmental flooding of 2007–08, wetlands were flooded in late December (summer) for operational reasons. Although the initial vegetation response and frog breeding was very good, plant condition declined rapidly and by March was poor, with subsequent declines in water quality. Despite initially promising calling responses from resident frogs, including the southern bell frog, actual recruitment was much lower than had been observed during spring flooding in previous years. No bird breeding was observed; had it occurred it is unlikely to have been completed because of declining productivity. This indicates that spring flooding is required for successful recruitment events in these wetlands in the south western region, and that changes in flooding regimes due to climate change will have significant negative impacts.

A dramatic reduction in the volume of winter rain will exacerbate the already heavily degraded areas of freshwater wetlands in the south western region. Even wetlands still supplied with water by irrigation are likely to be significantly affected owing to predicted changes in the irrigation patterns. The viability of agriculture is likely to decrease throughout the region, with less annual rainfall and increased temperatures, and competition for water resources will thus be markedly increased. The reduced frequency of flooding events and overall moisture availability in these wetlands will lead to a considerable overall decrease in the abundance of lignum, one of the most important sources of fauna habitat in the dry interior. The loss of lignum habitat will affect waterbirds in particular, with threatened species such as Australasian bitterns (*Botaurus poiciloptilus*), painted snipe (*Rostratula benghalensis*), brolgas (*Grus rubicundus*) and freckled ducks (*Stictonetta naevosa*) losing important breeding sites. The loss of winter rain for spring breeding events, combined with the loss of breeding sites, will see marked effects on the population dynamics of many wetland birds. The frequency of large breeding events will decrease, and the length of time between these events may actually exceed the life spans of some species, resulting in the loss of entire generations of birds. Declines in numbers of species such as egrets, spoonbills, ibis and crakes have already been observed since the 1980s, and the impacts of climate change are likely to intensify this decline. There have already been significant reductions in the flooding frequency of black box-lignum wetlands as a result of flow regulation. These pose a serious threat to many amphibians, which typically have short life spans. The southern bell frog appears to be particularly sensitive to altered flooding frequency and increased dry periods (e.g. the formerly robust populations that occurred at Avalon swamp within the Lowbidgee system went locally extinct because the wetland was dry for a 5-month period in 2006).

As noted in the north western region discussion, reductions in the volume of water entering the floodplain, coupled with increased evaporation rates and infiltration because of a lack of subsurface water, are likely to reduce wetland hydroperiods. Although many amphibians are relatively plastic in terms of development times, individuals that undergo rapid metamorphosis are typically smaller and may have reduced fitness/survivorship, so extinction risk will increase overall.

Decreases in moisture availability will have major impacts on the flora species composition and structure of these wetlands, with species reliant on water likely to be replaced by ephemeral dryland species such as unpalatable chenopods, copperburrs, pigface, samphire and halophytes. The drier areas to the west are predicted to be dominated by low saltbushes and copperburrs, as well as by dillon bush and African boxthorn, whereas communities in the east are likely to be weedier, with species such as Noogoora burr, Paterson’s curse and grasses being able to proliferate. This will result in massive reductions in productivity and loss of resources throughout the ecosystem.

Annex 7.1.13. Saline wetlands

The inland saline lakes are restricted to small patches in the landscape and were not mapped as occupying any area within either the north western or south western panel region owing to the coarse scale of mapping. No prior information was therefore supplied to panel members regarding this formation. The panel, however, decided that this community warranted discussion, and it acknowledged the potential for change throughout this system, although the direction of change could not be predicted owing to a lack of knowledge of changes in groundwater availability. Almost no changes in species composition and community structure are expected, but there may be some changes in geographic extent.

As saline open water or dry salt pans surrounded by open succulent herbfields, these ecosystems have been largely unaffected by land clearing and are less affected by grazing than other communities of the arid zone. The principal threats to these lakes include damage to the soil and vegetation by feral pigs, and from gypsum and sand mining.

Potential for impact due to climate change exists if groundwater extraction from underground basins increases in the area as a result of a decrease in local rainfall. Decreases in local rainfall may also cause surrounding lunettes to become unstable and erode, causing lake depressions to be filled.

The extreme conditions in saline lakes support a highly specialised flora and fauna endemic to these ecosystems. The constituent flora and fauna of these lakes show a high degree of endemism and have highly restricted distributions. The *Halosarcia lylei* low, open shrubland is an endangered ecological community known only from the saline lakes. This high level of endemism gives this community a lot to lose if any degradation occurs as a result of sand mining, trampling by grazing herbivores, or climate change.

With the predicted impacts of climate change, the potential exists for freshwater wetlands to resemble these saline lakes in structure, but they will not be equivalent floristically or ecologically. Instead, they will be species poor and will have a very simplified structure.

Annex 7.1.14. Arid shrublands (chenopod subformation) – south western region

Much of the assessment of the situation of chenopod shrublands in the North Western region also applies to that in the South Western region, but with the additional pressure of greatly reduced moisture availability. As in the North Western region, chenopod shrublands are likely to continue to undergo changes in the availability of palatable plants because of continued grazing impacts, with hotter, drier conditions compounding the effects of grazing in suppressing recruitment of the more palatable species. Marked changes in species composition and community structure are expected, with some potential changes in geographic extent. The chenopod shrublands of the South Western region are at higher risk of negative impacts from projected climate change than are those in the North Western region.

Major impacts

Decreased moisture availability:

- less winter rainfall:
    - loss of winter annuals and grasses
    - decrease in species diversity
    - decrease in productivity
    - increase in abundance of shrubs

Increased temperature:

- effects unknown, but is likely to have an impact.

A major decrease in moisture availability throughout this ecosystem in the South Western region will see major changes in species composition, with hardier species favoured that are more drought tolerant and resilient to higher temperatures. Black bluebush (*Maireana pyramidata*) will have a competitive advantage over other species such as pearl bluebush (*Maireana sedifolia*), as it recruits easier and is more resilient to both heat and the impacts of grazing. Plants such as grasses, and herbs and forbs [e.g. everlasting daisies (*Chrysocephalum* spp.)] occupying inter-tussock spaces will suffer considerable moisture stress with the loss of winter rain, with reductions in cover of winter-growing species such as speargrasses and increases in the cover of the more arid-tolerant species. This will result in a loss of species diversity, as well as a reduction in productivity. The reduction in grass cover will lead to less invertebrate activity and the associated impacts of lowered levels of decomposition and nutrient cycling throughout the system, as well as to changes to resource availability for fauna. The loss of palatable grasses and forbs will have major impacts on all fauna species, with flow-on effects throughout the entire food web. Herbivores and granivores such as Bolam's mouse (*Pseudomys bolami*), blue-winged parrots (*Neophema chrysostoma*), white-winged wrens, finches, chats and invertebrates will be directly affected by the removal of primary food resources. The rest of the community [e.g. ground-dwelling insectivores such as fat-tailed dunnarts, and skinks (*Morethia adelaidensis*, *Ctenotus uber*)] will suffer indirect flow-on effects from the reductions in productivity. The loss of ground cover species is also likely to result in elevated levels of erosion throughout the chenopod shrublands.

The overall structure of the community is predicted to change, with colonization by woodier shrubs likely because of the decreased rainfall. Species such as hopbush and bluebush may proliferate in concert with the reduction in grass and herb coverage, with a resulting decrease in species diversity. Grazing will continue to affect species composition in these shrublands, with the more palatable plants preferentially grazed, leading to a proliferation of the less palatable plants such as cotton bush.

Impacts on large proportions of the fauna in this region are difficult to predict, as their biology and ecology are poorly known (e.g. it is not known how long burrowing frogs can survive while buried). Impacts are likely to be due to changes in the frequency and intensity of rain events, which are difficult to predict. As these rain events are often localised, local extinctions may be patchy cross the region rather than having range shifts.

As with other formations of the arid zone, the effects of increased temperature were difficult to assess, given the potential unknown changes in agricultural land uses and the potential problems with thermal limits in constituent species within the ecosystem. However, an increase in temperature is likely to result in fewer incidences of frost, which may have implications for the germination of currently frost-limited species.

Annex 7.2: Climate change Impacts on land and natural ecosystems in Riverina region

Information for this Annex is extracted from a report by the NSW Department of Environment, Climate Change and Water: "Priorities for biodiversity adaption to climate change" (DECCW, 2010)

IMPACTS ON LAND

Reduced vegetation cover, caused by a reversal of seasonal rainfall patterns and overall drier conditions, is likely to leave many soils vulnerable to increased erosion. This risk is likely to be exacerbated by increased summer rain with more intense storms. Vulnerable areas include the alluvial plains of the Riverina and susceptible gullies on the south-west slopes and plains. Acidification hazards are likely to be reduced for the slopes. Salinity hazards are likely to change but the risk cannot yet be quantified.

Poorer conditions for plant growth are very likely to increase erosion hazards

Overall drying and a trend from winter-dominated to summer-dominated rainfall are very likely to result in reduced plant cover, exposing soils to additional erosion and degradation. The erosion risk is likely to be exacerbated by increased summer rainfall across the region and an increase in storm activity, particularly on the plains during spring.

Sheet and rill erosion are very likely to increase

Sheet and rill erosion, which have been major causes of land degradation in the region for a long time, are likely to increase in many areas as plant cover declines and summer rainfall increases.

Gully erosion is likely to become worse on the slopes and plains

Gully erosion, a particular problem on the cropping lands of the slopes, is likely to increase on both the slopes and plains because of increased summer rainfall and associated increases in run-off. Gully erosion in the tablelands is likely to be reduced, with a reduction in seepage flows that cause gully erosion of unstable subsoils.

Wind erosion is likely to increase

The wind erosion hazard, currently significant for the drier areas of the plains, is likely to increase because of reduced vegetation cover and lower soil moisture levels.

Sodic surface soils are particularly at risk

Sodic surface soils occur on the alluvial plains of the Riverina. Reduced plant cover is likely to make these soils more difficult to manage and result in degraded structure, increasing the risk of erosion. This risk is likely to be exacerbated by increases in summer rainfall and storm intensity.

Acidification hazards are likely to ease

Acidification is currently a significant issue for the tablelands and slopes. With the reduction in the potential for leaching in winter and increased summer rain that is likely to promote the growth of perennial plants, the soil acidification hazard is likely to be slightly reduced in the region. However, the overall response will depend on land management practices because the amount of leaching is only one factor in the acidification of soils.

Potential changes in salinity are difficult to predict

Increasing salinity has been a major problem for land and water in this region. The combination of wetter summers and drier winters is likely to increase the salinity hazard through mobilisation of salts and evaporation from discharge sites. However, the development of salinity is a complex process and will vary with local catchment conditions. Therefore, it is currently not possible to predict salinity changes in response to climate change with confidence without more detailed investigations at the local level.

Increased temperatures and changes to rainfall and run-off are likely to affect Aboriginal cultural heritage values

The Riverina-Murray region includes a variety of sites, places and objects that are culturally significant to Aboriginal people, including burial sites, earth mounds, hearths and scarred trees. Higher temperatures, decreased rainfall, decreased run-off and increased erosion are likely to result in the loss of culturally significant trees. Flooding and erosion are likely to result in damage to burial sites.

IMPACTS ON SETTLEMENTS

Despite the likelihood of drier conditions for much of the year, flood-producing rainfall events are likely to increase in frequency and intensity. Whether these changes lead to an increase in flooding of property will depend on catchment moisture levels and water levels in major storages at the time of the event. Changes in short, intense rainfall events are likely to increase flooding from smaller urban streams and drainage systems.

Changes in the risk of riverine flooding of property cannot yet be determined

Many settlements in the region are close to rivers and streams and have suffered serious flooding, particularly in 1956 and 1974. The experience of floods has led to the construction of levees, and local government now manages 150 km of levees protecting Wagga Wagga, Deniliquin, Albury, Hay, Balranald, Wentworth and other centres in the region.

Local government has reported that urban development in the Wagga Wagga area is subject to inundation in a flood of the size that occurs on average once every 100 years. The local impact of flooding varies with terrain and is influenced by man-made structures such as roads, embankments, bridges and culverts. On the headwaters of the streams within the region, flood levels depend on peak stream flows and the warning time is generally short. In the western areas of the region that are dominated by wide floodplains, warnings can be given earlier but floods stay near peak levels for long periods of time. Flooding can be a major problem for many weeks in some places.

The frequency and intensity of flood-producing rainfall events in the region are likely to rise, with potential impacts on the extent and frequency of flooding of property. However, flood levels also depend on the catchment conditions before each rainfall event, including soil moisture and water levels in reservoirs such as Hume and Burrinjuck and the numerous storages associated with the Snowy Mountains Scheme. Drier soils and lower reservoir levels will lessen the flood impact of this flood-producing rainfall. Catchment conditions are likely to change as a result of altered seasonal rainfall patterns, with drier conditions likely in spring and winter and wetter conditions in autumn and summer. Given the complex role of changes in catchment conditions, the degree to which climate change will alter the frequency of major floods in the region cannot yet be determined.

The risk of flooding along urban streams is likely to increase

Increases in rainfall intensities, particularly during short storms, are likely to cause additional flooding from local streams in towns such as Griffith, and may also exceed the capacity of stormwater systems through levees. Floodwaters from these events are likely to rise more rapidly, potentially increasing the danger of these local floods to the community.

Rural floodplain management plans are likely to need review

Floods also impact on small rural communities, individual rural properties and agricultural production. Rural floodplain management plans that coordinate development to minimise flood risk, while allowing for flood access to flood-dependent ecosystems, have been adopted or are under development on a number of floodplains in the Central Murray area and the lower Murrumbidgee floodplain. These plans will require review in future to respond to changes in floodplain hydrology, ecology and land use induced by climate change.

Changes in run-off are likely to have implications for water usage

If future run-off is at the drier end of the range of estimates, inflows to water storages are likely to decrease by up to 15% during drier periods. This will have most impact on towns with small storages. Pumping from unregulated streams is likely to be possible less often, but towns and irrigators with higher security water from major storages are likely to be buffered against reductions in inflows. Divertible volumes are likely to decline slightly for general security users.

IMPACTS ON ECOSYSTEMS

Higher temperatures, changes in the volume and seasonal distribution of rainfall, reduced snowfall and decreases in river flows are virtually certain to have major impacts on natural ecosystems in the region. All ecosystems are likely to be affected, with wetlands and ecosystems that are already under pressure suffering the most. Ecosystem productivity and nutrient cycling are likely to decline and some ecosystem types are virtually certain to be lost.

Higher temperatures and drier conditions are likely to cause major changes in ecosystems

Many ecosystems in the region are likely to change substantially as a result of increasing temperatures, substantial loss of snowfall and winter rainfall, reduction of flows in the Lachlan, Murrumbidgee and Murray river systems, and reversal of the rainfall seasonality to which many species in the region are adapted. Many species that cannot cope with reduced water availability and changed seasonality of rainfall are likely to decline in numbers, contract in distribution or become extinct.

Riverine, floodplain and wetland ecosystems are highly vulnerable

The region's many riverine, wetland and floodplain ecosystems that depend on periodic over-bank floods, particularly in spring, are highly vulnerable. River red gum/black box floodplain ecosystems and freshwater wetlands are almost certain to face severe declines in condition and extent. Inadequate water volumes and quality have caused mass tree deaths in these ecosystems in recent years, particularly on banks, floodplains and tributaries along the mid-to-lower reaches of the Murray, Murrumbidgee and Darling Rivers and much of the Lachlan River. The widespread death of mature trees and other plants has caused long-term loss of major structural components in these ecosystems that will continue to be problematic in future. Affected areas are widespread and include all of the Living Murray icon sites and the largest river red gum forests in the NSW Central Murray state forests and Yanga National Park on the lower Murrumbidgee River. The declines in these ecosystems are almost certain to continue with increasing extent and severity, and are very likely to ultimately result in ecosystem collapse unless major intervention occurs. Existing drought-related water quality problems such as toxic cyanobacterial blooms, salinity, acid sulfate soils, anoxic water, heavy-metal leaching and noxious gas release are all likely to increase, causing mass mortalities of invertebrates, fish, frogs, turtles, birds and other wildlife that depend on river systems and wetlands for water and habitat.

The decline of wetland ecosystems in the Riverina is likely to affect ecosystem services

Functioning ecosystems provide a range of services useful to humans such as water filtration, pollination and pest control. The substantial decline of riverine and wetland ecosystems in the Riverina is likely to lead to a loss of ecosystem services provided by these systems. For example, fish, dragonflies, diving beetles, turtles, microbats and birds are natural predators of mosquitoes and their larvae. Declines in populations of these natural predators are likely to lead to increases in mosquito numbers and the incidence of associated mosquito-borne diseases such as Barmah Forest virus, Murray Valley encephalitis and Ross River virus. Other changes are likely to compound this problem; stagnant river channels and temporary waters created by higher summer rainfall are likely to provide more mosquito habitat, and warmer temperatures are likely to foster rapid mosquito and virus development.

Wetland-dependent colonial birds are likely to be reduced in numbers

The extensive wetlands in the Riverina Murray such as Fivebough and Tuckerbil swamps, the Great Cumbung Swamp and the Booligal wetlands provide foraging and breeding areas for several trans-equatorial colonial bird species as well as many Australian species such as brolgas. Drier catchment conditions, substantially reduced winter and spring run-off, and river regulation may result in increased periods between winter/spring floods and shorter duration flooding. These conditions are likely to reduce the breeding success of these birds, the available habitat for breeding and possibly also the population numbers if the period between flood events exceeds the life expectancy of many individuals. Extended hot periods are likely to cause heat stress and death of nesting birds, substantially affecting local populations.

Productivity and nutrient cycling are likely to be affected

The primary productivity of almost all ecosystems in the region is likely to decline with increasing aridity, in some cases to a point where they are no longer recognisable. Lower plant growth rates will almost certainly result in reduced foliage biomass; winter growing grasses in particular are likely to decline. Decreased leaf palatability as a result of changes in species composition and elevated CO_2 levels is likely to cause a decline in plant-eating and detritivorous invertebrates such as termites, earthworms, mites, slaters and burying beetles. These insects make up most invertebrate biomass, play a key role in organic matter turnover and are a major food resource for vertebrates. Entire food webs are therefore likely to be affected, as are processes such as nutrient cycling. Lower soil moisture and reduced vegetation cover and organic matter are likely to lead to increased soil erosion and a further loss of nutrients, which will in turn reduce foliage and invertebrate biomass in a loop of declining productivity in most ecosystems.

Climate change is likely to increase stress on fragmented and degraded ecosystems and on threatened species

Ecosystems and species particularly vulnerable to climate change include those that have already undergone major declines because of land clearing, fragmentation, timber removal, grazing, weeds and other non-climatic pressures. Such ecosystems include the grassy box gum woodlands of the eastern Riverina, the riverine sandhill woodlands that are found on prior stream beds and source-bordering dunes throughout the region, and boree (*Acacia pendula*) woodlands on the Hay Plains. Climatic changes are likely to exacerbate many of the existing stresses on these communities. Species that have retracted to small, isolated populations are at high risk of extinction; for example, the southern bell frog (*Litoria raniformis*) was once common on the floodplains and tributaries of the Murray and Murrumbidgee rivers. It now exists only in isolated populations in the Coleambally Irrigation Area, the Lowbidgee floodplain and around Lake Victoria. Disease (*chytrid fungus*) is believed to be the primary cause of the frog's decline, and while it is unknown how the disease will respond to future climate, changes in water availability and quality at the location of these isolated populations could easily cause local extinctions and substantial losses for the species.

Climate change is likely to alter the size and frequency of plague locust outbreaks

Increased summer rainfall and warmer minimum temperatures are likely to favour the earlier breeding and hatching of the Australian plague locust, particularly in favourable years (e.g. La Nina years), with larger outbreaks impacting on vegetation cover. However, wetter summer conditions are also likely to favour parasites and diseases that control plague locusts, and reduced grass cover is likely to limit food availability. The broadscale use of pesticides to control locust outbreaks has potential to impact on invertebrate and vertebrate fauna through primary or secondary poisoning.

More mobile habitat generalists, including some pests and weeds, are likely to persist while species that are sedentary or specialists or have complex life cycles are at greatest risk of decline

Hardy, disturbance-tolerant, unpalatable shrubs, such as Dillon bush (*Nitraria billardierei*) and copper burrs (*Sclerolaena* spp.), are likely to persist in areas where other plant species decline. An increase in weeds is likely, particularly summer-growing opportunists. However, some Mediterranean-climate winter weeds such as barley grass (*Hordeum leporinum*) and capeweed (*Arctotheca calendula*) are likely to become less problematic because of the rainfall seasonality shift. Animals with special thermal requirements, high metabolic rates and low mobility – such as southern hairy-nosed wombats (*Lasiorhinus* spp.), malleefowl (*Leipoa ocellata*) and western pygmy possums (*Cercartetus concinnus*) – are likely to be most at risk. Highly mobile generalists e.g. Australian magpies (*Cracticus tibicen*) and those with lower metabolic requirements (e.g. skinks) are likely to cope better with the changes.

Fire and drought are likely to reduce seed and nectar production and affect granivores and nectarivores, including pollinators

Nectar-feeding vertebrates such as honeyeaters, gliders, possums and flying foxes are important pollinators of many plants, and in turn rely on the flowering of eucalypts in the dry forests and woodlands, particularly those on the western slopes in this region. Extensive fire and drought reduce the flowering of eucalypts, and hence impact on nectarivores. Such environmental conditions are likely in the predicted warmer El Nino periods, threatening nectarivore populations and pollination. In many eucalypt and casuarina species, fire and drought conditions also reduce seed production, decreasing food resources for specialist granivores such as gang gang (*Callocephalon fimbriatum*) and glossy black (*Calyptorhynchus lathami*) cockatoos.

Change is likely even in biological communities that are adapted to aridity

Species abundances and composition are very likely to change in all ecosystems, even those dominated by hardy species. For example, in the arid-adapted chenopod shrublands that are typically found on low sandy rises throughout the central and western Riverina, black bluebush (*Maireana pyramidata*) is likely to have a competitive advantage over pearl bluebush (*Maireana sedifolia*) because the former recruits more easily and is more resistant to heat and grazing. Perennial winter-growing grasses and forbs that intersperse with shrubs, such as the daisies (*Chrysocephalum* spp.), are also likely to decline because of reduced winter rainfall. These declines are likely to result in a loss of species diversity, food resources for animals and soil productivity.

Annex 7.3: Differential effects of climate change on Australian aquatic habitats

Habitat	Critical habitat	Current threat	Major climatic effect	Key driver
Freshwater systems	Snags and fallen logs	Water extraction (irrigation), habitat modification, and reduced connectivity	Reduced runoff and river flow	Reduced rainfall
Tidal wetlands	Mangroves and saltmarshses	Deforestation and habitat modification	Increasing tidal inundation	Sea level rise
Seagrass beds	Seagrasses	Increasing sedimentation and nutrient discharge	Increasing physical disturbance	Increasingly severe storms and cyclones
Coral reefs	Scleractinian corals	Cyclonic disturbances and outbreaks of coral-eating starfishes	Coral bleaching and loss of physical habitat structure	Ocean warming and acidification
Temperate reefs	Giant kelp and macroalgae	Marine pollution and pest species	Shifts in geographical ranges for habitat-forming species	Ocean warming and strengthening of the EAC

(Pratchett et al. 2011)

Chapter 8: Strategic Interventions and Knowledge Management

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8.1. Strategic interventions

Climate-related government programs, whether aimed at adaptation or mitigation (or both), should be mainstreamed into federal and state budgets in order to transform growing political will into concrete actions that help land managers adapt to and mitigate climate change. Thus, it is important to link and align on-the-ground interventions with a wider policy framework.

This section offers recommendations for Local Land Services to align with the federal climate change policy framework and NSW 2021. These recommendations aim to inform Local Land Services in preparing their Local Strategic Plan; providing and facilitating education and training in connection with agricultural production, biosecurity, natural resource management and emergency management; and communicating, consulting and engaging with the community, including the Aboriginal community, to encourage participation in the delivery of Local Land Services. **Error! Reference source not found.** utlines some key elements of the overall climate change policy landscape at federal level, the NSW 2021 at state level and strategic areas of interventions for Local Land Services.

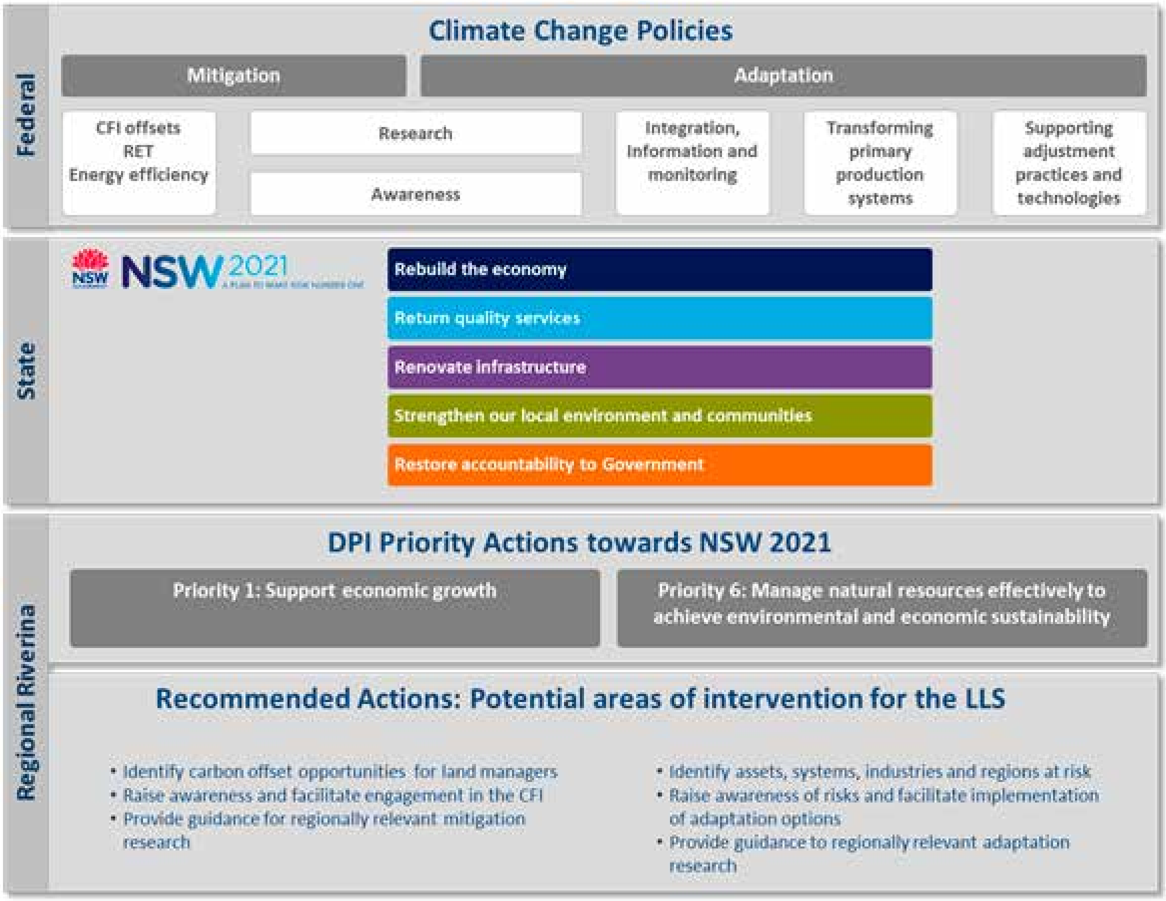

Figure 9 Climate change policy hierarchy from federal to state and Local Land Services with strategic areas of interventions for Riverina Local Land Services

There is bipartisan support for the Carbon Farming Initiative (CFI) as an incentive mechanism for agriculture to make its contribution to national mitigation targets. This policy has been supported by the Climate Change Research Program and subsequent Carbon Farming Futures package of funding for the Filling the Research Gap, Action on Ground and Extension and Outreach programs. There is a role therefore for Local Land Services to promote CFI opportunities to land managers. There is some uncertainty around the Renewable Energy Target and this may require clarification before clear opportunities can be promoted or communicated to land holders. However, energy efficiency should be promoted as a means of saving both money and improving environmental outcomes. In terms of adaptation, the focus of government has shifted more towards managing the short-term impact of extreme events on agriculture, rather than long-term plans for transformational adaptation.

Chapter 8: Strategic Interventions and Knowledge Management

At state level, "*NSW 2021- A plan to make NSW number one*" includes a commitment from the Government to minimise the impacts of climate change on communities. It is a 10 year plan to rebuild the economy, return quality services, renovate infrastructure, restore accountability to government, and strengthen our local environment and communities. This plan sets immediate priorities for action and guides NSW Government resource allocation in conjunction with the NSW Budget. Agencies need to identify cost-effective initiatives to achieve the goals and targets within the plan.

Refer to **Error! Reference source not found.** Climate change responses need to be hard-wired into he core business of regional NRM bodies. It should be considered not as a separate issue but as a core feature of the operating environment (Campbell 2008). Effective responses to climate change in NRM planning will contribute to achieve the 32 goals, under these five broad categories of NSW 2021. For example, mitigating impacts from climate change on primary industries and building their capacities to prepare and adapt in this context will ultimately improve their performance, thus contributes to the NSW economy (Goal 1). An integrated knowledge management system, developed and maintained by industries and communities (discussed in section 8.2), will increase opportunities and participation in environmental protection (Goal 22 and 28). This is also aligned with the DPI priority actions towards NSW 2021. It is important to note here that adaptation actions have occurred mostly at the local scale. While local councils are key agencies, they need support from higher levels of government. Financial resources, legislative recognition and training are the key areas that need support (CSIRO and UTS 2014).

In this context, a few key principles and areas of interventions are recommended for Local Land Services in the Riverina region:

- Although the Climate Change Research Program and subsequent Carbon Farming Futures funding will largely terminate in June 2015, opportunities for regional authorities to continue to promote this research and associated opportunities for farmers remain. There is a clear role for Local Land Services to raise awareness of and assist landholders in identifying carbon offset and energy efficiency opportunities and facilitate their engagement in the CFI where possible and cost-effective.
- Since impacts on agriculture are local and regional, Local Land Services needs to identify assets, systems, industries and regions at risk and to work with land managers to raise awareness of these risks and facilitate implementation of regionally relevant adaptation options.

- It is recommended that Local Land Services should build on and enhance their engagement with land managers to identify opportunities that require more regionally relevant mitigation and adaptation research. Local Land Services should bridge this knowledge with relevant research providers and industry.
- In such a complex policy environment where land managers find it hard to navigate, Local Land Services should work to ensure a consistency in mitigation and adaptation extension messages, thus avoiding conflicts and confusion around good practice guidelines and planning in order to maintain effective environmental services. Local government is crucial for on-ground adaptation, but needs to be effectively linked to national scale issues. Knowledge management is one of the entry points. This is further discussed under section 8.2 on Knowledge Management.
- Local Land Services regional adaptation efforts should focus on empowering of stakeholders in a way that increases resilience of the landscape system, involving both people and natural systems. Transfer of information needs to be supported by acceptance and ownership of the concept of change. This review reiterates the need for training, which is crucial to underpin effective leadership and provide the institutional support required for adaptation to advance.
- The overlap between best practice regional NRM and constructive climate change adaptation measures is significant. This provides lots of scope for regional NRM bodies to make a very useful contribution in the overall response to climate change (Campbell 2008). The recent integration of the Catchment Management Authorities, Livestock Health and Pest Authorities and some advisory services of the Department of Primary Industries to form Local Land Services with a shared focus could provide an impetus and necessary capacity to pursue the NSW 2021 goals. However, institutional limitations, resource constraints and competing agendas have been identified as barriers to climate change adaptation (CSIRO and UTS 2014). It is recommended that Local Land Services study ways to avoid potential mismatches between current organisational roles, assess the scale of adaptation and allocate sufficient institutional support.
- Multiple partnerships are necessary to manage multiple drivers, and new partnerships are needed between government, science, private sector and local communities to support local adaptation (CSIRO and UTS, 2014). Local Land Services partnerships with farmers, Aboriginal communities, local government, State agencies, Australian Government and industry will serve as a platform to initiate and maintain on-going support and knowledge management for

effective responses. To further enable this, leadership needs to be strong, and sufficient resources are required.

8.2. Knowledge management

As seen in Figure 9, research and awareness are the key themes that cut across both mitigation and adaptation responses. The idea of integrating knowledge and action across sectors is of particular pertinence to primary industries because of two reasons:

1. Its involvement in land, ecosystem services, and food issues overlaps extensively with the interests of numerous other sectors, namely conservation, water and health (as evidenced by the incomplete integration of NRM and production goals within primary industries);
2. Its character as a complex and community- and family-based undertaking (at least in the case of agriculture) means that it also intersects with other sectors such as health, infrastructure, IT, finance, insurance and emergency management.

Integrated knowledge for primary industries adaptation also requires that formal research is perceived as part of a larger knowledge or innovation system. Some specific research gaps are identified under each chapter in this review. Annex 8.1 provides an overview of existing and missing research for climate change adaptation in the primary industries. However, it is important to note that framing climate change adaptation in such a way that it engages broad audiences is an ongoing challenge for both researchers and practitioners.

Studies to date have found that there is a broad range of knowledge, beliefs and attitudes within farming populations about climate change trends, impacts and attribution. Some of the farming community seem to believe (on the basis of first hand observations) that the climate may be changing and are making, or plan to make, (minor) adaptations in response. It is, therefore, recommended that Local Land Services considers approaches to move towards the **co-production of knowledge** with research users such as farmers in this process. Specifically, appropriate knowledge systems on responses to climate change needs to include an on-going platform in which farmers and other members of the public contribute fully to the creation and evaluation of new knowledge. It is also suggested that science and government may need to consider utilising alternative strategies to distribute climate change knowledge within the rural sector. A better approach would build on the local sociocultural, economic and biophysical environment of the people (Evans, Storer & Wardell-Johnson 2011).

As mentioned above, Local Land Services also has a role in bridging this knowledge with relevant research providers and industry. The value of generalised knowledge for context-specific adaptation and vice versa is an important issue for adaptation but one that agricultural research has a long history of tackling. It is recommended that Local Land Services should **tap and contribute to the knowledge pool** generated by the NSW Adaptation Research Hub. Comprehensive monitoring, synthesis and assessment of adaptation in action and the wide range of factors bearing on it, together with more traditional knowledge transfer could be a starting point.

Finally, it is recommended that Local Land Services should identify avenues and resources to lead and promote far greater integration of agricultural extension and social science knowledge into innovation development to identify key mitigation and adaptation priorities and issues.

Annex 8.1. Overview of existing and missing research for climate change adaptation in the primary industries

	General status of research[1]			
Broad area of research	**Refining**	**Consolidating**	**Emerging**	Missing
Overall	Assessments of agriculture's risk exposure and the associated cost of risks[2] Estimates of the economic value of multifunctionality in agriculture, including carbon sequestration[2]	Understanding of the main types of adaptation options and principles/strategies for good adaptation Tools and means of participatory exploration of adaptation approaches Need for and examples of integrated research	Adaptation options that take account of the full range of stressors on adaptors, including the impacts of variability, extremes & uncertainty [5] Meta-analyses of case-based studies More integrated, dynamic, spatially-explicit & participatory models that incorporate a broader range of impacts, contextual factors & uncertainty Methods to better link different types of modelling studies, and field-based & model-based studies Empirical validation of model parameters & findings including vegetation maps How CC affects accuracy & usefulness of conventional research & management tools Feedbacks between (mal)adaptation responses & abiotic & biotic conditions Approaches to decision-making under uncertainty Relationship between different levels & types of adaptation How we can best learn from the past for new & uncertain situations How to address adaptation deficits & how this affects the costs & benefits of future adaptations Critical understanding of different integration approaches How to identify, monitor and evaluate	**Broad-scale monitoring of basic agro-ecological conditions, CC impacts, other stressors, adaptation efforts and adaptation effects** **Understanding of appropriate monitoring& research protocols to capture CC & adaptation effects** **Basic understanding of some fundamental system functions, processes & status, & associated uncertainties** **Custom-made models to investigate specific scenarios of effects & responses** **Understanding of the leverage points in primary industries systems where interventions can most easily positively influence system behaviour**[3] **How sources of vulnerability and adaptive capacity shift over time as climatic conditions, regions & other factors change**[4] **Comprehensive, open, inter-linked, spatially explicit information systems that integrate human, ecological and production variables**[6] **Identification of most effective measures for detecting thresholds in agro-social ecological systems in face of multiple drivers of change**[7] **Timing of different actual and desirable adaptations between groups & regions, & relationship to the speed at which various**

			adaptation	**CC impacts are manifesting** **Understanding of possible and desirable adaptation pathways (sequences of adaptations) in primary industries & their determinants** **How to use adaptation M&E to inform collective learning and adjust practices**
Impacts	Projections of abiotic conditions under CC at the regional scale Exposure & sensitivity of the growth & yield of major commercial species to projected conditions Effects of elevated CO2 on nutrient levels of major crop species	Exposure & sensitivity of production systems to various patterns & combinations of climatic factors & extremes Links between abiotic variables & vegetation dynamics at landscape scale Identification of most exposed & sensitive geographic regions Sensitivity of different life & succession stages of different species & communities to various climatic conditions Flows of impacts across whole farm systems GHG dynamics across whole farm systems, value chains, sectors & regions Identification of GHG emission hot spots Carbon sequestration potential of different forestry & ag systems Effects of projected climatic conditions on water availability from plant to catchment scale Identification of bio-indicators of climatic changes Effects of CC trends on rural health determinants Long-term effects of climatic extremes on farm households &	Exposure & sensitivity of production systems to various patterns & combinations of indirect & nonlinear effects CC impacts on vector- disease-host complexes & on soil & water contaminants Multi-impact studies: interaction of direct & indirect CC impacts & contextual factors (e.g. salinity) & their effect on multiple PI objectives Cross-scale studies, including scaling up, inter-regional tele-connections, land use & hydro-climatic feedbacks Comparison, integration & refinement of different impacts methodologies Sensitivity of pest & uncommon ag species Changes to species populations & assemblages across scales Drivers & implications of indirect land use change Global warming potential of diverse ag enterprises & products, management practices & systems Water-intensity of different production systems & products Co-products of biofuels & reuse of ag wastes Longitudinal & cross-scale effects of biochar Carbon sequestration potential of systems under different conditions Ecological factors affecting systems' recovery from different combinations of stressors Effects of changes in distribution of ag &	**Understanding of some fundamental biophysical systems & processes (e.g. aspects of soil health, biogeochemical cycles, plant water use)** **CC effects on beneficial non-commercial species** **Analyses of how CC effects in other sectors affect PI & rural communities** **Longitudinal studies of flow-on effects of CC impacts over time** **Unintended effects of adaptation & mitigation responses** **Generation, flow & accumulation of uncertainties through systems** **Effects of different combinations of future conditions on the relative advantage of different adaptation & mitigation options** **CC effects on relationships between components of production systems & landscapes** **CC effects on relative advantages of different carbon sequestration & biofuel options** **Use of self-produced alternative energy in ag systems** **Potential for third & fourth generation biofuels in Australia** **Effects of climatic extremes on animal injury & mortality** **CC effects on production system infrastructure (e.g. ag machinery, dams, rail, broadband)** **CC effects on ag labour requirements &**

		rural communities	forestry on native species' adaptive capacity Effects of CC on ag trade, consumption patterns & ag adaptation options Effects of CC policies on PI & rural communities	**availability** **Effects of CC on freshwater aquaculture** **Interaction of speciation, CC effects & elevated CO2** **Effects of CC of food processing & distribution systems** **Integration of complex components of human behaviour into models of agricultural systems**[8]
Adaptive capacity – role & status	Role & status of producers' financial capacity Status of rural individuals' human capital, notably physical & mental health and climate change attitudes & knowledge	Pros & cons of various indicators of adaptive capacity Role of different cognitive capacities & understanding of decision making Role & status of social capital Relationship between rural & agricultural populations & its influence on each group's adaptation Relationship between soil, water and ecological characteristics & production system resilience	Role & status of natural capital Spatial & social distribution of, and changes in, different types of capital In-depth bottom-up analysis of actual factors affecting adaptive capacity & actions Cultural, social, political & cognitive influences on CC attitudes and decisions including observed conditions, social norms & the perceived relative risks of perceived adaptation & mitigation options Impact of CC on political economy of rural Australia and flow on effects to businesses' and households' adaptation decisions Adaptation pros and cons of different business paradigms (e.g. long-term v. short-term profitability, on-farm v. off-farm investments) Adaptation pros & cons of property & equipment ownership	**Longitudinal empirical analysis of adaptation processes, interactions between different types of capital & their context-specific and dynamic value** **Longitudinal empirical analysis of relationship between adaptation experience & adaptive capacity** **Analysis of adaptive capacity & adaptation by rural professionals (notably ag advisors), agribusiness, & RDE, & its affect on producers** **Adaptation pros and cons of existing rural policies & infrastructure** **Cross-scale analysis of current and potential status, vulnerability, and adaptation role of infrastructure in rural areas**
Adaptation levels, practices and options	Adaptation options for major crop types in response to familiar stressors such as water scarcity Adaptation options for reducing heat stress in livestock Need to increase adoption of existing soil best management practices	How to improve the perceived quality & value of climate forecasts & other risk management tools for practitioners Adaptation options for less common crop types & diverse CC impacts Adaptation options for pasture management & animal management in response to diverse CC impacts	Role of policy, biophysical & market interactions in feasibility & desirability of various land use changes Relative advantages & disadvantages of soil management options as CC adaptations Extent to which different adaptation options are easy to implement (e.g. trial-able) & are otherwise appealing, or not, to producers How to build organizational capacity in learning and adapting to CC trends and extremes[9]	**Longitudinal studies of adaptation before, during & after climatic extremes to understand factors enabling & constraining adaptation options at different stages** **How to foster anticipatory, collective responses to CC among producers** **Advantages & disadvantages of different approaches to facilitating transitional change in most vulnerable communities & businesses, including relocations**

Adaptation implementation, monitoring and evaluation	**Knowledge integration needs, notably cross-scale, cross- disciplinary and cross-sectoral research**	**Broad brush empirical examples of integration efforts and challenges** **Barriers to integration** **Comparison of mitigation & adaptation research**	**Closely analysed empirical examples of integration efforts and challenges** **Critical awareness of the pros & cons of different approaches to & aspects of integration** **Efforts to identify, assess & track adaptation in practice**	**Trade-offs and skills in implementing different types of adaptation in different settings** **How to usefully measure and assess benefits and costs of adaptation options & efforts given that they are relative, context-specific, subjective, multi-faceted, dynamic, interactive & uncertain**

[1]Abbreviations: CC = climate change; PI = primary industries; ag = agriculture/al; [2] Chavas (2011); Meinke *et al.* (2009); [4]Simelton *et al.* (2009) ; [5]Challinor *et al.* (2009); [6]Bebbington *et al.* (2012); Tomich *et al.* (2011); [8]Plaganyi *et al.* (2011); [9]Linnenleucke and Griffiths (2010) Source: (Rickards, 2013)

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