Environment Institute – Landscape Futures Program

Climate Change, Community and Environment

Technical Report
(With an emphasis on Eyre Peninsula)

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Chapter 1

INTRODUCTION

1.1 Landscape Ecology

Landscapes stretch as far as the eye can see, taking in landforms such as hills and valleys, plants and animals, and including weather effects, human activity, land uses and the built environment. Landscapes are active and changing as soils form and erode, as plants and animals respond to climate and as humans use and change soils, water, plants, animals and the atmosphere i.e. our life giving resources.

Landscape ecology studies the relationships between and within ecosystems and external influences such as weather, land uses, built environments and human activities. This multi-disciplinary science looks for patterns, processes and relevant scales in broad-scale environmental issues. A key goal is to identify management options and develop tools which will enable the vital natural resources to be improved, maintained and made renewable.

Biodiversity can be defined as the totality of genes, species, and ecosystems of a region, and is often used as a measure of the health of biological systems. Understanding biodiversity is critical to sustainable management of ecosystems. But how best to measure biodiversity? This is a major challenge in Australian landscapes, to cover large areas, to document variations in vegetation communities, and to capture ecological responses to conditions ranging from drought to flood.

The Eyre Peninsula Natural Resources Management Board recognises climate change as a core future influence on the natural resources of the region, placing pressure on native ecosystems, production systems and water resources. The Board's ten year Strategic Plan (EP NRM Board, 2009) places a priority on helping communities to understand, adapt to and mitigate the impacts of climate change. Adaptive farming systems will be essential in a changing climate and variable economic market, crucial groundwater resources may become stressed and require different management, and special attention will be required for the management of areas of native habitat that are at risk from climate change.

1.2 Landscape Scale Research

Understanding and managing Australian landscapes is a special challenge because of two key factors - variability and patchiness. Rainfall is highly variable and patchy, with frequent droughts lasting several seasons. The European agricultural systems known by our immigrant forefathers are generally reliable and predictable especially in the temperate and humid environments of the northern hemisphere. Much of Europe relies on perennially flowing rivers and annual rainfall recharge of shallow groundwater reserves for water supplies. In contrast, Australia has highly variable and unreliable water supplies.

Australian ecosystems have developed a 'boom and bust' approach to recruitment, adapting to the highly variable cycles of flood and drought. The Australian population, on the other hand, wants regular and predictable supplies of food and water, creating conflicts between society's needs and Australia's highly evolved ecosystems. Managing this conflict is critical because the long term success of the economy is increasingly dependent on the provision of services from the environment such as basic food supplies, clean water, detoxification and fresh air.

The introduction of urban and agricultural development to our landscapes has led to significant problems which undermine the sustainability of ecosystem services. Loss of vegetation cover exposes soil to erosion, and diversions of water from rivers dries floodplains and river channels. Replacing perennial ever-green vegetation with short-lived annual crops alters water and salt balances, while changes in land management can reduce or increase run-off water and water quality.

The life sustaining system of a landscape is composed of many interacting and dependant components. Understanding this complexity and the major interactions is essential for wise and sustainable management. Australia's natural resources are declining due to increasing pressures, including climate change, urbanization, and intensive agriculture. These problems are being addressed through regional plans which attempt to prioritize among a range of possible actions, often using a limited and inadequate information base. ‘Landscape Futures’ science is developing tools for integrated solutions to manage natural resources. These tools will be used to manage whole landscapes and ecosystems, and to select the most effective management actions.

1.3 Landscape Futures Program

The Landscape Futures Program at The University of Adelaide, led by Professor Wayne Meyer, has been established to respond to the growing need for integration solutions to the management of natural resources. It brings together a talented and dedicated group of researchers, teachers, managers and communicators to develop tools and research projects to provide answers to crucial questions around the issue of sustainable management of our precious natural resources. It has developed a systems-wide research approach to explore management options for improving agricultural productivity while conserving and restoring natural ecosystems. Developing strategies for local governments to adapt to climate change is one key research focus of the new Envisioning Future Landscapes Initiative.

Participants in the Landscape Futures Program hold a vision of a renewable Australian landscape that will be used for production consistent with its capacity. It will give due recognition to livelihoods and lifestyles as well as retaining endemic biodiversity and it will, in time, be in energy, nutrient and water balance. It will contain a mosaic of connected endemic ecosystems and its aesthetic and spiritual qualities will be valued. The regional population will be supported by the resources of the region, they will have access to services that assist with a high quality of life and our measure will be improvement in human well being.

How we use the land, and where we do it, will need to change to adapt to:

- changed climate,
- changed markets,
- changed community values,
- changed opportunities.

Landscape Futures analysis allows us to identify future land use options to give the best combination of environmental, ecological, economic and social outcomes in the face of climate and market changes.

The Landscape Futures Program aims to develop:

- new methods and models for landscape futures analysis that better inform managers and policy makers of conservation, repair and maintenance options for sustainable land use;
- improved information systems to assess and monitor natural resource condition and provide a basis for projecting likely environmental condition into the future;
- skills and knowledge for planning, implementing and monitoring for improved natural resource management.

The expected outputs produced by the Landscapes Futures Program will:

- improve and verify models used in estimating the water, carbon and nutrient balances of different crops and vegetation types with current and future climate conditions;
- identify the economic and community consequences (jobs and services) of changing land use practices to improve and conserve resource conditions;
- develop alternative methods for assigning economic, social and environmental values to agricultural production, community services and ecosystem services;
- improve methods for assessing and prioritising biodiversity values of different land use configurations;
- develop and demonstrate new methods for assessing and monitoring natural resources at landscape scales;

- identify new ways of demonstrating and communicating possible regional landscape arrangements and functions using animation and visualisation technology.

1.4 Climate Change, Community and Environment

One of the projects within the Landscape Futures Program is “Climate Change, Community and Environment: Building research capability to identify climate change vulnerability and adaptation options for South Australian landscapes”, which was funded by the South Australian Government through the Premier's Science and Research Fund (PSRF). This project (CCCE) was initiated in 2008/09 and looks at planning for adaptation to climate change in the Eyre Peninsula (EP) NRM and SA Murray-Darling Basin (SA MDB) regions. It will position South Australian natural resource management research and regional implementation in the vanguard of climate change vulnerability assessment and adaptation strategies at the landscape scale.

The overall project aims were achieved through the implementation of three sub-projects:

- EP- *Eyre Peninsula Landscape Future (EPFL)* - Applying the Climate Change (CC) adaptation methodology to the Eyre Peninsula NRM region, including the impact on dryland farming (wheat production), biodiversity, and carbon sequestration, and examining future social and economic viability.
- SA MDB - *Climate Change impact assessment, adaptation and emerging opportunities for the SA Murray-Darling region (SBC CCAP)* - Applying the Climate Change adaptation methodology in the SA MDB, examining future options for CC adaptation across horticulture, tourism, carbon capture and bio-fuel production. Led by the SA MDB NRM Board in strong partnership with local councils.
- SA MDB- *Developing Landholder Capacity to adapt to Climate Risks and Variable Resource Availability in the Bookpurnong and Pyap to Kingston On Murray Regions of the Riverland South Australia (MDP LAP)* - Developing tools and building capacity to respond to CC within the irrigation/horticulture communities of the riverland in South Australia, major focus on forward looking business decisions including allocation of water and choice of crop types.

The first project was funded entirely by the PSRF, however the second two received additional funding from Strengthening Basin Communities and the CSIRO. This reflected the overall project approach of seeking additional resources to increase project scope and capacity and further test project methodologies within a range of scales and contexts.

This three year project had contribution from seven partners:

- The University of Adelaide,
- CSIRO Climate Adaptation Flagship,
- South Australian Research and Development Institute (SARDI) / Primary Industry and Resources SA (PIRSA),
- Department of Water, Land and Biodiversity Conservation (DWLBC),
- Department for Environment and Heritage (DEH),
- SA Murray-Darling Basin Natural Resources Management Board,
- Eyre Peninsula Natural Resources Management Board.

Note:
On July 1st 2010 the natural resources section of DWLBC combined with DEH to form the new Department of Environment and Natural Resources (DENR).

This report focuses on the analyses and results for the Eyre Peninsula NRM region.

In addition, some results from the completion of the Lower Murray Landscape Future Project (LMLF) in the South Australian Murray-Darling Basin and two CMA regions in Victoria are presented. This analysis built on the baseline dataset that had been developed by this project (LMLF) to investigate the impact of climate change on natural resources and on the achievement of NRM plan targets.

1.4.1 Aims

Through the CCCE project, we expect to develop the understanding, expertise and tools that result in more evidence based planning and implementation of regional NRM. The net result will be more cost effective conservation and more resilient viable regional communities.

We will identify those land use practices and conservation areas that are most at risk from adverse effects of climate change and identify adaptation strategies and policy options to support planning and implementation by regional natural resource management agencies. In so doing we will identify the management investments that get the best improvement in natural resource condition while looking after jobs and services for the regional community.

The research team aims to use Landscape Futures Analysis to estimate responses of regional agricultural and carbon production, biodiversity and economics to climate change scenarios which can then inform regional scale climate change adaptation strategies within the EP and SA MDB NRM regions by 2012.

1.4.2 Objectives

To achieve the aims of this project, a number of specific objectives were established:

- agree on future climate scenarios (one baseline and three potential climate change scenarios);
- defining sub regions that recognise the climate, soil and land use differences across the Eyre Peninsula NRM region;
- acquire and assemble a variety of both spatial and non-spatial data covering a range of biophysical, ecological, social and economic aspects of the EP and SA MDB regions;
- model the impacts of climate (under each of the four future climate scenarios) on each of these aspects as a separate module (only some modules wereimplemented for SA MDB);
- gather soil and crop yield data from different locations on Eyre Peninsula to use for crop production model validation;
- identify potential changes in plant species distribution under climate change scenarios and;
- developing an analysis framework for assessing sub regional vulnerability to climate change.

The outputs from this project will be used to inform community and NRM plans, with the choice of preferred options to be made by the community and NRM Board.

1.4.3 Project Governance and Management

The University of Adelaide was the agent for the Climate Change, Community and Environment (CCCE) project, and a number of groups were established to run this program (Appendix 1).

An **Advisory Group** of senior representatives from the two NRM regions, independent NRM consultants and a senior ecological researcher met bi-annually. The role of the Advisory Group was to provide advice to the Project Leader and Research Team on

- the scope and direction of the research consistent with the agreed project objectives,
- how best to ensure good connection with stakeholders and
- identifying growth and influence opportunities for the project research and its delivery

Members of this group engaged fully in the project and provided valuable direction to the research team, particularly in identifying connections within the two NRM regions, and flagging communication needs for the various stakeholder groups.

The Project Leader, Professor Wayne Meyer, worked with a partner **Management Group** to deliver the project. Structured meetings of the Management Group were held on the first Monday of each month with most members being present in person, others by teleconference.

The **Research Team** met each Monday morning for a brief catch-up in which team members informally reported on latest developments.

1.4.4 Publication, Consultation and Community Involvement

A principal function of the membership of the Advisory and Management Groups was to ensure links between the project partners and also to extend the influence of the project through the networks of the members with existing projects and activity.

Annual reports were complemented with a vigorous publication effort (Appendix 2). Numerous meetings, consultations, presentations and workshops were also undertaken during the course of the project (Appendix 3), with the Project Logic workshop deserving special mention.

1.4.5 Program Logic

The mid way point of the CCCE project was used as an opportunity to look ahead to ensure key CCCE research project partners understand their roles and responsibilities to maximise the research outcomes. Rural Solutions SA was engaged to conduct a program logic workshop with key CCCE project partners in Port Lincoln on 16 September 2010, focusing on the Eyre Peninsula NRM region, and in Adelaide on 2 February 2011 focusing on the SA MDB NRM region.

Program logic is an approach that aims to record the rationale (logical hierarchy) behind a program and the expected cause and effect relationships between project activities, project outputs and outcomes, project goal, intermediate and long term outcomes and aspirational vision (Lucy, 2010; Lucy, 2011).

A key benefit of recording the program logic is that it can be used as a communication tool to increase understanding of 'what' a project is expected to achieve, and 'how' it is expected to achieve that, subject to the underlying key assumptions and factors (both internal and external) (Lucy, 2010).

The program logic workshops were used to facilitate:

- a strategic discussion – 'what are the CCCE research project outcomes?'
- an operational discussion – 'how is the CCCE research project going to achieve the outcomes?' and

- align expectations.

The developed program logic was interrogated by the participants including identifying assumptions and internal and external factors. The remainder of the workshop focused on a ‘detail’ level by developing a plan for delivery, stakeholder analysis and key reporting. A flowchart of the program logic developed for the CCCE research project in the Eyre Peninsula and SA MDB can be seen in Appendix 4. Full details can be found in the commissioned reports (Lucy, 2010; Lucy, 2011).

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Chapter 2

SETTING THE SCENE:

STUDY AREA, MODELLING MODULES AND DATASETS

2.1 Eyre Peninsula NRM Region

The Eyre Peninsula (EP) Natural Resource Management (NRM) region accounts for a significant proportion of the state of South Australia, covering over 55,000 square kilometres (5.5 million hectares) of land, or 80,000 square kilometres including marine areas. It includes part of the upper Spencer Gulf and the city of Whyalla, stretching across the southern boundaries of the Gawler Ranges, past Ceduna to the edge of the Nullarbor Plain and south to the fishing hub of Port Lincoln. This region has a third of South Australia's coastline (over 1,800 kilometres) and 254 offshore islands.

The region is typified with gentle to low topographic relief mostly less than 150 metres above sea level. The most significant topographic features are the Gawler Ranges in the north with peaks of around 500 metres, while the Koppio Hills in the south cover an area of over 100 square kilometres.

Climate within the Eyre Peninsula is characterised as Mediterranean with cool, wet winters and warm, dry summers. Due to the proximity to the coast areas in the south experience a cooler, wetter climate than those regions in the north. Mean annual rainfall ranges from 250 millimetres in the north and northwest to more than 500 millimetres in the south.

Eyre Peninsula retains 45% (about 2,187,560 ha) of the pre-European extent of remnant native vegetation and contains important mallee habitat, several woodland communities and a high number of endemic species. Clearance of native vegetation ranges from 14% cleared in the far west to 72% cleared in the south. About 15% of the region, used mainly for grazing, is covered with scattered native vegetation (Figure 1). Forty-four per cent of the remnant native vegetation is protected in government reserves or by heritage agreements. The region is a significant ecotone (a transition zone between two adjacent but different plant communities), being the western limit to a range of eastern Australian species and the eastern limit to many western Australian species. There are 61 nationally listed threatened plant and animal species and 46 migratory species.

Surface water on Eyre Peninsula is scarce, with only one limited surface catchment (the Tod) utilised for storage. Groundwater is the major source of water for the region, with the major basins within the Southern Basins Prescribed Wells Area and the Musgrave Prescribed Wells Area. There are other localised groundwater lenses that provide limited quantity and varying quality of water. The region features fresh and saline wetlands, of which 14 are listed in the Directory of Significant Wetlands in Australia. It also has a long and relatively undisturbed coastline with important adjacent marine habitats.

The Eyre Peninsula region supports a population of 55,000 people concentrated in the towns of Whyalla, Port Lincoln, Port Augusta and Ceduna and makes a significant contribution to the State’s economy. Aboriginal communities represent approximately 5% of the region’s total population, with the largest community located close to Ceduna.

Agriculture is the major land use within the region, with dryland cropping dominated by cereals such as wheat and barley. The soils of the Eyre Peninsula are typically low in fertility and water holding capacity and are deficient in plant nutrients. Despite their relative infertility, the area provides significant economic returns from agricultural production producing 33% of South Australia’s grain harvest. Other agricultural activities include grazing and wool production, and horticulture which is increasingly specialising in grapes and olives. The region’s coastline sustains a number of major rural town centres acting as major tourism destinations, and supports a fishing and aquaculture industry that represents 65% of South Australia's seafood harvest. Eyre Peninsula also has an established mining sector with a variety of mineral resources (mineral sands, gypsum, salt, graphite, marble and jade) and a steel industry with iron ore smelting in Whyalla.

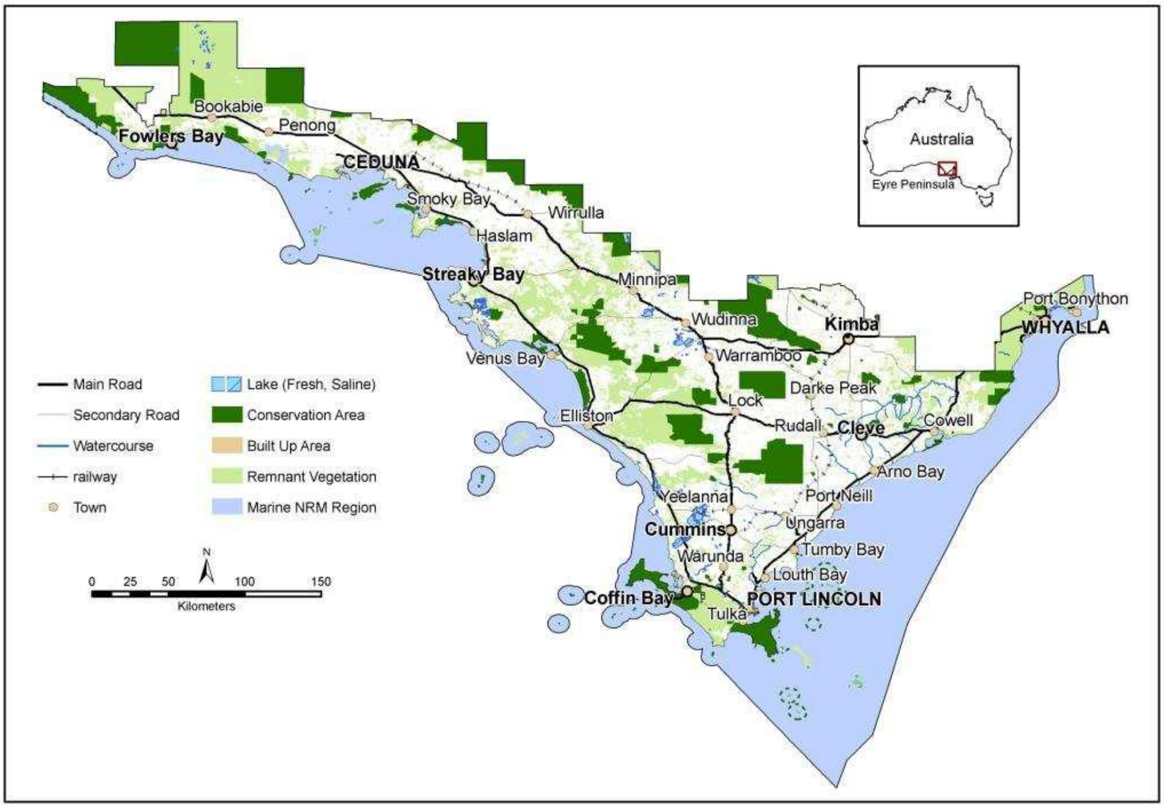


Figure 1: Eyre Peninsula NRM region

Source: (Ward and MacDonald, 2009)

2.2 Lower Murray Region

Some analysis was carried out in the entire Lower Murray region of southern Australia (Figure 2) as part of the Lower Murray Landscape Futures project. This region is defined by the South Australian Murray-Darling Basin (SA MDB) Natural Resource Management (NRM) region in South Australia and the Mallee and Wimmera Catchment Management Authority (CMA) regions in Victoria. The Lower Murray covers a total area of 11,871,363 ha with 51% used for dryland agriculture which consists mostly of cropping cereal (e.g. wheat, barley), oilseeds (e.g. canola) and pulses (e.g. lupins, beans), and grazing sheep. Along the course of the River Murray there are also large areas of high value irrigated agriculture. Approximately 45% of the area is remnant vegetation with approximately half of this under formal protection. The historical climate in the Lower Murray ranges from cool and temperate in the south to semi-arid in the north. While results for the entire region are presented, we are particularly interested in the SA MDB NRM region.

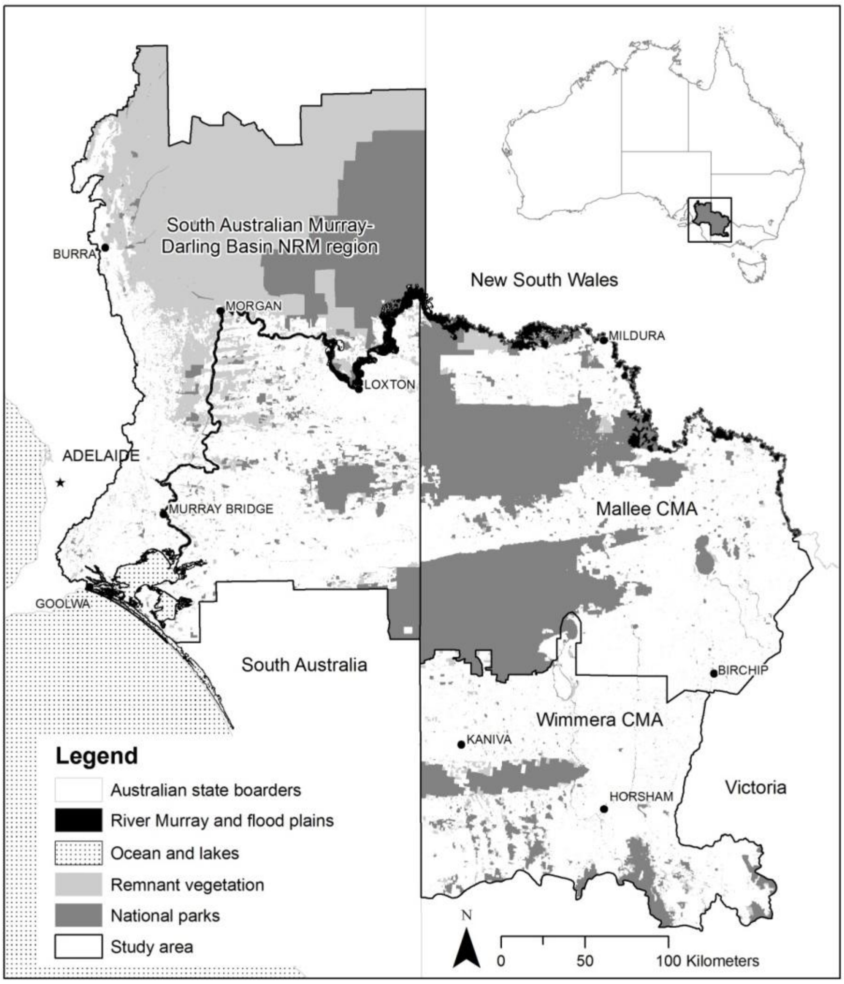


Figure 2: Lower Murray study site consisting of the South Australian Murray-Darling Basin NRM region and the Mallee and Wimmera CMA regions in Victoria

2.2.1 South Australia Murray Darling Basin NRM Region

The South Australian Murray-Darling Basin (SA MDB) Natural Resource Management (NRM) region supports a population of approximately 126,000 people and extends over more than 5.6 million hectares, from the Victorian and New South Wales' borders to the catchment boundary along the Mount Lofty Ranges, to the Murray Mouth and up to 14 kilometres into the Southern Ocean (Figure 3).

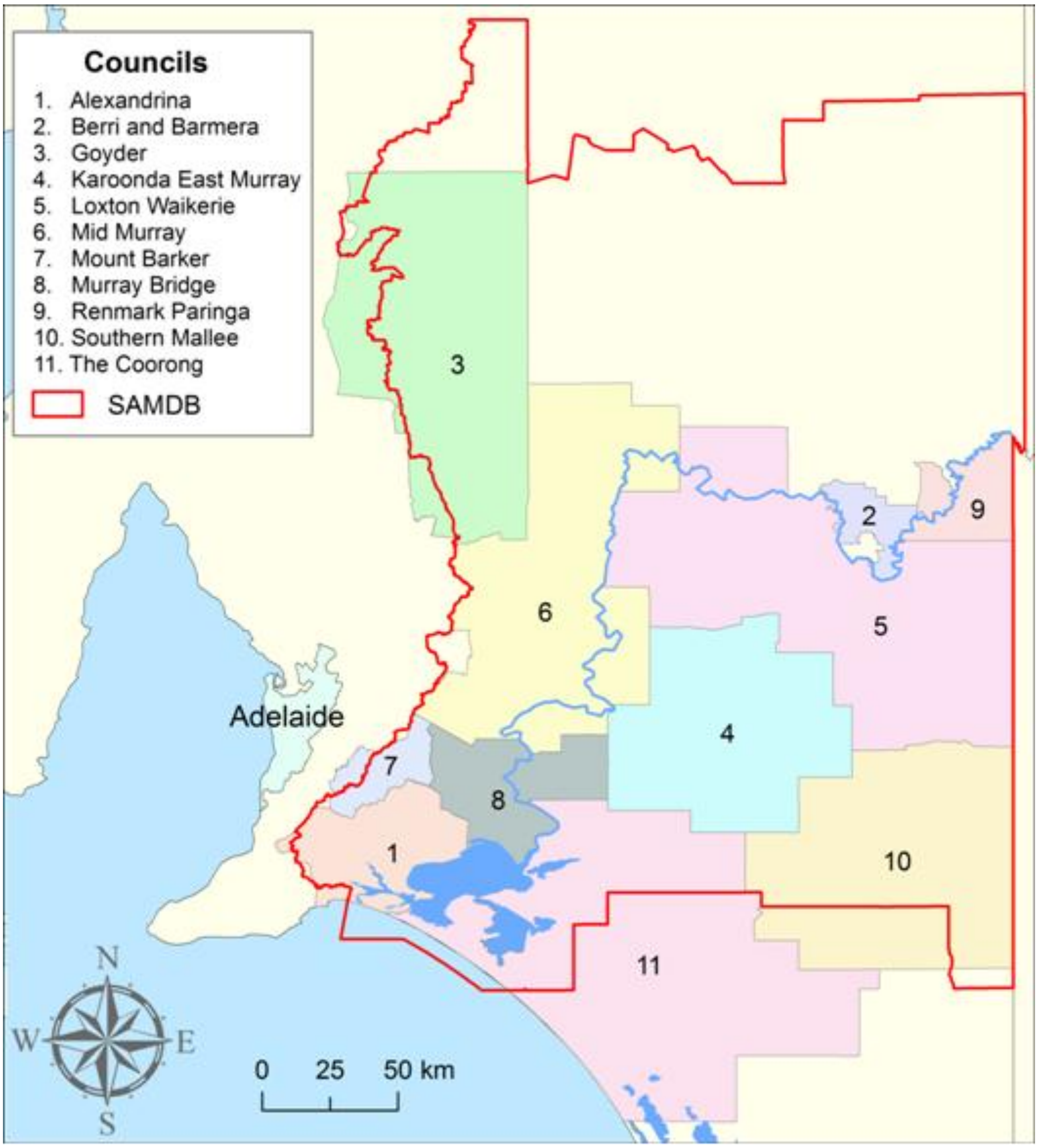


Figure 3: The South Australian Murray-Darling Basin showing overlay of local government boundaries relevant to this project

Source: (Meyer et al., 2010)

This is one of South Australia's most ecologically diverse and agriculturally productive regions. It supports a wide range of flora, fauna, natural environments and human activities. The SA MDB is in the rain shadow of the Mount Lofty Ranges, resulting in a marked reduction in rainfall compared to the country to the west. Even over short distances, a large reduction in rainfall can occur. Annual rainfall ranges from an unreliable 260 mm at Renmark in the northern part of the SA MDB, to 387 mm at Lameroo, near the south-eastern corner of the SA MDB, to 768 mm at Mount Barker near the western edge of the SA MDB.

The SA MDB's natural resources support a wide range of human activity including irrigated and dryland agriculture, tourism and recreation and various manufacturing industries (notably food products, wine and beverages). Many South Australian towns and urban centres, including Adelaide, rely heavily on the River Murray for a large proportion of their annual potable water supply needs. The SA MDB also faces significant urban growth pressures around some of its major towns, most notably Mount Barker, Murray Bridge and Goolwa, placing increased pressure on natural resources in these localities.

Primary production utilises about 82% of the land area of the SA MDB consisting mostly of pastoral lands (43%) and dryland cropping and higher rainfall pasture areas (38%). Grazing of the rangelands is a major land use north of the River Murray. Adjacent to the River Murray, within part of the Mallee and along the Eastern Mt Lofty Ranges, horticulture is a major land use consisting of wine grapes, citrus, stone fruit and vegetables. There are also areas of dairy production on the Lower Murray Reclaimed Irrigation Areas and around the Lower Lakes. In the agricultural areas, broadacre farming is largely mixed cereal and livestock grazing, although pulse and oilseed crops are increasing as cropping intensifies, particularly in the more reliable rainfall areas to the south.

The SA MDB has been gripped by severe drought in recent years, with whole of River Murray system inflows during the past two years being the lowest on record. Particularly dry winter seasons throughout the Murray-Darling Basin have resulted in low inflows, as well as declining river and groundwater levels in many areas. The impact of drought is particularly evident at the downstream end of the River Murray system and other catchments, including the Eastern Mount Lofty Ranges, Burra and the Marne and Saunders.

Reductions in allocations, limited water access and worsening water quality have significantly affected horticultural, agricultural and dairy industry output and, in turn, have had wider impacts on local communities and economies. Whilst irrigators along the River Murray system have been hit hard with reduced water allocations since 2006/2007 (e.g. closing allocations of 60% in 2006/2007 and 32% in 2007/2008), water users in other areas have also been impacted by either reduced access to water and/or poor water quality. Little improvement is expected without significant rainfall and runoff.

Major threats to the natural resources of the SA MDB arise from past and current uses or from broader global processes. Some arise from decisions and actions made within the SA MDB while others arise from the decisions and actions of upstream states or from global processes (e.g. climate change). Of particular note are:

- the impact of introduced pest plant and animals;
- the continued fragmentation and decline of remnant native ecosystems;
- ongoing land degradation processes such as dryland salinity and soil acidity;
- the allocation, capture and non-licensed extraction of water resources beyond sustainable limits;
- altered quantity and timing of flows within river systems;
- declining water quality due to increasing salinity, nutrients and pollution; and
- inappropriate development practices.

Many of these threats are further compounded by the risk of a warmer, drier region under climate change predictions.

2.3 Modelling Modules

The CCCE project was conceived and conducted as a series of modules which were designed and structured as stand-alone pieces of research (Figure 4). These model the biophysical (APSIM - The Agricultural Production Systems Simulator (Keating et al., 2003); 3PG - Biomass and Carbon Sequestration Modelling (Landsberg and Waring, 1997); Species Vulnerability to Climate Change (Summers et al., 2012)), economic and social impacts of 4 possible future climate scenarios. The key objectives of each module are listed in Table 1.

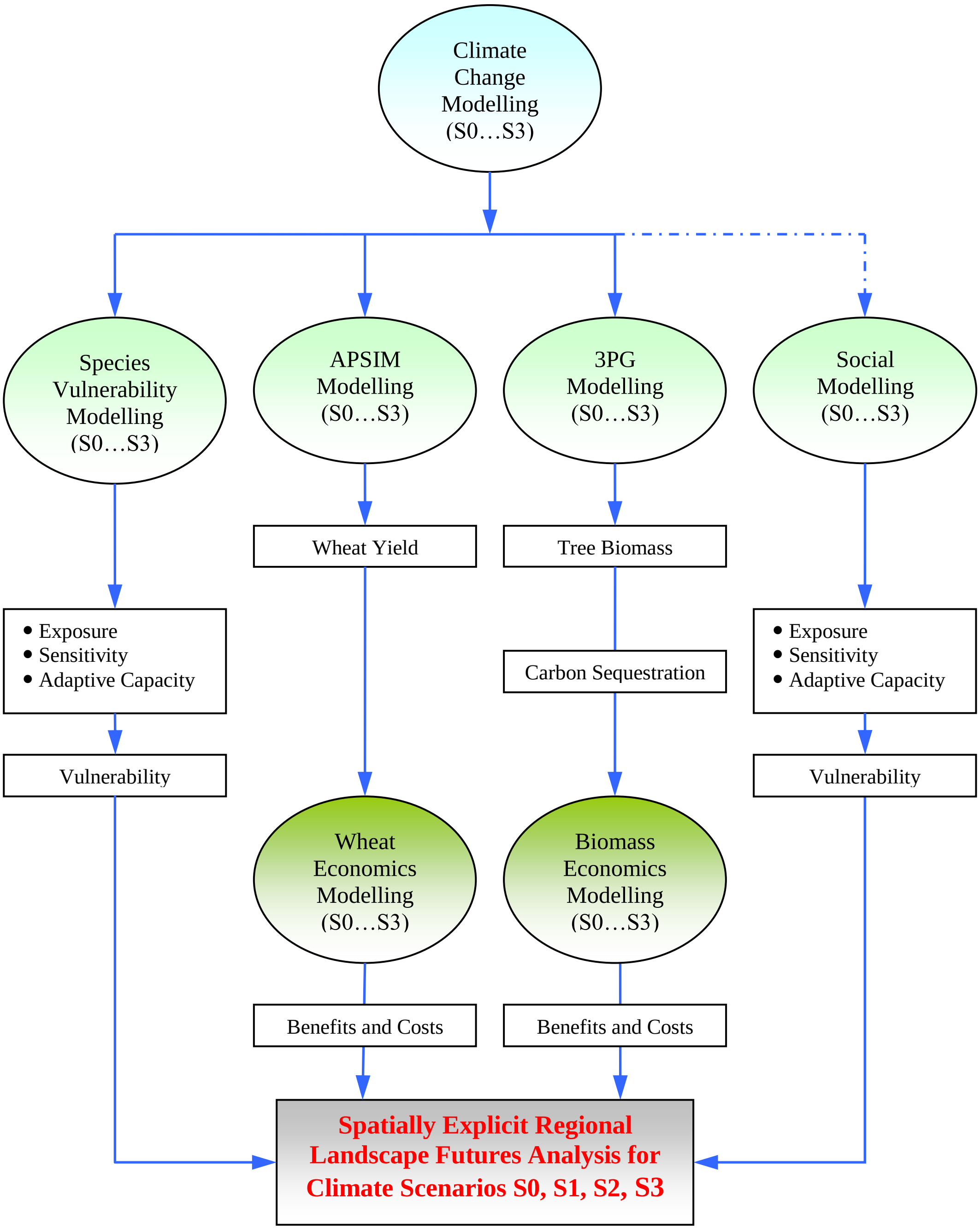


Figure 4: Modular structure of the CCCE project

Table 1: Modelling modules and key objectives

Module	Key Objectives of Module
Climate Change Scenarios	
Climate Change Modelling	Model climate change for both the Eyre Peninsula NRM region and the Lower Murray region (consisting of the South Australian Murray Darling Basing NRM region and the Mallee and Wimmera CMA regions in Victoria). Define a baseline climate scenario (S0) and 3 suitable climate change scenarios (S1, S2, S3) and associated estimates of rainfall, precipitation and atmospheric CO_2 from regional climate models. Model spatial climate surfaces for each scenario using SILO Patched Point Data or ECOCLIM data for both the EP and Lower Murray regions.
Biophysical Modules	
APSIM - Wheat Productivity Modelling	Classify EP into sub-regions based on historic climate data for input to the APSIM Model. Classify EP into sub-regions based on soil characteristics for input to APSIM. Define the parameters for wheat cropping under traditional farm management on EP. Use APSIM to model wheat yield on EP under the baseline and future climate scenarios to inform agricultural economics.
$3PG_2$ – Biomass and Carbon Sequestration Modelling	Model the biomass productivity of a homogenous hardwood plantation of a Eucalyptus species, a multi-species environmental plantation, and an oil malle e plantation for input into the biomass economic modelling. Do this under the baseline and each of the future scenarios for both the EP and Lower Murray regions. Calculate the carbon productivity (based on biomass) associated with the homogenous plantations of a Eucalyptus species, the multi-species environmental plantation and the oil mallee plantation. Do this for the baseline and future climate scenarios for both the EP and Lower Murray regions.
Species Vulnerability Modelling	Quantify the vulnerability of native plant species to climate change based on exposure, sensitivity and adaptive capacity, for use in the landscape futures analysis. (584 native plant species in the Lower Murray region and 285 native plant species in the Eyre Peninsula NRM region) • Quantify exposure as species' geographic range under climate change using species distribution models. • Calculate sensitivity as a function of the impact of climate change on species' geographic ranges. • Quantify adaptive capacity as species' ability to migrate to new geographic ranges under climate change scenarios, using a dispersal kernel. Using *Zonation*, assess the impact of individual components of vulnerability (exposure, sensitivity and adaptive capacity) on spatial conservation priorities and levels of species representation in priority areas under each climate change scenario. Use the full vulnerability framework as a basis for identifying spatial conservation priorities under climate change.
Benefit and Cost (Economic) Modules	
Wheat Economics Modelling	Quantify the economic returns and costs of wheat production in the EP NRM region. Model the spatial distribution of economic returns from wheat production on EP under the 4 climate scenarios, plus a number of extra scenarios to account for

	seasonal variations.
Biomass and Carbon Sequestration Economics Modelling	Quantify the economic returns and costs of biomass production for both the EP and Lower Murray regions. Model the spatial distribution of economic returns from biomass production under the baseline and future climate scenarios for the homogenous plantations of a Eucalyptus species and the multi-species environmental plantation. Quantify the economic returns and costs of carbon sequestration. Model the spatial distribution of economic returns from carbon sequestration (carbon trading) under the baseline and future climate scenarios for the homogenous plantations of a Eucalyptus species and the multi-species environmental plantation. Quantify the economic returns and costs of biofuel production from an oil mallee plantation. Model the spatial distribution of economic returns from biofuel production under the baseline and future climate scenarios for the oli mallee plantation.
Social Modules	
Social Modelling	Review the literature from Australia and internationally on social indicators that have been used to characterise regional social vulnerability to natural hazards such as drought. Perform surveys of the social relationships within Eyre Peninsula, and perform network modelling using these results to determine who influences who in the decision making process at various levels.

2.4 Datasets

A large amount of data was collated for the Eyre Peninsula NRM and Lower Murray regions - meteorological, land use, cadastral, vegetation distribution, soils, geological, demographic and regional economic data. This data comes from many sources including the Bureau of Meteorology, Australian Soils Resource Information System, Australian Bureau of Agricultural and Resource Economics and Australian Bureau of Statistics as well as State data from Department of Water, Land and Biodiversity Conservation, Department for Environment and Heritage and Primary Industries and Resources South Australia.

Table 2 lists the key datasets used in each modelling module for the Eyre Peminsula and Table 3 those for the Lower Murray.

A full list of the spatial datasets used in this project, and their custodians, can be found in Lyle (2010) for the Eyre Peninsula, and Summers and Lyle (2010) for the Lower Murray. These reports contain a more detailed description of each of the datasets.

Table 2: Key modelling datasets for the Eyre Peninsula by module

Module **Datasets**	**Custodian**	**Year**	**Comments**
Climate Change Modelling			
IPCC Global Predictions	IPCC (2007)		Climate change projections
The Suppiah refinement of global scale projections for southern Australia	Suppiah et al. (2007)		Climate change projections
APSIM - Wheat Productivity Modelling			
Weather station locations - Point data	Bureau of Meteorology		For APSIM Zones
Daily rainfall - Gridded data	Bureau of Meteorology	1900 to 2008	To classify sub-regions
SILO Patched Point Dataset - Daily weather station data – Point data	QCCCE	1900 to 2010	Baseline climate data
• maximum temperature			
• minimum temperature			
• rainfall			
• solar radiation			
Soils database - Polygon data	DENR		
APSIM/APSOIL soil sites database - Point data	APSRU		
Wheat cropping system and management parameters	APSRU & published research		Non spatial
Initial nitrogen and applied nitrogen levels	Scientific lit. and unpublished EP measurements (RSSA)		Broad spatial scale
Eyre Peninsula historic wheat yield data			Validation data
• data from precision agriculture aggregated to paddock/soil averages	RSSA & Grower records		
• farmer records of paddock yield from Minnipa over 25 years	Growers records & MAC		
• EP red brown earth trails (10 years of data), EP grain and graze upper EP trials	RSSA		
• Regional wheat yields	PIRSA		
$3PG_2$ – Biomass and Carbon Sequestration Modelling			
Australian Soil Resource Information System (ASRIS) - level 5 (1:100 000), level 4 (1:250 000) & level 3 (1:1 000 000)	CSIRO Land and Water	2007	
• soil type			

• available soil water			
SRTM Digital Elevation Model (DEM) – 3’ sec 90m, - Corrected by Brett Bryan • used to model solar radiation in ArcGIS 9.3 • used as an input to ESOCLIM	PIRSA		
ESOCLIM module of ANUCLIM 5.1 – Output grids (100 m) of long-term mean monthly • maximum temperature • minimum temperature • rainfall	ANU	1892 to 2000	Baseline climate data
Species Parameters • E. cladocalyx • E. kochii (oil malle) • Environmental plantations	$3PG_2$ - Almeida et al. (2007) • Paul et al. (2007) • Bryan et al.(2010a) • Almeida et al. (2007)		Non-spatial
Biodiversity Modelling			
Australian Soil Resource Information System (ASRIS) - level 5 (1:100 000), level 4 (1:250 000) & level 3 (1:1 000 000) • clay content • soil pH	CSIRO Land and Water	2007	
SRTM Digital Elevation Model (DEM) – 3’ sec 90m, - Corrected by Brett Bryan • used to model solar radiation in ArcGIS 9.3 • used as an input to ESOCLIM	PIRSA		
ESOCLIM module of ANUCLIM 5.1 – Output grids (500 m) of long-term mean annual • maximum temperature • minimum temperature • rainfall	ANU	1892 to 2000	Baseline climate data
Biological survey database	DENR		
Wheat Economics Modelling			
Information on costs from gereralised PIRSA and ABS data			
Biomass and Carbon Sequestration Economics Modelling			

?
Social Modelling
Rodolphe’s Survey results

Table 3: Key modelling datasets for the Lower Murray and South Australia Murray-Darling Basin by module

Module **Datasets**	**Custodian**	**Year**	**Comments**
Climate Change Modelling			
IPCC Global Predictions	IPCC (2007)		Climate change projections
The Suppiah refinement of global scale projections for southern Australia	Suppiah et al. (2007)		Climate change projections
$3PG_2$ – Biomass and Carbon Sequestration Modelling			
Australian Soil Resource Information System (ASRIS) - level 5 (1:100 000), level 4 (1:250 000) & level 3 (1:1 000 000) • clay content • bulk density • available soil water	CSIRO Land and Water	2007	
SRTM Digital Elevation Model (DEM) – 3' sec 90m, - Corrected by Brett Bryan • used to model solar radiation in ArcGIS 9.3 • used as an input to ESOCLIM	PIRSA		
ESOCLIM module of ANUCLIM 5.1 – Output grids (100 m) of long-term mean monthly • maximum temperature • minimum temperature • rainfall	ANU	1892 to 2000	Baseline climate data
Species Parameters • E. cladocalyx • E. kochii (oil malle) • Environmental plantations	$3PG_2$ - Almeida et al. (2007) • Paul et al. (2007) • Bryan et al.(2010a) • Almeida et al. (2007)		Non-spatial
Biodiversity Modelling			
Australian Soil Resource Information System (ASRIS) - level 5 (1:100 000), level 4 (1:250 000) & level 3 (1:1 000 000) • clay content	CSIRO Land and Water	2007	

• soil pH			
SRTM Digital Elevation Model (DEM) – 3’ sec 90m, - Corrected by Brett Bryan • used to model solar radiation in ArcGIS 9.3 • used as an input to ESOCLIM	PIRSA		
ESOCLIM module of ANUCLIM 5.1 – Output grids (500 m) of long-term mean annual • maximum temperature • minimum temperature • rainfall	ANU	1892 to 2000	Baseline climate data
Biological survey database	DENR		
Biomass and Carbon Sequestration Economics Modelling			
?			

Chapter 3

MODELLING CLIMATE CHANGE SCENARIOS

3.1 Defining Climate Change Scenarios

The Intergovernmental Panel on Climate Change predicted that climate change will bring about an increase in global temperature between 1.1 and 6.0 ^{0}C by 2100, an increased variability in rainfall and an increase in atmospheric CO_2 (IPCC, 2007). Based on this, we defined four scenarios in this study for the year 2070 - a baseline climate (S0) and three possible climate change scenarios (S1, S2 and S3) (Table 4).

The climate change scenarios (S1, S2, S3), representing exposure to increasingly severe climatic warming and drying, were defined using the Suppiah et al. (2007) refinement for southern Australia of IPCC global scale projections (Table 4). These are consistent with those used in previous landscape futures analyses and with those being used by other State Government Departments (Bryan et al., 2010a; Bryan et al., 2007; Bryan et al., 2011; Bryan et al., 2010b; Summers et al.,2012). This ensures a consistency of message in relation to climate change effects based on current knowledge.

Table 4: Climate scenarios

Scenario	Description	Temperature	Rainfall	CO_2 (Parts per Million)
S0	Baseline	Historical mean	Historical mean	390
S1	Mild warming and drying	1°C warmer	5% dryer	480
S2	Moderate warming and drying	2°C warmer	15% dryer	550
S3	Severe warming and drying	4°C warmer	25% dryer	750

3.2 Data Used to Define the Baseline Climate Scenario

The baseline scenario S0 is based on historical daily climate records (Table 4). A number of climate databases were used by the different modules in this project for modelling, depending on the climate inputs required by each (Table 2 and 3 and Figure 5). The APSIM model (Keating et al., 2003) requires daily climate data; the 3PG model (Landsberg and Waring, 1997) requires monthly data, while our biodiversity modelling (Summers et al.,2012) uses annual means.

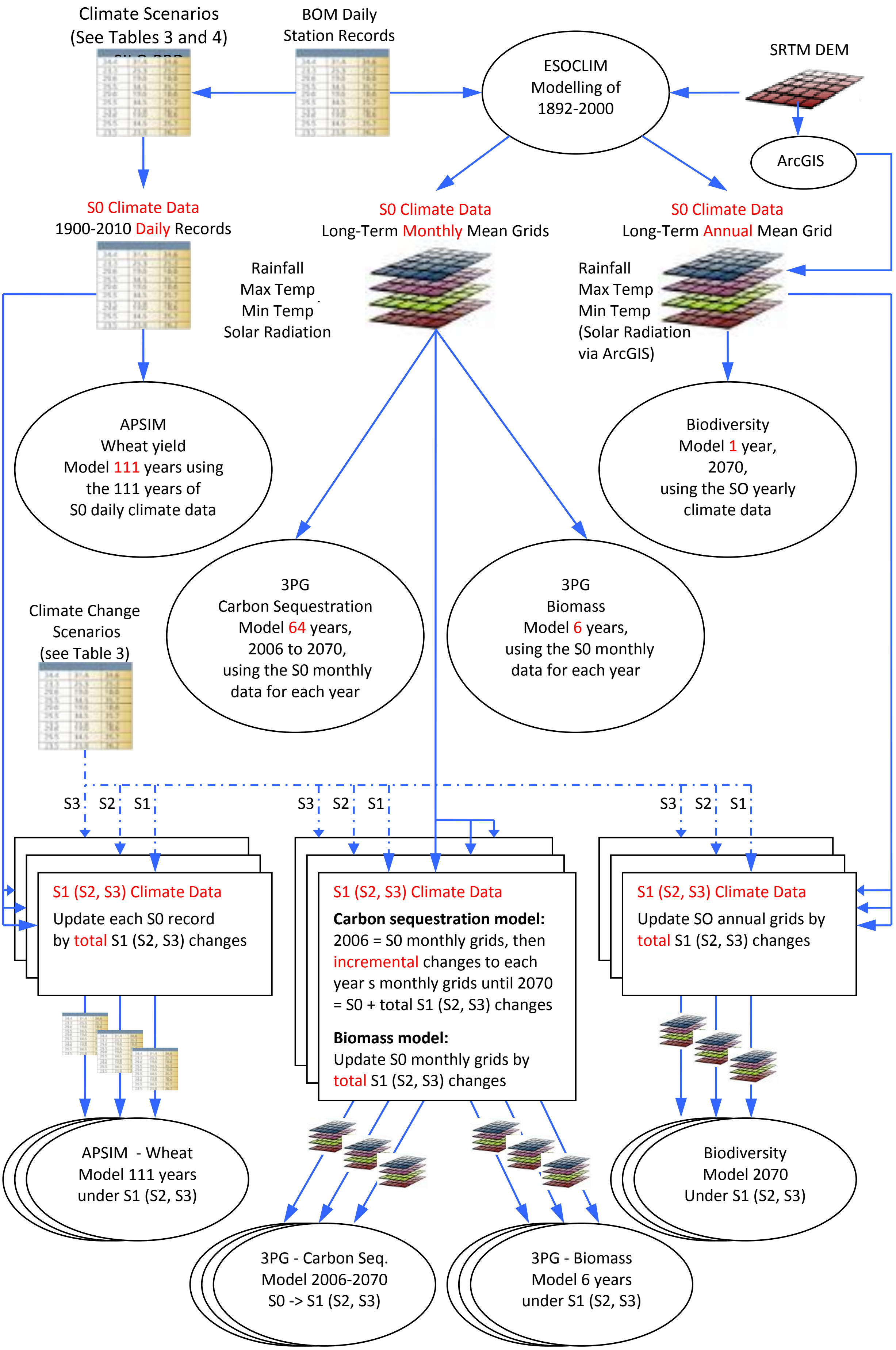


Figure 5: Climate change modelling (baseline climate S0, and 3 climate change scenarios S1, S2, S3)

APSIM models agricultural productivity for individual sites in the landscape, and requires daily weather data including solar radiation, rainfall, and maximum and minimum temperatures. (See Section 4.1 for APSIM modelling.) This climate data came from the SILO Patched Point Dataset (PPD), an enhanced climate data bank hosted by the Queensland Climate Change Centre of Excellence (QCCCE) (QCCCE, 2012). The Patched Point Dataset provides continuous daily climate data from the original Bureau of Meteorology records for each of the Bureau's stations, but uses interpolated data to fill ("patch") any gaps (missing days) in the observation records. To reflect the natural variation in the annual yield over time, including times of drought and flood, as well as average years, the baseline scenario S0 used 111 years of data (1900 to 2010).

Both the 3PG (tree growth) and biodiversity models are spatial models requiring gridded (raster) climate data. (See Sections 4.2 and 4.3 for 3PG and biodiversity modelling.) To define the baseline scenario S0 for these models we used ESOCLIM a component of the ANUCLIM software package of programs (Houlder et al., 1999). ESOCLIM uses thin plate smoothing splines and a digital elevation model of the area of interest to interpolate climate surfaces from point data recorded at meteorological stations. We used climate data from 109 years (1892 to 2000) and the three second Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) as input for the ESOCLIM interpolation. Output grids characterising the spatial distribution of the long-term (1892 to 2000) monthly means of various climate variables including maximum temperature, minimum temperature, rainfall and solar radiation were used by the 3PG model (i.e. 12 grids per climate attribute). On the other hand, biodiversity modelling used output grids of the long-term annual means of maximum temperature, minimum temperature and rainfall (1 grid per climate attribute), but solar radiation was modelled based on the STRM DEM using the *Area Solar Radiation* tool within the ArcGIS 9.3 toolbox (ESRI, 2009).

3.3 Modelling the Climate Change Scenarios

For each of the datasets defining the baseline scenario for the various modules, data for the climate change scenarios [mild (S1), moderate (S2), and severe (S3) warming/drying] were created by modifying the baseline temperature, rainfall and CO_2 records by the relevant amounts. Solar radiation was kept constant for the change scenarios.

Modelling methodology was different for the various modules.

For the baseline scenario S0, APSIM modelled wheat productivity on a daily time scale for each of 111 years (1900-2010) of historical daily SILO PPD climate records (QCCCE, 2012). (See Section 4.1 for APSIM modelling.) For modelling the climate change scenarios S1, S2 and S3, daily climate records for each were created by adjusting the 111 years of daily baseline records by the relevant temperature, precipitation and CO_2 changes (i.e. for S1, add 1°C to every daily record for the 111 years, decrease the rainfall records by 5% and set the CO_2 level to 480 parts per million).

3PG models tree growth on a monthly time scale. (See Section 4.2 for 3PG modelling.) Two different models were run. The first used long term average monthly climate data from 2006 to 2070 for modelling non-harvested carbon (carbon sequestration) and environmental plantations. 3PG modelling for the baseline climate scenario (S0) assumes the S0 monthly data will remain constant from 2006 to 2070 (i.e. the model is run for 64 years using the same long-term monthly climate averages, output from ESOCLIM (Houlder et al., 1999), for each year). For the three climate change scenarios, climate values were calculated by altering the baseline (S0) temperature and rainfall grid values in annual increments from 2006 to reach either the S1, S2 or S3 values by 2070, thus modelling the possible progression of climate change over the next 64 years. The second 3PG model used a single year of long term monthly average data (either the S0, S1, S2, or S3 monthly values) for modelling biomass (oil mallee) under a 6 year rotation.

The impact of climate change on species and biodiversity was modelled using species distribution models (see Section 4.3 for biodiversity modelling). This is done by predicting species distributions based on the relationship between independent variables (including climate variables) and known species occurrence. The baseline scenario S0 modelling used the long-term annual mean grids output from ESOCLIM. Species distributions can be predicted under climate change by substituting current climate for future climate layers, reflecting where plant species would struggle or thrive under changed climate conditions. Annual mean precipitation and annual mean temperature under the three climate change scenarios S1, S2 and S3 were created by adjusting the baseline climate grids created in ESOCLIM by the relevant temperature increase and rainfall decrease.

Chapter 4

MODELLING THE BIOPHYSICAL IMPACTS OF CLIMATE CHANGE

4.1 APSIM – Wheat Productivity Modelling

The ability to accurately simulate current yield potential of agricultural soils at a regional scale is an important first step for determining the impacts of and gaining an understanding of the vulnerability of agricultural areas to climate change. Within Australian Mediterranean agricultural areas where wheat is the major crop grown, climate (in particular rainfall) and its interaction with soil properties are major growth limiting factors. Quantifying the yield potential of these soil types for particular sub regions is the first step to understanding climate change vulnerability in agricultural areas. The ability to both reflect on past yields and simulate future yields is an advantage of crop modelling and provides a valuable and cheaper alternative to long term trials in agricultural areas. Previous studies have used crop models to simulate our understanding of these interactions at various scales. For regional studies like this one, Asseng et al., 2001a applied the APSIM model to five soil types across 2 transects which incorporated 25 locations across a low to high rainfall gradient. Results from the cumulative probability distributions for the soil types were then mapped using interpolation to identify the spatial distribution of drainage potential for wheat crops. This methodology was adapted further by Pracilio et al., 2003 producing a high spatial resolution estimates of deep drainage for a small catchment based on probabilistic digital soil mapping. Similarly, Luo et al., 2005 used 8 sites across South Australia using one representative soil for each location to simulate the effects of a range of probabilistic climate change scenarios. Wang used 16 climate stations and 14 soil profile types deemed representative of the broad soil classes over Lower Murray study region. While Bryan et al., used crop modelling to understand the spatial variation in production across the cropping regions of South Australian Murray Darling Basin. Their method involved classifying the study area into representative climate zones. Once these were established, data was gathered to identify the representative soil profiles and farming systems for the region. The APSIM model was then used to model the growth of agricultural plants and an assessment of the overall performance of current and alternative farming systems was made.

In this study we further this research by using the APSIM crop model to simulate wheat yield at regional scale keeping a fine scale approach by applying spatially dense network of long term climate stations and a range of potential soil types that are likely to be found across the Eyre Peninsula.

APSIM parameter set -up

The Agricultural Production Systems Simulator (APSIM) is a point based farming systems model capable of simulating plant growth, water use and water balance under representative climate and farm system management inputs. It was developed to simulate the dynamic biophysical process under changes in climate, cropping stems and fertiliser management. The parameterisation of the model and its outputs has been validated in Australian conditions to estimate biophysical and ecological outcomes within a farming system under a variable climate (Keating et al., 2003). It has been used and validated extensively in Australia (Probert et al., 1995; Asseng et al., 1998b) and has corroborated its simulation reliability under variable growing conditions (Asseng et al., 1998a; Asseng et al., 2001). Focus of previous modelling has related to identifying the affect of climate variability on yield performance and profits, the assessment of different crop management strategies such as optimal nitrogen applications (Wang et al., 2009), and environmental impact of cropping in agricultural areas. Several studies have been undertaken in southern Australia and the Eyre Peninsula.

The Agricultural Production Systems Simulator (APSIM) model can simulate numerous plant growth scenarios but for this study wheat (*Triticum aestivum* L.) performance was the primary focus. The model simulate wheat growth by utilising modules that incorporates aspects of soil, water, nitrogen, crop residues, crop growth and development and their interactions within a crop/soil system that is driven by daily weather data (Keating et al., 2003). It calculates the potential yield, which is the maximum yield reached by a crop in a given environment that is not limited by pests, disease, weeds, lodging but is limited by temperature, solar radiation, water and nitrogen supply (Asseng et al., 2004).

Multiple simulations can be run to understand the crop growth of plants based on their response to climate, soils and their interactions and the evaluation of management intervention based on tillage, irrigation, fertilisation and rotation selection.

APSIM requires the following input data:

- Daily weather data including global radiation, rainfall, maximum and minium temperatures;
- Soil surface characteristics including soil albedo, water entry and retention capacity, evaporative potential and surface residue cover;
- Hydraulic properties of soil profile including water contents at saturation drained upper limit and 15 bar suction and drainage coefficient for each soil layer;
- Crop variety information (maturity type) and maximum rooting depth in the simulated soil profile;
- Cropping systems type including crop type, rotation type and management details such as tillage, irrigation and fertilisation

The APSIM 7.3 crop model was parameterised for this study. Hayman, 2010 suggest that in any simulation exercise it is a matter of judgement in the setting of fixed or variable parameters and when or if to reset soil water and N conditions. Simulated grain yields are sensitive to sowing time, starting soil conditions (especially water stored in the soil) and seasonal conditions.

APSIM calculates outputs for individual sites in the landscape. Certain steps were followed in order to capture the spatial variation in agricultural production across the Eyre Peninsula through crop simulation modelling. The involved the population of model inputs based on their geographic representation with the dominating factors being climate, soil and fertiliser, all of which vary spatially.

A simplified dryland wheat-fallow farming system was adopted to represent a wheat crop that was sown every year (continuous wheat monoculture) followed by summer fallow period up until the next sowing. The 'Janz' wheat variety, a mid to late maturity variety, was chosen to be sow yearly during the timing window between 1st May and 1st July of each year. Sowing occurred when cumulative rainfall over three consecutive days was greater than 10mm or when the end of the sowing window was reached. Sowing density was set to 180 plants/m^2 , sown to a depth of 40mm and at a row spacing of 220 mm. Surface residue was assumed to be wheat stubble and initialised to 1 t/ha. Soil organic carbon level was reset to the starting value for the soil. The ratio of carbon to nitrogen was set to 80. Wheat grain was harvested at maturity. The soil moisture, soil nitrogen and surface organic matter were reset at 1st January each year to remove the impact of the previous crop and season on the following crop. Resetting soil N and organic matter also avoided problems such as fertility rundown in a continuous wheat monoculture which would make interpretation difficult (CRIMP- Garnaut). Soil moisture was set to 30% of maximum available water for each soil characterisation which was evenly distributed down the profile. This followed the method used by Luo et al., 2009 and Hayman et al., 2010 who set moderate soil water values to ensure reasonable emergence rates (17-36%) to eliminate modelled crop failures in order to trace and detect the patterns of climate change impact. One difference between our study and those previous was that we set our soil water parameter to reset at 1st January rather than at the 30th March. This choice was made to include the influence of the projected reduction in summer rainfall caused by climate change on the summer rainfall analogue.

Rainfall variation across the Eyre Peninsula has an effect on the amount of Nitrogen mineralised in the soil and the amount applied for crop management. For the model this was varied across three generalised rainfall regions (low, medium and high) informed by the results from regionalisation of the Eyre Peninsula by rainfall.

The model incorporates two sources of fertilisation which represent a fixed amount of nitrate mineralisation and ammonium at the start of a simulation and an applied amount at sowing and in some circumstances a “top dress” amount at particular crop growth stage. For initial parameterisation mineral nitrogen and ammonium concentration (NO_3-N) values in the 0-100cm soil profile were set to rainfall zone specific variables, varied linearly across particle size differences and distributed uniformly across the rooting depths. The magnitude of values were derived from published (Adcock, 2005) and unpublished measurements of soil nitrate and ammonium levels for specific soil textures from Eyre Peninsula soils. We stratified these measurements based on soil texture ranging from sandy loam to clay loam and rainfall zone. Linear extrapolation bounded by expert opinion was then undertaken to populate these initial nitrogen and ammonium settings across rainfall, rooting depth and texture variables. See Appendix 5 for the values used.

Common agricultural practice is to place nitrogen fertiliser as a blanket rate when sowing is undertaken. Further top-up rates are also applied in medium and high rainfall regions at a particular crop growth stage. Appendix 5 highlights the top up rates that were applied in the model between Zaddocks stages 30 and 32.

Soil type parameterisations of the APSIM model were defined by geographic location. The typological definition of soils through particle size (texture) differences allowed us to distinguish variations of soil evaporation parameters in the model. These variables U which is the amount of cumulative evaporation in mm, since soil wetting, before soil supply becomes limiting and CONA which is the coefficient used to calculate subsequent soil evaporation in stage 2 that is a fraction of the square root of time since the end of first stage evaporation can be changed for each soil characterisation. We linearly adjusted the soil evaporation values based on minimum and maximum values of U and CONA from the APSOIL database for the Eyre Peninsula and the degree of variation across the textural differences in the soil types (Appendix 5).

4.1.1 Climate Sub-Region Classification

One of the first steps in conducting regional climate change impact assessments is to understand the variety of localised climatic profiles which currently exist. However, quality datasets on climate variation across regional Australia over time are limited. We therefore concentrated on differentiating sub-regions based on the rainfall which is both the most dominant factor in agricultural productivity and mostly widely measured climate variable across the Eyre Peninsula. For agricultural areas this is significant in two ways. First, any change in the seasonal distribution of rainfall has a potentially large effect on rain dependant cropping practices. Second, any potential adaptation to changed climate conditions through changed land uses will need to be cognizant of potential changes in seasonal rainfall and temperatures.

The Bureau of Meteorology produces interpolated surfaces of estimated values of daily rainfall across the Australian continent. These interpolated surfaces have an archive back to the year 1900. For the analysis, daily rainfall surfaces from 1920-2009 were selected to maximise the number of rainfall stations used in the interpolation process. The surfaces were aggregated to monthly totals and clipped to the EP NRM study region with a 50 kilometre inland buffer. Cluster analysis highlighted the statistical, spatial and temporal distributions of monthly rainfall variation across the Eyre Peninsula (Appendix 5). The monthly datasets were then resorted into growing season rainfall analogues, April to October for the time period 1920-2009 and cluster analyse was re-run to identify the long term growing season rainfall zones. While a total of 15 rainfall cluster zones were identified, only nine of these fell mainly in the EP NRM region, with the other six mainly in the 50km buffer (Figure 6).

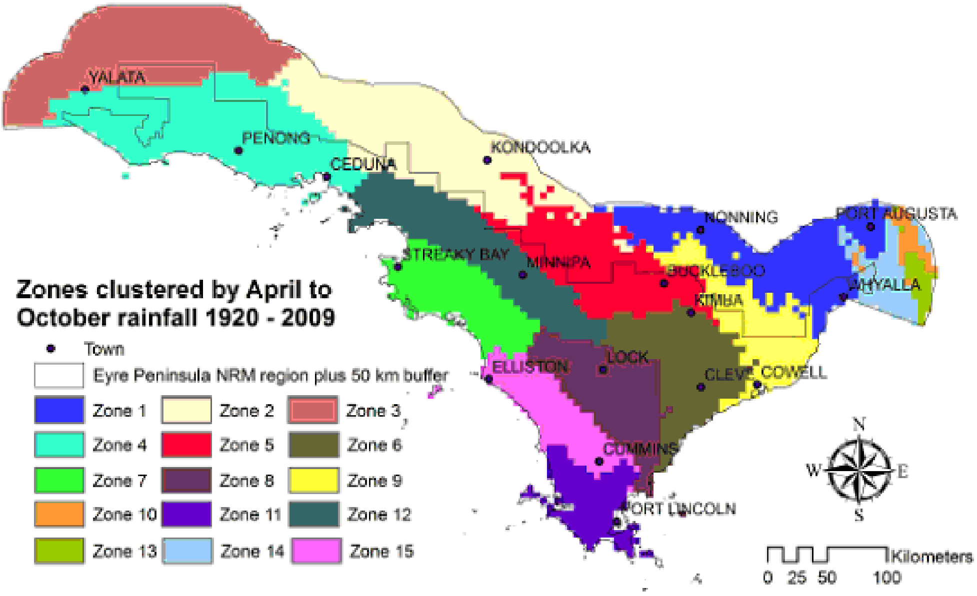


Figure 6: Rainfall cluster zones in Eyre Peninsula NRM region plus a 50 km inland buffer

Cluster zones for the aggregated dataset - April to October rainfall over the 1920 to 2009 time period

4.1.2 Soil characterisation of the Eyre Peninsula

The most important soil factor that controls yield in much of the Australian grain-production regions is the quantity of plant available water (Rab et al., 2009). Variations in the soil moisture or water retention can be explained in general terms by texture, soil structure, clay mineralogy and texture (Williams et al., 1983). Plant available water is also a major input into simulating wheat crop yield potential within the APSIM crop modelling process. The model requires the quantification of the plant available water holding capacity to identify how much water is stored within the soil profile over variations in rooting depth. Burk et al., 2008 provides a method to characterise soil-water interactions based on field capacity (drained upper limit) and permanent wilting point (lower limit) to characterise the. Differences between the drained upper limit and the lower limit for wheat represent PAWC for the specific rooting depth. Plant available water holding capacity is the total of all differences across all rooting depths. Recent research on Australia (Rab et al., 2011) has shown an increasing relationship between field capacity and permanent wilting point with soil texture. Calculation of the PAWC values also showed an increasing relationship with soil texture up until the clay-loam soil type category where PAWC values remained relatively constant after this category. Figure 7 shows the lower limit and drained upper limit measurements for wheat across three soil types surveyed on the Eyre Peninsula. All soils were characterised at a rooting depth of 1200mm and recorded a PAWC of greater than 100mm (sand=113mm, sandy-loam=132mm and clay loam=271mm). While the lower limits for the three soils shown fairly similar levels, the greatest differences are in the magnitudes of drained upper limits across the soil textures. Figure 7 shows that PAWC increases with the increase in particle size classifications from sand to sandy-loam to clay-loam soil types.

The majority of APSIM based studies reflect Plant Available Water Capacity (PAWC) as the total mm held within a rooting depth usually over 100 cm (Wang et al., 2009 etc…). Asseng et al., 2001a derived PAWC characteristics down to 250cm but limited the potential rooting zone in their analysis to 150cm for deep sands, 230cm for loamy sand, 150cm acid loamy sand, 70cm for shallow duplex and 130cm for clay soil types. Holding rooting depth constant means that PAWC differ in soil texture only. In reality, spatial variations in the magnitude of rooting depth and soil textures mean different definitions for similar PAWC values. For example, a PAWC measurement of 100mm could be a variety of rooting depths and texture combinations such as a deep sand soil type with a rooting depth of 100cm or a clay soil type with a rooting depth of 60cm. Both of which may potentially simulate different wheat yield values within the crop modelling software. While previous studies have assumed rooting depth to be greater than 1m, in reality the root zone depth is dependent on seasonal factors and soil constraints. In the Victorian Mallee, Armstrong et al., 2009 found that maximum rooting depth was 0.75m and Rab et al., 2009 found that 95% of the root mass was found in the top 60cm of the soil profile.

In order to characterise the wheat yield potential of the Eyre Peninsula we break the variation in PAWC magnitudes that is apparent across the Eyre Peninsula into a number of different rooting depth and texture categories.

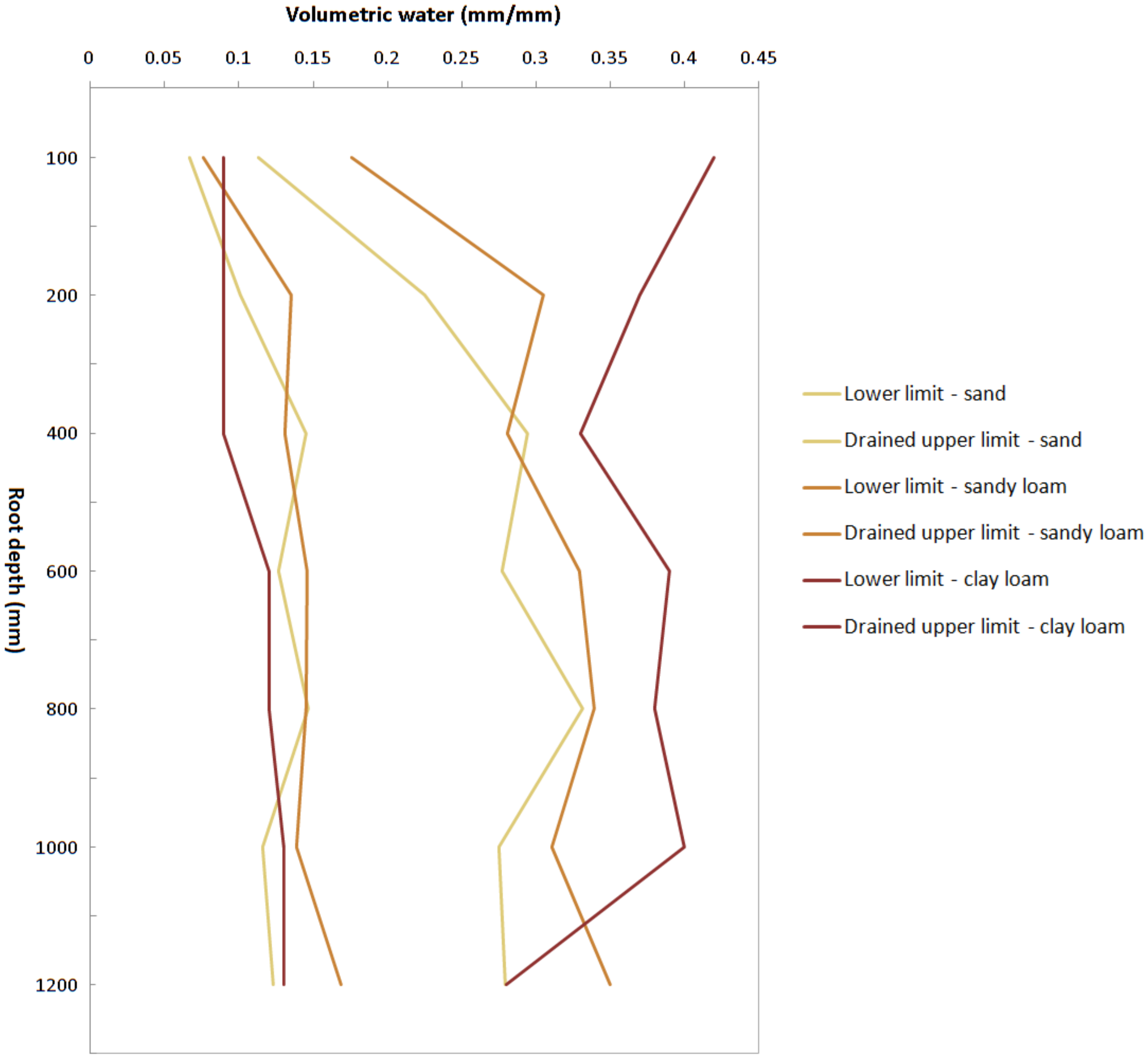


Figure 7: Lower and drained upper limit for three soil characterisations for a sand, sandy-loam and clay loam

Identifying texture and rooting depth classifications

The APSOIL database has 69 soil characterisations for the Eyre Peninsula describing information on texture specific variables such as the texture classification and measured values for lower limit and drained upper limit and crop rooting depth.

To characterise these soil parameters into a range of texture categories we examined the texture description and difference in the drained upper limit and lower limit in the top 10cm and PAWC of each soil characterisation. Studies form the literature (Gijsman et al., 2003; Rab et al., 2011) and Figure 7 suggest that PAWC in the top 10cm can reflect different water holding capacities due to soil texture differences caused by the amount of clay content present. Texture categories were quantified by the distribution of field capacity values in Rab et al., 2011 and the particle size distribution for soil texture grades in Taylor et al., 2006 and sorted into the texture categories. Generalised categories of rooting depth and PAWC were also created to reflect the variations in these variables. These were 0-20cm, 20-40cm, 40-60cm and 60-100cm for rooting depth and following Hall et al., 2009, 0-20mm, 20-40mm, 40-70mm, 70-100mm, 100+mm for PAWC magnitude categories. The 69 soil characterisations were sorted into their corresponding, rooting depth, PAWC and texture categories producing a matrix of potential soil types which potentially reflected the range of rooting depths, plant available water capacities and textures categories on the Eyre Peninsula. Where soil characterisations for particular rooting depths and PAWC categories did not exist we manipulated the existing rooting depth to create synthetic representations. A total of 96 measured and synthetic soil characterisation populated the rooting depth, PAWC and texture matrix (Table 5) however not all combinations were filled. For particular rooting depth, PAWC and texture categories a number of multiple occurrences were available to provide a range of simulated yield comparisons. This dataset provided a degree of rooting depth, PAWC and texture variation that potentially highlight the spatial variation of soils across the Eyre Peninsula.

Table 5: Observed and synthetic plant available water capacities for specific rooting depth, plant available water capacity and texture categories used in the APSIM crop modelling. Bolded values within the categories are the chosen characterisations used in the final simulations of wheat yield

Root Depth (cm)	PAWC) (mm)	Sand (0-6mm)	Loamy sand (6-9mm)	Sandy loam (9-15mm)	Loam (15-18mm)	Sandy clay loam (18-24mm)	Clay loam (24-35mm)
0-20	0-20	**10**	*	*	*	*	*
0-20	20-40	33.3	**21**,27	21,**22**,22.5,33.3	**29.5**,35.4	32.7*	*
0-20	40-70	*	*	*	*	**61**	*
0-20	70-100	*	*	*	*	*	**75**
0-20	100+	*	*	*	*	*	*
0-40	0-20	**14**	*	*	*	*	*
0-40	20-40	**20.9**	26.6	30,37,38,**38.1**	*	*	*
0-40	40-70	**46.8**,51.4	*	46.2,49.4,54,60.7,62.7,**69.6**,	*	45.3,59.5,63,**67.4**,68.3	*
0-40	70-100	**78.5**	*	**74.7**	70.4,75	71,75.5,**88**	*
0-40	100+	*	*	*	*	*	109,**111**
0-60	0-20	*	*	*	*	*	*
0-60	20-40	**29**,36	*	**33**	*	*	*
0-60	40-70	**57.1**,63.6	51.9,64.3	48,**51.9**,64.3	69.6	**53.9**,63.6,	*
0-60	70-100	**76.8**	**79.2**,82.2	**84**,86.9,90.3,94.2	*	**87.8**	**83.5**
0-60	100+	*	*	**104.5**	*	**112.5**	**165**
0-100	0-20	*	*	*	*	*	*
0-100	20-40	37,**40**	*	*	*	*	*
0-100	40-70	**70**	**43.9**,58.6,60	55,**58**,58.6	*	59.5	*
0-100	70-100	**84.5**	74,**86.8**	**86,**99.1	78.6	**78.6**	*
0-100	100+	103.6,**113.6**	**114.8**,164.1	107.8,125.8,129.8,**132.4**		**139**	166,**271**

Selection of soil characterisations that represent the range of rooting depths, PAWC and texture categories across the Eyre Peninsula

A four step process was used to identify the appropriate soil characterisation to represent average wheat yield for each rooting depth, PAWC and texture category.

Exploratory Analysis -

The first step involved using the APSIM crop model to simulate the average wheat yields over 110 years for each of the 96 soil characterisations across the 76 climate stations within the low, medium and high rainfall zones (Appendix 5). To determine the general trends in the soil characterisation dataset we created box plots graphs to visualise the variation in the simulated yields from soil characterisation with three or more measured soil water profiles. The majority of which are described as a sandy-loam soil across different ranges of rooting depth and PAWC categories. Figure 8 shows the general increase in simulated yield values with an increase in root zone depth and PAWC. Across all root zone depths, the greatest variation in simulated yield was in the 0-20cm and 20-40 mm PAWC category. The use of the synthetic representations of the sandy loam at this root zone show higher simulated yields than would be expected for the 0-20cm root zone depth. Within the 0-40cm rooting depth a range of simulated yields for three PAWC categories across the three rainfall zones are shown across two different soil texture categories. Tight yield distributions are evident for the 20-40mm PAWC category while the simulated yields for the 40-70mm PAWC category are more variable. The yield distribution for the six characterisations show a large outlying maximum simulated yield across all rainfall zones which was double that of the minimum yield value. Simulations for the 40-70mm PAWC sandy clay loam soil characterisation show a tight distribution of yield values for the low rainfall zone with variation increasing for the medium and high rainfall zones. For the high rainfall zone, visualisation of the box plot constructed from five soil characterisations shows the median of the simulated yield values is closer to the maximum yield value. Comparison across texture variations for the 40-70mm PAWC show that simulated yields declined with the change in soil texture from the sandy-loam to the sandy-clay-loam category across all rainfall zones. Changing PAWC categories across this rooting depth shows that simulated yields increase for the first two categories and then flatten out at the 70-100mm PAWC category. This is highlighted in the low and medium rainfall zone where median yield magnitudes and distributions are fairly constant. In contrast, the estimates for the high rainfall zones show a slight increase in median simulated yield. For the 0-60cm rooting depth 40-70mm PAWC and sandy loam texture categories the variation in simulated yield values tend to the minimum yield value highlighted by the median value with tighter distributions in the low rainfall zone. Large maximum values of yield are simulated for all rainfall zones.

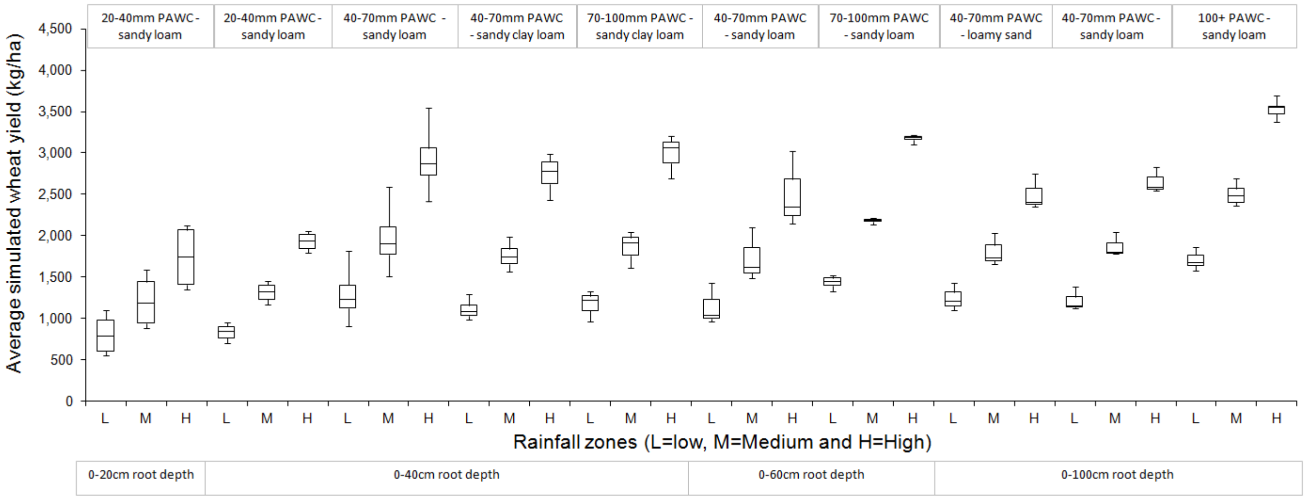


Figure 8: Magnitudes of average simulated wheat yield (kg/ha) for variations in rooting depth, plant available water content and texture categories for low (L), medium (M) and high (H) rainfall zones

The 70-100mm PAWC and loamy-sand soil category which had four soil characterisations had the tightest yield distributions across all categories. Comparison between the 40-70mm PAWC and the 70-100mm PAWC category showed a marked increase in yield with a greater increase apparent in the high rainfall zone. Comparison across the 100cm rooting depth 40-70mm PAWC show rising simulated yield values across both loamy-sand and sandy-loam texture classifications. Similar yield variation between texture categories is apparent in the low rainfall zones highlighted by similar box plots. Differences in yield magnitudes are more noticeable for the yields simulated in the medium and high rainfall zones with the sandy-loam soil characterisation generating high average yield values. The simulated yields for the 100+ PAWC sandy-loam category show a tight distribution of yield values with median value closer to the minimum in the low rainfall region and closer to the maximum value in the high rainfall region. Figure 8 shows a large simulated yield value for the high rainfall zone compared to the other two zones. Comparison across the PAWC categories shows large differences in simulated yields across all rainfall regions. Interestingly, comparisons for yield simulated from different rooting depths for the 40-70mm PAWC sandy-loam category showed small yield differences across all rainfall zones. This highlights the trade-offs between the ability to grow roots to depth and the ability to access a greater amount of soil. For example, given that we have a fixed soil moisture value of around 60 mm within the PAWC category, categorising the soil as a sandy-loam texture means that 10-15mm are distributed in the top 10cm. This means in a modelling context that a higher content of water is available in the 0-40cm rooting depth category than in the 0-60cm and 0-100cm. This interaction may mean that simulated yields will be larger in smaller rooting depths with large PAWC values and therefore the applied physical restriction will influence simulated yield potential.

From our limited results and the review of the literature we propose a number of general rules with certain caveats to choose a representative sample of soil characterisations to derive potential yield distributions.

(1) Within a root zone depth, increases in PAWC will simulate increases in wheat yield.

This positive relationship between PAWC and simulated grain yield has been highlighted by Gijsman et al., 2003; Wong et al., 2006 Wang et al., 2009 however Rab et al., 2009 has also found results to contrary. Results from our limited dataset showed positive relations between simulate yield and PAWC with rooting depth categories held constant. The simulation over the synthetic soil characterisations showed that decreases in yield were possible but only in a small number of cases. One caveat to this is the case where low root zone depths are simulated. Here, steps from mid-to large PAWC categories may produce similar yield magnitudes especially in low and medium rainfall zones.

Given a defined PAWC category, increasing soil texture provided several general rules.

(2) The movement from coarser sandy textured soil types to the sandy-loam soil type will show an increase simulated wheat yields in high rooting depths and medium and high rainfall zones. For lower rooting depths and low rainfall zones, simulated wheat yields will increase or stay constant for textural increases up to the sandy-loam soil classification. The movement from sandy-loam to finer textured soil classifications may show a reduction in yield in low rainfall areas with low root zones.

Gijsman et al., 2003 showed increases in simulated soya bean yield were related positively to the movement from coarser to finer textures in 5,000 synthetically created soils, after a specific texture class (silty loam) the yield trends declined. Rab et al., 2009 showed textural difference in the comparison of low to high yielding production areas. Within a study area that had a mean rainfall of 239mm, the low yielding area had significantly higher mean clay content in the top 20cm than the higher yield area. Wang et al., 2009 also found that in drier regions, soils with greater PAWC are not fully utilised due to incomplete wetting of the soil profile caused by limited rainfall. Their study also showed that higher PAWC values had little impact on yield magnitude but increased yield variability at dry sites. In low rainfall regions, increases in simulated wheat yield with increasing PAWC values were much smaller due to rainfall limitations. In medium rainfall zones, the trend in simulated wheat yield was positive with increased PAWC values but diminished with subsequent increments in PAWC caused by the graduation to finer textured soils.

(3) Finer textured soils in high rooting depths and higher rainfall zones may show increases in simulated wheat yield from the sandy-loam texture category.

Wang et al., 2009 highlighted that higher PAWC (shown in their selection of higher textured soil types) led to higher and less variable yields in wetter sites stating that higher PAWC had a greater reserve to meet crop water demand during dry periods. Ludwig et al., 2006 also found similar results with higher yields in a clay soil type compared to coarser textured acid sandy-loams and duplex soils in a high rainfall zone. Rab et al., 2009 showed that over a range of seasons, the consideration of the spatial variability in the soil's drained upper and lower limits provides a logical explanation for zones that may flip-flop between being high and low yielding areas, depending on the rainfall distribution.

Simulated yield values for each soil characterisation were placed into their corresponding rooting depth, PAWC and soil texture categories to determine the categorical trends and variations in simulated yield by climate station and rainfall region. Values of average yield for each soil characterisation were then averaged by the rainfall zone classification in order to understand how yield and soil characterisation differences varied over different rainfall gradients. To provide consistency within the PAWC categories we attempted to select consistent magnitudes of PAWC over and across the texture variations for each root depth and PAWC category. This consistency was reliant on the range of soil characterisations measured across the EP and consequently certain textures within a rooting depth, PAWC and texture categories had some PAWC differences. After this categorisation process, we looked at the distribution of yield variation across rooting depth, PAWC and texture categories to define a subset of soil characterisation that agreed to the identified selection rules. Table 5 shows the 41 soil characterisation (in bold) chosen from the 96 potential soil characterisations created for the Eyre Peninsula. Figure 9 shows the variation of simulated yields over the defined rooting depth, PAWC and texture categories. Lack of characterisations across all category distributions meant that not all categories could be simulated.

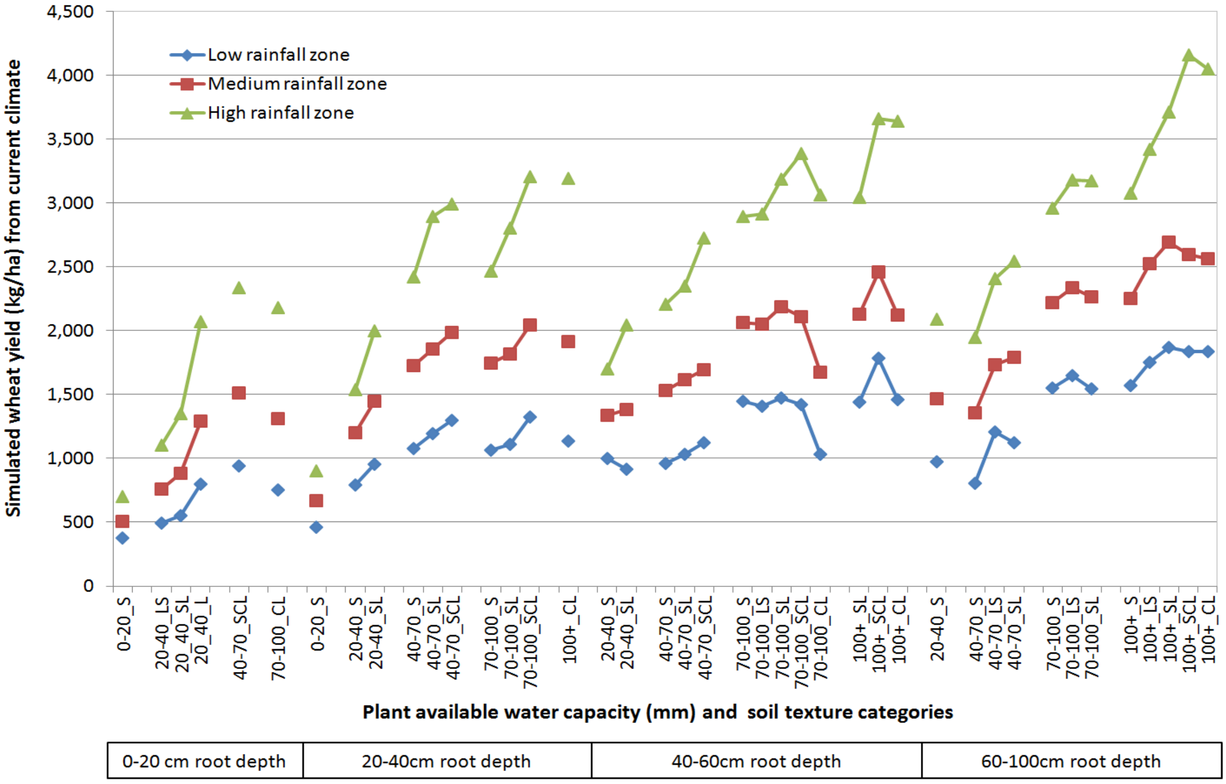


Figure 9: Simulated wheat grain yield (kg/ha) for the variation in root zone depth (cm), PAWC (mm) and soil texture categories (S =sand, LS=loamy sand, SL=sandy-loam, SCL=sandy-clay-loam, L=loam, CL=clay-loam) across the low, medium and high rainfall zones

Figure 9 shows that for the lowest rooting, yields increased with the increase in PAWC. Graduations in texture in the 20-40mm PAWC category saw an increase in yield while in higher PAWC categories and finer textured soils simulated wheat yield declined. This pattern occurred over all rainfall zones. Within the 40cm root zone, magnitude of simulated yield rose with PAWC and texture up until the 70-100 mm PAWC category. Simulated yields for this category were similar for the 40-70mm PAWC category with only the sandy-clay-loam yielding higher in the high rainfall category. Simulated yields for the 100+ mm PAWC were similar to those yields simulated in the finer texture soil characterisations in the previous PAWC category. For the 60cm rooting depths, simulated wheat yields decreased in the graduation from sand to sandy-loam soil classifications in the 20-40 mm PAWC in the low rainfall zones while yields increased slightly in the medium and more substantially in the high rainfall zones. Movement to the next PAWC category saw simulated yields gradual increase both in the low and medium rainfall zones while yields rose higher for the high rainfall zone across texture classification gradients. Comparisons across PAWC contents showed that for the sand texture classification higher yields were simulated for the 20-40mm PAWC category when compared to the 40-70mm PAWC category. At the 70-100 mm PAWC category, soil texture showed minimal yield variation from the yields simulated from the sand to sandy-clay-loam texture classes in the low and medium rainfall zones. For the high rainfall zone, the sand and loamy-sand classifications had similar simulated yields. The movement from the loamy-sand to sandy-clay-loam saw a rise in simulated yields which was in contrast to the yield change for the other two rainfall zones. Simulated yields decreased across all rainfall zones when moving to the finest textured soil in this PAWC category.

For the 100+ PAWC category, simulated yield trends were similar across the low and medium rainfall zones, with the sandy-loam yielding similar to the clay-loam. This changed in the high rainfall region where the clay-loam had a similar yield to that simulated for the sandy-clay-loam soil characterisation. The magnitude of simulated yield rose with changes in rainfall gradients across the sand to sandy-loam soil characterisations. Both the low and medium rainfall zone recorded lower simulated yield estimates for the loamy sand whereas this classification recorded an increase in the high rainfall zone. For the low rainfall zone, the clay-loam showed an increasing trend from the loamy-sand but was still lower than the simulate yield for the sandy-loam soil classification. Simulated yields for the finer textured soils after the sandy-loam soil characterisation showed a decreasing yield trend. For this rooting depth and PAWC category, simulated yield in the high rainfall zones showed a positive relationship between simulated yield and finer textured soils.

In order to reflect the variability of yield across a region we have typified through the use of selection rules 41 soil characterisations which are hoped to match the potential spatial variation of physical soil parameters across Eyre Peninsula. We expect that simulating yield for each of the 41 soil types would create different yield distributions due to these soil characterisation differences. If the yields simulated by crop modelling do not simulate different yield distributions then a range of specific field measurements may not be needed. Specifically, we test whether changing PAWC values in defined rooting depth and texture characterisations produce statistically significant differences in simulated mean yields. Secondly we test whether changing rooting depth in defined PAWC and texture classifications produce statistically significant differences in simulated mean yields. Thirdly, we test whether changing rooting depth and PAWC values in defined texture classifications produce statistically significant differences in simulated mean yields. Finally, we test whether within defined rooting depth and PAWC category, does the texture classification produce statistically significant differences in simulated mean yields. Appendix 5 shows the method and results used to test these hypotheses.

4.1.3 Modelling climate change with the APSIM model

Several studies have used the APSIM model to undertake climate change impact assessments on crop yields. Analysis of historical rainfall across the Eyre Peninsula has shown three discrete rainfall regions. The effect on wheat yield of the projected changes in climates will have different impacts across these distinct regions. Impacts will occur across two interacting levels. The first level is climate interaction, the reduction in rainfall and increases in temperature and carbon dioxide on the current climate used to simulate wheat yield. The second is the interaction of the first effect with the different soil types which lie within the region.

Several studies have reviewed this interaction at the first level. Wang 1992 assessed the interactive impacts of CO_2 concentration and temperature on wheat yields. They suggested that the doubling of CO_2 to 700ppm would increase yield by 28-43% but increases in temperature of 3C would decrease yields by 25-60%. Luo in southern Australia highlighted

Ludwig et al., 2006 provide a description of how the APSIM model deals with increases in CO_2. The model handles elevated CO_2 effects using two function; (1) through increased radiation use efficiency and (2) through increased transpiration efficiency. These changes have been tested and widely used in the literature (Tubiello et al., 2007) and are described by Reyenga et al., 1999 Luo, 2003 - check and Asseng et al., 2004. Asseng et al., 2004 focused on the models ability to simulate yield under elevated CO_2 levels, temperature increases and water shortages. Comparison and sensitivity analysis of model simulations with data from free air CO_2 enrichment and water deficit and temperature experiments showed that the model was found suitable to use for studies trying to identify directional impacts of future climate change on wheat production (Asseng et al., 2004). Conclusions from this seminal study showed elevated CO_2 will simulate growth in certain situations of water deficit (Kimball, 1995), higher temperatures will usually shorten the growth cycle of a given cultivar and together with reduced water supply reduce crop yield. These effects of climate change on growth processes in the context of natural climatic and soil variability and a large range of crop management options make it extremely difficult to foresee and quantify any consequences of future climate change on crop production (Asseng et al., 2004).

How climate data was used in the climate change scenarios

Table 4 inSection 3.1 shows the predicted climate changes for the southern part of Australia (CSIRO-DENR-Bom references). To model these affects of climate change on regions within the Eyre Peninsula we followed the method developed by Reyenga et al., 1999. For each rainfall station within a specific region we took the 110 year historical climate analogue and modified the daily historic climate data by adding fixed temperature offsets and percentage reductions to the historic data. This meant that for each station the episodic event of rainfall remained the same but the intensity was reduced. Ludwig et al., 2006 states that using this method is useful because it shows what the effect is of reduced rainfall using the same inter-annual variation of the historic climate.

To account for the natural variation in climatic conditions over time, 111 years (1990-2010) of daily weather data were extracted from the SILO Patched Point Dataset for the current climate scenario (S0) (Table 6?). This data was adjusted to the projected levels for the three climate change scenarios (S1, S2 and S3) within the APSIM parameter set-up (see Section 3.1). We also modelled an additional 3 scenarios (S4, S5 and S6) to model variations in seasonal rainfall (Table 6). These seasonal projections for Eyre Peninsula are based on data from the Bureau of Meterology and CSIRO (summary publication by DENR). Once again, the SILO Patched Point Dataset was adjusted by their seasonal values outside the APSIM program to mimic the projected levels for S4, S5 and S6. This process followed the methodology shown in Figure 10.

Table 6: Additional seasonal projection scenarios for APSIM modelling

Scenario	Temperature (degree C)	Summer Rainfall (%)	Autumn Rainfall (%)	Winter Rainfall (%)	Spring Rainfall (%)	CO_2 (PPM)
S4	+0.80	-3.5	-3.5	-7.5	-7.5	480
S5	+1.75	-7.5	-7.5	-15.0	-15.0	550
S6	+2.25	-7.5	-7.5	-15.0	-30.0	550

We ran additional simulations to understand the effect of CO_2 increases on wheat yield for each of the scenarios. Table 7 shows the ranges of carbon dioxide used in to illustrate the effect of carbon dioxide within the scenario analyses.

Table 7: Range of carbon dioxide rates for each climate scenario

Scenario	Carbon dioxide scenario
S1	390, 480
S2	390, 480, 550
S3	390, 480, 550, 750
S4	480
S5	390, 480, 550
S6	390, 480, 550

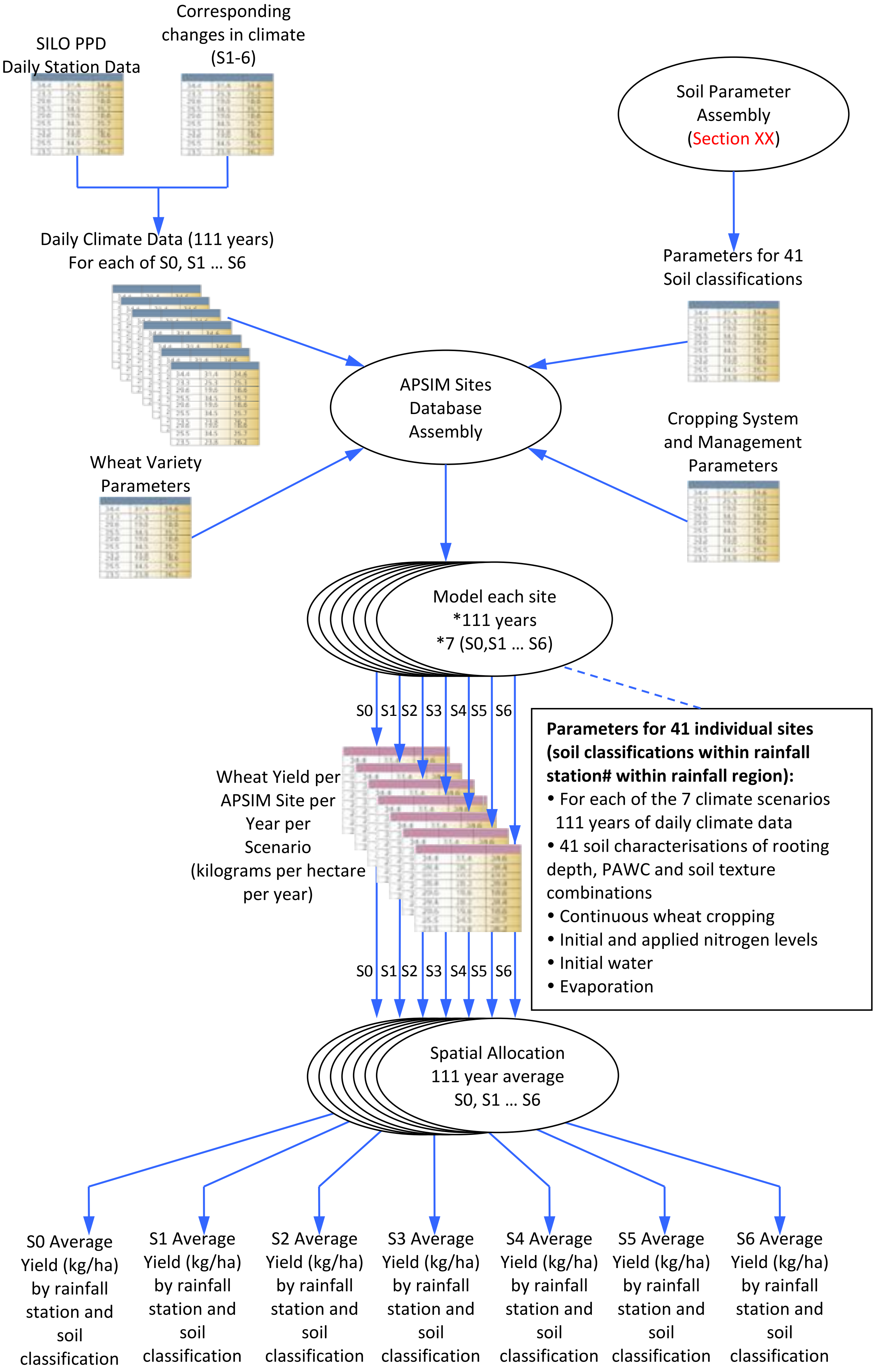


Figure 10: Crop modelling methodology to simulate wheat yield for the current climate and six climate change scenarios (S1-S6)

The APSIM set-up was run for each of 76 stations across 44 soil types for 110 years for all scenarios (S1-S6) as well as the additional carbon dioxide scenarios. This produced a dataset that allowed comparison to the current climate scenario.

4.1.4 Climate Change Impacts on Wheat Yields

Three climate change projections (S1,S2 and S3) are based on mitigation story lines from the IPCC. The S4, S5, S6 are based on downscaling of the Bureau of Meteorology and CSIRO climate predictions for the Eyre Peninsula (BOM reference). These scenario can be interpreted as either climate change in the next 10, 25 or 70 years or if concerted mitigation efforts are undertaken - rephrase.

Simulation of wheat yields for the climate change scenarios. Appendix 5 shows the ranges in impacts for the climate change scenarios presented in Table 7.

Mild climate change scenarios

Wheat crop modelling simulations for the S1 and S4 climate change scenario show a slight variation both positively and negatively in simulated yields from the temperature and carbon dioxide increases and a block shift in a 5% reduction in rainfall across the whole rainfall analogue in the low and medium rainfall zones (Appendix 5). The scenario S4 had a similar temperature and carbon dioxide increase but had seasonal rainfall reductions with the main difference being a 7.5% reduction in Spring. This change in rainfall timing has more impact in the low rainfall zones,

In the high rainfall zone, **Error! Reference source not found.** shows larger increases in simulated yields (<200 kg/ha) when compared to the low and medium rainfall zone. These increases range across all rooting depths and PAWC and soil texture classifications.

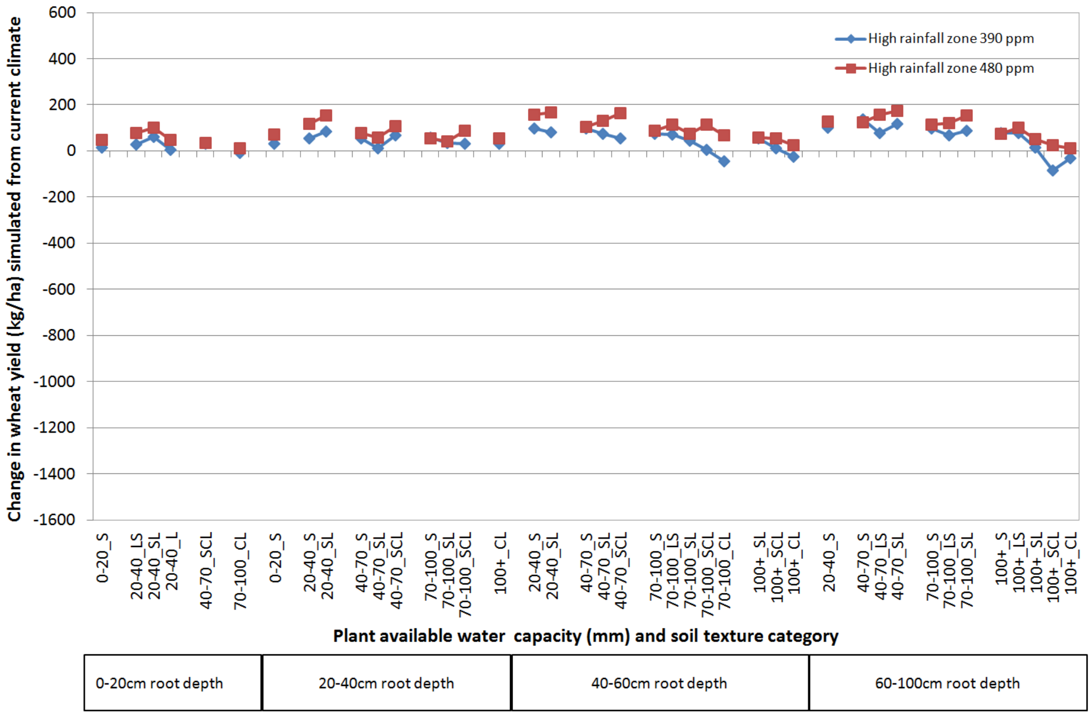


Figure 11: Simulated average yield (kg/ha) for the S1 climate change scenario for the high rainfall zone

Moderate changes in climate

The S5, S2 and S6 scenarios have the greatest relevance because they represent potential short term climates for the year 2030 if no mitigation action is taken (REFS).

For the milder climate change scenarios (S3-S5), simulated yield results highlight that only a small reduction in production will be evident in the low rainfall zone. While this seems small (around 200kg/ha) in absolute terms, the reduction is quite significant because of the regions current yield capacity (current average production for a farm is around 1-1.2 t/ha). Textural differences between soil types in this zone have only a minor influence with rainfall the limiting factor. Economic analysis will show the impact of these yield losses on low rainfall region productivity. Given this may represent a climate for 2030 there may be some urgency to change in this region either through the adoption of different agronomic practices or adoption of different land uses.

Milder CC projections for the medium rainfall zone show similar reductions in average yields but these reductions do not have the same relative impact due to these regions generating higher yields.

Milder CC or short term projections for the high rainfall zone show increases in simulated wheat yields across the region with negligible reductions across soil types.

For the S2 scenario, crop modelling simulations shows reductions in simulated yields across the low and medium rainfall zones. For low rainfall zones, reductions are apparent in the finer textured soils across each specific rooting depth and PAWC category around a 15-20% reduction. Figure 12 illustrates the reductions in simulated yield apparent for the low rainfall zone.

Highest reductions are in the 0-60cm rooting depth and 70-100mm PAWC category for both the low and medium rainfall zone. For the high rainfalll zone, simulated wheat yields for the S2 scenario show increases across the majority of soil characterisations under all carbon dioxide levels. Largest percentage increases are in the lower PAWC categories and coarser textured soils. However, reductions in yields are apparent in the finer textured soils in the higher PAWC categories.

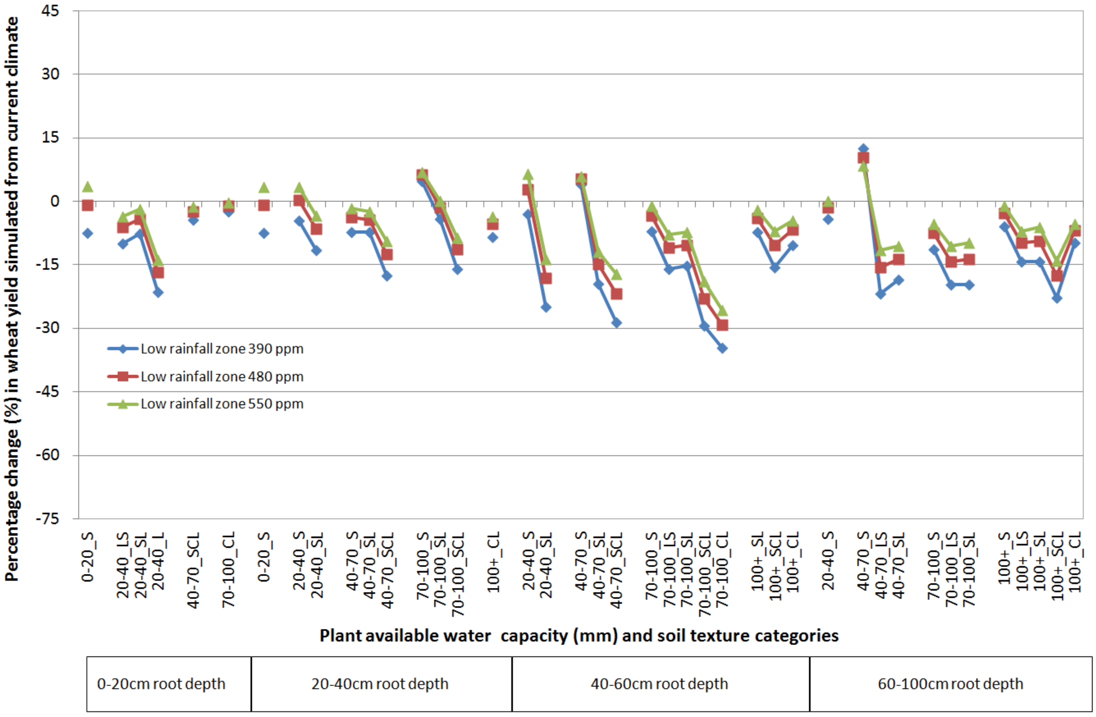


Figure 12: Percentage change in simulated wheat yield when S2 is compared to the current climate over three carbon dioxide levels for the low rainfall zone

Sever climate change scenario

For the S3 scenario represents the most severe climate change scenario. Crop modelling simulations showed the envelope of simulated wheat yields for four carbon dioxide levels. In the low rainfall zone, largest reductions in yield were in the 0-60cm rooting depth and 70-100mm PAWC finer soil textures

For the medium rainfall zones, simulated yield reductions are similar to those in the low rainfall zone.

For extreme or longer term CC projections the distribution of soil types will play a more dominant factor especially for soils with deep finer textured soils. Economic analysis of cropping enterprise will come into play in this region to determine farm business and community viability.

Longer term or more extreme CC projections show yield increase with coarser textured soils and decrease on finer textured soils. Although different yield trends exist, increases in yield on coarser textured soils show only small relative increases because they come from a smaller yield base. These simulated yield increases do not offset the reduction on the finer textured soils. While this CC projection causes large yield reductions, the productivity of the soils still remains substantially high.

4.1.5 Conclusions

We created 44 soil characterisation that spanned the potential physical characteristics of Eyre Peninsual soils. This showed the range in possible impacts of climate change projections on simulated yields. The simulations showed that there are a variety of impacts with the interactions in temperature and carbon dioxide increases and rainfall reductions, soil types and current climate. The low and medium rainfall regions had the greatest percentage reductions in yield. But this will depend on the magnitude area associated with the corresponding soil types and where they are within the Eyre Peninsula since there is a degree of spatial variation in the impact of the CC projections within the two rainfall zones.

Applying S1 and S4 scenarios gives an indication of what potential climate could be in the next ten years or if significant mitigation efforts are undertaken globally. Results show increases in wheat yield due to the increase in temperature and CO_2 level and limited reduction in rainfall across all rainfall zones.

Applying the S2, S5 and S6 CC projections, a possible climate for 2030, show a reduction in average yields in the majority of regions that make up the low rainfall zone. Changes in soil texture, a graduation from coarser to finer textures, show an increase in yields for the coarser textured soil in the medium and high rainfall zones. Spatial variation in the impacts of these CC projections exists across all rainfall zones.

Applying the S6 CC projection shows large yield reductions in the low rainfall area, apparent on finer textured soils. In medium rainfall zones, slight increases in yield on coarser textured soils but yield reductions (10-30%) across finer soil types. In higher rainfall areas, similar simulated yield trends are apparent with greater increases (0-20%) on average on coarser and 0-20% yield reduction on finer soil types.

The management of different textured soils through opportunistic cropping or selection of soil types for land –uses change will play an important part in CC management in areas across the EP.

4.1.6 Spatial Representation of Eyre Peninsula Soils

The ‘South Australian State Land and Soil Information Framework’ (SASLSIF) generated from the South Australian State Land and Soil mapping program provides state format attribute soils datasets in a spatially distributed format (Soil and Land Program, 2007). The framework uses a polygonal representation to classify the agricultural districts of South Australia according to soil or landscape attributes. These attributes are land surface and soil features which affect land use, land management and agricultural productivity. The framework uses land types to define the dominant geological and topographical setting and broad soil grouping within an area. The spatial distribution of land types has been formulated based on past soil and geological mapping data and stereoscopic analyses of aerial photographs. These distributions have been ground truthed through field based observations and laboratory analyses and reflect the current understanding of the regional landscapes processes and stratigraphy. While these undertakings provide consistent and spatially valid classifications, there is still significant extrapolation and interpolation from limited datasets with heavily reliance on local knowledge and experience of field operators.

To give an overview of the soils which encompass the region of southern south Australia, the large magnitude of soils have been organised into 15 soil groups and a subset of 61 subgroup soils. Soil groups are differentiated based upon soil profile features of major significance to land use and natural resource management. Within the soil subgroups, soil distribution and extent, characteristics and features of each soil, factors affecting fertility, rain-fed agricultural potential and limitations, together with soil conservation issues are described and quantified. These characteristics are land surface and soil features that affect land use, land management and agricultural productivity.

There are several caveats with the use of this information. Firstly, soils information and land and soil attribute maps are derived from limited field inspections and entail significant generalisation. Secondly, boundaries between mapping units should be treated as transition zones. Thirdly, maps are intended to provide a regional overview and should not be used to draw conclusions about conditions at specific locations. Fourthly, a specified attribute class map will apply to only 50% or less of a soil landscape unit. This is acceptable in a regional, subregional or catchment level context where maps are intended to provide visualisation of where specific conditions are likely to occur.

In APSIM soil section we highlighted a conceptual model that illustrated the variation of Eyre Peninsula soils. The potential buckets are defined by root zone depth, PAWC magnitude and texture. Within the SASLSIF similar mapped soil attributes are broadly defined. Root zone for wheat however is not mapped explicitly.

Defining and mapping rooting depth for wheat

Defining the magnitude of and mapping the rooting depth for wheat was accomplished using a two part process based on mapped area. The first part identified the magnitude of rooting depths across particular sub-soil classes and the second relied on distributing these percentage based on the mapped area for the sub-soil types.

Magnitude of rooting depth for wheat

Hall et al., 2009 identifies the "likely growth of cereal plant roots within the representative soil profile" for 33 soil groups across the Eyre Peninsula agricultural area (Appendix 5) and four rooting depth categories were created 0-20cm, 20-40cm, 40-60cm and 60-100cm. These values were examined by an expert in soil science based on the Eyre Peninsula in order to refine the broad percentage to reflect local regional variations (Table 8). The creation of this information provided a potential distribution of rooting depths for wheat by sub-soil type across the Eyre Peninsula region.

Mapping of rooting depth of wheat crops across the Eyre Peninsula

While a sub-soil class distribution of rooting depth has been created, rooting depth for wheat will differ for sub-soil classes across rainfall zones due to the influence of physical and chemical constraints. For example, in high rainfall regions chemical constraints may not restrict root growth because of the greater access to water while in drier environments chemical constraints have a far greater impact on rooting depths. To reflect climate and constraint variation we use the rainfall regionalisation dataset to spatially identify rainfall differences and the soil attribute data available within the SASLSIF to highlight the magnitude of the physical and chemical constraints across the Eyre Peninsula within each sub-soil class. Seven mapped soil attributes were selected that would potentially restrict rooting depth across the Eyre Peninsula. These were physical constrictions (depth to hardpan, hard rock) and chemical constrictions (depth to sodium and boron toxicity, aluminium toxicity, degree of acidity and dry-land salinity) and the variations in levels of magnitude are shown in Appendix 5. For each sub-soil class, a unique eight digit identifier was created. The first value represented the sub-soil class while the next seven represented the magnitudes of the seven identified soil constraints. This dataset highlighted the magnitude and spatial distribution of soil constraints with each sub-soil class. This spatial distribution of each identifier was then spatially assigned to the corresponding rainfall region. From the SASLSIF, the number of hectares corresponding to each identifier was calculated and the hectares for each code were apportioned into the four rooting depth categories based on the severity of physical and chemical constraints within the three different rainfall zones. Percentage area contributions in each of the four rooting depth categories were then calculated and hectares reapportioned to correspond to the regional percentage distributions of rooting depth by sub-soil class. The mapped wheat rooting depths by sub-soil class are highlighted in Table 8.

Table 8: Potential and mapped percentage distribution of root zone depth for wheat within each rooting depth categories (cm) for each soil class based on expert opinion and adjustments made by geographic attributes (physical and chemical constraints and rainfall gradient)

		Potential percentage distribution of rooting depth within rooting depth categories (cm)				Mapped percentage distribution of rooting depth within rooting depth categories (cm)			
Class	**Description**	**0-20**	**20-40**	**40-60**	**60-100**	**0-20**	**20-40**	**40-60**	**60-100**
A1	Highly calcareous sandy loam	10	20	45	25	3	8	76	13
A2	Calcareous loam on rock	10	20	65	5	0	0	89	11
A3	Moderately calcareous loam	0	15	45	40	0	0	48	52
A4	Calcareous loam	5	15	45	35	1	21	66	12
A5	Calcareous loam on clay	0	10	25	65	0	6	65	29
A6	Calcareous gradational clay loam	0	15	35	50	0	5	58	38
A8	Gypseous calcareous loam	15	55	30	0	13	64	12	12
B1	Shallow highly calcareous sandy loam on calcrete	25	45	30	0	17	47	36	0
B2	Shallow calcareous loam on calcrete	70	25	5	0	33	39	27	0
B3	Shallow sandy loam on calcrete	70	25	5	0	18	70	12	0
C3	Friable gradational clay loam	0	5	55	40	0	0	100	0
C4	Hard gradational clay loam	0	5	25	70	0	0	0	100
D1	Loam over clay on rock	5	15	25	55	0	11	79	10
D2	Loam over red clay	0	10	30	60	0	0	48	52
D3	Loam over poorly structured red clay	0	15	45	40	0	42	50	8
D5	Hard loamy sand over red clay	0	15	45	40	0	28	32	40
D6	Ironestone gravelly sandy loam over red clay	0	5	5	90	0	0	72	28
F1	Loam over brown or dark clay	0	5	5	90	0	0	2	98
F2	Sandy loam over poorly structured brown or dark clay	5	10	30	55	0	0	92	8
G1	Sand over sandy clay loam	0	10	75	15	0	0	66	34
G2	Bleached sand over sandy clay loam	0	20	65	15	0	0	91	9
G3	Thick sand over clay	0	25	60	15	0	16	73	11

G4	Sand over poorly structured clay	5	45	50	0	0	36	43	21
H1	Carbonate sand	0	45	55	0	0	3	93	4
H2	Siliceous sand	0	35	30	35	0	13	81	6
H3	Bleached siliceous sand	0	35	45	20	0	0	30	70
J1	Ironstone soil with alkaline lower subsoil	5	15	75	5	0	0	77	23
J2	Ironstone soil	5	20	65	10	0	7	76	17
L1	Shallow soil on rock	75	25	0	0	63	34	3	0
M2	Deep friable gradational clay loam	0	0	25	75	0	0	22	78
M3	Deep gravelly soil	0	0	0	100	0	0	0	100
M4	Deep hard gradational sandy loam	5	10	55	30	0	0	38	62
N2	Saline soil	100	0	0	0	78	17	5	0

Validation of rooting depths

The apportioning of mapped SASLSIF area to the regional percentage distribution of rooting depths by sub-soil class provided a general way to map wheat rooting zone depths across the Eyre Peninsula region. We attempted to validate the modelled spatial distribution of rooting depths by using point based measurements of rooting depth which have been recorded across the Eyre Peninsula. Rooting depths for a total of 181 data points were investigated 112 from the SASLSIF soil profile dataset and 69 from the soil characterisation available in the APSOIL database (Dalgliesh et al., 2006) for the Eyre Peninsula. Appendix 5 shows a map of their spatial distribution across the Eyre Peninsula. Where two or more soil pit fits were spatially located within the same defined area the lower rooting depth value was taken. Table 9 shows the resultant spatial agreements between the modelled and observed root zone depth.

Table 9: Percentage agreement between the modelled and observed rooting depths in the low, medium and high rainfall zones. The number of observations used for each zone are identified in brackets

Rainfall zone	SASLSIF observations	APSOIL observations
Low	65 (34)	38 (37)
Medium	40 (47)	52 (23)
High	52 (31)	100 (1)

The table shows low to moderate agreement between the two datasets. This is not surprising since the scale of the modelled root zone depths is broad, sub catchment at best and the observed soil pit data is substantially finer at a soil pit resolution collected to measure deep into the profile to understand the soil profile. Nonetheless, the comparison allowed for some independent ground truthing of the results. Where the modelled results did not agree we again used expert opinion to refine the results.

Figure 13 show the resultant spatial distribution of wheat rooting depth across the Eyre Peninsula cropping area. This defines one variable for determining the spatial distribution of soil types.

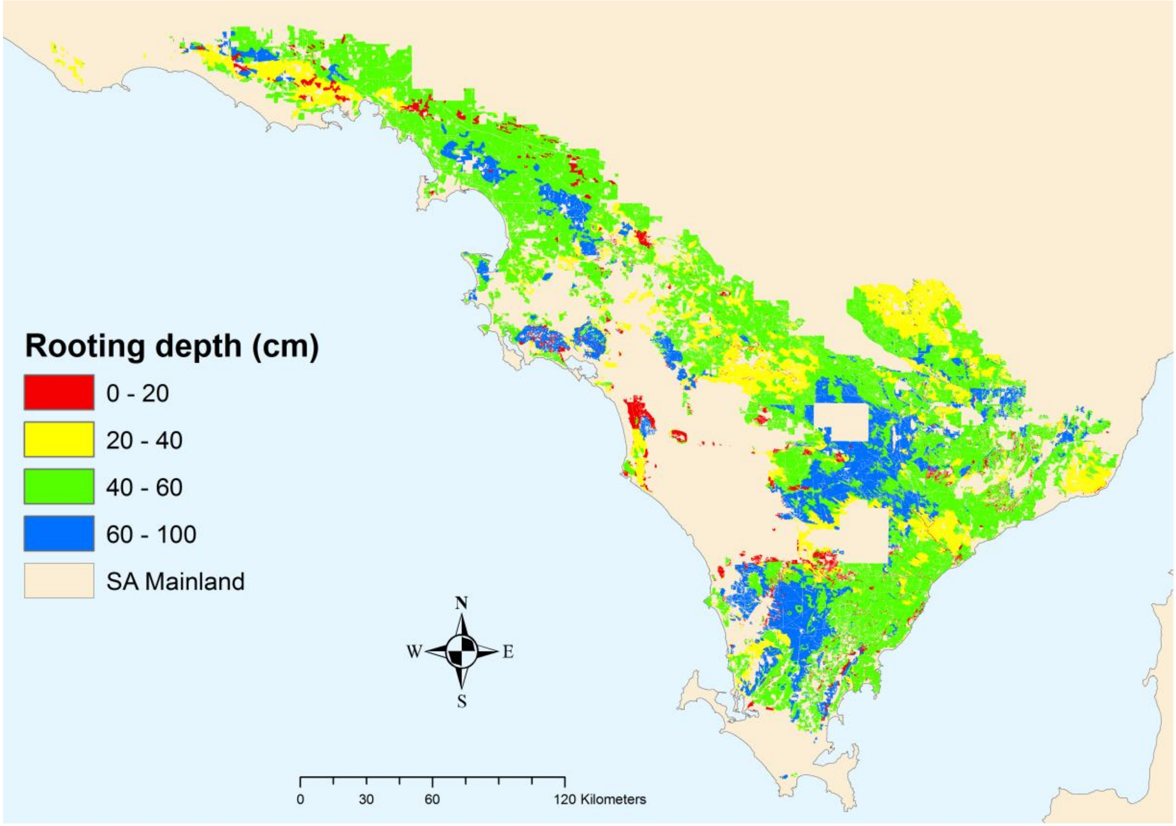


Figure 13: The spatial distribution of modelled root zone depth for wheat across the Eyre Peninsula cropping area

4.1.7 Mapping and Measurement of Plant Available Water Holding Capacity (PAWC)

The categories of PAWC in the APSIM modelling have been purposely categorised to match the Available Water Holding Capacity (AWHC) defined in the SASLSIF, as the amount of water effectively available to wheat plants within a soil profile. See Appendix 5 for the description and category classifications. For the framework estimates are mapped based on AWHC values for various texture classes (Dent et al., 1981;Wetherby, 1992). From the mapping 11 classes of soil texture are defined ranging from sand to clay loam. These category classes are shown in Appendix 5. The magnitude of AWHC is affected by rooting depth and soil characteristics such as porosity, texture (particle size) and texture structure. We assumed that the mapping of texture differences was of a high quality since it was derived from information (geological mapping data and stereoscopic analyses of aerial photographs) which illustrate natural processes. We reviewed the spatial distribution of AWHC values to determine if they corresponded to our redefinition of wheat root zone depth and assumed texture categories. Expert knowledge was used to redefine AWHC values in areas where either the value did not correspond to the rooting depth and texture values or did not reflect local knowledge of the area. A validation of the mapping of AWHC values was undertaken using the 69 APSOIL sites as an independent dataset. The measured PAWC values were investigated to determine if they fell within the defined AWHC range. The spatial agreement between these datasets was 49%. Where differences occurred, expert knowledge was used to redefine the spatial distribution of AWHC. Figure 14 and Figure 15 show the spatial distribution of the magnitude of AWHC values and texture categories for the Eyre Peninsula cropping area.

A unique combination of values was then created by joining the three soil attributes wheat rooting depth, AWHC and soil texture. This variable showed the spatial distribution of the soil attribute variations and was used as the inputs to spatially distribute the simulated wheat yield values for the corresponding crop modelling soil characterisations.

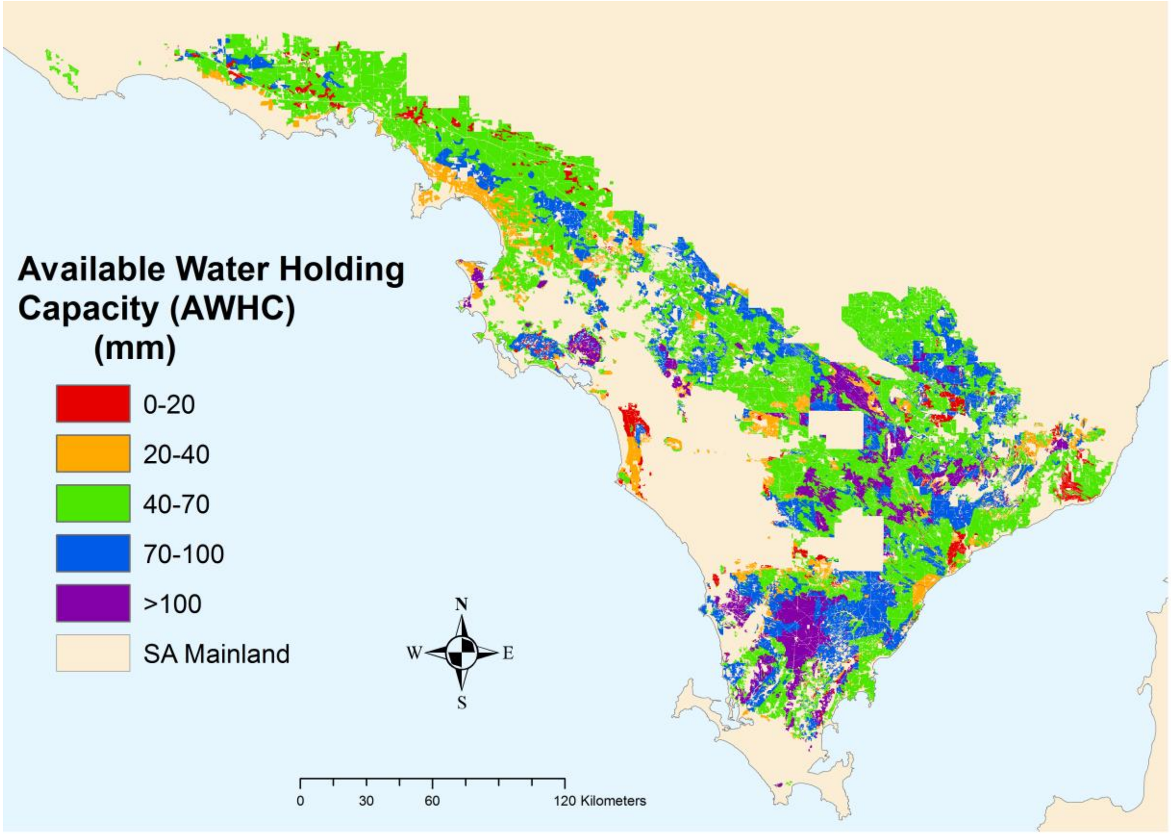


Figure 14: Spatial distribution of Available Water Holding Capacity (AWHC) across the Eyre Peninsula cropping region

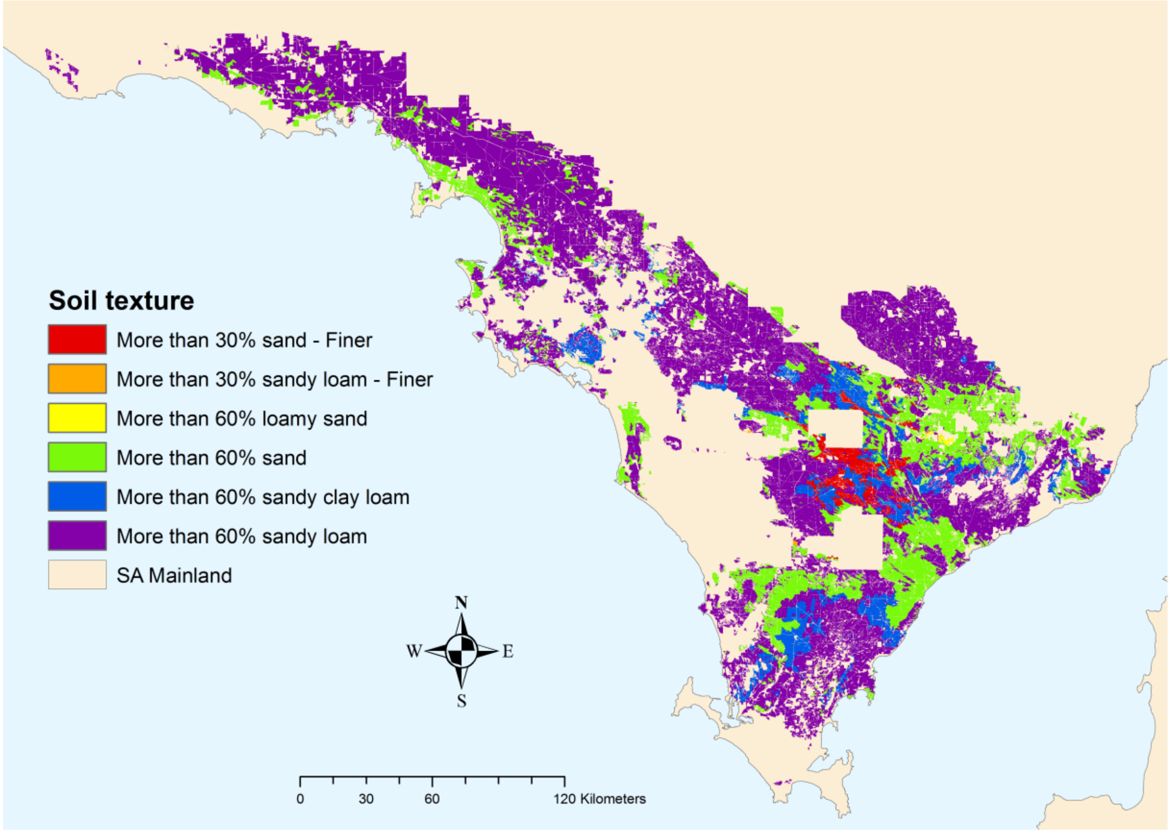


Figure 15: Spatial distribution of soil texture across the Eyre Peninsula cropping region

Figure 16 represents the percentage of the Eyre Peninsula area which is associated with the defined rooting, depth, plant available water capacity and soil textures classifications. Both the low and medium rainfall zones have fairly similar cropping areas with over 1.1 million hectares each. The high rainfall zone is significantly smaller with around 310 thousand hectares. The greatest amount of area is mapped to the 40-60cm rooting depths with majority being classified as 40-70mm PAWC sandy loam soil texture in the low and medium rainfall zone. For the low rainfall zone, the 20-40cm 40-70 sandy loam classification also has a significant area mapped to this classification. The high rainfall zone has a variety of smaller areas mapped to it soil classifications with the highest being in the 70-100mm PAWC and sandy loam soil texture classification.

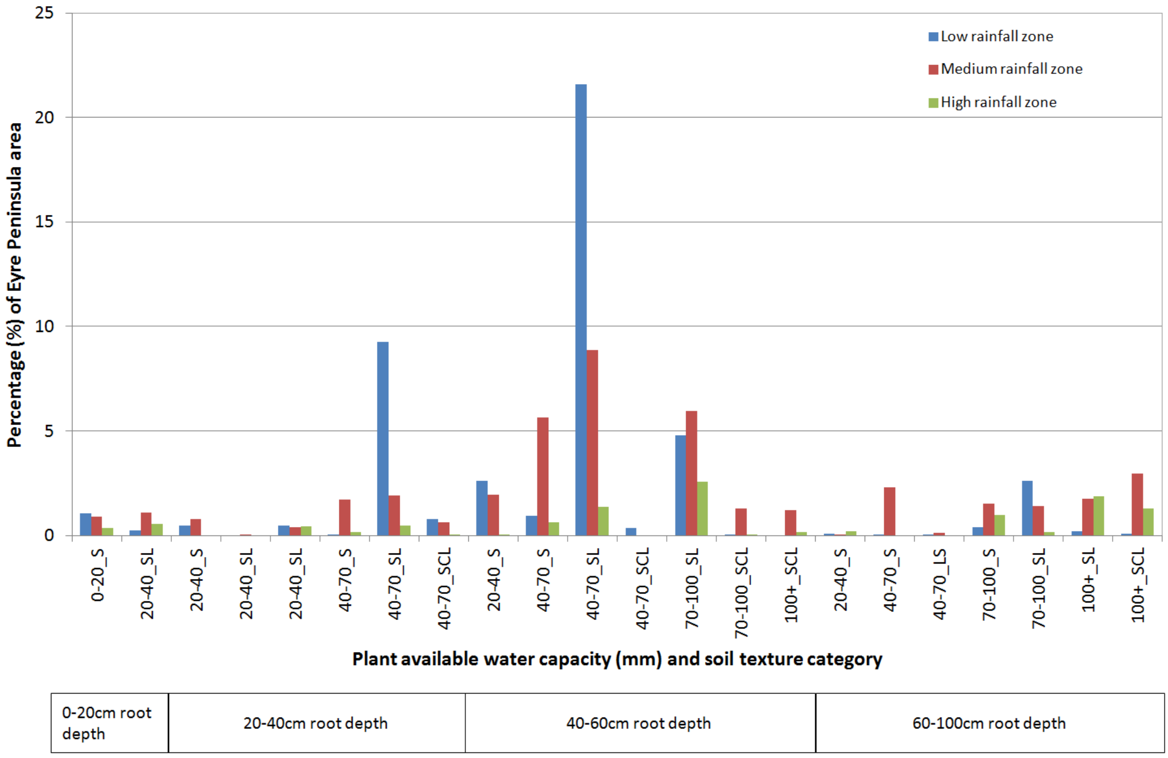


Figure 16: Percentage of the Eyre Peninsula area which is associated with the defined rooting, depth, plant available water capacity and soil textures classifications

Figure 17 shows the distribution of area associated with specific rooting depth, plant available water capacity and soil texture categories as a percentage of their corresponding rainfall zones. The majority of mapped area was associated with the 40-60cm rooting depth across all rainfall zones with 66% in the low, 59% in the medium and 43% in the high. For the low rainfall zone, the largest area was attributed to the 40-60cm rooting depth, 40-70mm PAWC and sandy loam soil texture classification with 47%. The next two highest were both sandy loam soil textures with 20-40cm rooting depth and 40-70mm PAWC and40-60cm 70-100mm PAWC both of which represented 20% and 10% of the area for the low rainfall zone. Similar to the low rainfall zone, the 40-60cm rooting depth, 40-70mm PAWC and sandy loam soil texture classification had the largest amount of area associated to it with 21%. The remaining 38% of area is then distributed across other PAWC and texture categories within this rooting depth. Around 7% of the areas have been classified in the 60-100cm 100+ mm PAWC sandy-clay-loam classification. This figure shows for the high rainfall region the largest area was attributed to the 40-60cm rooting depth 70-100mm sandy loam texture category. Both the 60-100cm rooting depth 100+PAWC soil texture categories make up around 27% of the high rainfall zone area.

Both figures show the contributing area of each classification as a percentage the EP for regional analysis and as a percentage of the rainfall zone to understand the distribution at a sub-regional scale. The amount of area assigned and the spatial distributions of soil classifications will affect the impact of climate change on the Eyre Peninsula as a whole and in the specific rainfall regions.

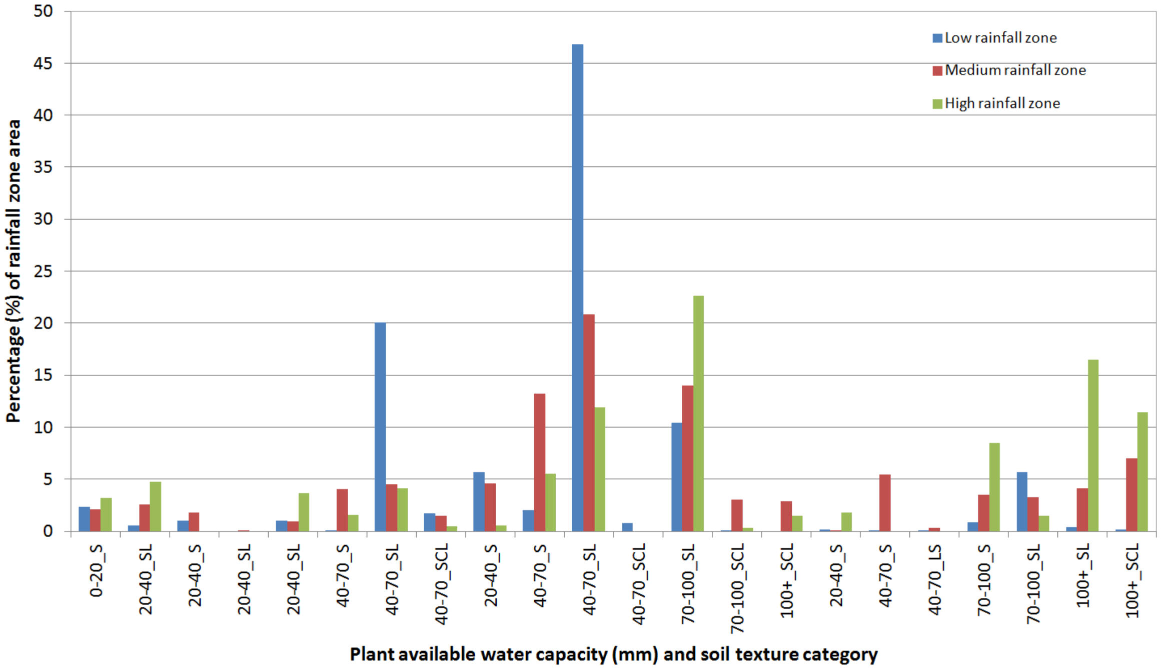


Figure 17: Distribution of area associated with specific rooting depth, plant available water capacity and soil texture categories as a percentage of their corresponding rainfall zones

4.1.8 Mapping the Spatial Distribution of Simulated Wheat Yields

The previous section focussed on identifying the impact of a variety of climate change scenarios in rainfall aggregated zones (low, medium and high) for 44 potential soil across the Eyre Peninsula. Within these zones, spatial variation and impacts on yields may exist due to localised climate variation and its interaction with the extent of mapped soil classifications. To map these local interactions we followed the methodology developed in Figure 18. The first step used cluster analysis on monthly gridded rainfall to identify nine rainfall regions with similar rainfall amounts across the Eyre Peninsula. The second step involved retrieving rainfall station data from the SILO patch point dataset where rainfall records were greater than 50 years. A total of 76 stations were selected across the Eyre Peninsula. These datasets were then inputted into a geographic information system (GIS) where a spatial analysis function was used to divide up the nine rainfall regions into 76 individual areas based on the geographic relationship between the station and rainfall zone datasets such that the boundaries of the regions define the area that is closest to each station relative to all other stations. This datasets represented the climate data required for the crop modelling. The previous section describes how soil classifications were mapped through spatial datasets and expert knowledge. The GIS was then used to spatially join both datasets to define the extent of mapped soil classifications for each Thiessen polygon defined rainfall station area. A look-up table was then created listing the rainfall station number and soil classification which was used to match with the multiple simulated yield outputs from the crop modelling.

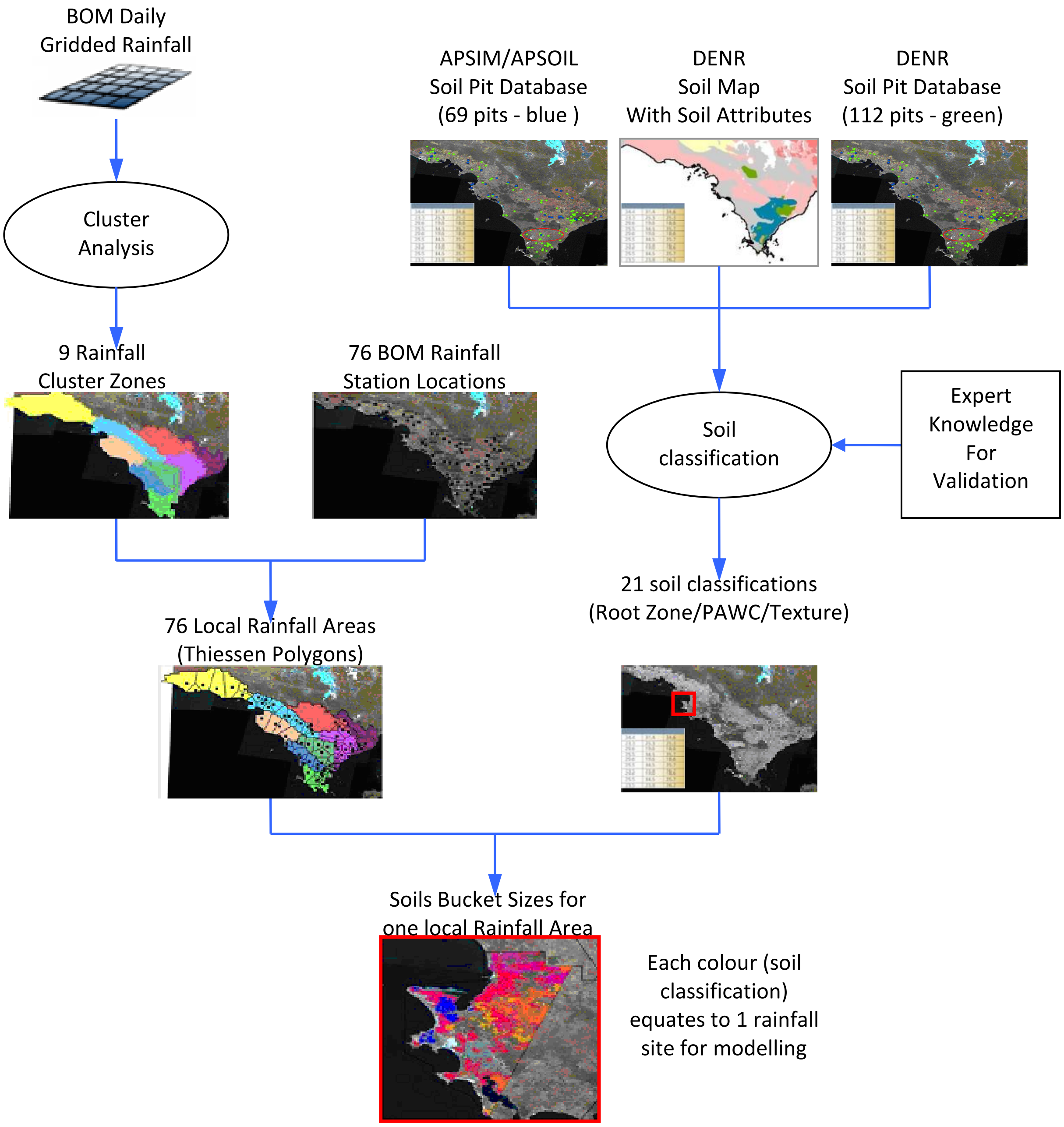


Figure 18: Methodology used to map the rainfall station specific soil classification for the Eyre Peninsula

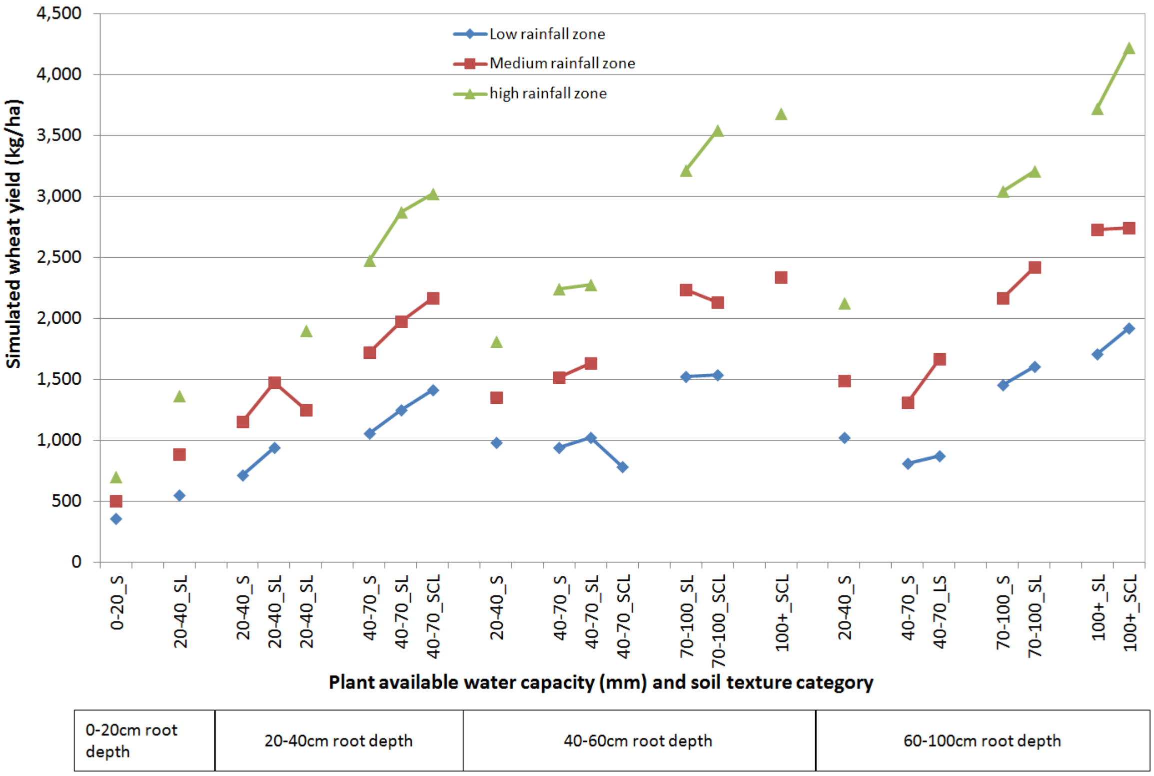


Figure 19: Simulated wheat yields for the current climate by rooting depth, plant available water capacity and soil texture categories

Figure 19 represents the corresponding soil classifications mapped on the Eyre Peninsula and their associated simulated yields These yields were matched to the corresponding soil classifications to identify the spatial distribution of simulated wheat yield across the Eyre Peninsula. The reductions in simulated yields for the ranges of climate change scenarios for the low, medium and high rainfall zones are presented in Appendix 5.

Figure 20 illustrates the spatial variability of simulated wheat yield for the Eyre Peninsula. Yield variability ranges 150-1,500 kg/ha in the upper part of the Eyre Peninsula (low rainfall zone) and increases to 1,500-2,500 kg/ha in the middle medium rainfall zone. The bottom part of the figure illustrates simulated wheat yield for the smaller high rainfall zone with yields varying from 2,500 - 4,500 kg/ha.

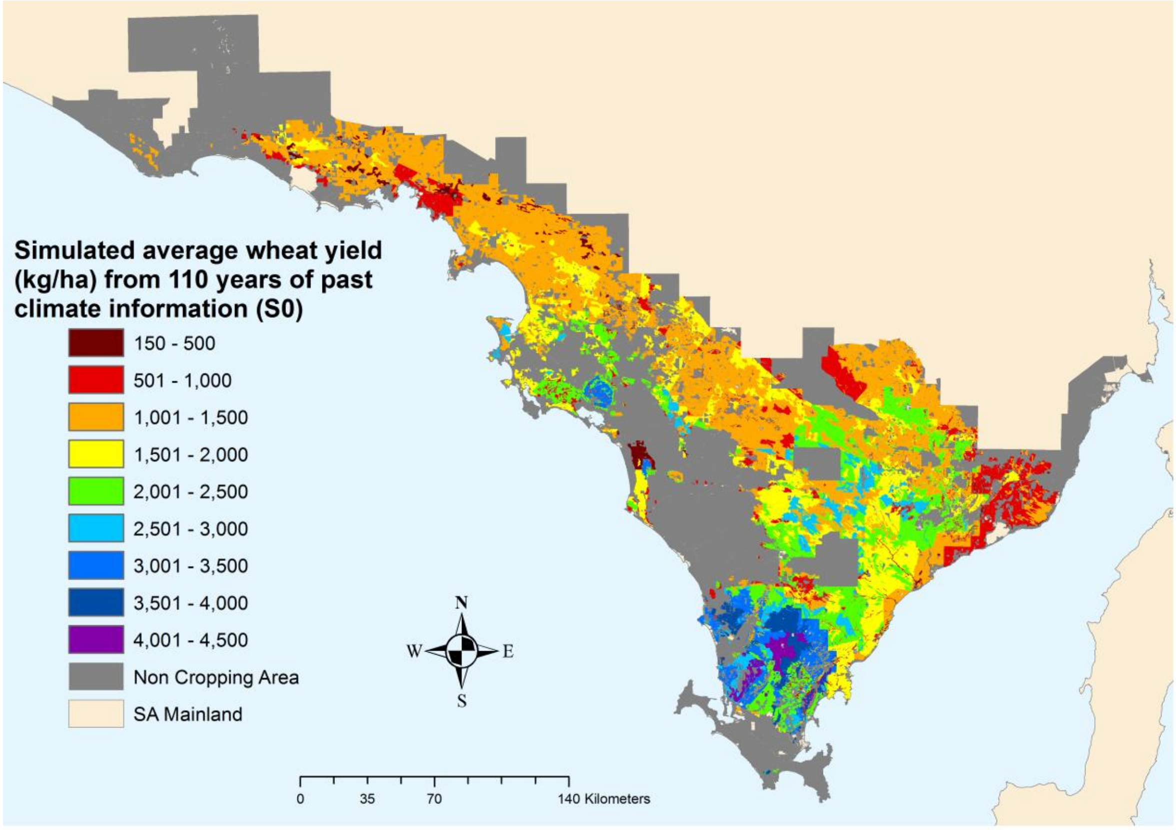


Figure20: Simulated average wheat yields for the Eyre Peninsula based on 110 years of climate information

4.1.9 Validation

Yield and hence productivity projections associated with future climate scenarios are an essential part of developing adaptation options with the landscape futures analysis. Collection of sound local yield data is important in establishing the credibility of the crop growth and yield models that are used to estimate yields, and hence economic activity, under different climate change scenarios. We collated on-ground crop yield and soil data across a variety of scales to validate the crop models used to make yield projections with the different climate change scenarios.

In collaboration with the EP research officer, we identified particular farms located on the major soil classes within the climatic sub-regions discussed above. We used the analysis of two spatial datasets, the Department of Environment and Natural Resources soils database and the EP based Rural Solutions grower database, to identify these farms. Subsequently we collected any previous records of within paddock crop yields. This included:

- Data from precision agriculture aggregated to paddock/soil averages
- Farmer records of paddock yield from Minnipa over 25 years

- EP red brown earth trails (10 years of data), EP grain and graze upper EP trials
- Regional PIRSA wheat yields

This data forms the basis for high resolution spatial analysis of current yield stability on the EP and validation of future climate effected yield predictions using the Agricultural Production Systems Simulator (APSIM).

4.1.10 Spatial distribution of climate change impacts on simulated wheat yield

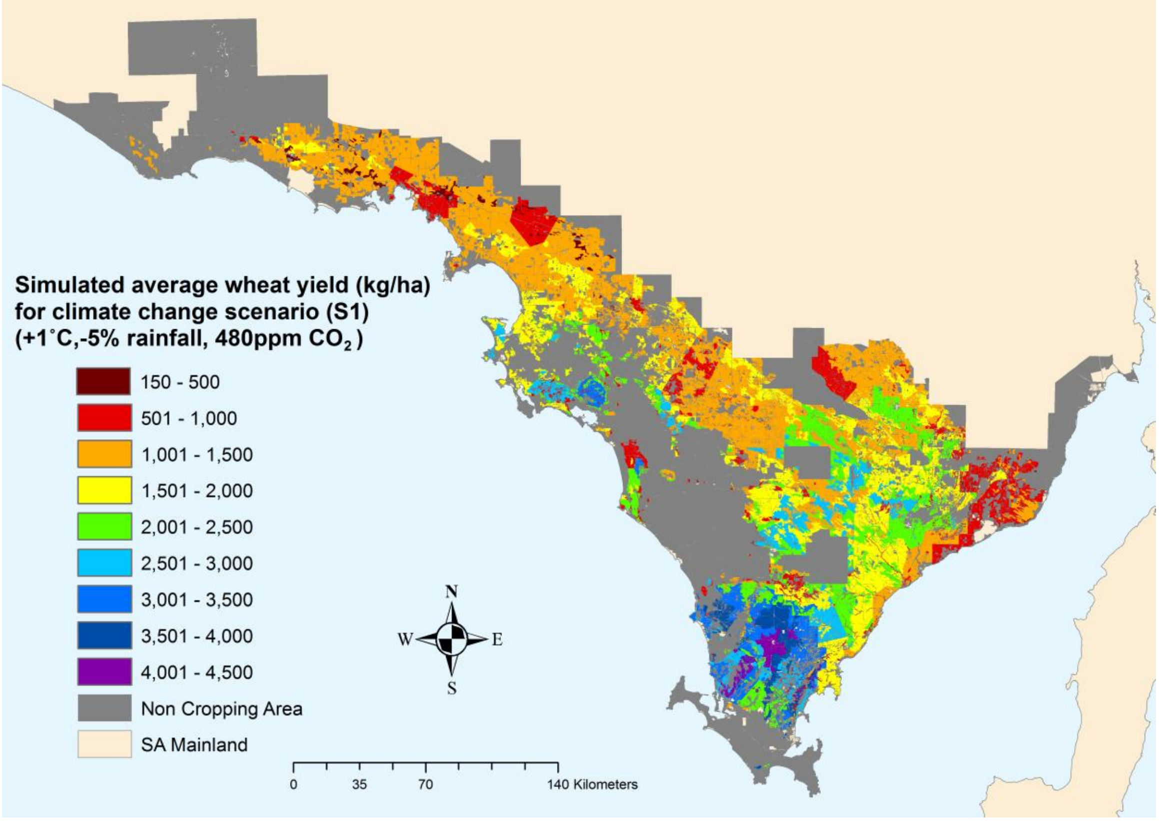


Figure 21: Simulated average wheat yields for the Eyre Peninsula based on 110 years of climate change scenario (S1)

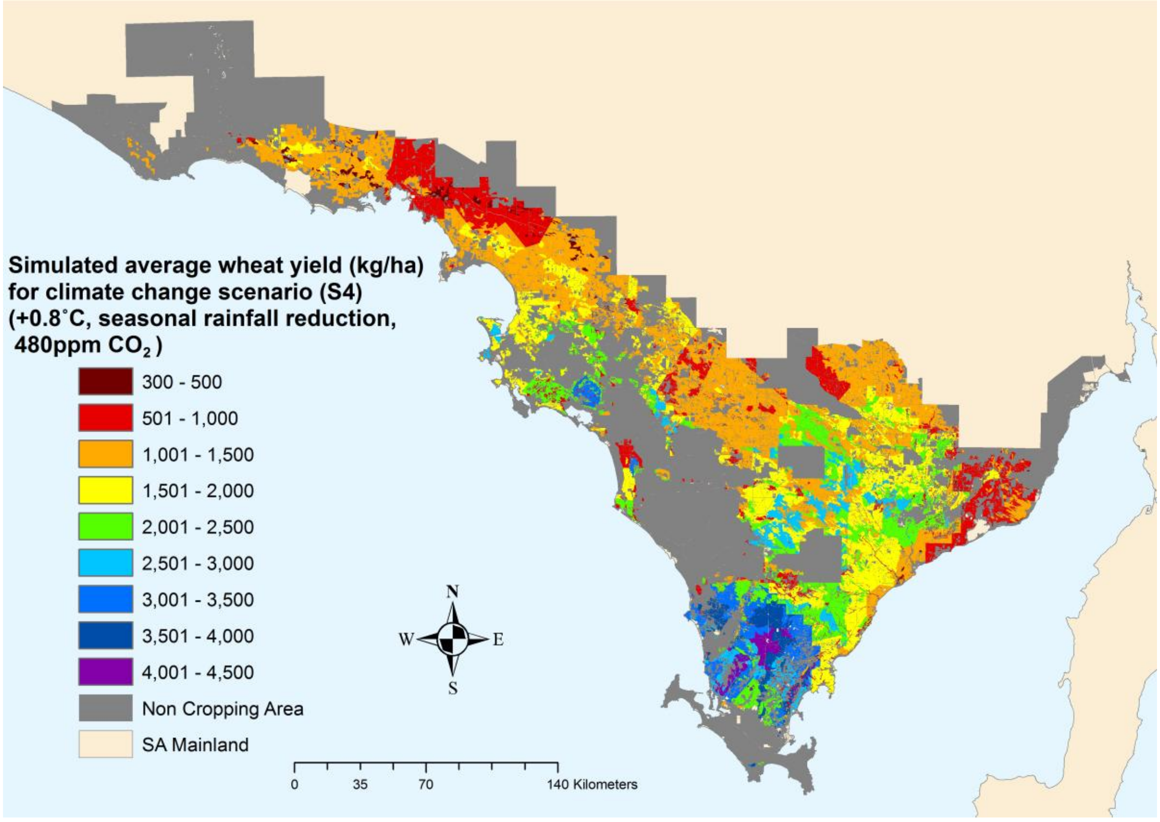


Figure22: Simulated average wheat yields for the Eyre Peninsula based on 110 years of climate change scenario (S4)

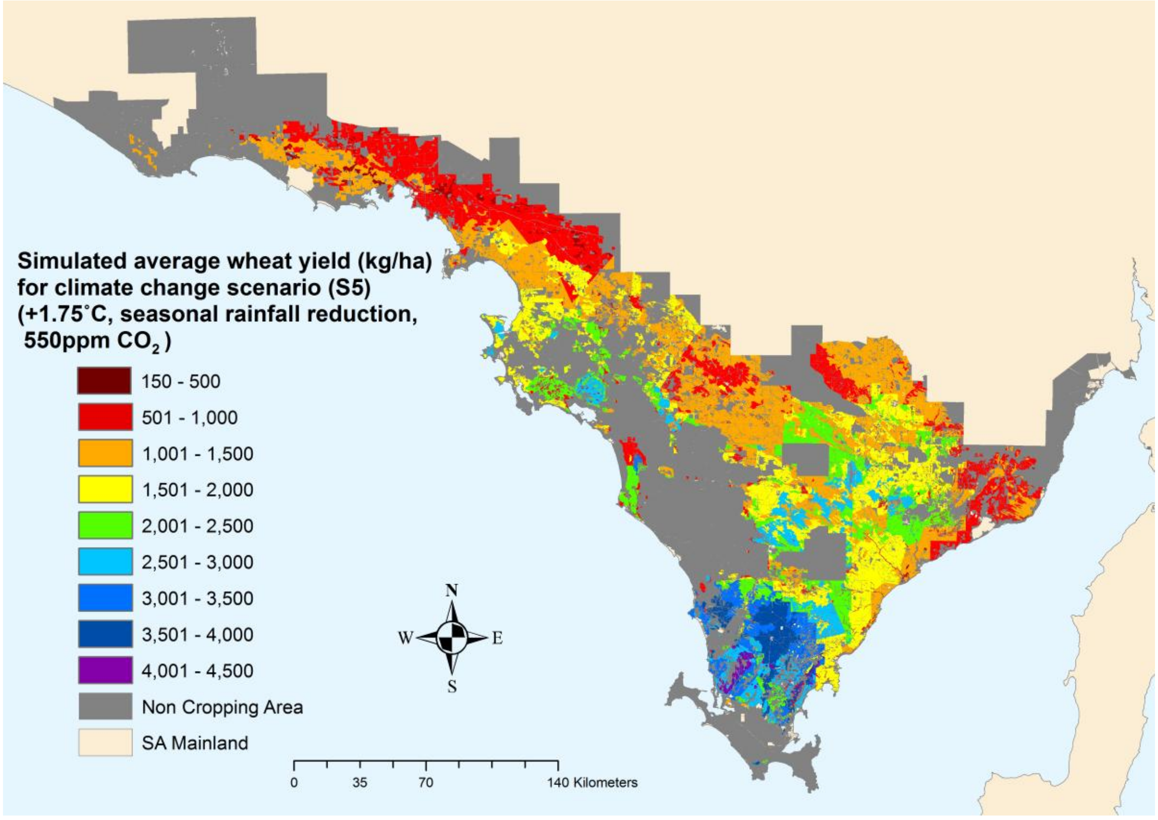


Figure 23: Simulated average wheat yields for the Eyre Peninsula based on 110 years of climate change scenario (S5)

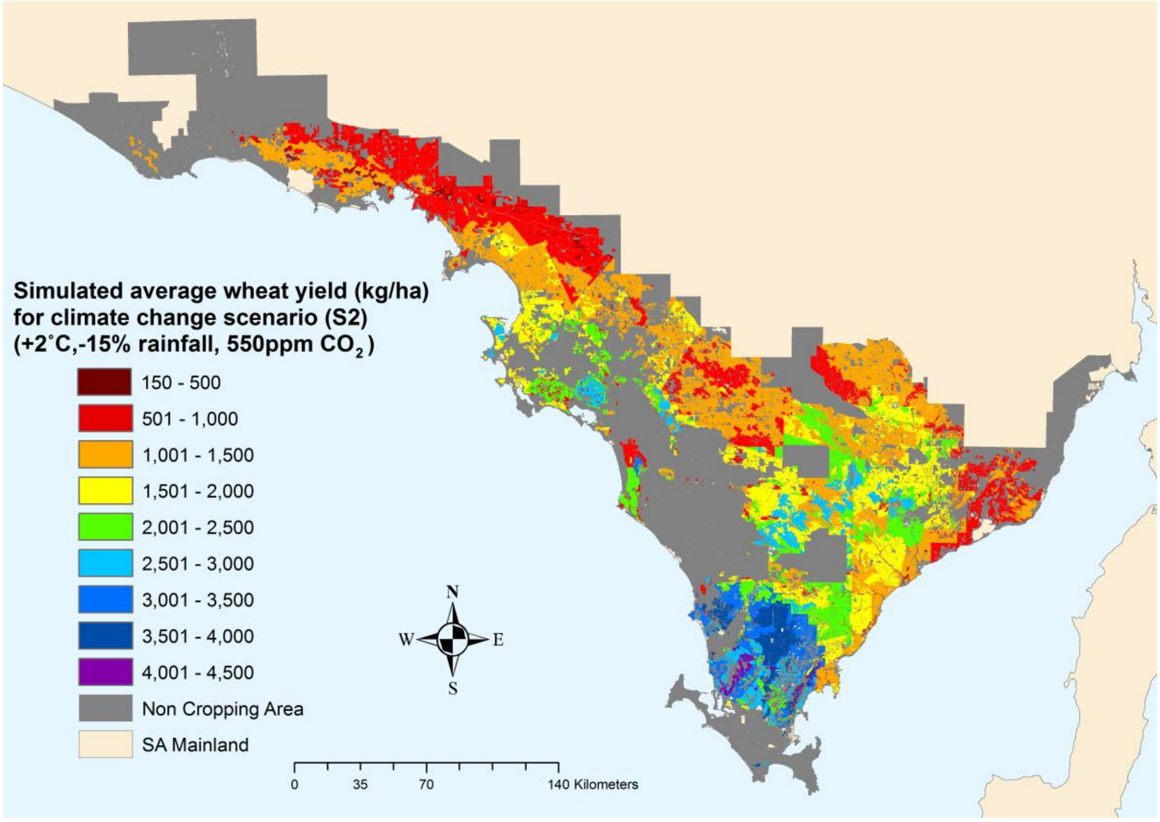


Figure 24: Simulated average wheat yields for the Eyre Peninsula based on 110 years of climate change scenario (S2)

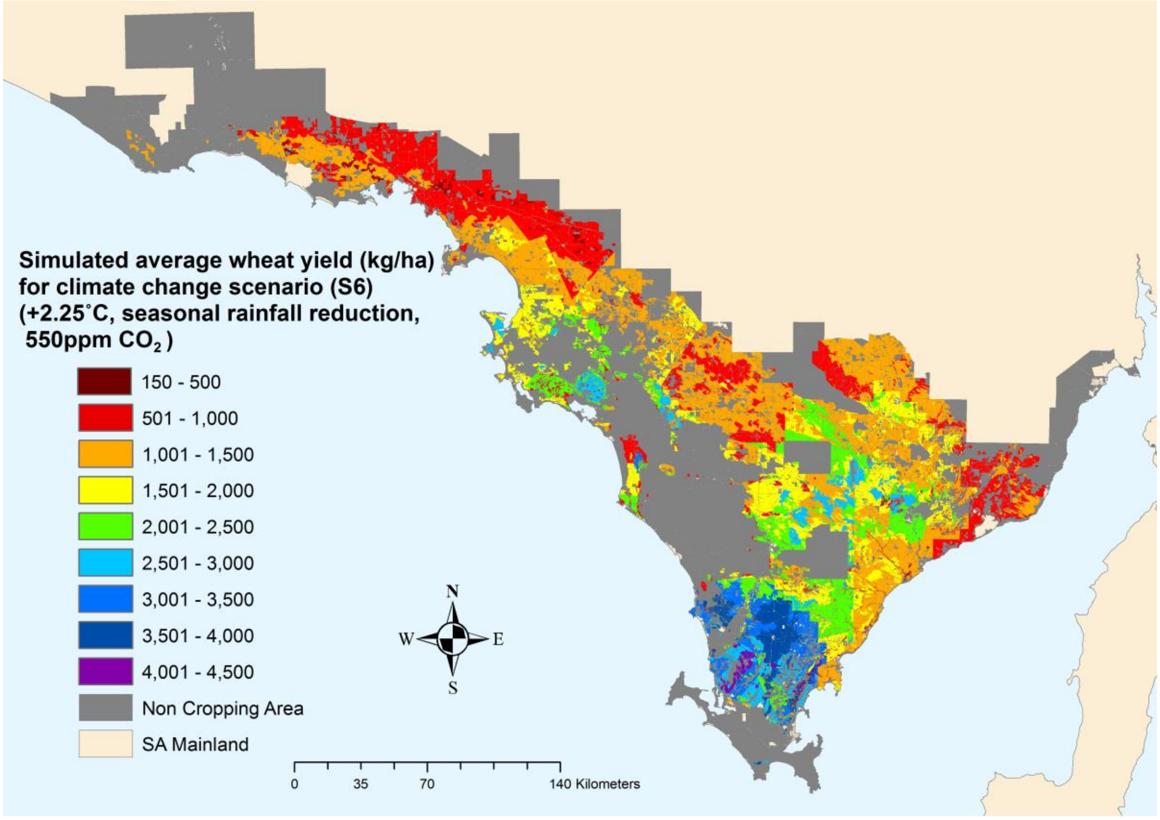


Figure 25: Simulated average wheat yields for the Eyre Peninsula based on 110 years of climate change scenario (S6)

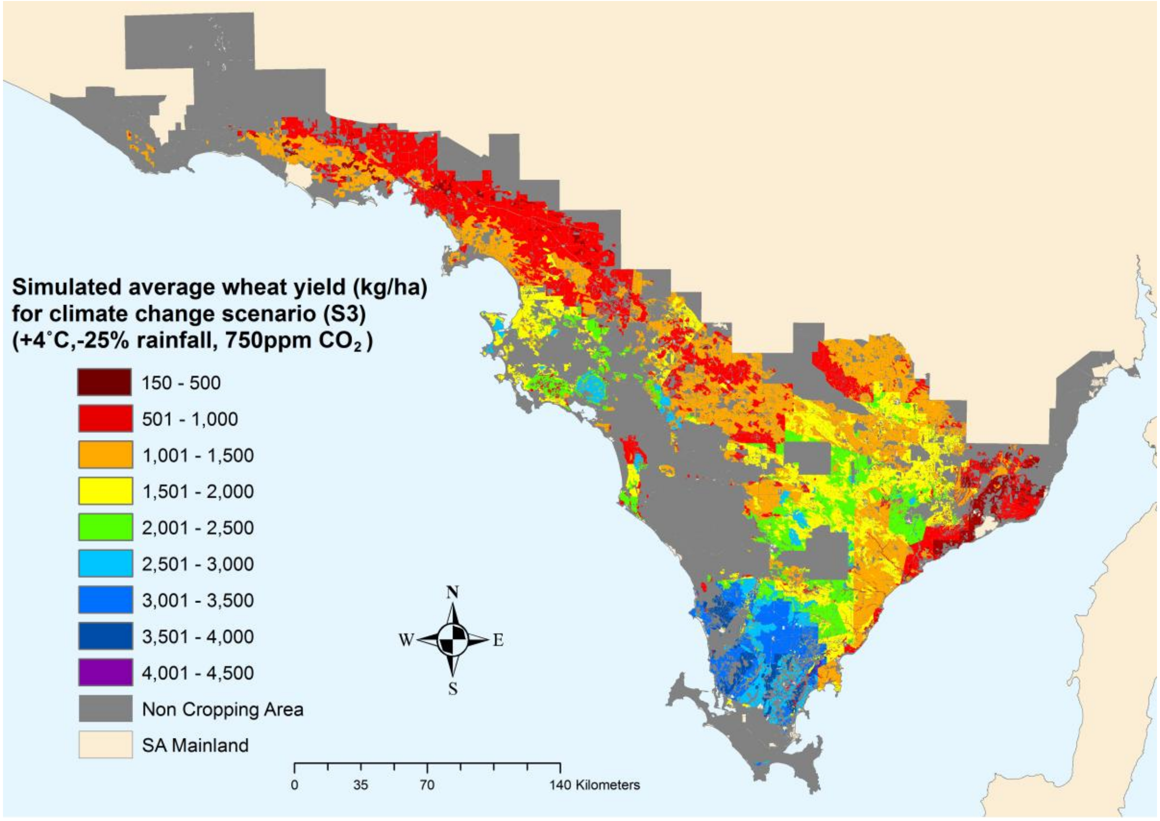


Figure 26: Simulated average wheat yields for the Eyre Peninsula based on 110 years of climate change scenario (S3)

4.2 Modelling Biomass and Carbon Sequestration under Climate Change

Increased levels of greenhouse gases in the atmosphere from the clearing of forests for agricultural production over the short, medium and long-term are likely to contribute to the impacts of global climate change, resulting in the reduction and potential loss of vital ecosystem services (Albrecht and Kandji, 2003; Rodriguez et al., 2006). As a consequence, there is a growing interest in the study of alternative land uses in agricultural regions including the production of biomass, and reafforestation for carbon sequestration. Each of these strategies provides potential benefits including reduced greenhouse gas emissions and economic returns for farmers (Bryan et al., 2010a; Bryan et al., 2010b). Eucalypt biomass could supply the renewable electricity, activated carbon and eucalyptus oil industries, whereas the benefits of environmental plantations and hardwood plantations include the mitigation of dryland salinisation and soil erosion (Bryan et al., 2010a; Bryan et al., 2010b; Jackson et al., 2005). Environmental plantations also provide support for biodiversity (Foley et al., 2005; Jackson et al., 2005).

Process-based models utilize the biophysical parameters of tree species to simulate how characteristics including growth patterns, carbon storage and water cycles will be affected by external factors (Almeida et al., 2004b; Feikema et al., 2010). Models such as 3-PG (***P***hysiological ***P***rinciples to ***P***redict ***G***rowth) (Landsberg and Waring, 1997; Sands and Landsberg, 2002) have been employed to determine forest productivity for a range of forest types, as well as assess site productivity and economic returns under different plantation management regimes and environmental conditions (Almeida et al., 2004a; Almeida et al., 2004b; Amichev et al., 2011; Battaglia and Sands, 1998; Bryan et al., 2010a; Bryan et al., 2007; Coops and Waring, 2001; Coops et al., 1998; Coops et al., 2005; Landsberg et al., 2001; Landsberg et al., 2003; Nightingale et al., 2008). 3PG models forest growth patterns on a monthly time scale and has become the default process-based model for forest management due to its simplicity and the fact that it is freely available (Sands, 2004). The CSIRO Land and Water division has recently developed a new version of 3PG, named $3PG_2$, which includes improvements to the water balance predictions by incorporating daily rainfall data, as well as including variables for an understorey, site salinity and ambient CO_2 (Almeida et al., 2007; Polglase et al., 2008).

We used $3PG_2$ to predict forest productivity (biomass yield) for a homogenous hardwood plantation (*E.cladocalyx)*, a generic oil mallee species and a multi-species environmental plantation, based on climate data modelled using the ESOCLIM module of ANUCLIM for each of the four climate scenarios (S0, S1, S2, S3) (Section 3.1). (See technical report in Appendix 6).

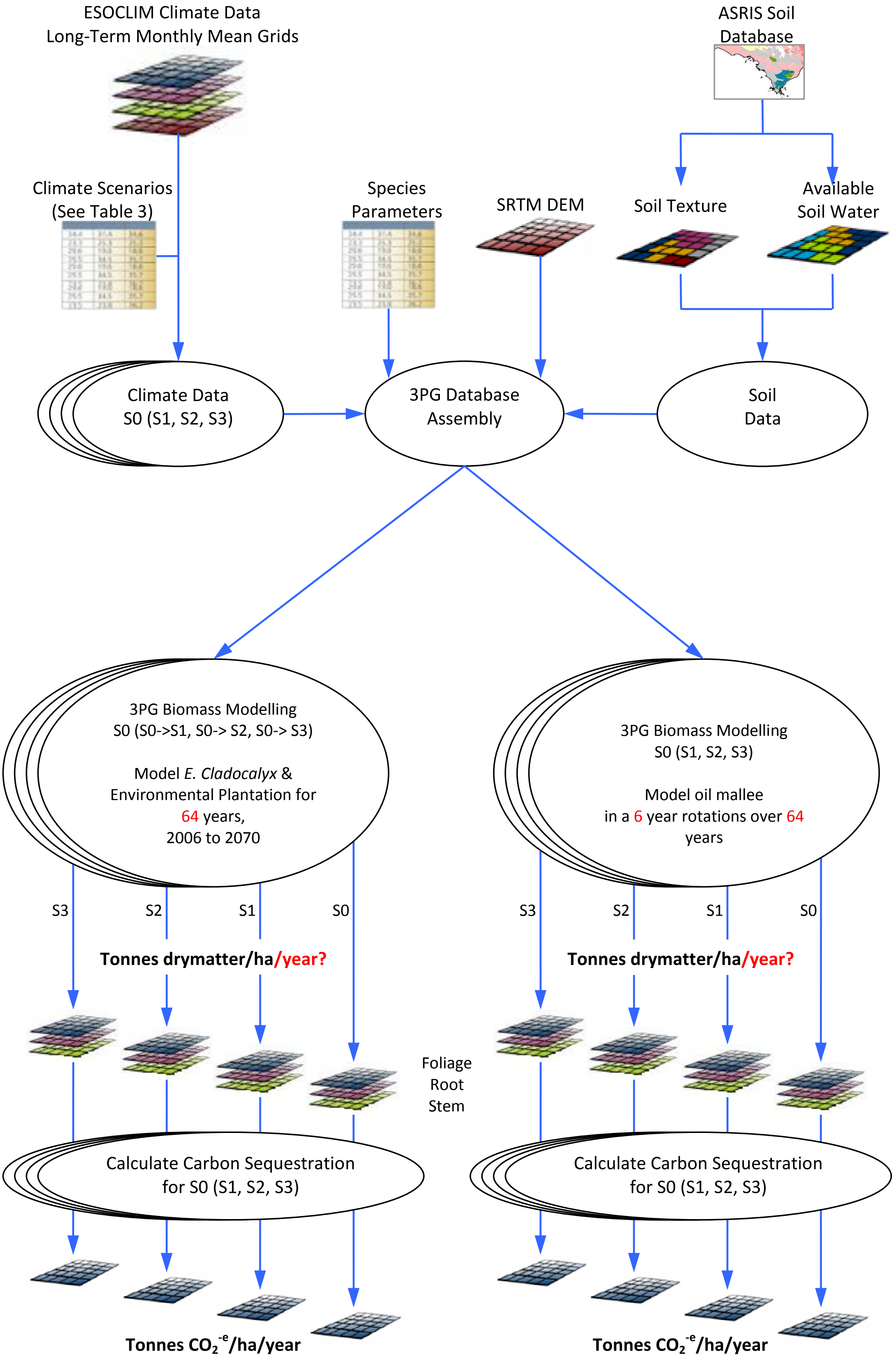


Figure 27: Structure of 3PG biomass and carbon sequestration simulation

4.2.1 Modelling Forest Growth with $3PG_2$

$3PG_2$ models forest growth patterns based on the absorption of photosynthetically active radiation (PAR) and constrained by environmental variables including temperature, vapour pressure deficit (VPD), frost, available soil water (ASW), stand age and site nutritional status. The spatial version of $3PG_2$ (Coops et al., 1998) can model productivity using raster data representing spatial variance in soil characteristics and climate for an area. The basic structure of $3PG_1$ is outlined in Figure A6-1, and of our simulation modelling in Figure 27.

$3PG_2$ requires a number of input data sets (Table 2 and 3):

- Monthly climate data including total solar radiation, total rainfall, average temperature, average vapour pressure deficit (VPD), rain days per month and frost days per month
- Soil texture and soil depth
- Individual species parameters

Long term average monthly climate data were sourced from ESOCLIM (Houlder et al., 1999). The specific layers used in this modelling were maximum temperature, minimum temperature, rainfall, rain days and solar radiation. The baseline climate scenario (S0) was based on the 2006 climate data remaining constant for a 64 year period (2006 to 2070). Data for the climate change scenarios [mild (S1), moderate (S2), and severe (S3) warming/drying] were created by altering the baseline temperature and rainfall records in annual increments from 2006 to 2070 (see Chapter 3). Solar radiation for the initial year was kept constant for each year under the three climate change scenarios, and the amount of frost days was set to zero.

A raster layer describing the soil type was extracted from the Australian Soil Resource Information System (ASRIS) (ASRIS, 2007). This involved combining three different individual databases at three different scales. The finest scale soil information – ASRIS soil level 5 (≤ 1:100 000) – covered the largest area (4,603,900 ha) but in order to cover the whole study area databases with broader spatial scales were also included. These included the ASRIS soil level 4 (~ 1:250 000) covering 111,500 ha of the study area and ASRIS soil level 3 (~ 1:1 000 000) covering 371,100 ha (see Figure 28). A soil depth raster layer was obtained from Polglase et al (2008) which used MrVBF to estimate soil depth for soils greater than 2 metres deep.

The original species parameters for 3PG were obtained from continued observations and measurements of forests and plantations (Landsberg et al., 2001). Almeida et al. (2007) recalibrated the original parameter files for use with $3PG_2$ in order to incorporate the enhanced growth and water balance components of the new model. Species parameters used in this study are presented in Appendix 6.

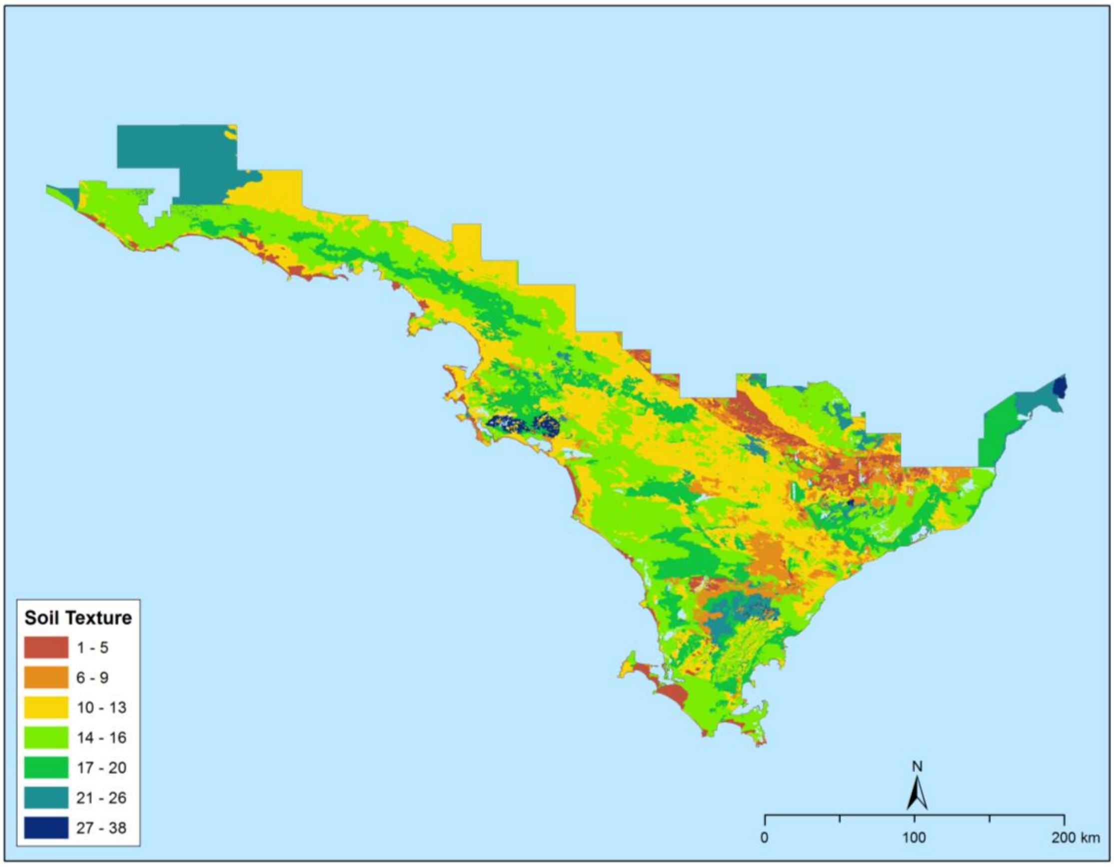


Figure 28: Soil texture in the Eyre Peninsula for 3PG2 modelling

Fix Map

Add one for Lower Murray too?

Hardwood plantations were modelled using a species parameter file for *E.cladocalyx. E.cladocalyx* is endemic to the Eyre Peninsula and Flinders Ranges regions and is among the most common species used in commercial plantations in southern Australia, with the potential to store large amounts of carbon through reafforestation over the long-term (Almeida et al., 2007; Polglase et al., 2008). Species parameter files were calibrated for *E. cladocalyx* (Almeida et al., 2007; Paul et al., 2007), with parameter adjustments made to the temperature modifiers based on the environmental limits outlined by Brooker et al. (1999). Adjustments were also made to the maximum stem mass per tree at 1000 trees per hectare, and the maximum age in order to model the productivity of carbon plantations over the 65 year period from 2006 to 2070.

Environmental plantings offer additional benefits over single species plantations including support for biodiversity, resilience to climate change and lower ongoing management costs (Bryan et al., 2007; Polglase et al., 2008; Polglase et al., 2011). There is also the potential that in some areas, environmental plantations may store more carbon than single species plantations over long periods of time (Polglase et al., 2008; Polglase et al., 2011). The calibration of species parameters for the environmental plantings was based on a mixture of eucalypts, shrubs and acacias (Almeida et al., 2007; England et al., 2006; Polglase et al., 2008). Species parameters were recalibrated manually by adjusting parameters related to species sensitivity to environmental factors, age, and conductance. Due to limited calibration data availability for the Eyre Peninsula, environmental plantings parameters were calibrated using 36 measurements from low to moderate rainfall areas within the Eyre Peninsula and South Australian Murray-Darling Basin NRM regions. Environmental planting models were run over the same climate conditions and over the same period as *E.cladocalyx* (i.e. 2006 to 2070).

Drought-resistant mallee species have the potential to be useful in the production of bioenergy from biomass and eucalyptus oil when coppiced on short rotation under dry conditions (Bryan et al., 2010a; Wildy et al., 2004). Parameters for oil mallee were based on the average of *E. Loxophleba lissophloia, E. polybractea,* and *E. kocchii* (Polglase et al., 2008), and used to represent the productivity of a typical oil mallee over a 6 year rotation. Oil mallee parameters used were calibrated by Polglase et al. (2008).

Site parameter files were used to define the study area and modelling scenario. The start age of each species was set to one year with assumed values set for initial stem mass, foliage mass and root mass, and the initial number of stems per hectare was set to 1000 for each modelled species. For the purpose of this study understorey and pasture components were not modelled due to the fact that biomass is only simulated for the understorey (Polglase et al., 2008). As 3PG2 does not currently account for the effect of atmospheric CO2, ambient CO2 was set to a default value of 350ppm for each species under each climate change scenario.

The selected outputs from $3PG_2$ were the total biomass of forest trees per hectare (tonnes dry matter/ha), allocated between foliage, root and stem. Gifford (2000) suggests that a figure of 50±2%C is a suitable figure to represent the percentage of carbon stored in the total biomass by weight. A multiplication factor (3.67) was then used to determine the total amount of CO_2 stored in the carbon (Standards Australia, 2002). Thus, 3PG estimates of biomass were converted to CO_2 using the formula:

$$E = \frac{(W_F + W_R + W_S) \times 3.67}{2}$$

Where:

E = Carbon sequestered (tonnes CO_2^{-e}/ha)
WF = Foliage biomass from 3-PG (tonnes dry matter/ha)
WR = Root biomass from 3-PG (tonnes dry matter/ha)
WS = Stem biomass from 3-PG (tonnes dry matter/ha)

4.2.2 Carbon Sequestration and Forest Growth in Eyre Peninsula

The total carbon sequestration for the modelled hardwood plantations in the Eyre Peninsula was around 326 tonnes/ha, averaging out to a carbon sequestration rate of approximately 5 tonnes CO_2^{-e}/ha/year over the 64 year simulation under the baseline climate scenario (Figure 29a). Across the study area sequestration rates varied significantly (Figure 30), ranging from 1.4 tonnes CO_2^{-e}/ha/year in the drier areas up to around 10 tonnes CO_2^{-e}/ha/year in higher rainfall regions .

Carbon sequestration rates of hardwood plantations decreased under warmer and drier conditions. The average annual sequestration rate over the 64 year simulation reduced by approximately 4.8% under climate change scenario S1, 15.3% under S2 and 26% under S3 (Figure 29a). Low productivity areas were affected significantly, with sequestration rates decreasing by up to 71% under severe climate change. The wetter, more productive regions experienced a less significant reduction in carbon sequestration, with sequestration rates decreasing by up to 2.36% under severe climate change (Figure 30).

Modelling of environmental plantings displayed an average sequestration rate of around 4.35 CO_2^{-e}/ha/year up to year 54, where the stand matures and the average carbon sequestration rate starts decreasing. In comparison to hardwood plantations, carbon sequestration estimates for environmental plantations were lower, with a total sequestration of around 227 tonnes/ha under the baseline climate scenario. This averaged out to an annual carbon sequestration rate of approximately 3.5 tonnes CO_2^{-e}/ha/year over the 64 year simulation (Figure 29b). Spatially, sequestration rates varied significantly across the study area (Figure 30, ranging from 0.9 tonnes CO_2^{-e}/ha/year in the arid regions up to around 12.5 tonnes CO_2^{-e}/ha/year in the higher rainfall regions.

Average annual carbon sequestration rates of environmental plantings increased by 2.33% under climate change scenario S1, and then decreased by around 3.5% under S2 and 9.4% under S3. Overall, environmental plantings were more resilient to climate change scenarios than hardwood plantations. As with the hardwood plantations, low productivity areas experienced a significant decrease in carbon sequestration rates, with sequestration rates decreasing by up to 54.3% under severe climate change. More productive regions experienced an increase in carbon sequestration rates under each climate change scenario, with an increase in carbon sequestration rates of up to 2.4% under climate change scenario S3.

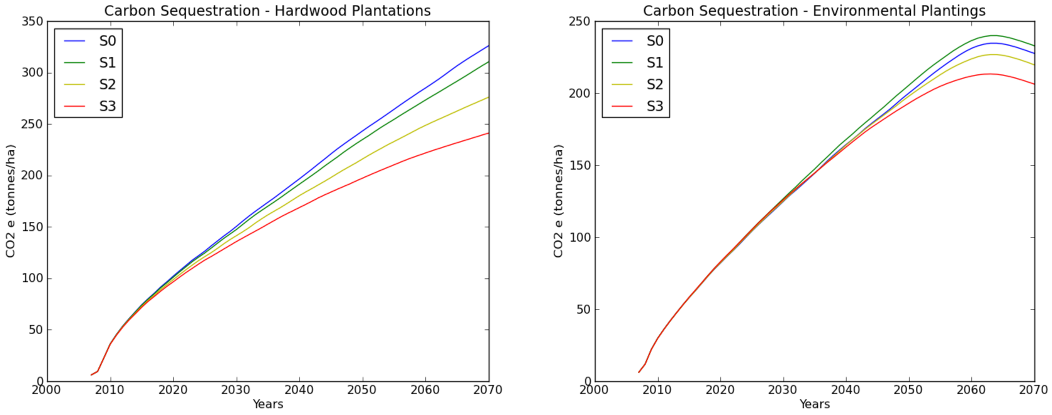


Figure 29: (a) Temporal dynamics and variation in carbon sequestration for hardwood plantations (left) and (b) environmental plantings (right) in the Eyre Peninsula under the baseline and climate change scenarios

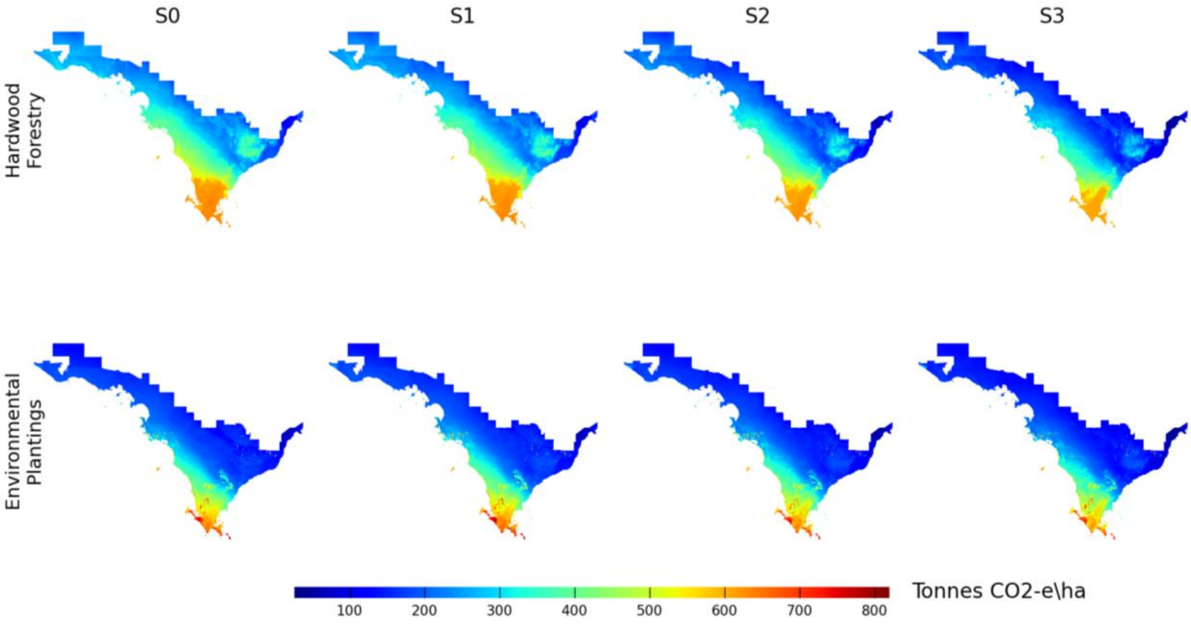


Figure 30: Estimated CO_2 sequestration potential of hardwood plantations and environmental plantings in the Eyre Peninsula after 64 years (t/ha)

$3PG_2$ modelling of oil mallee for biomass production under the baseline climate displayed an average total dry weight of 22.6 tonnes per hectare, averaging out to an annual growth rate of around 3.8 tonnes per year over the first 6 years before harvest. Across the study area, growth rates ranged from less than a tonne per year (0.72 tonnes/ha/year) in lower rainfall areas, to 6.7 tonnes per year in more productive, higher rainfall areas (Figure 31).

Average growth rates for oil mallee increased under climate change scenario S1 by 4.7%, but decreased by 10.8% under S2 and 34.5% under S3. In lower rainfall areas, growth rates decreased by up to 41% under the severe climate change scenario. In contrast, growth rates increased in high rainfall areas, with increases of 18.6%, 29.6% and 37.8% observed for S1, S2 and S3 respectively.

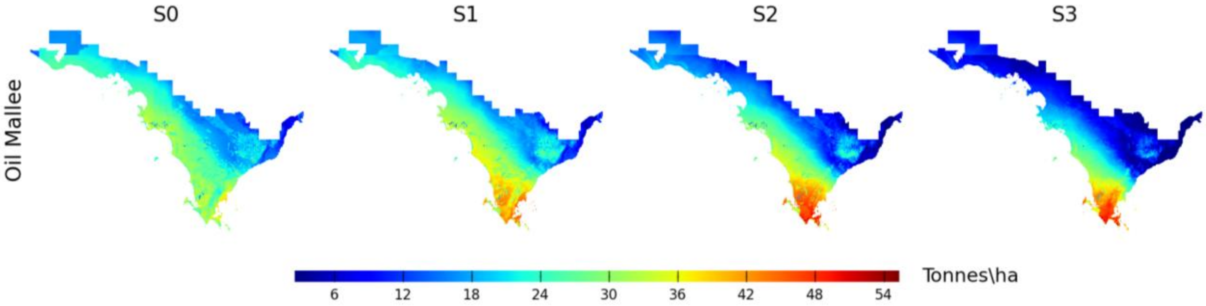


Figure 31: Productivity of oil mallee in the Eyre Peninsula after 64 years (t/ha)

4.2.3 Carbon Sequestration and Forest Growth in the Lower Murray

Total carbon sequestration of hardwood plantations across the Lower Murray region ranged from 3.7 tonnes/ha to 688.78 tonnes per hectare (Figure 33), with an average total carbon sequestration of 317.67 tonnes per hectare. This translates to an average annual sequestration rate of around 5 tonnes CO_2^{-e}/ha/year (Figure 32a).

Carbon sequestration rates of hardwood plantations decreased across the study area under each of the climate change scenarios, with the average sequestration rate decreasing by 8.3% under S1, 23% under S2 and 37.15% under S3. Sequestration rates remained stable in higher rainfall areas, with potential carbon sequestration decreasing by only 0.69% under severe climate change. Areas where sequestration rates were low under the baseline climate saw no change under each of the climate change scenarios.

Modelling of environmental plantings presented a total carbon sequestration amount of 290.44 tonnes/hectare on average across the study area, translating to an annual sequestration rate of 4.54 tonnes CO_2^{-e}/ha/year (Figure 32b). Sequestration rates varied across the study area (Figure 33), with sequestration rates of up to around 10 tonnes CO_2^{-e}/ha/year in more productive areas, to 0.07 tonnes CO_2^{-e}/ha/year in the arid regions.

Average annual sequestration rates decreased by nearly 9% under climate change scenario S1, 23% under S2 and 37% under S3. Sequestration rates remained relatively stable in higher production areas with carbon sequestration decreasing by up to 2% under the impact of severe climate change. In arid areas there was no change in carbon sequestration rates.

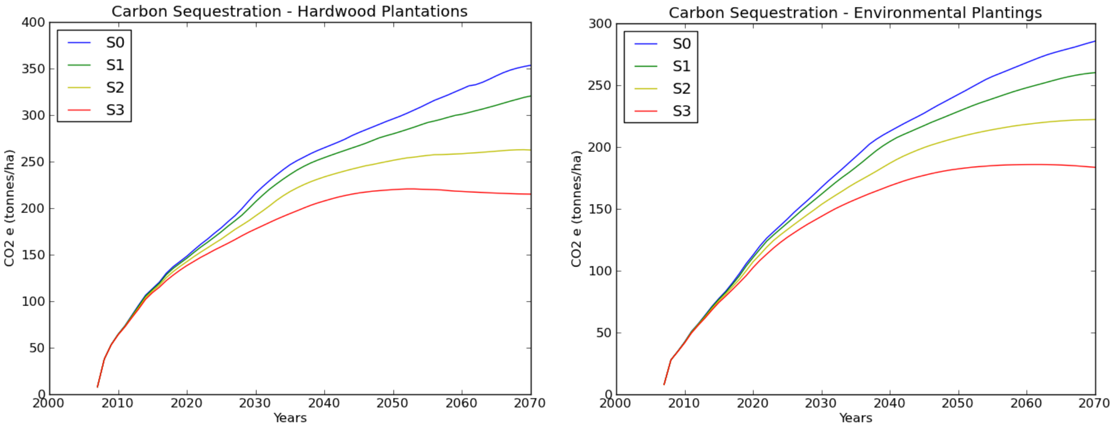


Figure 32: (a) Temporal dynamics and variation in carbon sequestration for hardwood plantations (left) and (b) environmental plantings (right) in the Lower Murray under the baseline and climate change scenarios

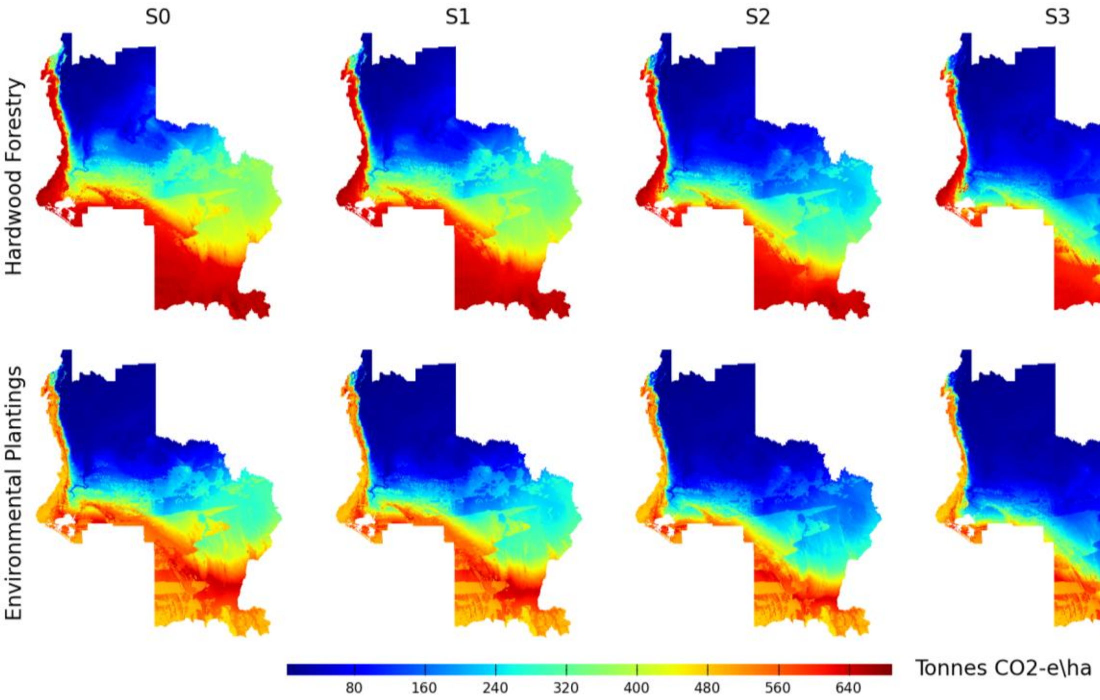


Figure 33: Estimated CO2 sequestration potential of hardwood plantations and environmental plantings in the Lower Murray after 64 years (t/ha)

$3PG_2$ modelling of oil mallee for biomass production displayed an average total dry weight of 43.7 tonnes per hectare, averaging out to an annual growth rate of around 7.3 tonnes per year over the first 6 years before harvest. Across the study area, growth rates ranged from less than a tonne per year (0.42 tonnes/ha/year) in lower rainfall areas, up to around 26 tonnes per year in more productive, higher rainfall areas (Figure 34).

Average growth rates for oil mallee decreased by 13% under climate change scenario S1, 30.2% under S2 and 46% under S3. Growth rates in high production areas increased by up to 3.3% under S1 and 1.7% under S2, but decreased by as much as 6.7% under S3. There was no change observed in the minimum growth rates in low rainfall regions of the study area.

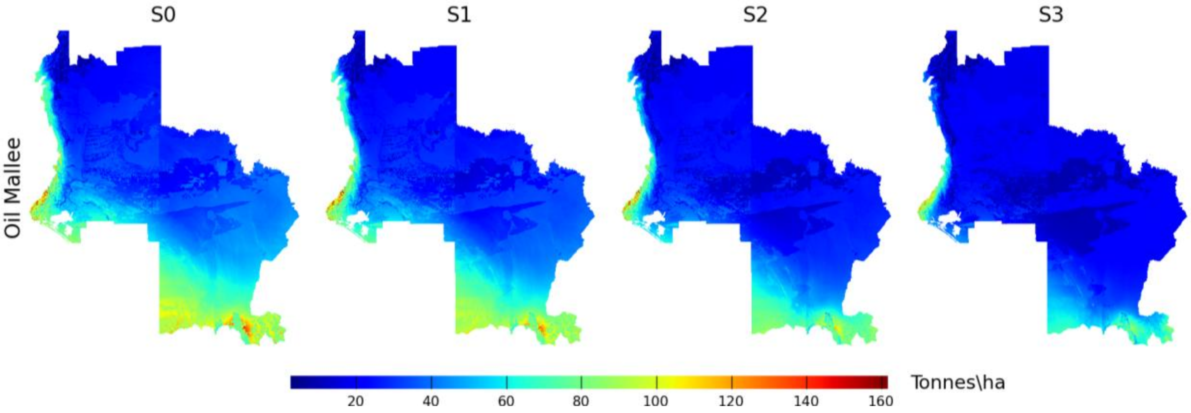


Figure 34: Productivity of oil mallee in the Lower Murray after 64 years (t/ha)

4.2.4 Discussion of Carbon Sequestration and Forest Growth

$3PG_2$ was used to model the biomass productivity of a hardwood plantation and environmental plantings for carbon sequestration over 64 years under a baseline and three climate change scenarios in the Eyre Peninsula and Lower Murray regions. Similarly, oil mallee was modelled over 6 years in these same regions to simulate biomass production.

In the Eyre Peninsula region, average carbon sequestration rates decreased for hardwood plantations under all of the climate change scenarios. In comparison, environmental plantations were generally more resilient to climate change, with an increase in average carbon sequestration observed under mild climate change, and decreases under moderate and severe climate change scenarios. Biomass production of oil mallee modelled over 6 years also displayed an increase in average growth rates under mild climate change, and more significant decreases under moderate and severe climate change. All three land uses displayed a high spatial variability across the study area.

In the Lower Murray region, average carbon sequestration rates decreased for both hardwood and environmental plantations under each of the climate change scenarios. Modelling of oil mallee over 6 years also displayed decreases in average productivity under warming and drying conditions.

4.3 Modelling Species Vulnerability under Climate Change

Climate change is likely to have significant effects on the distributions of many native plant species which may shrink, expand and/or shift their geographic range (Santos et al., 2009; Schneider et al., 2007; Vos et al., 2008). Some species will become more vulnerable if natural migration is hindered by landscapes altered by humans (Manning et al., 2009). Hence, targeted conservation is required to facilitate adaptation and migration, especially for the most sensistive native species.

Three distinct components of vulnerability have been identified including *exposure* to the stress, *sensitivity* to the stress, and the ability to adapt to the stress or *adaptive capacity* (Adger, 2006; Crossman et al., 2012; Schneider et al., 2007; Williams et al., 2008). Many studies have examined these components separately, but recently, studies have integrated the exposure, sensitivity, and adaptive capacity components of vulnerability (Carvalho et al., 2010; Crossman et al., 2012; Thuiller et al., 2005).

We modelled the vulnerability of 285 native plant species in the fragmented agricultural Eyre Peninsula NRM region under three climate change scenarios (S1, S2 and S3) (see Section 3.1), using a methodology developed for the Lower Murray which incorporates these three components of vulnerability (Crossman et al., 2012; Summers et al.,2012). Species distribution modelling was used to predict how individual species may move or shift geographically under climate change. We then assessed the effects of including various combinations of exposure, sensitivity and adaptive capacity in complementarity-based spatial conservation priorities for reducing vulnerability.

4.3.1 Data

Spatial layers of five independent environmental variables were used to predict habitat distribution in both the Eyre Peninsula (Table 2) and the Lower Murray (Table 3);

- Soil clay content
- Soil pH
- Temperature
- Rainfall
- Solar radiation

The two soil variables (clay content and pH) were extracted from the Australian Soil Resource Information System (ASRIS) (ASRIS, 2007) at a scale of 1:100 000. The three second Shuttle Radar

Topography Mission (SRTM) digital elevation model (DEM) was used to model solar radiation using the *Area Solar Radiation* tool within the ArcGIS 9.3 toolbox (ESRI, 2009), and to model mean annual temperature and precipitation layers within the ESOCLIM module of ANUCLIM (Houlder et al., 1999). These layers were used as the historical or baseline climate (S0). Annual mean precipitation and annual mean rainfall under the three climate change scenarios (S1, S2 and S3) were created by adjusting the baseline climate layers by the relevant temperature increase and precipitation decrease (see Chapter 3).

Biological data was sourced from the South Austalian Department of Environment and Natural Resources. In the Eyre Peninsula this database consisted of 365 269 geo-located, point-based, presence-only records of 4 776 plant species over 6 897 unique sites. This database was refined by omitting non-native species, water-dependent species, and species with less than 40 recorded observations. The refined database included 286 species with 52 692 records over 2 460unique sites. In the Lower Murray this database held 247 839 geo-located, point-based, presence-only records with a total of 4 410 plant species over 57 564 unique sites. Like the Eyre Peninsula this was refined by omitting non-native species, water-dependent species, and species with less than 40 recorded observations. The refined database included 584 species with 173,557 records over 27,810 unique sites.

4.3.2 Methods

Exposure

The exposure of plant species to climate change can be characterised as their predicted geographic range or distribution, and can be quantified using species distribution models (SDMs). These models quantify the relationship between independent variables and species occurrence based on known locations, and then predict species distributions using the independent variable layers. We selected three diverse models commonly used to predict species distributions, each using a different model: logistic regression (Márcia Barbosa et al., 2003; Schussman et al., 2006) using the ArcGIS geographic information system software, generalised additive models (GAM) (Elith et al., 2006; Guisan et al., 2002; Luoto et al., 2007) using the GRASP software package, and maximum entropy models using the Maxent package (MaxEnt) (Phillips et al., 2006) (see Appendix 7 for more details).

We predicted species distributions (exposure) based on the five independent variables under each climate scenario (S0, S1, S2 and S3) using the three models. Distributions were predicted under climate change by substituting the current climate layer with the future climate layers, and using the current distributions of species and their environmental correlates. For each species, we used the presence records and an equal number of absences randomly selected from the biological survey sites where the species was not recorded. To counter the potential bias from the generation of synthetic absence data, each of the three models was run ten times for each species for each climate scenario. For each run, unique calibration and validation datasets were created from the presence and absence species records through a random 70/30 split. The validation set was used to assess the predictive accuracy (using area under the curve (AUC) statistics) of individual models under the baseline climate (S0). Finally, an ensemble model was developed which combined the outputs of the logistic regression, generalised additive, and maximum entropy models into a single prediction of species distribution for each species under each climate scenario. The predictive accuracy was calculated for each ensemble forecast for baseline climate S0 to enable a comparison of accuracy with the three individual models.

Species sensitivity

The sensitivity of plants to climate change can be calculated based on the likely impact of climate change on their predicted geographic ranges. Those species experiencing the greatest shrinkage and shift in geographic range under climate change are the most-sensitive.

We calculated the sensitivity of species to climate change as a scalar sensitivity weight - i.e. the ratio of the change in species distribution to the extent of species distribution under each climate change scenario for each species. Higher sensitivity weights are assigned to those species whose spatial distribution was projected to contract or shift, particularly if their geographic range is already limited. Species with an extensive distribution receive lower sensitivity weights, especially where distributions are projected to increase under climate change (see Appendix 7 for more details).

Adaptive capacity

Adaptive capacity can be quantified as species' ability to migrate to and colonise new habitat under climate change scenarios, as future geographic ranges may be spatially dislocated from current locations. This can be quantified using a dispersal kernel from current known species locations.

We calculated the dispersal potential for each species under each climate change scenario (S1, S2 and S3) to provide a measure of adaptive capacity. This was calculated using a negative exponential dispersal kernel based on the Euclidean distance to the nearest known location of each species. The negative exponential function creates a dispersal potential layer with values ranging between zero (cells that are far away) and one (cells that are close by). Thus, a higher potential dispersal score is assigned to areas closer to known species locations (see Appendix 7 for more details).

Calculating and evaluating spatial priorities for mitigating species vulnerability

In order to reduce species vulnerability to climate change, the components - exposure, sensitivity, and adaptive capacity, need to come together to inform spatial priorities for conservation actions. Spatial priorities for conservation may be most effectively identified through the principle of complementarity, such that each unique element of biodiversity has a minimum level of representation.

We used the conservation planning software package Zonation (Moilanen and Kujala, 2008b) to identify priority areas for reducing species vulnerability under the three climate change scenarios S1, S2 and S3, and assessed the levels of species representation in these priority areas. Zonation uses a complementarity-based algorithm which iteratively removes cells from the analysis that incur the smallest marginal loss in conservation value (species representation) (Moilanen and Kujala, 2008a). This software includes a range of methods for identifying and evaluating the selection of conservation areas. It also allows for the inclusion of supplementary information such as species weights, conservation costs, and the location of existing reserves. In this study, we undertook core-area Zonation analyses to identify spatial conservation priorities under the three climate change scenarios. Core-area Zonation is designed to identify solutions that prioritise high-quality locations for all species while still accounting for priority weights attributed to them (see Appendix 7 for more details).

To assess the impact of including individual components of vulnerability (exposure, sensitivity and adaptive capacity), we calculated spatial conservation priority layers using Zonation at four levels of analysis:

1. *Exposure, sensitivity and adaptive capacity (exp+sens+ac)* - Full vulnerability framework which includes potential distribution layers multiplied by the dispersal potential for each species, and weighted by species sensitivity
2. *Exposure and adaptive capacity (exp+ac)* - Potential distribution layers multiplied by the dispersal potential for each species, with no species weighting
3. *Exposure and sensitivity (exp+sens)* - Potential distribution layers for each species (not multiplied by dispersal potential), weighted by species sensitivity
4. *Exposure only (exp)* - Potential distribution layers for each species (not multiplied by dispersal potential), and no species weighting

We quantified the degree of correlation in spatial conservation priorities between the four layers output from these four levels of analysis. To minimise spatial autocorrelation we extracted 200 random points, then calculated Pearson's *r* pairwise correlation coefficients between spatial conservation priority layers. This was repeated 1,000 times and the mean and standard deviation of the correlation statistics presented.

We also quantified the level of representation of each species achieved by each layer. AUC statistics were calculated based on species representation curves to quantify a threshold-independent measure of species representation by priority areas for each level of analysis and scenario. For a given scenario and level of analysis, if a particular species exhibits better than average representation by conservation priority areas then 0.5 < AUC ≤ 1, whilst 0.5 > AUC ≥ 0 reflects below-average species representation in spatial conservation priorites (see Appendix 7 for more details).

To evaluate the impact of including components of vulnerability, the mean level of representation was graphed and the mean AUC calculated under each climate change scenario and level of analysis for three indicators:

- all species
- the 50 most-sensitive species
- the five worst-performing species

4.3.3 Eyre Peninsula Results

Species vulnerability: exposure, sensitivity, and adaptive capacity

The generalised additive model (mean AUC = 0.830, S.D. ± 0.090) had the highest accuracy of the three individual species distribution models used in the analysis. This was followed by MaxEnt (mean AUC = 0.771, S.D. ± 0.129) and then the logistic regression (mean AUC = 0.769, S.D. ± 0.105). The ensemble model, which combined the three individual models performed better than all of the individual models (mean AUC = 0.832, S.D. ± 0.089).

Each of the individual models and the ensemble returned declining species distributions under each of climate change scenarios when compared to the current climate. Using the generalised additive model 140 (48.7%), 154 (53.7%) and 151 (59.6%) species had decreased distributions under the mild, moderate and severe climate change scenarios respectively. Similarly, using the logistic regression 128 (45.0%), 131 (45.6%) and 123 (42.9%) species had reduced projected distributions while for MaxEnt the numbers were 244 (85.0%), 248 (86.4%) and 252 (87.8%). The combined numbers for the Ensemble prediction were 150 (52.3%) 160 (55.7%) and 152 (53.0%).

The ensemble model projections were chosen for subsequent analysis because they provide a compromise between the inherent bias within the individual models without jeopardising model predictive ability. Ensemble projections for all but one species were sufficiently robust for one species (total n = 285) was sufficiently robust (AUC $\geq$ 0.6) for further analysis. The projected area of species distributions was calculated as the weighted sum of grid cell probabilities from the ensemble model. Under the current climate these ranged from 3830 Km^2 for *Xanthorrhoea semiplana* to 46,138 km^2 for *Austrostipa nitida*.

The sensitivity weights assigned to each species during the species distribution modelling ranged between 0.04 and 12.1 for the mild scenario, 0.08 and 216.8 for the moderate scenario and 0.08 and 1056.0 for the severe scenario. Figure 35 illustrate species' range shifts and sensitivity weights.

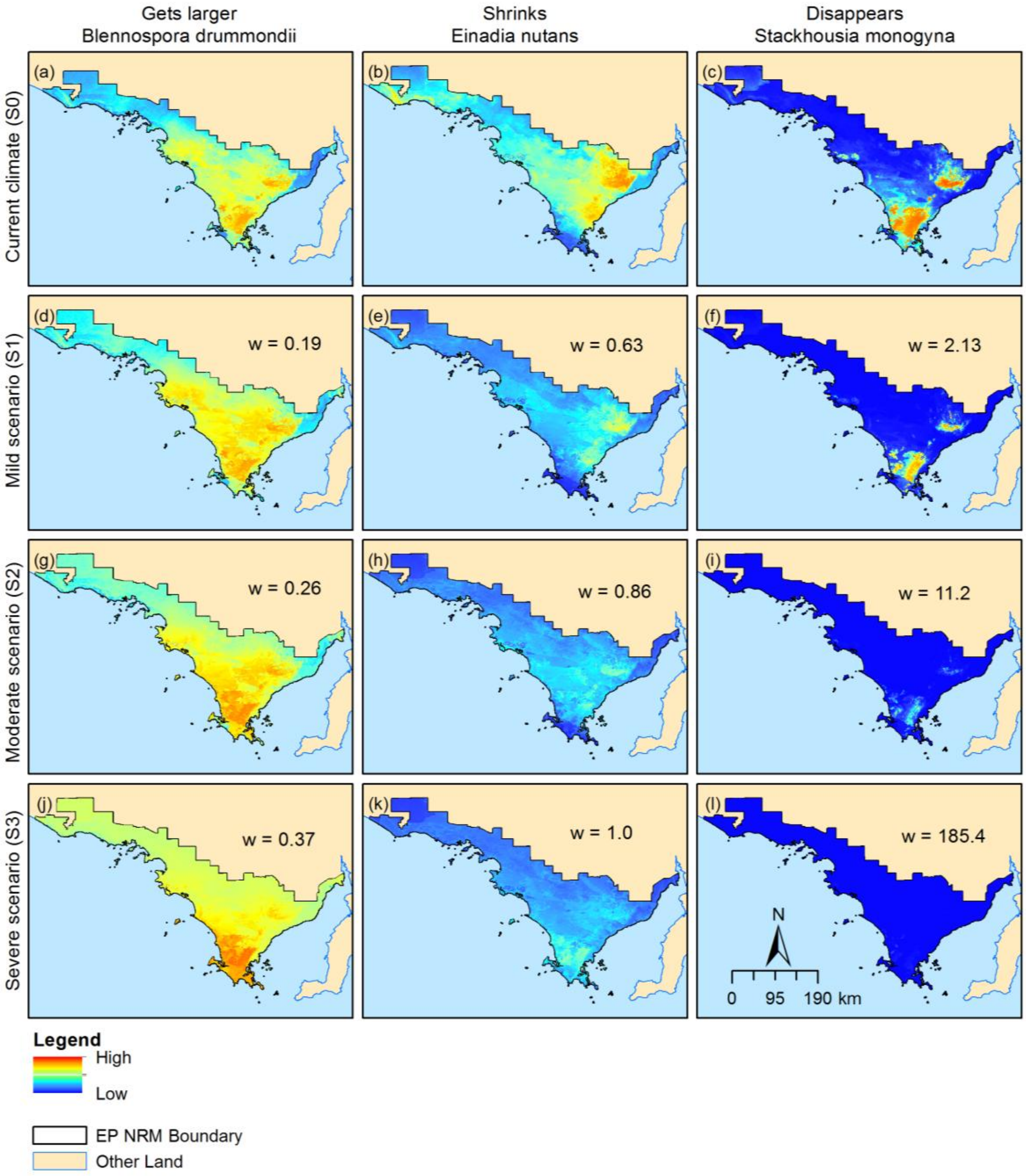


Figure 35: Examples of modelled species distributions in the Eyre Peninsula under climate change and resultant sensitivity weights

Examples of adaptive capacity, and adaptive capacity combined with exposure, under current climate, and the mild, moderate, and severe climate change scenarios are presented in Figure 36.

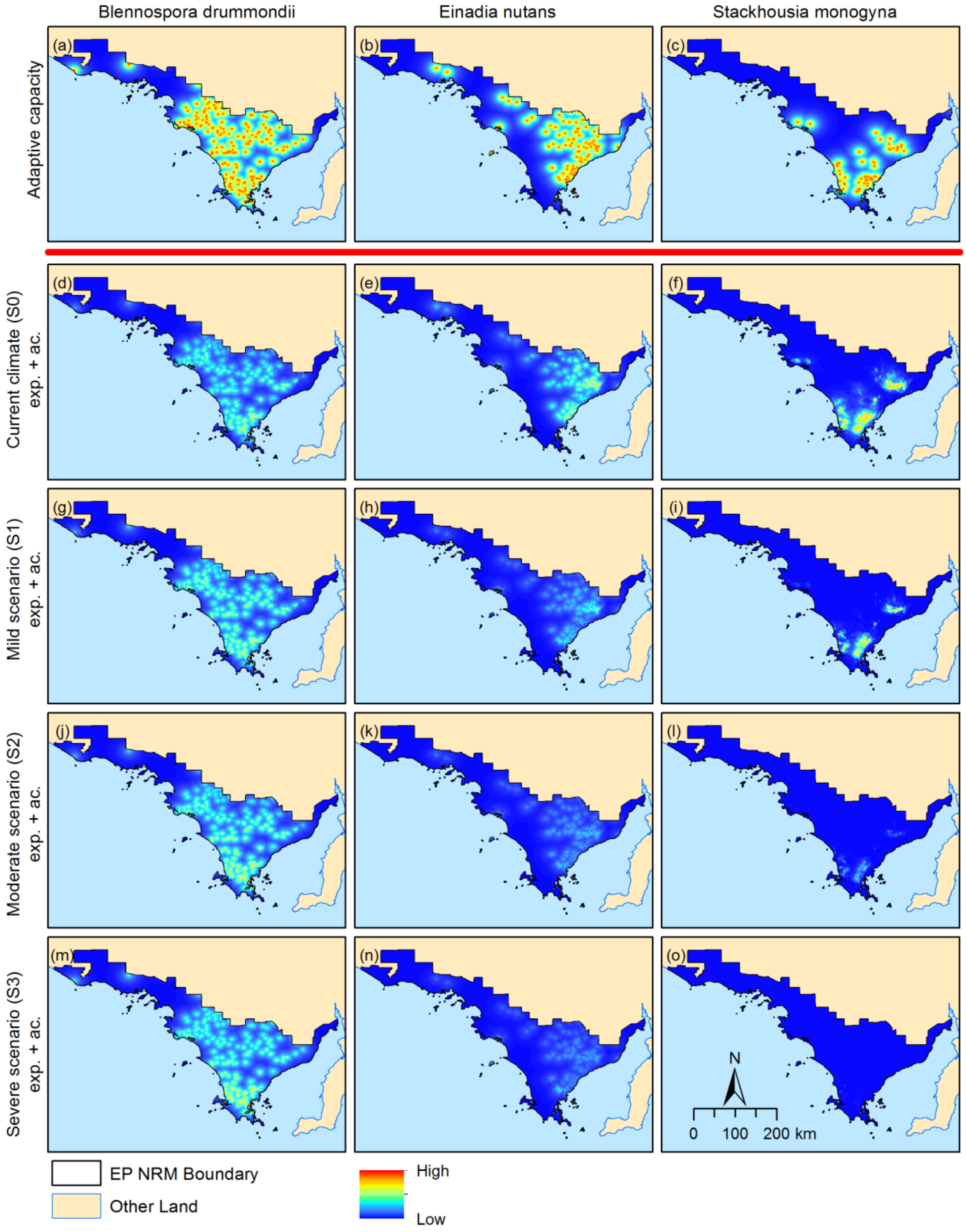


Figure 36: Examples of adaptive capacity, and adaptive capacity combined with exposure under current climate, and the mild, moderate, and severe climate change scenarios in the Eyre Peninsula

Calculating and evaluating spatial priorities for mitigating species vulnerability

Figure 37 shows spatial conservation priorities based on the four levels of analysis (exposure, sensitivity and adaptive capacity; exposure and adaptive capacity; exposure and sensitivity, and exposure only) under the three climate change scenarios. . Using all three components of vulnerability (exposure, sensitivity and adaptive capacity) priority areas were largely identified in the west, east and south of the EP NRM region under the various climate change scenarios (Figure 37a-c). For the most part the prioritisation identified large contiguous areas in the east and south with more localised priority in the central and western parts of the study area (Figure 37a-c). The eastern priority areas coincide with an area of slightly higher elevation. Under the mild climate change scenario there were more priority areas identified in the west and centre of the study area. Under increasing warming and drying (moderate and severe climate scenarios) there were fewer priority areas in the west and a higher concentration in the south and east. This can be seen comparing the prioritisations under the mild (Figure 37a), moderate (Figure 37b) and severe (Figure 37c) climate change scenarios.

Omitting sensitivity from the analysis (i.e. exposure and adaptive capacity layers only) created spatial conservation layers with priority areas dispersed through the landscape reflecting the influence of the dispersal kernel (Figure 37d-f). Omitting adaptive capacity from the analysis (i.e. using exposure and sensitivity only) resulted in a overall pattern similar to that achieved with the full vulnerability framework (Figure 37a-c), but with some significant local differences. Omitting both sensitivity and adaptive capacity (i.e. using exposure only; Figure 37j-l) results in a similar prioritisation as those calculated using exposure and sensitivity alone (Figure 37d-f) but with reduce spatial contiguity.

Correlations between spatial priorities calculated based on the full vulnerability framework, exposure and adaptive capacity, exposure and sensitivity, and exposure only, under each climate change scenario were largely found to be week (0.416) to moderate (0.757) (Table 10). There is one exception to this where a strong correlation (0.840) under the mild warming and drying scenario between the spatial priorities calculated with exposure and sensitivity and exposure alone.

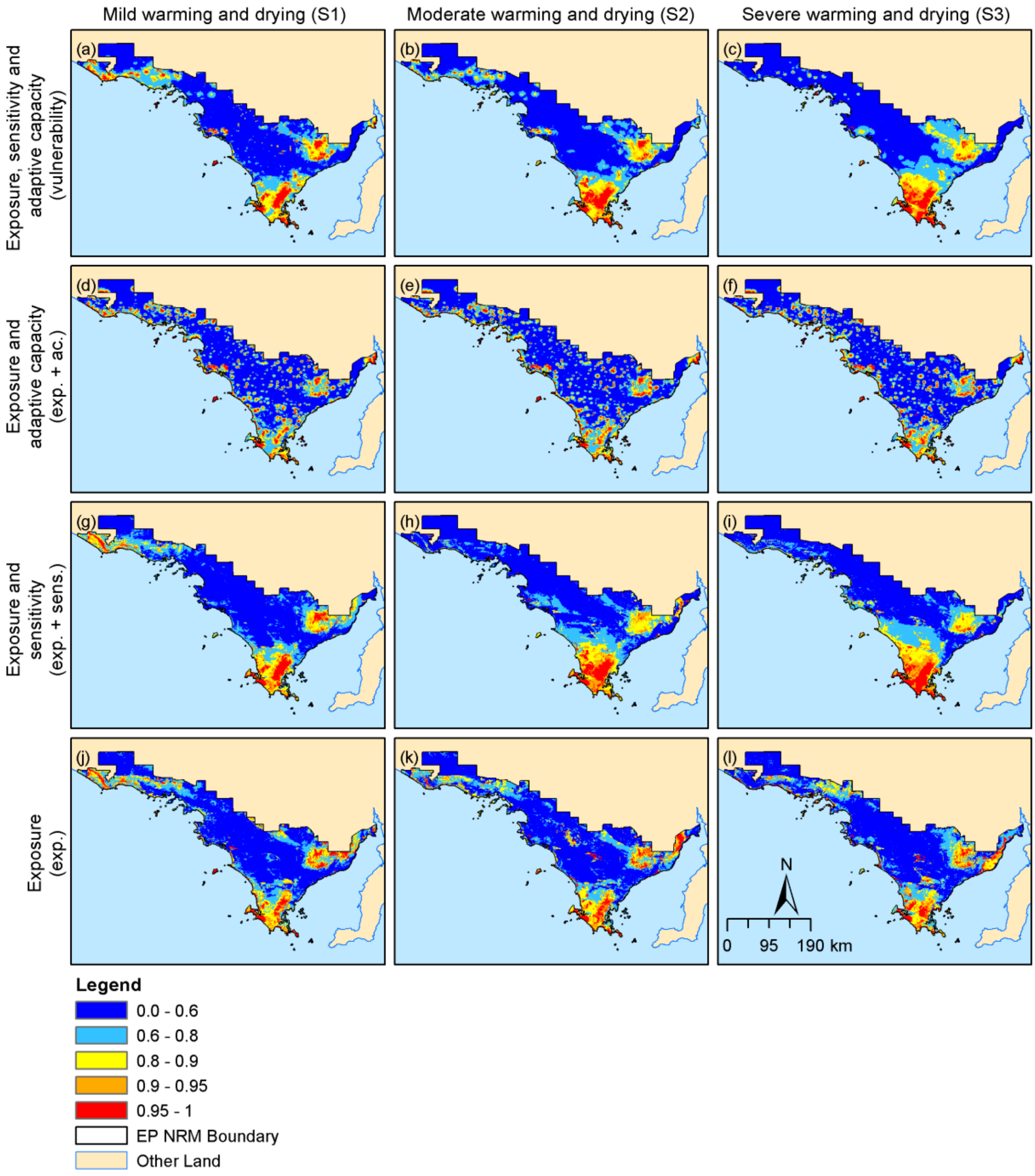


Figure 37: Spatial conservation priorities in the Eyre Peninsula. These were determined using exposure, sensitivity and adaptive capacity (vulnerability) (a-c); exposure and adaptive capacity (d-f); exposure and sensitivity (g-i); and exposure only (j-l)

Table 10: Mean and standard deviation of correlation coefficients between four levels of analysis under the three climate change scenarios in the Eyre Peninsula

	Mild scenario (S1)			Moderate scenario (S2)			Severe scenario (S3)		
Level	**Exp. +sens. +ac.**	**Exp. +ac.**	**Exp. +sens.**	**Exp +sens +ac.**	**Exp. +ac.**	**Exp. +sens.**	**Exp. +sens. +ac.**	**Exp. +ac.**	**Exp. +sens.**
Exp. + ac.	0.710 ± 0.036			0.611 ± 0.047			0.514 ± 0.055		
Exp. + sens.	0.726 ± 0.040	0.475 ± 0.057		0.716 ± 0.041	0.426 ± 0.060		0.757 ± 0.033	0.416 ± 0.062	
Exp.	0.674 ± 0.045	0.510 ± 0.030	0.840 ± 0.030	0.575 ± 0.054	0.427 ± 0.061	0.541 ± 0.050	0.505 ± 0.054	0.457 ± 0.059	0.545 ± 0.056

Comparing the species representation curves (Figure 38) and AUC indicators (Table 11) reveals variation in species representation by spatial conservation priority areas calculated using different components of the vulnerability framework. Omitting sensitivity in the identification of spatial priorities (Figure 38d-f, Table 11) reduced the mean representation of the 50 most sensitive species by 6.5 – 8.3% across the three climate scenarios. However, this also increased the mean representation of the 5 worst performing species (the mean of the five species with the lowest representation in the landscape) by between 14.3 – 46.0% and had a marginal impact on the mean representation of all species (-1.4 – 2.4%).

Omitting adaptive capacity in the identification of spatial priorities (Figure 38g-i, Table 11) had a limited impact on the 50 most sensitive species (-0.69 – -3.1%). However, this reduced the mean representation of the 5 worst performing species by 10.5 – 19.3% and had a variable impact on the mean of all species (-4.6 – 1.8%).

Omitting both sensitivity and adaptive capacity in the identification of spatial priorities (Figure 38j-l, Table 11) reduced the mean representation of all species and the 50 most-sensitive species by 4.8 – 9.6% and 4.4 – 8.9% respectively. The impact on the mean representation of the 5 worst-performing species was highly variable (-5.6 – 15.0%).

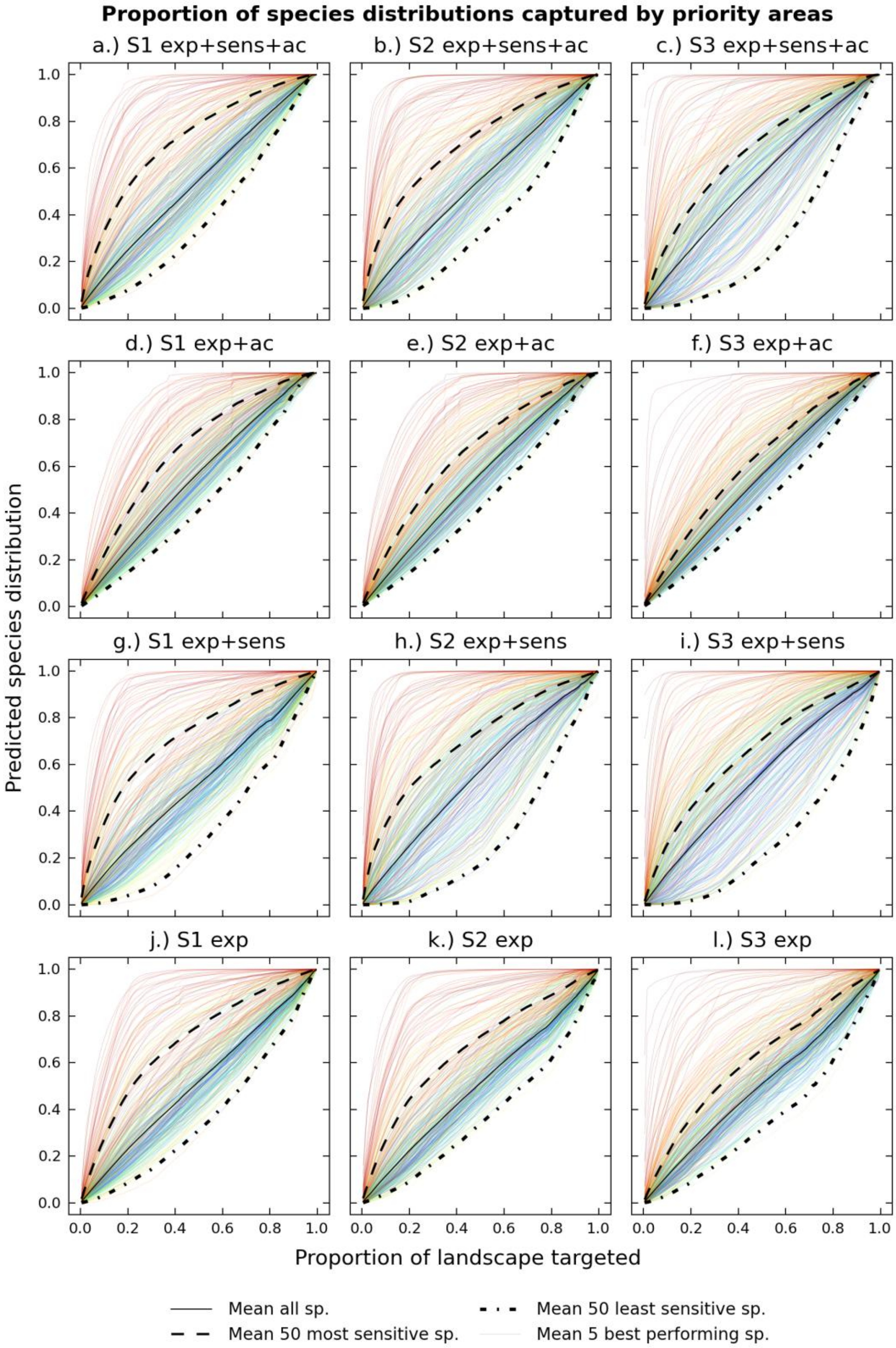


Figure 38: Species representation curves for spatial conservation priority layers calculated under each of the four levels of analysis and three climate scenarios in the Eyre Peninsula

The coloured lines indicate the most-sensitive (i.e. highest sensitivity weights) in red through to least sensitive (lower sensitivity weights) in blue

Table 11: Indicators of species representation (AUC) for conservation priority layers calculated using different components of vulnerability in the Eyre Peninsula

	Mild scenario (S1)				Moderate scenario (S2)				Severe scenario (S3)			
Layers	**Exp+ sens + ac**	**Exp+ ac**	**Exp+ sens**	**Exp**	**Exp+ sens + ac**	**Exp+ ac**	**Exp+ sens**	**Exp**	**Exp+ sens + ac**	**Exp+ ac**	**Exp+ sens**	**Exp**
Mean all species	0.540	0.553	0.515	0.514	0.541	0.550	0.551	0.505	0.555	0.547	0.545	0.502
50 most sensitive	0.721	0.674	0.716	0.689	0.708	0.657	0.698	0.659	0.673	0.617	0.652	0.613
Mean 5 worst performing	0.391	0.447	0.327	0.369	0.363	0.450	0.293	0.372	0.313	0.457	0.280	0.360

4.3.4 Lower Murray Results

Speceis vulnerability: exposure, sensitivity, and adaptive capacity

Looking only at the three individual models, the generalised additive model (mean AUC = 0.8565, S.D. ± 0.0820) and the maximum entropy model (mean AUC = 0.8535, S.D. ± 0.0811) performed best over the 584 species tested, followed by logistic regression (mean AUC = 0.8038, S.D. ± 0.0918). Under all of these models declines in area in species distributions were projected for most species. Declines of 376 (64.4 %), 355 (60.8 %) and 359 (61.5 %) species were projected under logistic regression, 349 (59.8 %), 353 (60.4%) and 360 (61.6 %) under the generalised additive model, and 272 (46.6 %), 304 (52.1 %) and 335 (57.4 %) under maximum entropy for the mild, moderate and severe climate change scenarios, respectively.

Similarly, the ensemble model also performed well. A high accuracy assessment was achieved (mean AUC = 0.8498, S.D. ± 0.0852) with predicted declines in the distribution of 342 (58.6 %), 347 (59.4 %) and 352 (60.3 %) species under the mild, moderate and severe climate scenarios respectively. Despite the slightly lower AUC value for the ensemble model projections they provided a compromise between the bias inherent in the individual models with little trade-off in model predictive ability and were therefore used in further analysis. All but one of the ensemble species distribution projections (total 584) were sufficiently robust (AUC ≥ 0.6) for further analysis. The area of projected species distributions under the current climate was calculated as the weighted sum of grid cell probabilities from the ensemble model. These ranged from 1,357 km2 for Pultenaea costata to 62,475 km2 for Ptilotus sp. The ensemble model outputs were used to quantify species exposure to climate change within the vulnerability framewok.

The sensitivity weights for each species were also assigned from the ensemble species distribution modelling. These ranged between 0.06 and 19.0 for the mild scenario, 0.1 and 224.5 for the moderate scenario and 0.12 and 2994.7 for the severe scenario. Examples illustrating species' range shifts (exposure) and sensitivity weights are presented in Figure 39.

A dispersal kernel from known species locations, as determined by the biological survey database was used to quantify adaptive capacity. Examples illustrating the dispersal kernel and adaptive capacity are presented in Figure 40. These maps demonstrate the higher values (dispersal potential) closer to known locations. Also provided in Figure 40 are example of adaptive capacity and exposure under the current climate and each of the climate change scenarios.

Spatial priorities for mitigating species vulnerability

Spatial conservation priorities determined using the four levels of analysis (exposure, sensitivity and adaptive capacity; exposure and adaptive capacity; exposure and sensitivity, and exposure only) under the three climate change scenarios are presented in Figure 41. Priority were mostly in the western SAMDB, the southern Mallee and large parts of the Wimmera, across all scenarios (Figure 41a-c) when identified using all three components of vulnerability (exposure, sensitivity, and adaptive capacity). Conservation priority areas are largely contiguous in the south and interspersed with localised priority areas (Figure 41a-c). There are localised priority areas in the eastern SAMDB and northern Mallee Under the mild climate scenario (Figure 41a) and with increasing warming and drying (moderate and severe climate scenarios) these priority areas move south and into areas of higher altitude. This is evident in Figure 41b (moderate scenario) and Figure 41c (severe scenario) where there are no longer priority areas on the northern border of the Wimmera and there is a higher concentration along the western and southern boundary. Also, fewer priority areas are identified in the northern half of the SAMDB rather there are increasing concentrations along the eastern Flinders Ranges and the southern SAMDB.

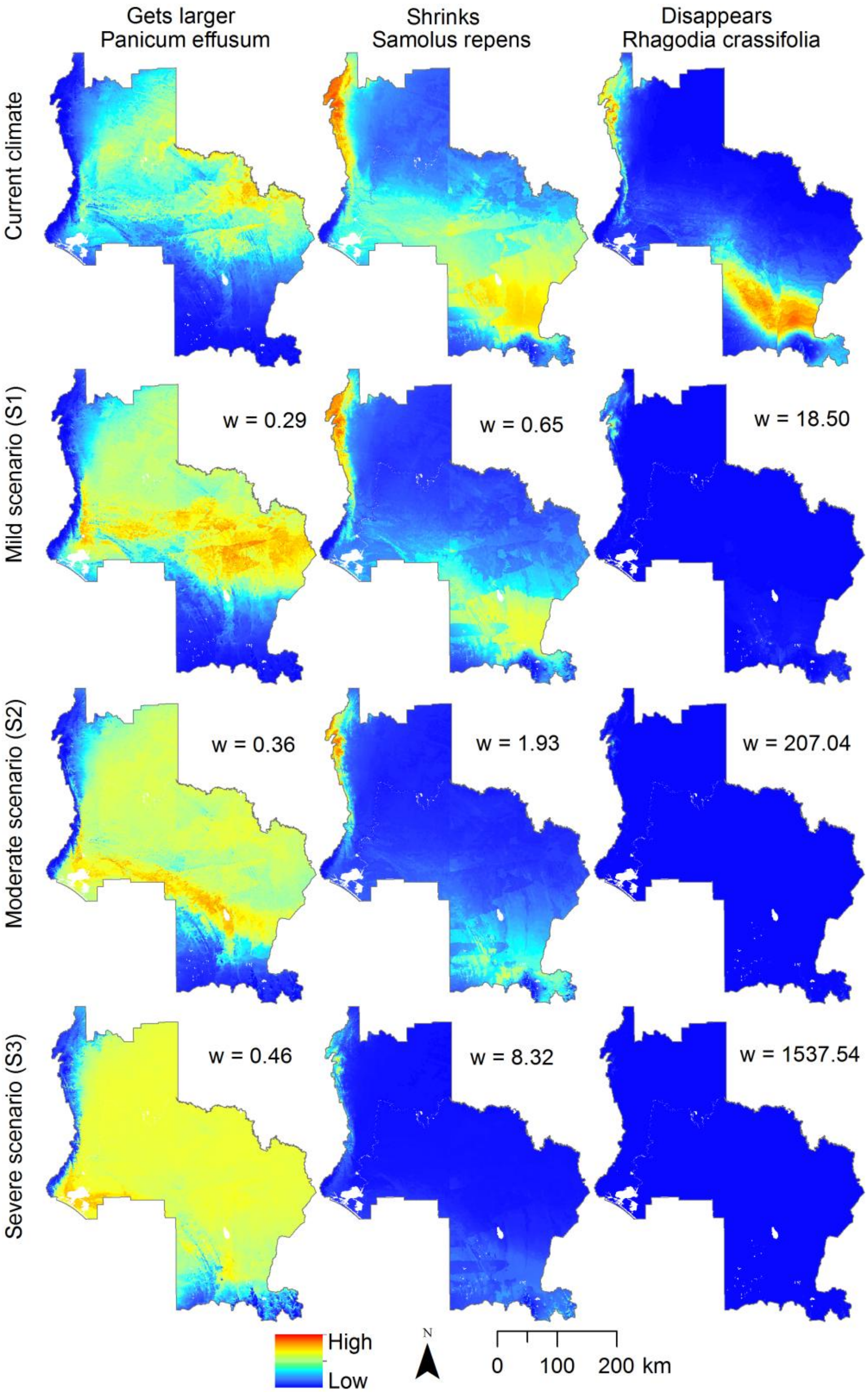


Figure 39: Examples of modelled species distributions in the Lower Murray under climate change and resultant sensitivity weights

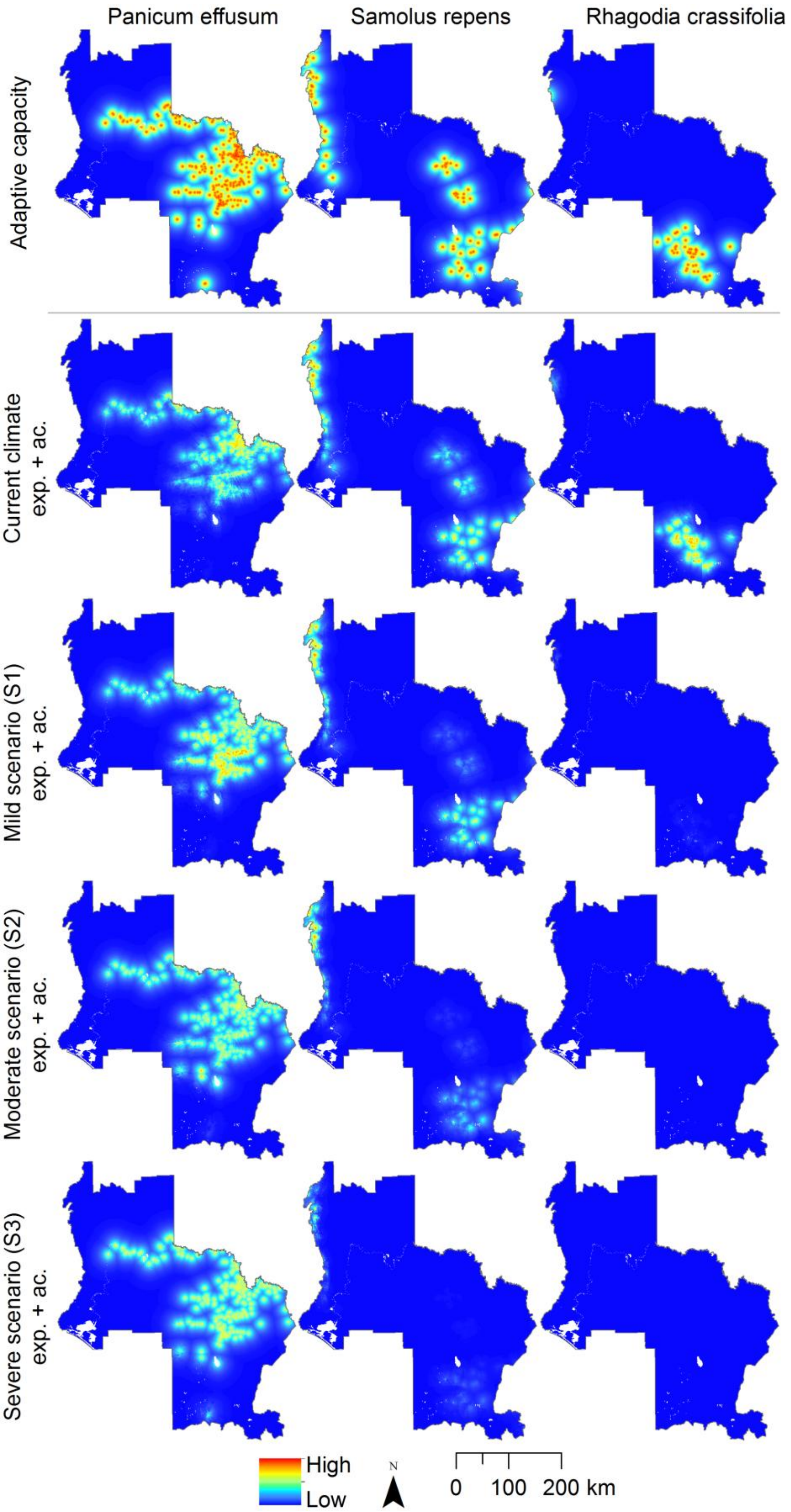


Figure 40: Examples of adaptive capacity, and adaptive capacity combined with exposure under current climate, and the mild, moderate, and severe climate change scenarios in the Lower Murray

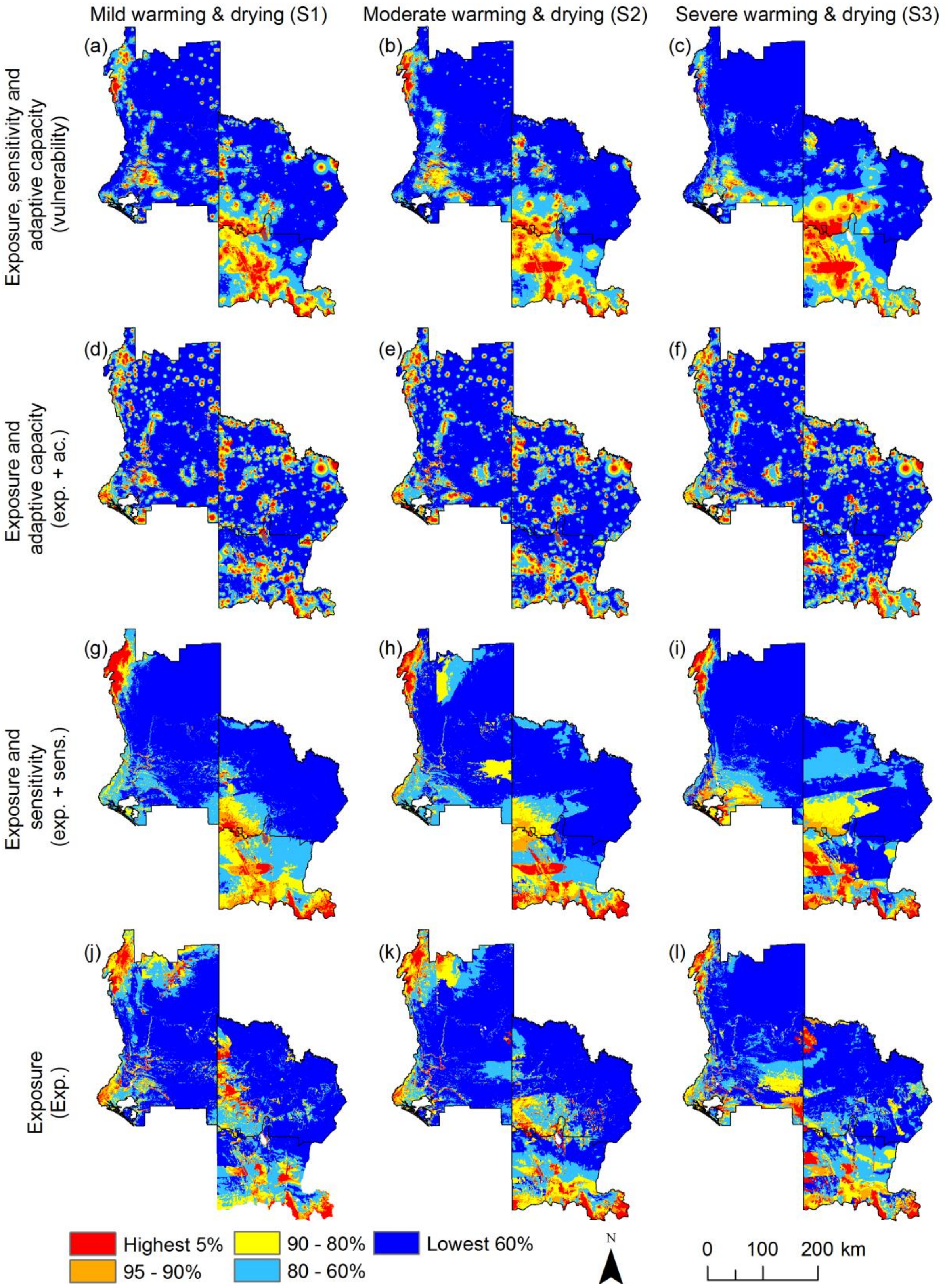


Figure 41: Spatial conservation priorities in the Lower Murray. These were determined using exposure, sensitivity and adaptive capacity (vulnerability) (a-c); exposure and adaptive capacity (d-f); exposure and sensitivity (g-i); and exposure only (j-l)

Spatial conservation priorities calculated with exposure and adaptive capacity layers only (i.e. sensitivity omitted) were dispersed through the landscape thus reflecting the influence of the dispersal kernel (41d-f). Priorities calculated with using exposure and sensitivity only (i.e. adaptive capacity omitted) display a similar broad pattern to those identified using the full vulnerability framework (Figure 41a-c), but with some significant local differences. Conservation priority layers calculated using only exposure (i.e. both sensitivity and adaptive capacity omitted; Figure 41j-l) show a similar pattern to those calculated using exposure and sensitivity alone (Figure 41d-f) but with less spatial contiguity.

Weak (r = 0.324) to moderate (r = 0.724) correlations were found between spatial priorities calculated with the inclusion of different elements of the vulnerability framwork (Table 12).

Table 12: Mean and standard deviation of correlation coefficients between four levels of analysis under the three climate change scenarios in theLower Murray

	Mild scenario (S1)			**Moderate scenario (S2)**			**Severe scenario (S3)**		
Level	**Exp. + sens. + ac.**	**Exp. + ac.**	**Exp. + sens.**	**Exp + sens + ac.**	**Exp. + ac.**	**Exp. + sens.**	**Exp. + sens. + ac.**	**Exp. + ac.**	**Exp. + sens.**
Exp. + ac.	0.676 ± 0.040			0.504 ± 0.052			0.421 ± 0.059		
Exp. + sens.	0.709 ± 0.042	0.352 ± 0.063		0.682 ± 0.048	0.389 ± 0.060		0.724 ± 0.033	0.324 ± 0.061	
Exp.	0.520 ± 0.056	0.388 ± 0.063	0.653 ± 0.045	0.582 ± 0.049	0.455 ± 0.059	0.764 ± 0.031	0.551 ± 0.042	0.376 ± 0.061	0.594 ± 0.046

Variation in species representation by spatial conservation priority areas can be interpreted by comparing the species representation curves (Figure 42) and AUC indicators (Table 13) calculated using different components of the vulnerability framework. Spatial priorities identified using exposure and adaptive capacity (Figure 42d-f, Table 13) reduced the mean representation of the 50 most-sensitive species by 14.7 – 18.0% across the three climate scenarios. However, this also increased the mean representation fo the 5 worst performing species (the mean of the five species with the lowest representation in the landscape) by 27.2 – 59.2% and the representation of all species by 4.2 - 7.5%.

Spatial priorities identified using using exposure and sensitivity (Figure 42g-i, Table 13) had a negligible impact on the 50 most-sensitive species (-2.2 – 0.9%). However, this reduced the mean representation of all species by 3.6 - 9.7% and had a variable impact on the 5 worst-performing species (-69.7 – 17.3%).

Spatial priorities identified using exposure only (Figure 42j-l, Table 13) reduced the mean representation of the 50 most-sensitive species by 6.6 – 11.0%. It also reduced the mean representation of all species by 2.4 – 8.8% and had a highly variable impact on the mean representation of the 5 worst-performing species (-23.6 – 33.3%).

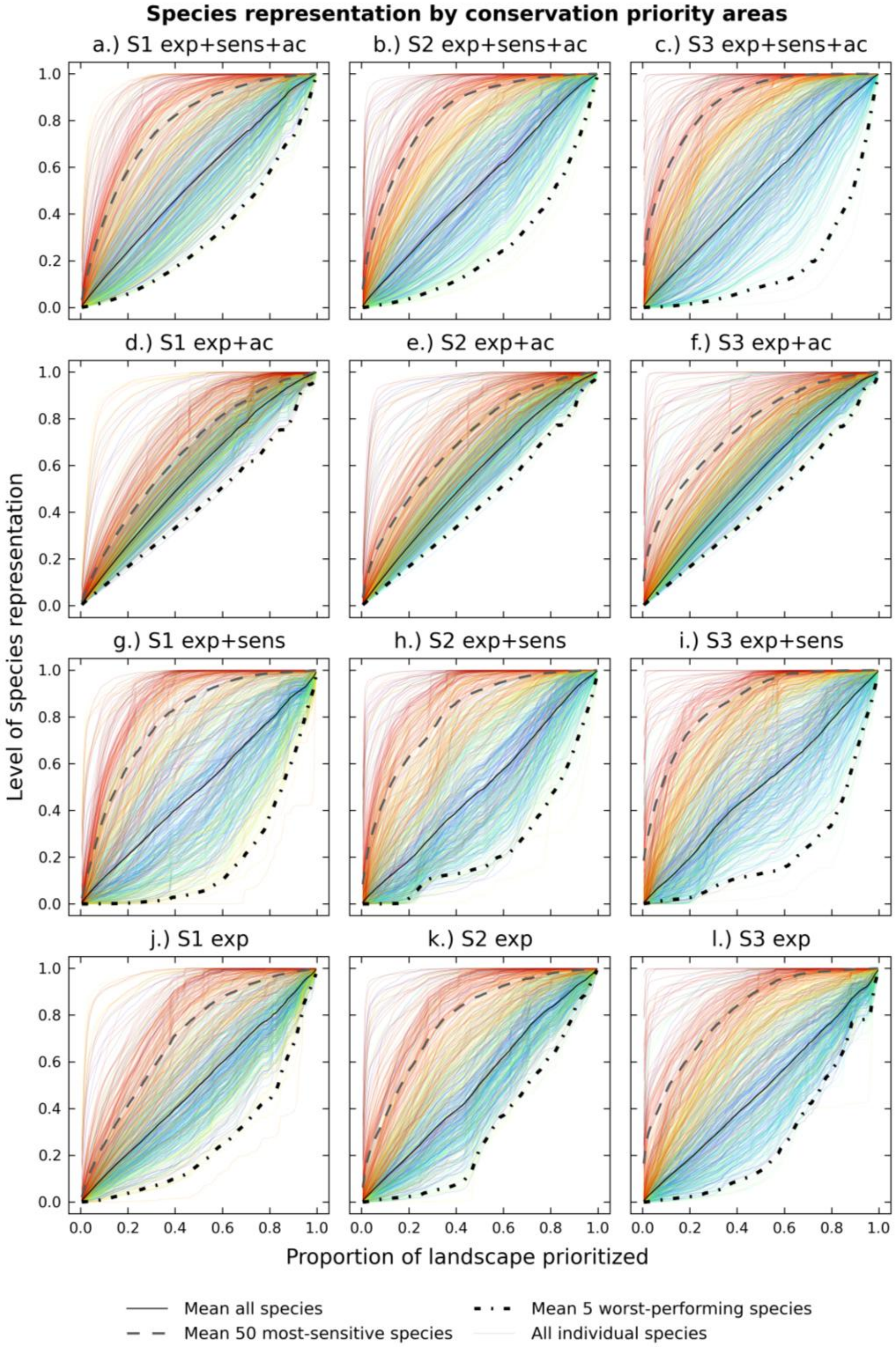


Figure 42: Species representation curves for spatial conservation priority layers calculated under each of the four levels of analysis and three climate scenarios in the Lower Murray. The coloured lines indicate the most-sensitive (i.e. highest sensitivity weights) in red through to least sensitive (lower sensitivity weights) in blue.

Table 13: Indicators of species representation (AUC) for conservation priority layers calculated using different components of vulnerability in the Lower Murray

	Mild scenario (S1)				Moderate scenario (S2)				Severe scenario (S3)			
Layers	**Exp+ sens + ac**	**Exp+ ac**	**Exp+ sens**	**Exp**	**Exp+ sens + ac**	**Exp+ ac**	**Exp+ sens**	**Exp**	**Exp+ sens + ac**	**Exp+ ac**	**Exp+ sens**	**Exp**
Mean all species	0.544	0.568	0.496	0.500	0.524	0.564	0.495	0.511	0.517	0.559	0.499	0.481
50 most sensitive	0.779	0.660	0.786	0.702	0.829	0.709	0.811	0.778	0.873	0.761	0.856	0.814
Mean 5 worst performing	0.319	0.438	0.188	0.258	0.263	0.449	0.252	0.316	0.182	0.446	0.220	0.273

4.3.5 Discussion: The most vulnerable species and ecosystems

Here we use a climate change vulnerability framework to identify complementarity-based spatial conservation priorities. Using SDMs and identifying plant species distributions we quantified the potential exposure of species to climate change. We identified the most adversely affected species and attributed sensitivity weights from the projected changes in species' distributions under climate change. We used dispersal kernels to identify migration and dispersal ability and provide a spatially explicit measure of adaptive capacity. These three components (exposure, sensitivity and adaptive capacity) were combined into a landscape prioritisation that enabled the identification of high priority areas for conservation actions to reduce species vulnerability to climate change in the Eyre Peninsula (e.g. Figure 37) and Lower Murray (e.g. Figure 41) study areas. Complementarity-based landscape prioritisation using Zonation provided a minimum representation for each element (species) within the landscape (Ferrier & Wintle, 2009; Moilanen, 2008a). Given the consistency of the results between the two study sites, this the following will focus on both areas and highlight any differences.

In both the Eyre Peninsula and Lower Murray regions conservation priorities identified using the full vulnerability framework were concentrated in more southern latitudes and higher altitudes (western priority areas). Typically, these areas have cooler and wetter climates and are generally thought to become more scarce under climate change. Similarly, the localised priority areas in the western districts of the Eyre Peninsula study area would typically have higher rainfall than the more inland central districts. The prioritisation of these areas (cooler, wetter) as important in reducing species vulnerability is consistent with the findings other studies (Carvalho *et al.*, 2010; Engler *et al.*, 2011; Garzón *et al.*, 2008; Thuiller *et al.*, 2005).

This analysis set out to identify conservation priorities within a vulnerability framework by accounting for the different mechanism of exposure, sensitivity and adaptive capacity. However, it is important to consider the impact of the each of the input components on the final conservation priorities. The findings of the analyses from both study areas indicate that the different components had substantial influence on the results and were more influential in the final spatial conservation priorities (EP Figure 37 and LM Figure 41), resulting in different levels of species representation (EP – Figure 38, Table 11 and LM – Figure 42, Table 13), than the climate change scenarios themselves.

Omitting sensitivity from the vulnerability framework (using only exposure and adaptive capacity) resulted in substantial changes compared to the full vulnerability framework in both the Eyre Peninsula and Lower Murray. Conservation priorities were less contiguous and there was less concentration in lower latitudes and higher altitudes when sensitivity is omitted (EP – Figure 37, LM – Figure 41). These differences in spatial priorities are also demonstrated in the low to moderate correlation values under the three climate change scenarios (EP – Table 10, LM – Table 12). There were also lower representation levels of the most sensitive species across all climate change scenarios (EP – Table 11, Figure 38d-f cf. Figure 38a-c and LM – Table 13, Figure 42d-f cf. Figure 42a-c) without sensitivity compared with the full vulnerability analysis. In the Eyre Peninsula, the mean representation of all species remained relatively unchanged while in the Lower Murry is was moderately higher. However, in both study areas the mean of the 5 worst-performing species was substantially higher. The species representation curves (EP – Figure 38a-c, d-f and LM – Figure 42a-c, d-f) also demonstrate this trade-off where the dashed lines (the 50 most-sensitive species and the 5 worst-performing species) are closer than under any other level of analysis presented in this study.

Omitting adaptive capacity from the analysis (using exposure and sensitivity only) also had some impact on the spatial prioritisation. Inspection of the Eyre Peninsula conservation priority maps (Figure 37) demonstrates that both the full vulnerability framework and the exposure and sensitivity analysis prioritised area in the east, south and west with some localised differences. Similarly, the Lower Murray (Figure 41) conservation priorities were identified in the east and south west with some localised differences. Relatively moderate correlation coefficients between the different priority layers in both study areas support these findings (EP – Table 10 and LM – Table 12). Representation of sensitive species was relatively unchanged in the Eyre Peninsula and the Lower Murray from the full vulnerability framework across all climate change scenarios. In the Eyre Penisula the mean representation of all species was relatively unchanged while in the Lower Murray it was somewhat reduced (EP – Table 10 and LM – Table 12).

Omitting both sensitivity and adaptive capacity (using exposure only) resulted in substantial changes in the spatial conservation priorities compared with the full vulnerability analysis. In The Eyre Peninsula both analysis prioritise large contiguous areas in the east and south (Figure 37a-c, cf, j-l). Similarly, in the Lower Murray, there are large contiguous areas of prirotisation in the east and south west (Figure 41a-c, cf, j-l) under full vulnerability framework and using the expsoure layer alone. However, in both study areas there are notable localised differences between the two analysis. This interpretation is supported by the low to moderate correlation coefficients between the different priority layers under each analysis (EP – Table 10 and LM – Table 12). Without sensitivity and adaptive capacity conservation priorities in the Eyre Peninsula and Lower Murray had lower levels of mean representation for both sensitive species and all species. In this analysis species prioritisation in the landscape is based purely on projected species distributions under the climate scenarios with no consideration given to processes such as lag effects and dispersal mechanisms that would likely alter deviations from baseline distributions.

These results are likely to have significant practical implications for conservation agencies. Including different elements of the vulnerability framework results in significantly different arrangements of conservation priority. Similarly, the complex trade-offs in species representation have significant implications for conservation investment. Conservation actions such as land acquisition, pest species eradication, ecological restoration, and fencing and livestock removal are expensive and need to be spatially targeted to achieve efficient outcomes (Wilson *et al.*, 2010). These results emphasis the need for clear conservation objectives when undertaking conservation actions.

We advocate the inclusion of all three components of the vulnerability framework (exposure, sensitivity, and adaptive capacity) for targeting spatial conservation with the aim of reducing species vulnerability to climate change (see also Crossman *et al.*, 2012, Summers *et al.* 2012). Failing to include all components of the vulnerability framework can result in conservation measures being applied to areas that do not not target species vulnerabilty to climate change (see also Carwardine *et al.*, 2008). More specifically, without inclusion of all elements, conservation measures could fail to prirotise species that are particularly sensitive to climate change and fail to priorities areas which help facilitate dipsersal, migration and adaptation to new climates.

Despite these benefits, our results show that targeting vulnerable species is not without its costs. For example, there as obvious trade-offs between a focus on sensitive species and levels of representation of other species. These trade-offs highlight the importance of complementarity-based spatial prioritisation and represent a significant advance over previous studies (e.g. Crossman *et al.*, 2012). These trade-offs are also the central theme in the various arguments around conservation triage (e.g. Bottrill *et al.*, 2008; Wilson *et al.*, 2011) including whether or not to undertake cost-effective allocation of conservation funds or whether to focus investment on priority species

Chapter 5

MODELLING THE ECONOMIC IMPACTS OF CLIMATE CHANGE

5.1 Economic Modelling of Wheat Production

5.1.1Profit at Full Equity

Profit at full equity -definition

Profit at full equity estimates were comprised of estimates taken from gross margin estimates

We assume that PFE equate to if all area was cropped to wheat removing the crop rotations and fallowing management.

The area assigned to the broad mapping of soil classifications will affect the financial implications of climate change. The volatility of global grain price will have a major effect on the impacts of climate change. While wheat yields are projected to decline, the fluctuations in price could severely affect business viability in the region. Table 14 shows the current PFE and significant variation in PFE between the $200 and $300 per tonne grain price based on the area associated with the broad mapping of soil classifications and estimated production costs.

Table 14: Range in PFE ($'million) based three grain prices for the current climate for the three rainfall zones and the EP region

	$200/tonne scenario ($'s million)	$250/tonne scenario ($'s million)	$300/tonne scenario ($'s million)
Current - low rainfall zone	22.8	95.6	168.4
Current - medium rainfall zone	62.3	171.0	279.8
Current - high rainfall zone	62.9	109.6	156.3
EP region	147.9	376.2	604.5

Small drop in yields due to climate change and a low grain price can have substantial financial ramifications especially on soil classification that have a large area and are marginal income producers.

This is especially the case for the low rainfall region where moderate climate change coupled with the annual occurrence of low grain prices will have drastic effects.

With the less severe climate change projections the Eyre Peninsula (+1˚C, 5% reduction in rainfall and 480 ppm CO_2) sees a positive change in PFE for the region across the price scenarios.

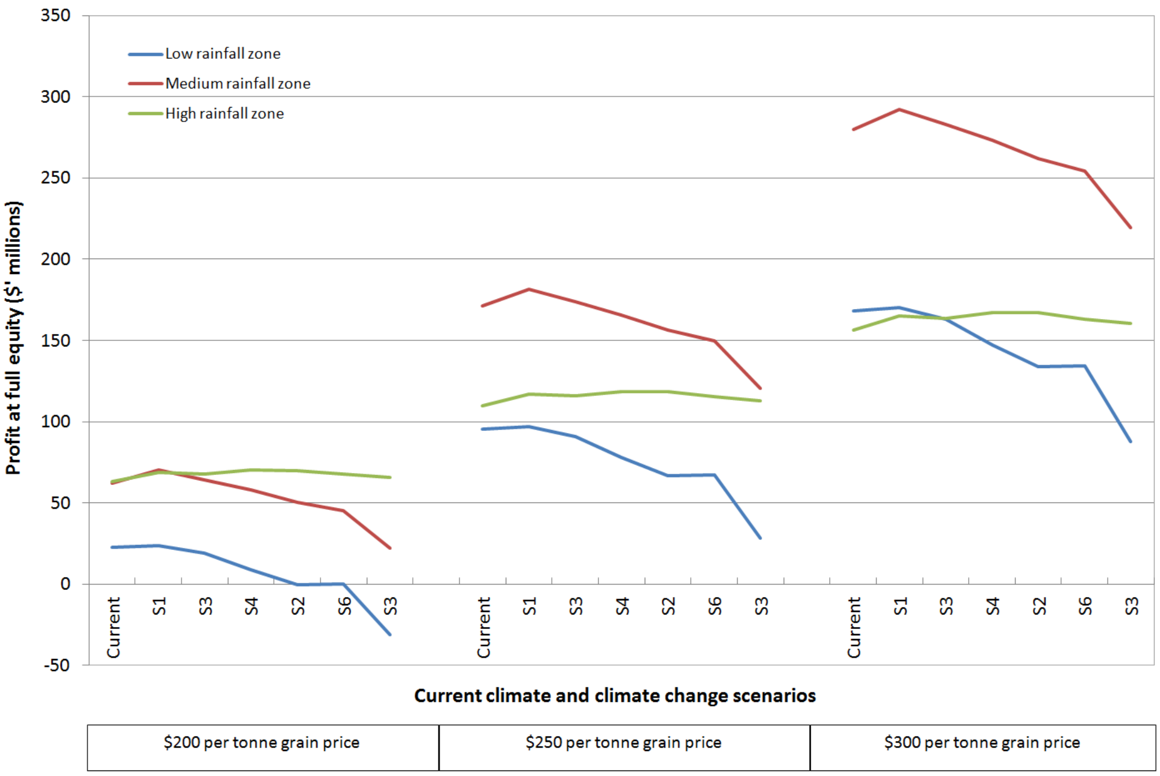


Figure 43: Profit at full equity for current and climate change scenario (by severity) for the low, medium and high rainfall zone

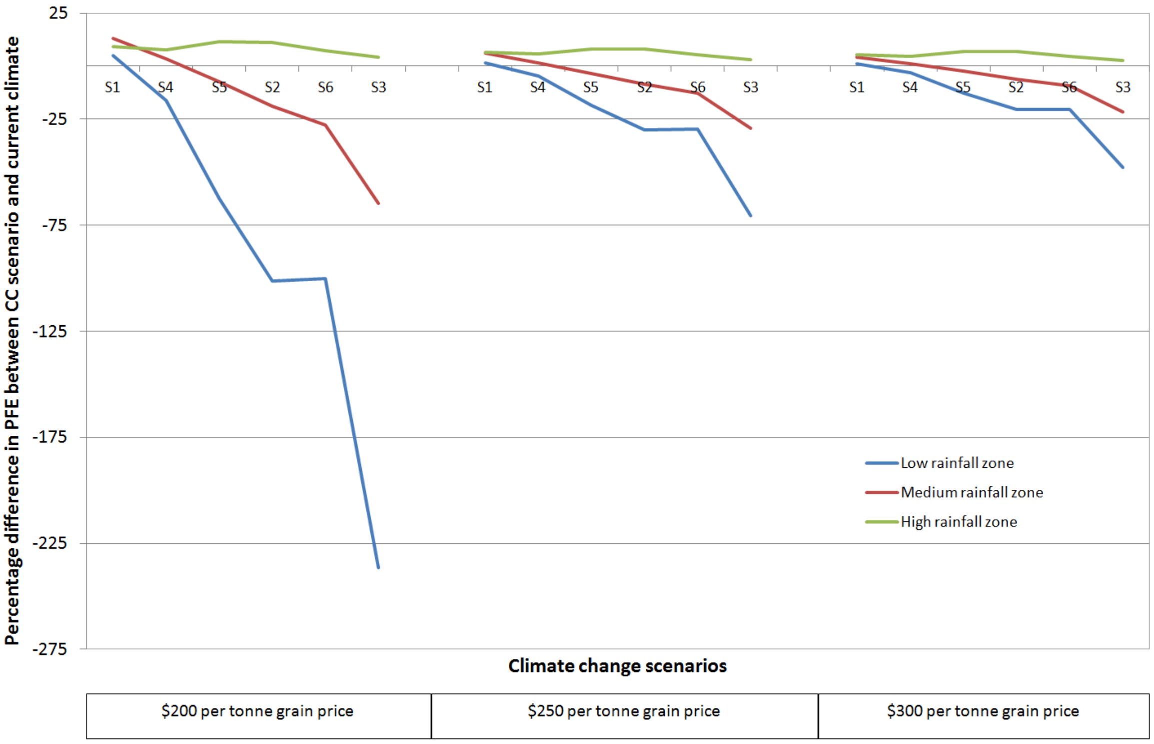


Figure 44: Percentage difference between profit at full equity (PFE) for climate change scenario (by severity) and current climate for the low, medium and high rainfall zone

Differences in Profit at Full Equity by rainfall zones.

PFE differences can be broken down further into the effect from the broad soil classifications.

High rainfall zone

For the two mild climate change scenarios,

The 20cm and 20-40mm PAWC loamy sand soil texture classification has a significant increase in PFE. The returns may not reflect the true yield variation since these soils may be susceptible to water logging.

Sands made up around XX of the high rainfall zone and these soil textures had the greatest increase in simulated wheat yields and combined with there mapping area represented increases in PFE across all grain prices.

Greatest increases in PFE are in the lowest rooting depth and PAWC magnitudes with sand

and loamy sand soil texture classification, with these areas making less of a loss at with the change in climate at the $200 per tonne grain price and moving into positive returns at the $250 and $300 per tonne grain price.

40-60cm rooting depth sandy loam has greatest rise in PFE across the grain prices

5.1.2 Wheat Production in Eyre Peninsula

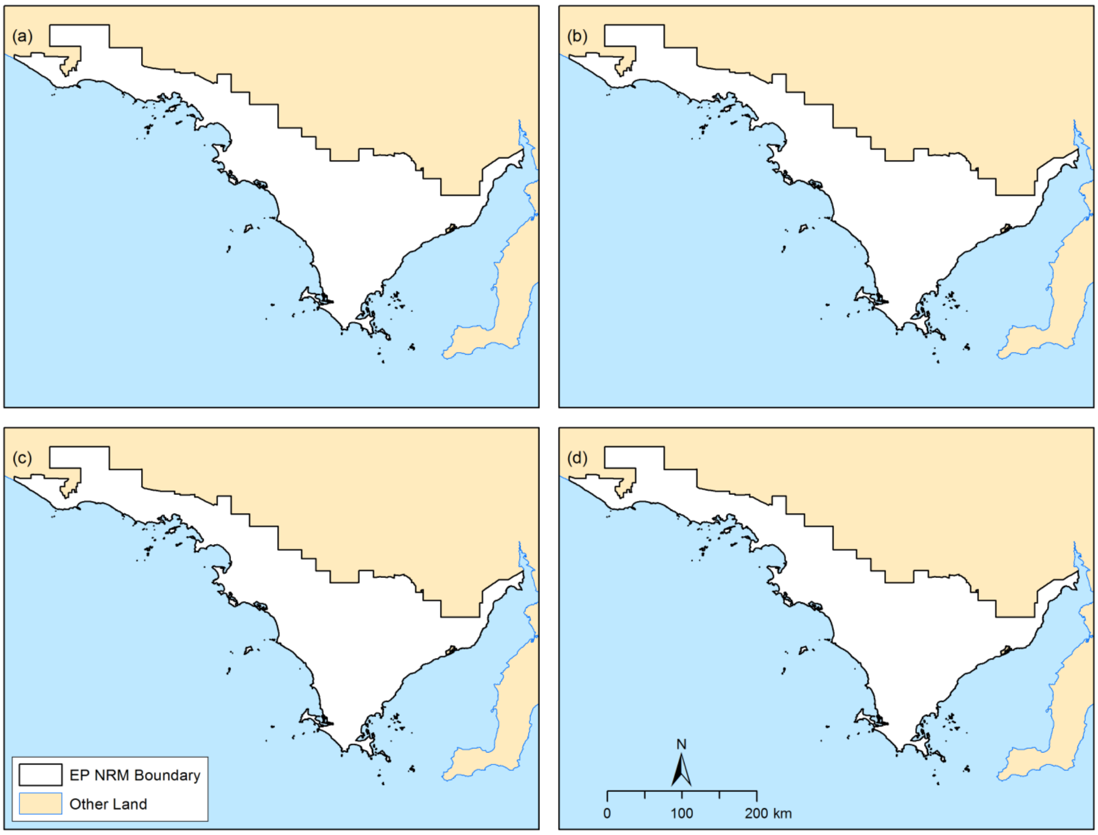
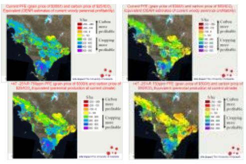


Figure 45: Wheat economics



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5.1.3 Discussion of Wheat Production Economics

5.2 Economic Modelling of Carbon Sequestration and Biomass Production

5.2.1 Economic Modelling of Carbon Sequestration

To calculate the economic revenue from carbon production, the amount of carbon sequestered was multiplied by the price per tonne (p):

$$r_t = E_t \cdot p$$

Where:

r_t = Revenue at year t
E_t = Carbon sequestration at year t in tonnes CO_2^{-e}/ha/yr
p = Price of carbon (CO_2^{-e}) per tonne

For carbon sequestration through reafforestation of carbon monocultures or environmental plantings, the economic costs are less than with other land uses such as biomass production or agriculture. For the first year of production an upfront establishment cost of $2000 was incurred along with an annual maintenance cost of $60 to cover management activities and an annual transaction cost of $60 to cover costs associated with carbon accounting, contracting and trading. Therefore, the total costs of reafforestation for carbon sequestration at year t were calculated as:

$$C_t = EC_t + MC_t + TC_t$$

Where:

EC_t = Establishment costs at year t (EC_t = \$2,000 for t = 1)
MC_t = Maintenance costs at year t (MC_t = \$60 for t >= 1)
TC_t = Transaction costs at year t (TC_t = \$60 for t >= 1)

The total revenue minus the cost figures was reduced to the Net Present Value using a discount rate to convert the total net returns of carbon sequestration into present day dollars. The Equal Annual Equivalent is the equivalent annual payment required to return the NPV derived from carbon trading. These measures were used to assess the potential profitability across the study area. Net Present Value (NPV) was calculated as:

$$NPV = \sum_{t=1}^{n} \frac{(r_t - c_t)}{(1+i)^t}$$

Where:

i = interest (discount) rate

r_t = the revenue at year t

c_t = costs at year t

n = the number of years.

The Equal Annual Equivalent (EAE) was then calculated as:

$$EAE = NPV \times \frac{i(1+i)^t}{(1+i)^t - 1}$$

NPV and EAE were calculated over the 64 year time frame with a discount rate of 7%. The model was run for a range of carbon prices ($10, $20, $30, $40 and $50).

5.2.2 Economic Modelling of Biomass Production

The economic revenue from biomass production was modelled for 64 years using the $3PG_2$ outputs for oil mallee modelled up to the time of first harvest (P_{6yr}) under the baseline and climate change scenarios. Biomass production was based on a 6 year rotation schedule where each rotation involved coppicing the above ground biomass. In order to account for an increase in productivity after coppicing, a coppicing productivity multiplier was applied ($\O_t$).

$\O_t$ = 1 (Where t = year of first harvest)
$\O_t$ = 1.5 (Where t = harvest year after first harvest)

A factory gate price per green tonne of biomass was determined using an economic model for an integrated tree processing plant. A biomass price for each of the modelled carbon prices was calculated using a relative electricity price based on treasury wholesale electricity price trajectories. Using this method, it was determined that biomass production was only viable at or above a carbon price of $30/tonne. Table 15 provides comparisons of relative biomass prices for each carbon price.

Revenue (r_t) in dollars was calculated by multiplying the tonnes of biomass harvested by the factory gate price per green tonne(p), adding an offset payment per tonne for CO_2 sequestered in the above ground biomass harvested, and adding a carbon payment per tonne for CO_2 sequestered in the roots.

Table 15:

Carbon Price	$30/tonne CO_2^{-e}	$40/tonne CO_2^{-e}	$50/tonne CO_2^{-e}
Relative Electricity Price	$68/MWh	$88/MWh	$103/MWh
Relative Biomass Price	$19.18/tonne	$100.18/tonne	$167.68/tonne

The total costs for biomass production were calculated and subtracted from each cell in the revenue layer (r_t). Establishment costs were incurred for the total area in the first year, and maintenance costs were incurred every year including years between harvests. Harvest, fertiliser and transport costs were incurred for the total area every harvest year.

Costs were also incurred through the transport of biomass from each grid cell to the nearest Integrated Tree Processing plant. For the purpose of this study, three hypothetical tree processing plants were established at Port Lincoln, Whyalla and Ceduna in the Eyre Peninsula, and Murray Bridge and Loxton in the SAMDB, Mildura in the Mallee and Horsham in the Wimmera. A cost-distance analysis was used to construct a cost-distance layer based on the distance from each cell to the nearest tree processing plant along the road network. In addition, a cost multiplier surface was created to account for the additional cost of traversing across cells serviced by unsealed roads and tracks. Transportation costs were assumed to be lowest along sealed roads (multiplier = 1), higher along unsealed roads (multiplier = 1.2) and highest along tracks (multiplier = 1.4). The cost-distance layer was multiplied by the cost multiplier surface to calculate the transportation cost of each grid cell. The total costs were calculated as:

$$\boldsymbol{C_t = EC_t + MC_t + HC_t + FC_t + TC_t}$$

Where:

EC_t = Establishment costs at year t (EC_t = \$1,000 for $t = 1$)
MC_t = Maintenance costs at year t (MC_t = \$10 for $t >= 1$)
HC_t = Harvest costs at year t (HC_t = \$12 for $t >= 6$)
FC_t = Fertiliser costs at year t (FC_t = \$40 for $t > 6$)
TC_t = Transport costs at year t (Note TC_t = \$60 for $t >= 1$)

The total revenue minus the cost figures was reduced to the Net Present Value using a discount rate to convert the total net returns of biomass production into present day dollars. The Equal Annual Equivalent is the equivalent annual payment required to return the NPV derived from biomass production. These measures were used to assess the potential profitability across the study area. Net Present Value (NPV) was calculated as:

$$NPV = \sum_{t=1}^{n} \frac{(r_t - c_t)}{(1+i)^t}$$

Where:

i = interest (discount) rate

r_t = the revenue at year t

c_t = costs at year t

n = the number of years.

The Equal Annual Equivalent (EAE) was then calculated as:

$$EAE = NPV \times \frac{i(1+i)^t}{(1+i)^t - 1}$$

NPV and EAE were calculated over the 64 year time frame with a discount rate of 7%. The model was run for a range of viable factory gate biomass prices ($30, $40 and $50).

5.2.3 Carbon Sequestration and Biomass Economics in Eyre Peninsula

Results from the economic modelling of hardwood plantations and environmental plantings for carbon sequestration, and oil mallee for biomass production in the Eyre Peninsula region are presented in Table 16 and Figures 46, 47 and 48.

Table 16: ??? in the Eyre Peninsula

Scenario	Land Use	Percentage of study area viable at:				
		$10/tonne	$20/tonne	$30/tonne	$40/tonne	$50/tonne
S0 -Baseline	Hardwood Plantations	0%	9%	24%	45%	84%
	Environmental Plantings	0%	3%	11%	19%	27%
	Biomass Production	n/a	n/a	19%	98%	99%
S1 -Mild Climate Change	Hardwood Plantations	0%	8%	21%	40%	73%
	Environmental Plantings	0%	4%	13%	20%	28%
	Biomass Production	n/a	n/a	23%	97%	99%
S2 - Moderate Climate Change	Hardwood Plantations	0%	6%	16%	33%	48%
	Environmental Plantings	0%	23%	11%	18%	25%
	Biomass Production	n/a	n/a	17%	92%	96%
S0 -Severe Climate Change	Hardwood Plantations	0%	5%	12%	24%	37%
	Environmental Plantings	0%	2%	10%	17%	23%
	Biomass Production	n/a	n/a	12%	67%	91%

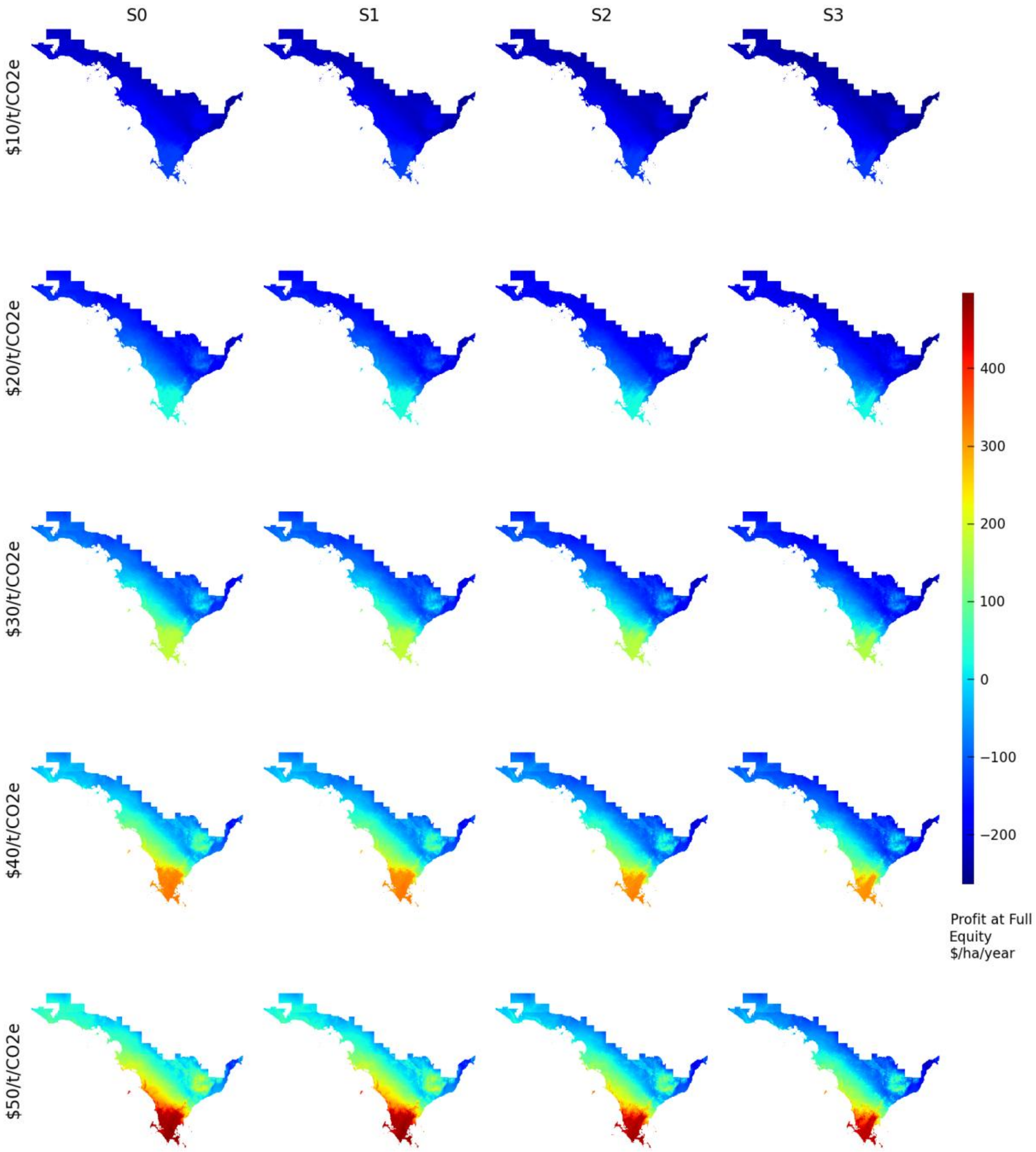


Figure 46: Equal Annual Equivalent (EAE) returns from hardwood plantations in the Eyre Peninsula

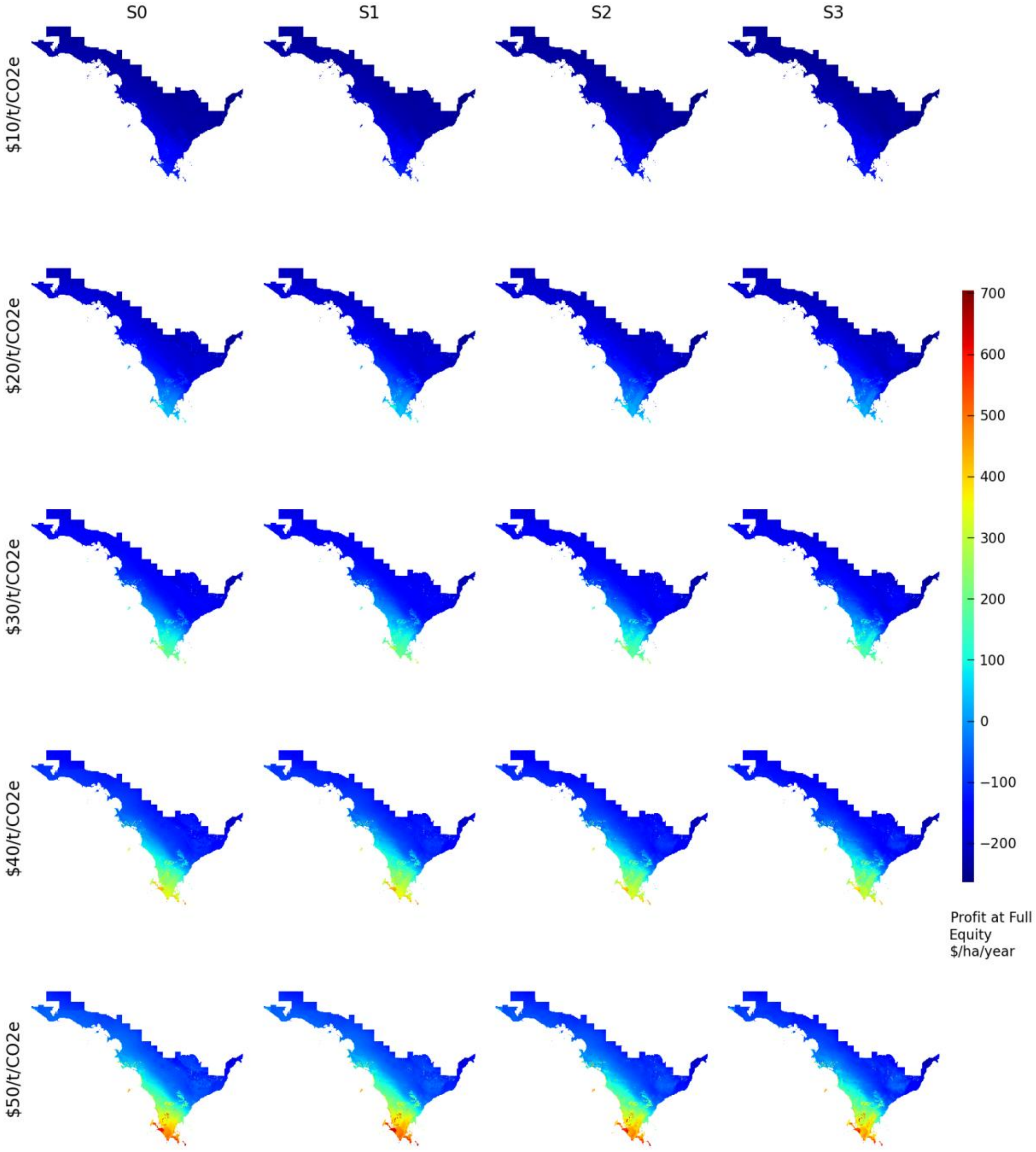


Figure 47: Equal Annual Equivalent (EAE) returns from environmental plantings in the Eyre Peninsula

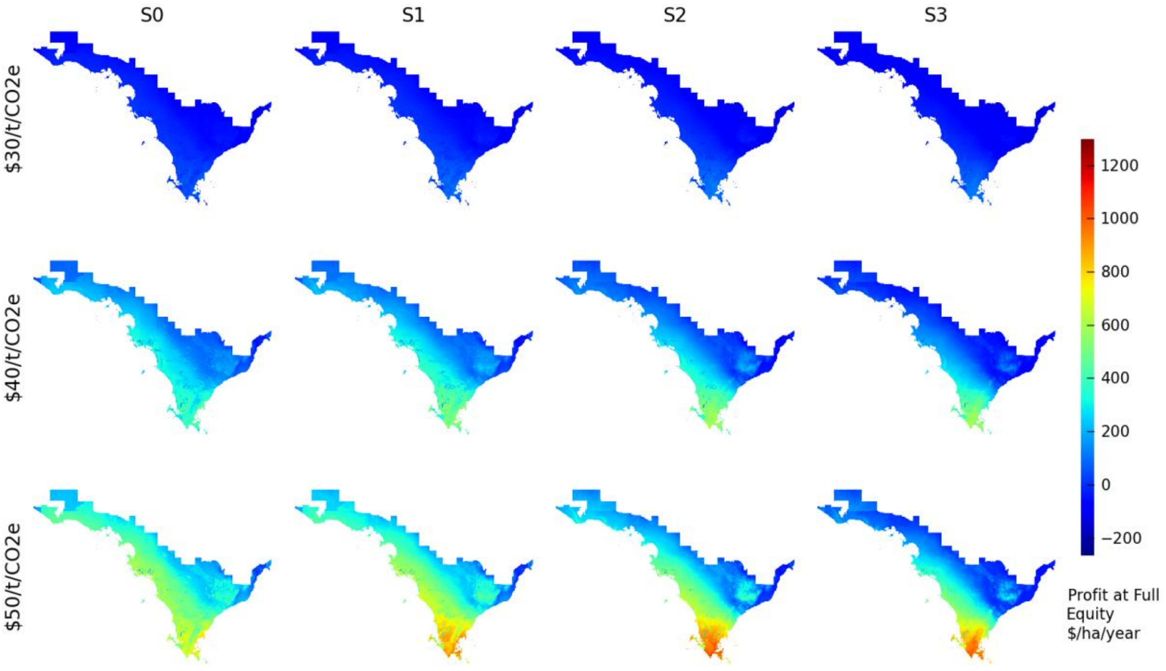


Figure 48: Equal Annual Equivalent (EAE) returns from oil mallee biomass production in the Eyre Peninsula under different carbon prices for the baseline and climate change scenarios.

5.2.4 Carbon Sequestration and Biomass Economics in Lower Murray

Results from the economic modelling of hardwood plantations and environmental plantings for carbon sequestration, and oil mallee for biomass production in the Lower Murray region are presented in Table 17 and Figures 49, 50 and 51.

Table 17: ??? in the Lower Murray

Scenario	Land Use	Percentage of study area viable at:				
		$10/tonne	$20/tonne	$30/tonne	$40/tonne	$50/tonne
S0 -Baseline	Hardwood Plantations	0%	24%	45%	62%	66%
	Environmental Plantings	0%	8%	39%	51%	59%
	Biomass Production	n/a	n/a	5%	59%	89%
S1 -Mild Climate Change	Hardwood Plantations	0%	21%	38%	56%	62%
	Environmental Plantings	0%	7%	33%	43%	53%
	Biomass Production	n/a	n/a	4%	56%	89%
S2 - Moderate Climate Change	Hardwood Plantations	0%	17%	27%	40%	50%
	Environmental Plantings	0%	5%	26%	31%	40%
	Biomass Production	n/a	n/a	3%	49%	88%
S0 -Severe Climate Change	Hardwood Plantations	0%	13%	20%	26%	33%
	Environmental Plantings	0%	3%	20%	24%	28%
	Biomass Production	n/a	n/a	3%	45%	85%

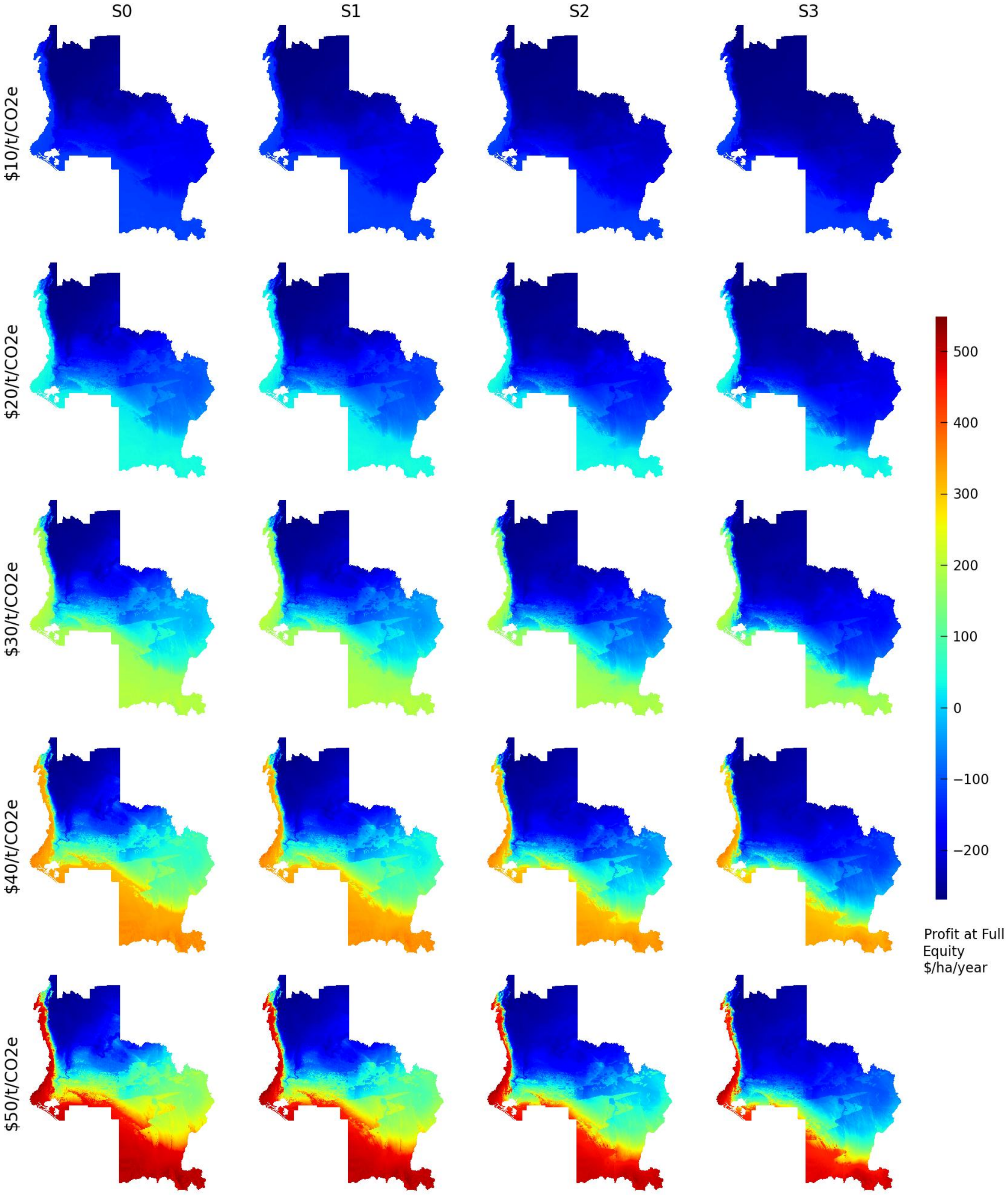


Figure 49: Equal Annual Equivalent (EAE) returns from hardwood plantations in the Lower Murray

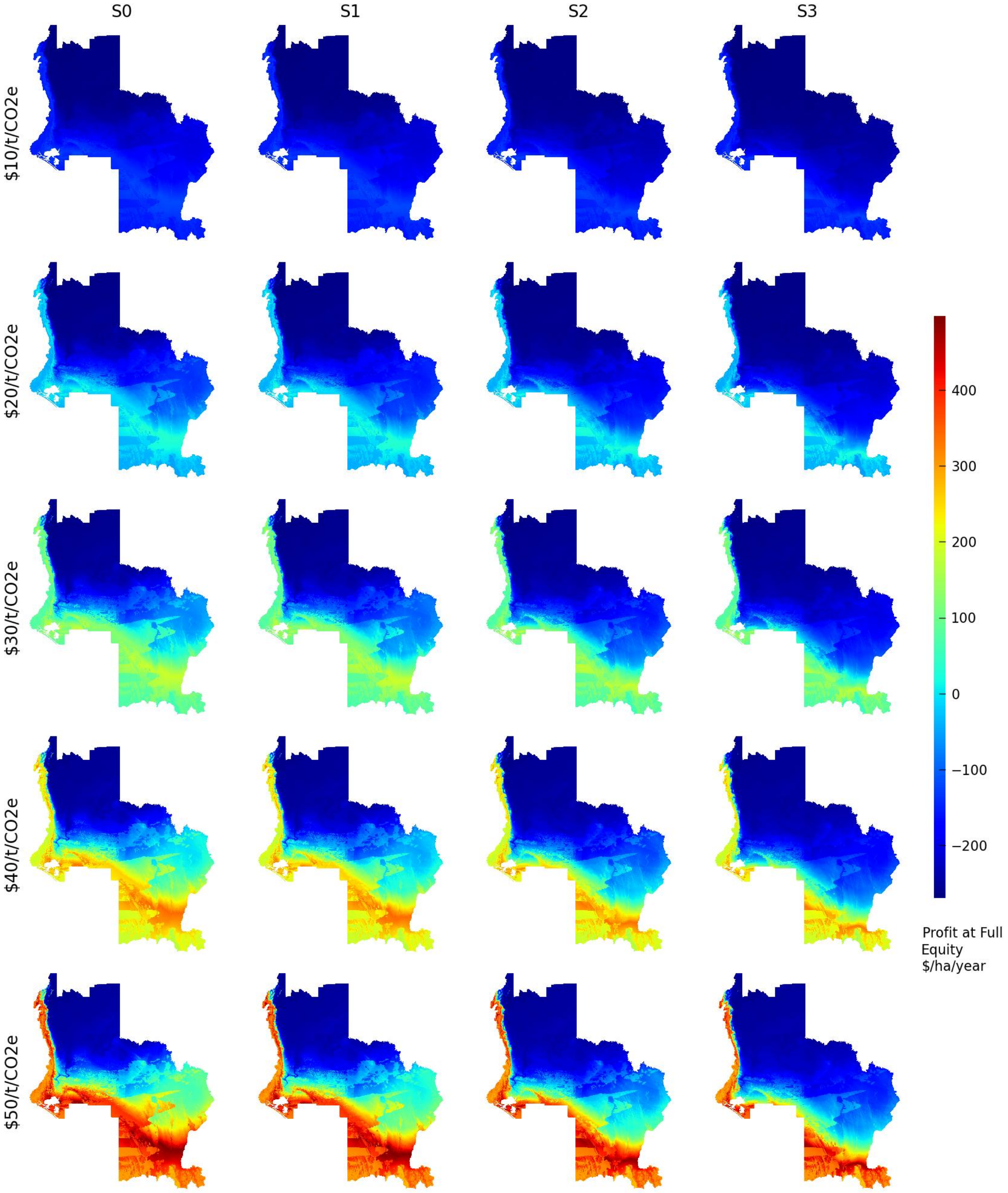


Figure 50: Equal Annual Equivalent (EAE) returns from environmental plantings in the Lower Murray

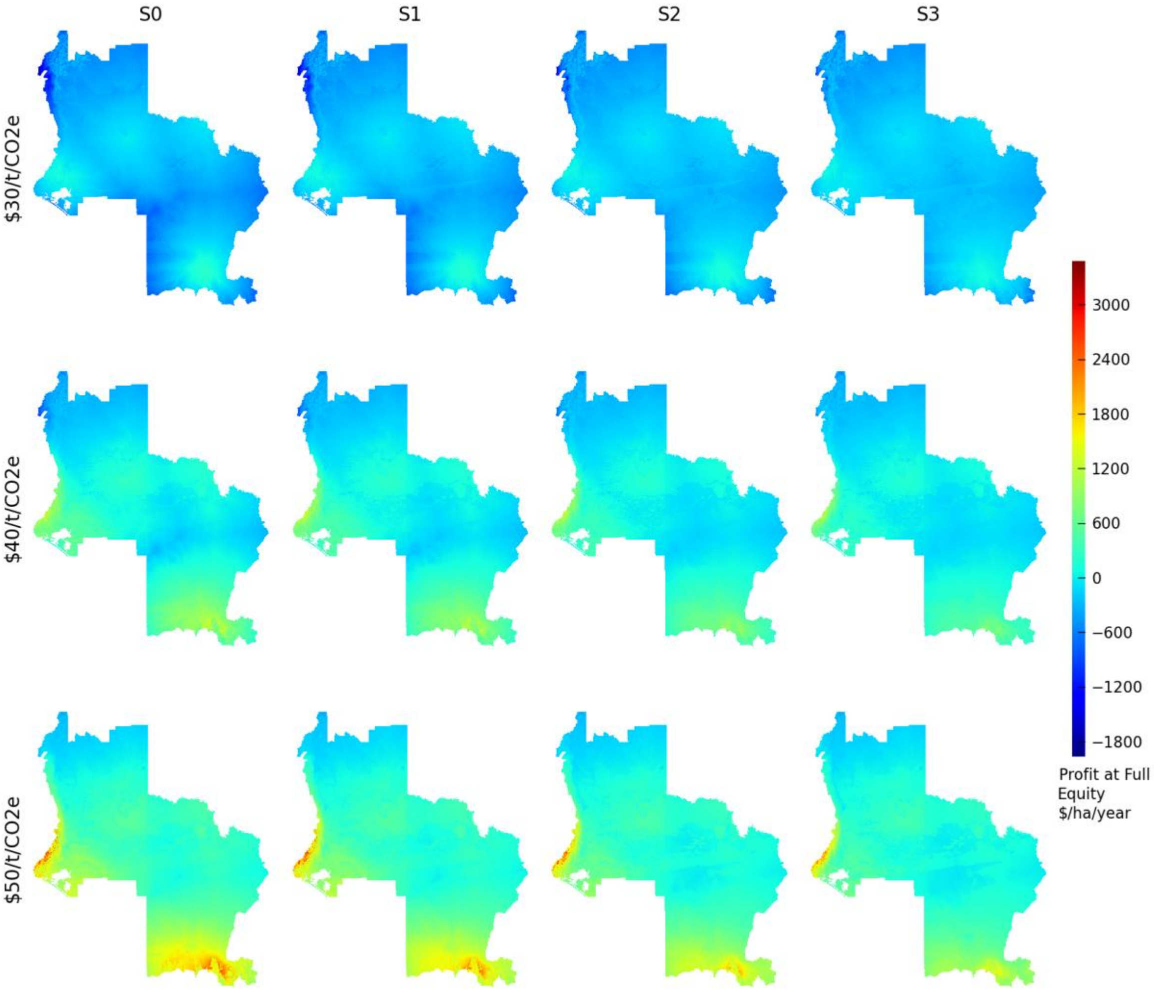


Figure 51: Equal Annual Equivalent (EAE) returns from oil mallee biomass production in the Lower Murray under different carbon prices for the baseline and climate change scenarios

5.2.5 Discussion of Carbon Sequestration and Forest Growth Economics

$3PG_2$ was used to model the biomass productivity of a hardwood plantation and environmental plantings for carbon sequestration over 64 years under a baseline and three climate change scenarios in the Eyre Peninsula and Lower Murray regions. Similarly, oil mallee was modelled over 6 years in these same regions to simulate biomass production. These outputs were used to assess the economic viability of each land use under a range of carbon prices.

The economic viability of hardwood plantations in Eyre Peninsula was sensitive to variations in both climate and carbon price. Environmental plantations were also sensitive to changes in carbon price, but less so than hardwood plantations. Under each climate change scenario, for carbon prices at and above $20/tonne/$CO_2^{-e}$, a higher percentage of the Eyre Peninsula was viable under hardwood forestry than environmental plantings. No areas within the Eyre Peninsula region were viable under a carbon price of \$10/tonne/CO_2^{-e} for either land use. Biomass production was also highly sensitive to carbon price. Under a carbon price of \$50/tonne/CO_2^{-e}, over 90% of the study was found to be viable under each of the climate change scenarios.

As with the Eyre Peninsula, no areas within the Lower Murray region were viable under a carbon price of \$10/tonne/ CO_2^{-e}. Economic viability of hardwood and environmental plantations were sensitive to variations in carbon price and climate for prices at and above \$20/tonne/CO_2^{-e}. Economic viability of biomass production was also sensitive to changes in carbon price. Only marginal areas were viable under a carbon price of \$30/tonne/ CO_2^{-e} whereas a majority of the study area was viable under \$50/tonne/ CO_2^{-e}.

Chapter 6

MODELLING THE SOCIAL IMPACTS OF CLIMATE CHANGE

6.1 Social Trend Modelling and Analysis

A further addition to the climate change assessment framework has been the focus on the social characteristics that can be used as part of the landscape futures analysis. Meetings with EP representatives in February 2010 highlighted the need for understanding the social aspects of the effects of and the adaptation to climate change.

A review of Australia and internationally literature on social indicators that have been used to characterise regional social vulnerability to natural hazards such as drought was carried out. This helped in the development of a nested scale framework to embed a variety of social datasets collected from Australian government agencies and previous local surveys on social characteristics (Table 2).

The important insight that came from this collation is that the measure of vulnerability or its reciprocal, resilience, needs to be relevant to the level of decision making. This means that to help understand the capacity of individuals to adapt to climate change requires a different set of questions than those needed to understand the adaptability of a community or a region.

Further, this framework has helped guide information gathering on social and influencing networking as part of understanding how the EP region might adapt to climate change through having informed leaders and community capacity.

6.2 Social-Ecological Vulnerability and Adaptive Capacity

Identifying vulnerability of components in the social-ecological EP NRM region – etc. GREG

A vulnerability framework.

- Exposure – e.g. climate change
- Potential impact (sensitivity of the object or thing – farm -> region)
- Adaptive capacity of the object or thing (farm -> region)

Social indicators of climate change vulnerability and adaptation were identified and collated through collection of matching data. - Data from ABS. + literature review.

Hierarchical – in terms of the decision making process and adoption choices.

Grower -> paddock -> farm-> local farmers groups (by type) -> regional climate-> governance structures.

6.3 Social-Ecological Network Modelling of Biodiversity Conservation Effort

6.3.1 Social-Ecological Network Analysis and Sustainability

The sustainable management of natural resources has been an important focus of concern for scientists and local populations throughout the world for a long time. In an effort to better describe the dynamics and interconnectedness of human communities interacting with their environment, new conceptual frameworks have been recently developed. These include the concepts of Social-Ecological Systems (Becker, 2010; Ostrom, 2009) and Social-Ecological Networks (SENs) (Cumming et al., 2010; Janssen et al., 2006).

A Social-Ecological System (SES) is a system composed of human elements and natural elements interacting with each other in different ways through temporal, spatial and organisational scales. It often describes a setting where a human community is in interaction with its natural environment through the exploitation of one or several natural resources (Gonzales and Parrott, 2012).

Social-Ecological Networks (SENs) are simplified representations of SESs, with nodes (vertices) representing discrete elements in an SES, and edges (links) representing interactions or relationships between the nodes. Nodes can have different characteristics distinguishing one from another, and they can be weighted to reflect their relative importance. Edges can also be weighted to indicate the relative strength of the relationship they represent, and can be directional or bi-directional. Networks can be composed of single or multiple types of nodes. They can display a single relationship, or many relationships through different linkage types (Gonzales and Parrott, 2012).

While network analysis has been around for over a hundred years and been widly used to analyse both social systems and, more recently, ecological ones, researchers have only recently tried to apply these tools to social-ecological systems (Cumming et al., 2010). It is speculated that properties of SENs could be analysed quantitatively, and the sustainability of an SES be assessed using the broad set of metrics from network theory (Cumming et al., 2010; Janssen et al., 2006).

On the Eyre Peninsula, a dense and intricate social-ecological network is shaped by stakeholders' collaborative efforts to promote and implement biodiversity conservation programs. The goal of this sub-project was to assess the strength (related to aspects of vulnerability and adaptive capacity) of the combined efforts of all stakeholders in promoting and implementing these programs.

6.3.2 Choosing the Actors, Boundaries and Edges of the Network

To obtain a reliable list of actors (stakeholders) (Prell et al., 2009; Reed et al., 2009) involved in biodiversity conservtion on the EP, six participants - who have a generally-perceived high understanding of the system - were interviewed. These individuals live in different places around the EP, and belong to a particular group, have a specific area of expertise and/or possess knowledge within the system (so that the description of the system wouldn't be circumscribed to one particular geographic or professional area). We asked these individuals to help us identify individuals or groups who had been involved in any project or program, directly or indirectly, related to biodiversity conservation on the EP (that is: directly if biodiversity conservation is considered a first goal of the program or indirectly if it is one of its positive outcomes). More precisely, we sought people who:

- promoted biodiversity conservation projects or programs (for example, by participating in scientific or industry publications or workshops); and/or
- implemented biodiversity conservation projects or programs (in general, these initiatives include land management efforts such as fencing remnant vegetation, planting windbreaks, controlling pests and weeds in native vegetation areas, some coastal management programs, etc.); and/or
- promoted and/or implementated projects or programs that are only remotely connected to biodiversity conservation (such as land use planning, carbon sequestration projects, saltbush forage systems, which can also have an impact on habitats and biodiversity).

This lead to the completion of a detailed list of what each individual thinks the list of important actors, as individuals or as formal or informal groups, should be. These data provided us with a preliminary classified list of stakeholders along three main axes:

- whether the stakeholder implements or promotes EP biodiversity conservation programs
- whether the stakeholder affects, or is affected by, EP biodiversity conservation programs
- how influential the stakeholder is perceived to be in pursuing his/her goals

This list effectively identified the main nodes of the network (Table 18), as well as setting its boundaries.

The edges chosen to bind the social network need to accurately approximate the function the system is meant to fulfill, that is, implementing programs that may have an effect on the habitat network of a selection of plant and animal species on the EP. We defined the edges of the network in terms of communication and collaboration (Table 18). The relationships were weighted according to the frequency of interactions and are either directional (for information and knowledge sharing), or bidirectional (as collaborations regarding programs promotion or implementation are typically equal both ways).

Table 18: List of nodes and edges describing the actor-network of biodiversity conservation on the EP

Classes of nodes	Edges
Farmers organizations EP NRM members State and Commonwealth agencies Local governments Consultants and/or independent advisers Non Governmental Organisations Local initiatives	Information and knowledge sharing Collaboration on promotion towards land owners and managers Collaboration on on-ground program implementation

6.3.3 Relationship Data Collection

A survey was developed in order to document actors' relationships with each other. Through a first round of 16 face-to-face interviews organized in November 2011, a set of relational questions (shown in Table 19) was asked to each interviewed actor about his/her professional relationships with the rest of the previously indentified actors. These face-to-face interviews also served as a name genetor, as interviewees were asked to add new relevant and previously unmentioned names. Based upon these new data, an online questionnaire was thereafter developed and sent to the remaining actors during the first two months of 2012. (https://www.surveymonkey.com/s/epbiodiversitynetwork). Additionally, and in order to help participants understand the goals as well as how to fill out the survey, a short online video was made (http://goo.gl/Xop9u). Finally, there was the option of adding data manually, if a participant's name did not appear on the list.

The questionnaire consisted of a series of tables dedicated to different stakeholders groups 1920). In order to describe their interactions with any of the individuals cited in the tables, participants were asked to choose options from drop-down menus.

Figure 52 represents the social network of information sharing and collaborations between the many stakeholders participating in natural resource management activities. The same kind of network was also mapped for collaborations on project promotions (Figure 53), as well as for on-ground implementation (Figure 54).

Table 19: Social network questionnaire

Question	Drop-down Options
Stakeholder	Stakeholder’s name and group
Information and knowledge sharing on biodiversity-related issues	I provide information/knowledge I gain information/knowledge All of the above
Collaboration on biodiversity-related programs	We collaborate on program promotion We collaborate on on-ground implemtation All of the above
On average over the 3 years, how often do you collaborate with this person?	Daily Weekly Fortnightly Every 1 to 3 months Every 4 to 6 months Every 7 to 9 months Every 9 to 12 months Less often
Which District Council are the projects situated in?	None in particular Ceduna Cleve Etc. - 15 councils in all

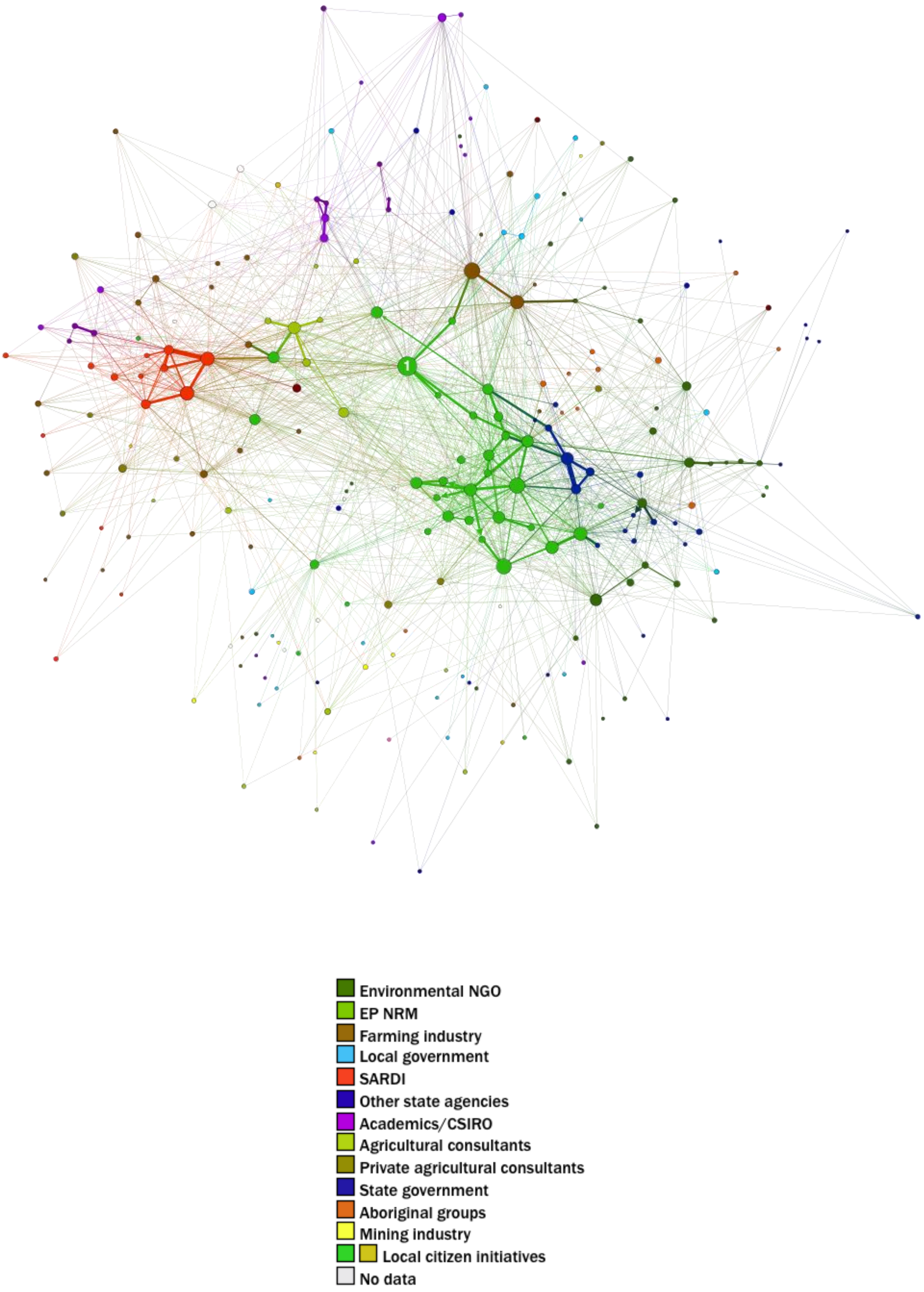


Figure 52: Presentation of the network of information and knowledge sharing among actors

Nodes represent actors (stakeholders), their colours represent the category or group they belong to, and the edges (whose thickness is relative to the frequency of interactions) represent information or knowledge sharing, or lack thereof. Finally, the size of nodes indicates their Eigenvalues, that is, the level to which they each contribute to the general connectivity of the network

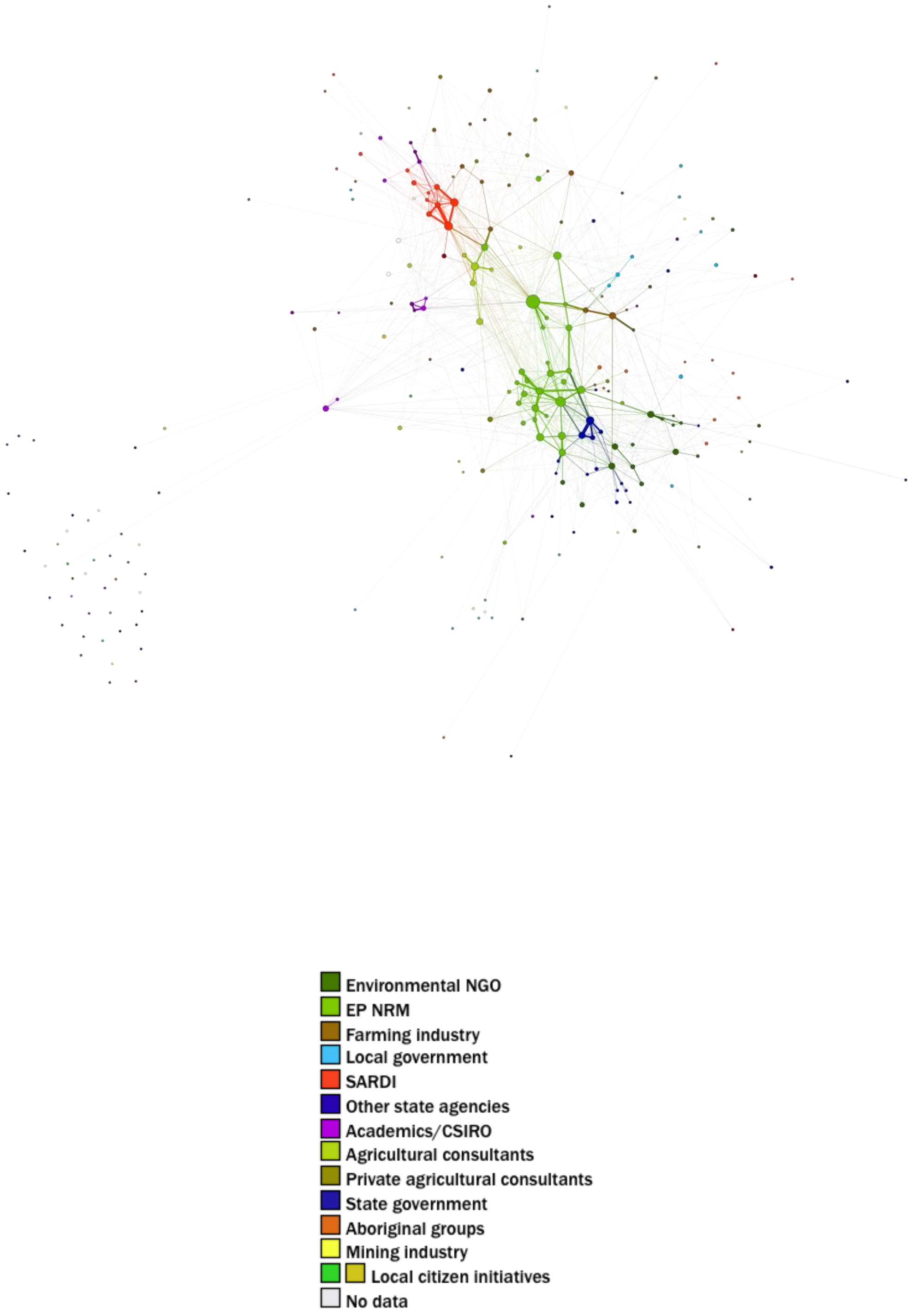


Figure 53: Presentation of the network of biodiversity programs promotion collaborations among actors

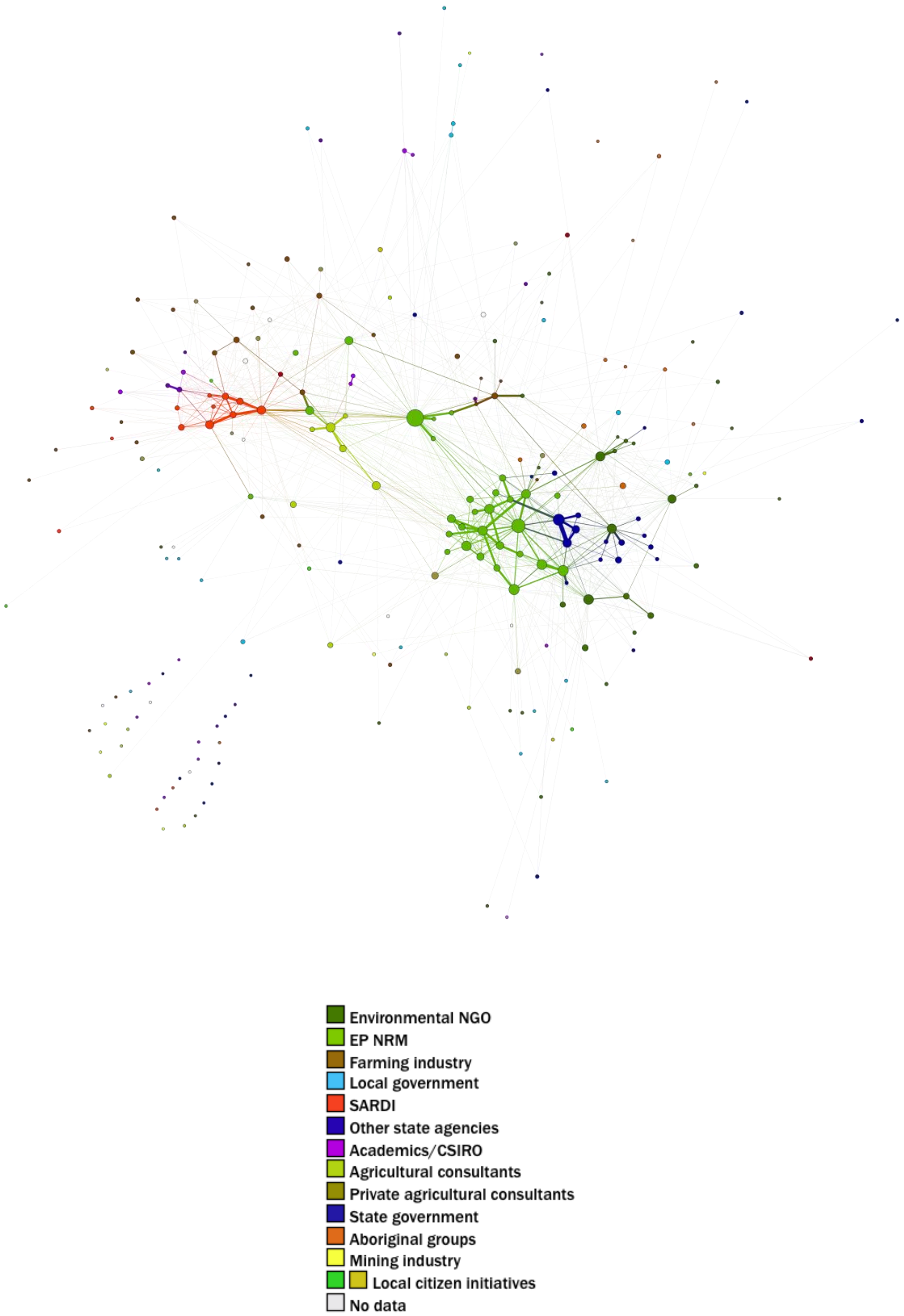


Figure 54: Presentation of the network of implementation collaborations among actors

6.3.4 Metrics to Assess Resilience in Natural Resource Management

Vulnerability and adaptive capacity are often connected to the concept of resilience, which can hold different meanings according to what we are looking at. In our case study, we consider vulnerability as the capacity of the actor network to retain its social capital (that is the interconnectiveness of its elements), often seen as important in organizing capacity for sustainable resource management (Crona, 2006), despite node removal. Adaptive capacity is here seen as the ability of the network structure to develop innovative ideas in a changing environment. In the field of network analysis, , a set of relevant metrics can be used to assess both these characteristics (Gonzales and Parrott, 2012) (Table 20).

Table 20: Non exhaustive selection of metrics used to assess EP's natural resource management social network

Source: (Bodin and Crona, 2009)

Metrics	Effect
Density of connections (number of effective connections out of the total number of possible connections)	More connectivity means better social capital and better general NRM outcomes (up to a certain level) (Sandstrom:2010).
Level of modularity (diverse measures of clustering. Scott, 2000 pp. 126-145) in the network.	Less modularity can mean better collaboration but more modularity can mean more specialised (and diverse) knowledge production.
Centrality at the network or node scales	At the network scale: Network centrality (which measures the difference of nodes centrality within the network) can help identify nodes which are the most influential in a network. At the node scale: Identifying nodes with a strong betweenness centrality (capacity of linking nodes that would otherwise not be linked) helps settle the previous opposition as a highly modular structure can still promote collaboration and information exchanges if strong bridges exist between the sub-group. In addition, nodes having many connections (which are more central than most others in terms of degree centrality this time) are important in the system: depending on their attitude, they could influence the outcome positively or negatively at the network scale. They are also sensitive nodes as their removal would influence the general structure more than other, less central nodes. Eigenvalue is also good measure of centrality in the context of social capital as it quantifies the contribution of each node to the whole network connectivity.

The network is not yet complete enough to be quantitatively analysed, as not all survey results are in. Results of this analysis will be published at a later date (Rodolphe's PhD + journal papers). However, keeping this in mind, the figures presented above can be commented on in light of these structural measures.

In the network of information and knowledge exchange (Figure 52), we clearly see a large number of connections between nodes. This indicates a high level of social capital, which can be valuable for achieving positive NRM outcomes. We can also observe a large heterogeneity between link strengths, where stronger ties seem to happen within nodes belonging to similar groups. This could indicate that the network of information and knowledge exchange is somewhat modular, a structure which may help in producing more specialized and diverse knowledge when new ideas are necessary to adapt to new situations. Looking at centrality at the node scale, we notice a few nodes showing large Eigenvalues (size of nodes). This indicates that a few nodes contribute to a large extent to the whole network connectivity. This is an important structural feature to keep in mind as if these nodes were to disappear, the social capital would most likely be greatly diminished. One node (noted "1" in the graph) seems to hold a particularly important position for two reasons: 1) it has the largest Eigenvalue, meaning that removing this node from the network would contribute more to reducing the connectivity that removing any other node in this network, and 2) it seems to be connecting several important subgroups (EP NRM, SARDI, members of farming industry). Hence, this node acts as a bridge connecting several key groups in the knowledge-sharing network. Finally, it is interesting to note that academic and research (CSIRO) nodes are all rather peripherical to the network and connect to several important groups.

Figures 53 and 54, representing collaboration efforts in promotion and implementing biodiversity conservation programs, show somewhat similar stuctures (the main difference seems to be the implication of nodes belonging to the academic field), thus I will describe them together. First of all, these networks show a much less connected structure. Once again, the strongest links bind nodes belonging to the same groups, hinting at a level of modularity in the network. In terms of centrality, one node (the same node noted "1" in Figure 52), appears to contribute to connectivity to a larger extent than any other nodes, it also seems to connect two subnetworks: EP NRM and governmental agencies on one side, and SARDI and agricultural consultants on the other. This node seems to hold a particularly important position in the three networks, and, therefore, in the governance system.

This sub-project will inform stakeholders on the strength and ability of the described structure to continue looking after the valuable biodiversity assets of EP in a changing environment. It will also contribute to a better understanding of biodiversity conservation efforts on the EP.

Ethics Approval:

This research has received University of Montreal's ethics committee approval number: CERFAS-2011-12-146-A.

Chapter 7

CONCLUSIONS

7.1 Key Messages

Historic rainfall records from more than 70 sites across the EP NRM region show the large spatial variation in rainfall that characterises the region. Using cluster analysis of these rainfall records enabled the classification of nine subregions that can then be generally grouped into low, medium and high rainfall zones.

Using the results of extensive soil surveys together with data associated with cropping experiments over the last couple of decades it is possible to develop a detailed spatial description of soil property distribution. Not surprisingly, this distribution shows considerable spatial variation. When combined with the spatial distribution of rainfall it is again evident that these factors, which substantially influence plant growth and crop yield, will cause very large variation of estimated wheat yields with a range from < 1t/ha to >4.5 t/ha.

Estimates of wheat yields from the APSIM model based on recent weather data were shown to be plausible and consistent with measured and averaged yields from field trials and regional crop statistics. With this validation there can be reasonable confidence that modelled yields using projected climate change weather conditions will be indicative of likely responses.

As climate conditions for the EP region become warmer and drier along with increased concentrations of CO_2 in the atmosphere estimated wheat yields show both decreases and increases depending on the locality being considered. In general, areas in the northern low rainfall zones show decreases while some areas in the southern, high rainfall zones show increases. This effect results from the interplay between temperature, rainfall and CO_2, with each factor affecting plant growth, crop season duration and or rate of dry matter accumulation. As climate change conditions become more severe with projections to 2070, then almost all areas in the region will have lower yields, and in the case of the northern low rainfall areas simulated yields are 30 to 50% less than current. Given that these areas are already rainfall limited and the yields are low now, it is extremely unlikely that current cropping practice would be financially viable.

While annual decreases in future rainfall become more limiting to crop production especially under the medium to severe CC projections, changes in seasonal distribution of rainfall will be even more limiting. Downscaled projections for the EP region indicate that there may be less winter and spring rainfall. If this eventuates then yield decreases will become more evident even with conditions associated with mild climate change conditions.

The initial assessment of the economic implications of changed wheat productivity as climate changes clearly illustrates the sensitivity to grain price. Small reductions in yields due to climate change combined with low grain prices can have substantial financial ramifications especially on large areas with poorer soils and marginal current rainfall. This is especially the case for the low rainfall region where moderate climate change coupled with the annual occurrence of low grain prices will have drastic effects. At the other end of this spectrum, mild and moderate climate change conditions in areas of medium to high rainfall and with quality soils will potentially see improved profitability especially if grain prices rise in real terms in line with demand from an increasing world population.

While the simulations of carbon sequestration and biomass production used less detailed soil descriptions but with similar climate change projection to those used in the wheat productivity simulations, the spatial distribution of biomass followed similar trends. Trends between rainfall zones in both the EP NRM and the SA MDB NRM regions were similar. Hardwood productivity varied from 1.4 tonnes CO-$_2$e/ha/year in the drier areas up to around 10 tonnes CO2-e/ha/year in higher rainfall regions. As conditions become warmer and drier the carbon sequestration rates of hardwood plantations decreased, with a 26% decrease under the most severe change conditions.

Environmental plantings with a mixture of regionally endemic species were simulated to respond in a manner similar to wheat. With mild warming and drying, environmental plantings sequester slightly more carbon than under current conditions especially in the higher rainfall zones. As conditions become more severe in the low rainfall zones, limited rainfall and higher temperatures are not offset by high CO_2 levels and the simulated annual sequestration rates decrease by up to 54%.

Simulations of oil mallee plantings clearly illustrate the different responses that can be expected in different zones of the region. In lower rainfall areas, growth rates decreased by up to 41% under the severe climate change scenario. In contrast, growth rates increased in high rainfall areas, with increases of 18.6%, 29.6% and 37.8% observed for mild, medium and severe climate change conditions respectively.

The economic viability of hardwood plantations in Eyre Peninsula was sensitive to variations in both climate and carbon price. Environmental plantations were also sensitive to changes in carbon price, but less so than hardwood plantations. Under each climate change scenario, for carbon prices at and above $\$20/\text{tonne}/CO_2^{-e}$, a higher percentage of the Eyre Peninsula was viable under hardwood forestry than environmental plantings. No areas within the Eyre Peninsula region were viable under a carbon price of $\$10/\text{tonne}/CO_2^{-e}$ for either land use. Biomass production was also highly sensitive to carbon price. Under a carbon price of \$50/tonne/CO_2^{-e}, over 90% of the study was found to be viable under each of the climate change scenarios.

As with the Eyre Peninsula, no areas within the SA MDB region were viable under a carbon price of \$10/tonne/ CO_2^{-e}. Economic viability of hardwood and environmental plantations were sensitive to variations in carbon price and climate for prices at and above \$20/tonne/CO_2^{-e}. Economic viability of biomass production was also sensitive to changes in carbon price. Only marginal areas were viable under a carbon price of \$30/tonne/ CO_2^{-e} whereas a majority of the study area was viable under \$50/tonne/ CO_2^{-e}.

The assessment of vulnerable species and ecosystems used a climate change vulnerability framework to identify complementarity-based spatial conservation priorities. The analysis on a species by species basis identified the most adversely affected. Then, by combining the assessment of species exposure, sensitivity and adaptive capacity, the high priority areas for conservation actions were identified. This analysis was applied to both the EP and SA MDB regions. The general results were remarkably consistent across both regions. Conservation priorities become more concentrated in the more southern latitudes and higher rainfall areas of both regions. Typically, these areas have cooler and wetter climates and are likely to become more limited in area as climate change intensifies. With this result it is obvious that greater tension between alternate land use will exist in these more favourable rainfall areas as climate becomes warmer and drier.

While the focus of the majority of the project has been on biophysical responses to climate change and in turn on the resultant economic implications there has also been an examination of some social interactions around decision influencing and making in the EP region. A small study of the social- ecological network highlighted that information transfer and decision making is not uniformly distributed among the community. Indeed it is highly concentrated on a limited number of individuals and organisations. The relationship analysis showed that one node appears to disproportionately connect to other nodes. This node also seems to connect to two subnetworks: EP NRM and governmental agencies on one side, and SARDI and agricultural consultants on the other. This node seems to hold a particularly important position in the three networks, and, therefore, in the governance system of the region. The implication of this is that this node is in the position of considerable influence and while this may be a great strength for social and ecological decision making it is also likely to have considerable negative ramifications if this node was to be changed or lost.

7.2 Conclusions

This project has extended our understanding of the change processes and forces that are changing our landscapes now and increasingly into the future. The learning over the three years has challenged researchers, stakeholders and community people involved in thinking about CC and how we might adapt.

Regional capacity to address and adapt to CC has significantly increased during the course of this project. The project has been able to simplify some of the complexity associated with CC projections and develop a robust research methodology to develop options for adapting at a regional scale. It has greatly extended the work of the Landscape Science program and capitalised on the ground breaking work of the LMLF project.

The PSRF project has supported the development of regional scale assessment of likely changes and helped identify possible CC adaptation. The sub-projects developed have well complemented the primary research base to improve the capacity to develop regional level outcomes and engage the community and stakeholders. The project has led CC research and implementation in the NRM regions but it is acknowledged that developing CC adaptation strategies takes time and concerted planning.

The process itself has been as important as the outcomes to improve confidence in CC research and development of agreed shared outcomes with high levels of engagement and cross collaboration.

The projects key emphasis on addressing risks and harnessing opportunities was important for developing future viable options and testing these in a real world context. Identifying short term opportunities such as linking to national strategies including the Clean Energy Futures Plan will be important for harnessing momentum and resources to build change. Strategic and landscape based planning is vital for supporting this process.

The legacy of the project will continue through building on the methodology of Landscape Futures Analysis and the insights that it enables. There with be a focus on building CC adaptation into planning strategies and further refining CC models, CC projections and CC adaptation particularly in relation to optimising CC strategies across the landscape.

BIBLIOGRAPHY

Adcock, D. P. (2005). Soil water and nitrogen dynamaics of farming systems on the upper Eyre Peninsula, South Australia. School of Earth and Environmental Sciences, University of Adelaide: 190.

Adger, W.N., 2006. Vulnerability. Global Environmental Change-Human and Policy Dimensions 16 (3), 268-281.

Albrecht, A., Kandji, S.T., 2003. Carbon sequestration in tropical agroforestry systems. Agriculture Ecosystems & Environment 99 (1-3), 15-27.

Almeida, A.C., Landsberg, J.J., Sands, P.J., 2004a. Parameterisation of 3-PG model for fast-growing Eucalyptus grandis plantations. Forest Ecology and Management 193 (1-2), 179-195.

Almeida, A.C., Landsberg, J.J., Sands, P.J., Ambrogi, M.S., Fonseca, S., Barddal, S.M., Bertolucci, F.L., 2004b. Needs and opportunities for using a process-based productivity model as a practical tool in Eucalyptus plantations. Forest Ecology and Management 193 (1-2), 167-177.

Almeida, A.C., Paul, K.I., Siggins, A., Sands, P.J., Polglase, P., Marcar, N.E., Jovanovic, T., Theiveyanathan, S., Crawford, D.F., England, J.R., Falkiner, R., Hawkins, C., White, D., 2007. Development, calibration and validation of the forest growth model 3-PG with an improved water balance. Final Report July 2007. Client Report No. 1786.

Amichev, B.Y., Hangs, R.D., Van Rees, K.C.J., 2011. A novel approach to simulate growth of multi-stem willow in bioenergy production systems with a simple process-based model (3PG). Biomass & Bioenergy 35 (1), 473-488.

Armstrong, R. D., J. Fitzpatrick, M. A. Rab, M. Abuzar, P. D. Fisher and G. J. O'Leary (2009). "Advances in precision agriculture in south-eastern Australia. III. Interactions between soil properties and water use help explain spatial variability of crop production in the Victorian Mallee." Crop and Pasture Science 60(9): 870-884.

ASRIS, 2007. Australian soil resource information system. CSIRO Land and Water, Canberra, Australia.

Asseng, S., I. R. P. Fillery, G. C. Anderson, P. J. Dolling, F. X. Dunin and B. A. Keating (1998a). "Use of the APSIM wheat model to predict yield, drainage, and NO3/- leaching for a deep sand." Australian Journal of Agricultural Research 49(3): 363-377.

Asseng, S., I. R. P. Fillery, F. X. Dunin, B. A. Keating and H. Meinke (2001a). "Potential deep drainage under wheat crops in a Mediterranean climate. I. Temporal and spatial variability." Australian Journal of Agricultural Research 52(1): 45-56.

Asseng, S., P. D. Jamieson, B. Kimball, P. Pinter, K. Sayre, J. W. Bowden and S. M. Howden (2004). "Simulated wheat growth affected by rising temperature, increased water deficit and elevated atmospheric CO2." Field Crops Research 85(2-3): 85-102.

Asseng, S., B. A. Keating, I. R. P. Fillery, P. J. Gregory, J. W. Bowden, N. C. Turner, J. A. Palta and D. G. Abrecht (1998b). "Performance of the APSIM-wheat model in Western Australia." Field Crops Research 57(2): 163-179.

Asseng, S., N. C. Turner and B. A. Keating (2001). "Analysis of water- and nitrogen-use efficiency of wheat in a Mediterranean climate." Plant and Soil 233(1): 127-143.

Battaglia, M., Sands, P.J., 1998. Process-based forest productivity models and their application in forest management. Forest Ecology and Management 102 (1), 13-32.

Becker, E., 2010. Social-ecological systems as epistemic objects. Institute for Social-Ecological Research (ISOE), Frankfurt/Main.

Bodin, O., Crona, B.I., 2009. The role of social networks in natural resource governance: What relational patterns make a difference? Global Environmental Change-Human and Policy Dimensions 19 (3), 366-374.

Bryan, B., King, D., Wang, E., 2010a. Biofuels agriculture: Landscape-scale trade-offs between food, energy, carbon, and regional development. Global Change Biology - Bioenergy.

Bryan, B.A., Crossman, N.D., King, D., McNeill, J., Wang, E., Barrett, G., Ferris, M.M., Morrison, J.B., Pettit, C., Freudenberger, D., O'Leary, G.J., Fawcett, J., Meyer, W., 2007. Lower Murray Landscape Futures.Volume III: Data Analysis, Modelling and Visualisation for Dryland Areas. CSIRO Land and Water; Primary Industries Research; Victoria (PIRVic); CSIRO Sustainable Ecosystems; Econsearch Pty. Ltd.;The University of Adelaide.

Bryan, B.A., Crossman, N.D., King, D., Meyer, W.S., 2011. Landscape futures analysis: Assessing the impacts of environmental targets under alternative spatial policy options and future scenarios. Environmental Modelling & Software 26, 83-91.

Bryan, B.A., King, D., Wang, E., 2010b. Potential of woody biomass production for motivating widespread natural resource management under climate change. Land Use Policy 27, 713-725.

Burk, L. and N. Dalgliesh (2008). Estimating plant available water capacity-a methodology. Canberra, CSIRO Sustainable Ecosystems: 40 pp.

Carvalho, S.B., Brito, J.C., Crespo, E.J., Possingham, H.P., 2010. From climate change predictions to actions - conserving vulnerable animal groups in hotspots at a regional scale. Global Change Biology 16 (12), 3257-3270.

Coops, N.C., Waring, R.H., 2001. Assessing forest growth across southwestern Oregon under a range of current and future global change scenarios using a process model, 3-PG. Global Change Biology 7 (1), 15-29.

Coops, N.C., Waring, R.H., Landsberg, J.J., 1998. Assessing forest productivity in Australia and New Zealand using a physiologically-based model driven with averaged monthly weather data and satellite-derived estimates of canopy photosynthetic capacity. Forest Ecology and Management 104 (1-3), 113-127.

Coops, N.C., Waring, R.H., Law, B.E., 2005. Assessing the past and future distribution and productivity of ponderosa pine in the Pacific Northwest using a process model, 3-PG. Ecological Modelling 183 (1), 107-124.

Crossman, N.D., Bryan, B.A., Summers, D.M., 2012. Landscape planning for biodiversity conservation under climate change. Diversity and Distributions 18, 60-72.

Cumming, G.S., Bodin, O., Ernstson, H., Elmqvist, T., 2010. Network analysis in conservation biogeography: challenges and opportunities. Diversity and Distributions 16 (3), 414-425.

Dalgliesh, N. P., G. Wockner and A. Peake (2006). Delivering soil water information to growers and consultants, Proceedings of the 13th Australian Agronomy Conference, 10-14 September 2006. Perth Western Australia. Australian Society of Agronomy. .

Dent, D. and A. Young (1981). Soil survey and land evaluation, George Allen and Unwin. London.

England, J., Paul, K.I., Falkiner, R., Theiveyanathan, T., 2006. Rates of carbon sequestration in environmental plantings in north-central Victoria. In: Presented at Veg Futures as: What is the value of environmental plantings in sequestering carbon and how can this be monitored and evaluated? Ensis (the joint forces of CSIRO and Scion), Albury, New South Wales in March 2006, pp. 11.

EP NRM Board, 2009. Managing Our Resources: Strategic Plan for the Management of the Natural Resources of Eyre Peninsula. Eyre Peninsula Natural Resources Management Board.

ESRI, 2009. ArcGIS 9.3. Environmental Systems Research Institute (ESRI), Redlands, California.

Fawcett, T., 2006. An introduction to ROC analysis. Pattern Recognition Letters 27 (8), 861-874.

Feikema, P.M., Morris, J.D., Beverly, C.R., Lane, P.N.J., Baker, T.G., 2010. Using 3PG+ to simulate long term growth and transpiration in Eucalyptus regnans forests. In: D.A. Swayne, W. Yang, A.A. Voinov, A. Rizzoli and T. Filatova (Editors), International Congress on Environmental Modelling and Software: Modelling for Environment's Sake. International Environmental Modelling and Software Society (iEMSs), Ottawa, Canada. July, 2010.

Fielding, A.H., Bell, J.F., 1997. A review of methods for the assessment of prediction errors in conservation presence/absence models. Environmental Conservation 24 (1), 38-49.

Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N., Snyder, P.K., 2005. Global consequences of land use. Science 309 (5734), 570-574.

Gifford, R.M., 2000. Carbon contents of above-ground tissues of forest and woodland trees. National Carbon Accounting System Technical Report No. 22. Australian Greenhouse Office.

Gijsman, A. J., S. S. Jagtap and J. W. Jones (2003). "Wading through a swamp of complete confusion: how to choose a method for estimating soil water retention parameters for crop models." European Journal of Agronomy 18(1–2): 77-106.

Gonzales, R., Parrott, L., 2012. Network theory in the assessment of the sustainability of social-ecological systems. Geography Compass, Network theory for social-ecological system analysis 6, 76-88.

Hall, J. A. S., D. J. Maschmedt and B. N.B. (2009). The soils of Southern South Australia, The South Australian Land and Soil Book Series, Volume 1: Geological Survey of South Australia, Bulletin 56, Volume 1. Department of Water, Land and Bioversity Conservation, Government of South Australia.

Hayman, P. T., A. M. Whitbread and D. L. Gobbett (2010). "The impact of El Nino Southern Oscillation on seasonal drought in the southern Australian grainbelt (vol 61, pg 528, 2010)." Crop & Pasture Science 61(8): 677-539.

Houlder, D.J., Hutchinson, M.F., Nix, H.A., McMahon, J.P., 1999. ANUCLIM User Guide, Version 5.0. Centre for Resource and Environmental Studies, Australian National University, Canberra.

IPCC, 2007. Summary for Policymakers. In: S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (Editors), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jackson, R.B., Jobbagy, E.G., Avissar, R., Roy, S.B., Barrett, D.J., Cook, C.W., Farley, K.A., le Maitre, D.C., McCarl, B.A., Murray, B.C., 2005. Trading water for carbon with biological sequestration. Science 310 (5756), 1944-1947.

Janssen, M.A., Bodin, O., Anderies, J.M., Elmqvist, T., Ernstson, H., McAllister, R.R.J., Olsson, P., Ryan, P., 2006. Toward a network perspective of the study of resilience in social-ecological systems. Ecology and Society 11 (1).

Keating, B.A., Carberry, P.S., Hammer, G.L., Probert, M.E., Robertson, M.J., Holzworth, D., Huth, N.I., Hargreaves, J.N.G., Meinke, H., Hochman, Z., McLean, G., Verburg, K., Snow, V., Dimes, J.P., Silburn, M., Wang, E., Brown, S., Bristow, K.L., Asseng, S., Champman, S., McCown, R.L., Freebairn, D.M., Smith, C.J., 2003. An overview of APSIM, a model designed for farming systems simulation. European Journal of Agronomy 18 (267 - 288).

Landsberg, J.J., Johnsen, K.H., Albaugh, T.J., Allen, H.L., McKeand, S.E., 2001. Applying 3-PG, a simple process-based model designed to produce practical results, to data from loblolly pine experiments. Forest Science 47 (1), 43-51.

Landsberg, J.J., Waring, R.H., 1997. A generalized model of forest productivity using simplified concepts of radiation-use efficiency, carbon balance, and partitioning. Forest Ecology Management 95 (209-228).

Landsberg, J.J., Waring, R.H., Coops, N.C., 2003. Performance of the forest productivity model 3-PG applied to a wide range of forest types. Forest Ecology and Management 172 (2-3), 199-214.

Lucy, S., 2010. Climate Change, Communities and Environment Research Project (Eyre Peninsula NRM Region): Plan for Outcomes and Key Actions. Draft report from Rural Solutions SA.

Ludwig, F. and S. Asseng (2006). "Climate change impacts on wheat production in a Mediterranean environment in Western Australia." Agricultural Systems 90(1-3): 159-179.

Luo, Q.Y., Bellotti, W., Williams, M., Bryan, B., 2005a. Potential impact of climate change on wheat yield in South Australia. Agricultural and Forest Meteorology 132 (3-4), 273-285.

Luo, Q., W. Bellotti, M. Williams and E. Wang (2009). "Adaptation to climate change of wheat growing in South Australia: Analysis of management and breeding strategies." Agriculture Ecosystems & Environment 129(1-3): 261-267.

Luo, Q.Y., Bryan, B., Bellotti, W., Williams, M., 2005b. Spatial analysis of environmental change impacts on wheat production in Mid-Lower North, South Australia. Climatic Change 72 (1-2), 213-228.

Lyle, G., 2010. Climate change, community and environment: Eyre Peninsula spatial datasets. The University of Adelaide, Environment Institute, Landscape Futures Program.

Lyle, G., 2011. Climate change, community and environment: Eyre Peninsula climate regionalisation. The University of Adelaide, Environment Institute, Landscape Futures Program.

Manning, A.D., Fischer, J., Felton, A., Newell, B., Steffen, W., Lindenmayer, D.B., 2009. Landscape fluidity - a unifying perspective for understanding and adapting to global change. Journal of Biogeography 36 (2), 193-199.

Meyer, W., Siebentritt, M., Hayman, P., Alexander, B., Kellett, B., Summers, D., Bryan, B., Connor, J., Spoehr, J., Sharma, V., Sharley, T. and Lyle, G., (2010). Climate change impact assessment, adaptation and emerging opportunities for the SA Murray-Darling basin. Literature Review. Milestone 1 Report. A report prepared by The Environment Institute, The University of Adelaide, as part of the Strengthening basin communities program – Planning Component Consultancy SBC033A.1/2, 68 pages.

Moilanen, A., Kujala, H., 2008a. Zonation spatial conservation planning framework and software v. 2.0 user manual. Helsinki, Findland.

Moilanen, A., Kujala, H., 2008b. Zonation: Conservation planning software, Helsinki, Findland.

Nightingale, J.M., Hill, M.T., Phinn, S.R., Davies, I.D., Held, A.A., Erskine, P.D., 2008. Use of 3-PG and 3-PGS to simulate forest growth dynamics of Australian tropical rainforests - I. Parameterisation and calibration for old-growth, regenerating and plantation forests. Forest Ecology and Management 254 (2), 107-121.

Ostrom, E., 2009. A General Framework for Analyzing Sustainability of Social-Ecological Systems. Science 325 (5939), 419-422.

Parrott, L., Chion, Gonzales, R., C., Latombe, G., (2012). Agents, individuals and networks: Modeling methods to inform natural resource management in regional landscapes. Ecology & Society (accepted June 2012)

Paul, K.I., Booth, T.H., Jovanovic, T., Sands, P.J., Morris, J.D., 2007. Calibration of the forest growth model 3-PG to eucalypt plantations growing in low rainfall regions of Australia. Forest Ecology and Management 243 (2-3), 237-247.

Polglase, P., Paul, K., Hawkins, C., Siggins, A., Turner, J., Booth, T., Crawford, D., Jovanovic, T., Hobbs, T., Opie, K., Almeida, A., Carter, J., 2008. Regional Opportunities for Agroforestry Systems in Australia. RIRDC Publication No. 08/176. RIRDC Project No CSF-68A. Rural Industries Research and Development Corporation (RIRDC).

Polglase, P., Reeson, A., Hawkins, C., Paul, K., Siggins, A., Turner, J., Crawford, D., Jovanovic, T., Hobbs, T., Opie, K., Carwardine, J., Almeida, A., 2011. Opportunities for carbon forestry in Australia: Economic assessment and constraints to implementation. CSIRO.

Portnoy, S., Willson, M.F., 1993. Seed Dispersal Curves - Behavior of the Tail of the Distribution. Evolutionary Ecology 7 (1), 25-44.

Pracilio, G., S. Asseng, S. E. Cook, G. Hodgson, M. T. F. Wong, M. L. Adams and T. J. Hatton (2003). "Estimating spatially variable deep drainage across a central-eastern wheatbelt catchment, Western Australia." Australian Journal of Agricultural Research 54(8): 789-802.

Prell, C., Hubacek, K., Reed, M., 2009. Stakeholder Analysis and Social Network Analysis in Natural Resource Management. Society & Natural Resources 22 (6), 501-518.

Probert, M. E., B. A. Keating, J. P. Thompson and W. J. Parton (1995). "Modelling water, nitrogen, and crop yield for a long-term fallow management experiment." Australian Journal of Experimental Agriculture 35(7): 941-950.

QCCCE, 2012. SILO climate data. Queensland Climate Change Centre of Excellence (QCCCE). Available online at http://www.longpaddock.qld.gov.au/silo/.

Rab, M. A., S. Chandra, P. D. Fisher, N. J. Robinson, M. Kitching, C. D. Aumann and M. Imhof (2011). "Modelling and prediction of soil water contents at field capacity and permanent wilting point of dryland cropping soils." Soil Research 49(5): 389-407.

Rab, M. A., P. D. Fisher, R. D. Armstrong, M. Abuzar, N. J. Robinson and S. Chandra (2009). "Advances in precision agriculture in south-eastern Australia. IV. Spatial variability in plant-available water capacity of soil and its relationship with yield in site-specific management zones." Crop & Pasture Science 60(9): 885-900.Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C.H., Stringer, L.C., 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. Journal of Environmental Management 90 (5), 1933-1949.

Reyenga, P. J., S. M. Howden, H. Meinke and G. M. McKeon (1999). "Modelling global change impacts on wheat cropping in south-east Queensland, Australia." Environmental Modelling & Software 14(4): 297-306.

Rodriguez, J.P., Beard, T.D., Bennett, E.M., Cumming, G.S., Cork, S.J., Agard, J., Dobson, A.P., Peterson, G.D., 2006. Trade-offs across space, time, and ecosystem services. Ecology and Society 11 (1).

Sands, P.J., 2004. Adaptation of 3-PG to novel species: Guidelines for data collection and parameter assignment. Technical Report 141. Project B4: Modelling Productivity and Wood Quality. Cooperative Research Centre for Sustainable Production Forestry, CSIRO Forestry and Forest Products, Hobart.

Sands, P.J., Landsberg, J.J., 2002. Parameterisation of 3-PG for Plantation Grown Eucalyptus globulus. Forest Ecology and Management 163, 273-292.

Santos, X., Brito, J.C., Caro, J., Abril, A.J., Lorenzo, M., Sillero, N., Pleguezuelos, J.M., 2009. Habitat suitability, threats and conservation of isolated populations of the smooth snake

(Coronella austriaca) in the southern Iberian Peninsula. Biological Conservation 142 (2), 344-352.

Schneider, S.H., Semenov, S., Patwardhan, A., Burton, I., Magadxa, C.H.D., Oppenheimer, M., Pittock, A.B., Rahman, A., 2007. Assessing key vulnerabilities and the risk from climate change. In: M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. Van Der Linden and C.E. Hanson (Editors), Climate change 2007: Impacts, adaptation and vulnerabilities. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K., pp. 779-810.

Standards Australia, 2002. Carbon accounting for greenhouse sinks - Part 1: Afforestation and reforestation. Interim Australian Standard AS 4978.1(int)-2002.

Summers, D.M., Bryan, B.A., Crossman, N.D., Meyer, W.S., 2012. Species vulnerability to climate change: Impacts on spatial conservation priorities and species representation. Global Change Biology 18(7), 2335-2348.

Suppiah, R., Hennessy, K.J., Whetton, P.H., McInnes, K., Macadam, I., Bathols, J., Ricketts, J., Page, C.M., 2007. Australian climate change projections derived from simulations performed for the IPCC 4th assessment report. Australian Meterological Magazine 56, 131-152.

Taylor, J. A. and B. Minasny (2006). "A protocol for converting qualitative point soil pit survey data into continuous soil property maps." Australian Journal of Soil Research 44(5): 543-550.

Thuiller, W., Lavorel, S., Araujo, M.B., Sykes, M.T., Prentice, I.C., 2005. Climate change threats to plant diversity in Europe. Proceedings of the National Academy of Sciences of the United States of America 102 (23), 8245-8250.

Tubiello, F. N., J. S. Amthor, K. J. Boote, M. Donatelli, W. Easterling, G. Fischer, R. M. Gifford, M. Howden, J. Reilly and C. Rosenzweig (2007). "Crop response to elevated CO2 and world food supply - A comment on "Food for Thought..." by Long et al., Science 312 : 1918-1921, 2006." European Journal of Agronomy 26(3): 215-223.

Vos, C.C., Berry, P., Opdam, P., Baveco, H., Nijhof, B., O'Hanley, J., Bell, C., Kuipers, H., 2008. Adapting landscapes to climate change: examples of climate-proof ecosystem networks and priority adaptation zones. Journal of Applied Ecology 45 (6), 1722-1731.

Wang, E., H. Cresswell, J. Xu and Q. Jiang (2009). "Capacity of soils to buffer impact of climate variability and value of seasonal forecasts." Agricultural and Forest Meteorology 149(1): 38-50.

Ward, J., MacDonald, D.H., 2009. Encouraging landholder participation in natural resource incentive programs on the Eyre Peninsula. Eyre Peninsula Natural Resources Management Board.

Webb, C., Bodin, Ö. 2008. A network perspective on modularity and control of flow in robust systems. In: J. Norberg and G.S. Cumming (Editors), Complexity theory for a sustainable future. Columbia Press, New York, pp. 85–118.

Wetherby, K. G. (1992). Soil description handbook, South Australian Department of Agriculture (unpublished).

Wildy, D.T., Pate, J.S., Sefcik, L.T., 2004. Water-use efficiency of a mallee eucalypt growing naturally and in short-rotation coppice cultivation. Plant and Soil 262 (1-2), 111-128.

Williams, J., R. E. Prebble, W. T. Williams and C. T. Hignett (1983). "THE INFLUENCE OF TEXTURE, STRUCTURE AND CLAY MINERALOGY ON THE SOIL-MOISTURE CHARACTERISTIC." Australian Journal of Soil Research 21(1): 15-32.

Williams, S.E., Shoo, L.P., Isaac, J.L., Hoffmann, A.A., Langham, G., 2008. Towards an Integrated Framework for Assessing the Vulnerability of Species to Climate Change. Plos Biology 6 (12), 2621-2626.

Wong, M. T. F. and S. Asseng (2006). "Determining the causes of spatial and temporal variability of wheat yields at sub-field scale using a new method of upscaling a crop model." Plant and Soil 283(1-2): 203-215.

Note to self: References with dates in brackets e.g. (2010) are not in the Endnote library yet. (i.e. APSIM references)

APPENDICES

Appendix 1: Governance and Management

Advisory Group

- Dr Roger Wickes, private NRM consultant - Chair
- Dr Patrick O’Connor, Director, O’Connor NRM Pty Ltd
- Mr John Johnson, General Manager, or Ms Denise Fowles, Deputy General Manager, SA MDB NRM Board
- Ms Kate Clarke, General Manager, or Ms Annie Lane, Regional Manager, EP NRM Board
- Ms Sheridan Alm, Member, SA MDB NRM Board
- Ms Cecilia Woolford, Member EP NRM Board

Management Group

- Wayne Meyer, The University of Adelaide – Project Leader
- Brett Bryan, CSIRO
- Michael Cutting, SA MDB NRM Board
- Gerry Davies or Greg Cock, PIRSA
- Peter Hayman, SARDI
- Megan Lewis, The University of Adelaide
- Mark Stanley, EP NRM Board
- Susan Sweeney or Andrew Fisher, DENR
- Stephanie Williams, DENR
- Susan Saunders (part time administrative help and minute secretary)

Research Team

- Prof Wayne Meyer – The University of Adelaide, Project Leader
- Dr Brett Bryan – CSIRO, economic and resource senior researcher
- Mr David Davenport – Rural Solutions SA, contracted Research Officer on Eyre Peninsula
- Dr Bart Kellett – The University of Adelaide, Postdoctoral researcher with a focus on the MDB region and social and policy settings
- Dr Greg Lyle – The University of Adelaide, Postdoctoral researcher with a focus on Eyre Peninsula Landscape Futures analysis
- Dr David Summers – CSIRO, Postdoctoral researcher with a focus on conservation and biodiversity analysis in both EP and SA MDB NRM regions
- Travis Moon – CSIRO, research officer
- Rodolphe Gonzales – University of Montreal, PhD candidate, social network modelling
- Dr Dorothy Turner – The University of Adelaide, Postdoctoral Fellow, technical report

Appendix 2: Publications

Published Papers

- Bryan, B.A. (2010). Robust, cost-effective investment decisions for managing natural capital and ecosystem services. Biological Conservation 143, pp.1737-1750. doi:10.1016/j.biocon.2010.04.022.

- Bryan, B.A., Crossman, N.D., King, D. and Meyer, W.S. (2011). Landscape futures analysis: assessing the impacts of environmental targets under alternative spatial policy options and scenarios. Environmental Modelling and Software 26(1), 83-91.

- Bryan, B.A., Grandgirard, A., and Ward, J.R. (2010). Quantifying and exploring strategic regional priorities for managing natural capital and ecosystem services given multiple stakeholder perspectives. Ecosystems 13, pp. 539–555. doi: 10.1007/s10021-010-9339-0.

- Bryan, B.A., King, D., Wang, E. (2010). Biofuels agriculture: landscape-scale trade-offs between fuel, economics, carbon, energy, food, and fiber. Global Change Biology – Bioenergy 2(6), pp. 330-345. doi: 10.1111/j.1757-1707.2010.01056.x.

- Bryan, B.A., King, D., and Wang, E. (2010). Potential of biomass production for achieving widespread natural resource management under climate change. Land Use Policy 27(3), pp.713-725. doi: 10.1016/j.landusepol.2009.09.012

- Bryan, B.A. King, D., and Ward, J. (2011). Modelling and mapping agricultural opportunity costs to guide landscape planning for natural resource management. Ecological Indicators 11(1), pp. 199 – 208. doi:10.1016/j.ecolind.2009.02.005

- Bryan, B.A., Raymond, C.M., Crossman, N.D. and Hatton MacDonald, D. (2010). Targeting management of ecosystem services based on community values: where, what and how? Landscape and Urban Planning 97(2), pp. 111-122. doi: 10.1016/j.landurbplan.2010.05.002

- Bryan, B.A., Raymond, C.M., Crossman, N.D., and King, D. (2011). Comparing spatially explicit ecological and social values for natural areas to identify effective conservation strategies. Conservation Biology 25(1), pp.172-181. doi: 10.1111/j.1523-1739.2010.01560.x

- Crossman, N.D., Bryan, B.A. and Cooke, D.A. (2011). An invasive plant and climate change threat index for weed risk management: Integrating habitat distribution pattern and dispersal process. Ecological Indicators 11(1), pp. 183 – 198. doi:10.1016/j.ecolind.2008.10.011.

- Crossman, N.D., Bryan, B.A., Summers, D.M. (2011). Carbon payments and low-cost conservation. Conservation Biology 25(4), 835-845.

- Crossman, N.D., Bryan, B.A., and Summers, D.M. (2012). Identifying priority areas for reducing species vulnerability to climate change. Diversity and Distributions 18(1), 60-72.

- Gonzales, R. and Parrott, L. (2012). Network theory in the assessment of the sustainability of social-ecological systems. Geography Compass, Network theory for social-ecological system analysis 6(2), 76-88.

- Higgins, A.J., Bryan, B.A., Overton, I.C., Holland, K., Lester, R.E., King, D., Nolan, M. and Connor, J.D. (2011). Integrated modelling of cost-effective siting and operation of flow-control infrastructure for river ecosystem conservation. Water Resources Research 47, W05519. doi:10.1029/2010WR009919.

- Kandulu, J.M., Bryan, B.A., King, D., and Connor, J.D. (2012). Mitigating economic risk from climate variability in rain-fed agriculture through enterprise mix diversification. Ecological Economics 75, pp. 105-112. doi:10.1016/j.ecolecon.2012.04.025

- Pettit, C., Raymond, C.M., Bryan, B.A., and Lewis, H. (2011). Strengths and weaknesses of visualisation for communicating landscape planning. Landscape and Urban Planning 100(3), pp. 231-241. doi:10.1016/j.landurbplan.2011.01.001

- Summers, D.M., Bryan, B.A., Crossman, N.D. and Meyer, W.S. (2012). Species vulnerability to climate change: Impacts on spatial conservation priorities and species representation. Global Change Biology 18(7), 2335-2348.

- Yang, W., Bryan, B.A., Hatton MacDonald, D., Ward, J.R., Wells, G., Crossman, N.D., Connor, J.D. (2010). A conservation industry for sustaining natural capital and ecosystem services in agricultural landscapes. Ecological Economics 69, pp. 680-689. doi:10.1016/j.ecolecon.2009.11.028

- Zerger, A; Lefroy, T; Bryan, B.A. (2011). Science to improve regional environmental investment decisions. Environmental Modelling and Software 26(1), p.1.

Accepted Papers

- Briere, M. and Meyer, Wayne S. (in review). Contrasting farms are carbon accumulating. Agricultural Science, AIAST (accepted subject to revision August 2011).

- Parrott, L., Chion, Gonzales, R., C., Latombe, G. (in review). Agents, individuals and networks: Modeling methods to inform natural resource management in regional landscapes. Ecology & Society (accepted June 2012)

- Parrott, L. and Meyer, W.S. (in review). Future landscapes: managing within complexity. Frontiers in Ecology and the Environment (accepted May 2012).

- Paterson, S.E. and Bryan, B.A. (in review). Food-carbon trade-offs between agriculture and reforestation and the efficiency of market-based policies. Ecology & Society (submitted Feb 2012).

Submitted Papers

- Bryan, B.A., Higgins, A., Overton, I.C., Holland, K., Lester, R.E., King, D., Nolan, M., Hatton MacDonald, D., Connor, J.D. (in review). Rebalancing ecological health and socio-economic values of river ecosystems: information integration for the operational management of environmental flows. Ecological Applications (submitted May 2012).

- Bryan, B.A. and Crossman, N.D. (in review). Interacting financial incentives display synergies, tensions, and dependencies in the supply of multiple ecosystem services. Conservation Letters, (submitted January 2012).

Papers in Preparation

- Bryan, Brett A., Crossman, Neville D. Interacting markets, land use change potential, and the supply of ecosystem services. Proceedings of the National Academy of Sciences.

- Lyle, G. Place and nested scales: A review of potential influencing factors affecting decision making for climate change adaptation in Australian agriculture.

- Lyle.G, and Davenport, D. Evaluating the ability to simulate regional wheat yields in Australian agricultural landscapes: A case study of the Eyre Peninsula.

- Lyle.G, and Davenport, D. Integrating spatial soil information, crop simulation modelling and expert opinion to assess the spatial impact of climate change on wheat production in the Eyre Peninsula agricultural region.

- Lyle.G, and Davenport, D. Applying simulation modelling to understand the climate change impacts on wheat yield within the Eyre Peninsula agricultural region.

- Meyer, W.S. and Kellett, B.M. A prosperous horticultural region changing in response to drought and commodity prices: limits to irrigated landscape change (draft completed, journal submission pending).

Reports

- Connor, J., Doble, R., Elmahdi, A., Walker, G., Stenson, M., Jolly, I., Ferris, M., Morrison, J., Kirby M., Kaczan, D., King, D., Pickett, T., Overton, I., Pettit, C. (2007). Lower Murray Landscape Futures River Corridor Component. Final Report. Volume 5 - Futures Modelling Methods and Data. Policy and Economic Research Unit, CSIRO Land and Water. Available at http://www.landscapefutures.com.au/publications.html Client Report

- Connor, J.D., Banerjee, O., Kandulu, J., Bark, R.H. and King, D. (2011). Socioeconomic implications of the Guide to the proposed Basin Plan – methods and results overview. Goyder Institute for Water Research Technical Report Series No. 11/3, Adelaide.

- Crossman, N.D. Summers, D.M. and Bryan, B. (2010). Opportunities and threats for South Australian agricultural landscapes from reforestation under a carbon market. CSIRO client report.

- CSIRO (2008). Water availability in the Murray-Darling Basin. A report from CSIRO to the Australian Government. Canberra, CSIRO.

- EBC et al. (2011). EBC, RMCG, Marsden Jacob Associates, EconSearch, G. McLeod, T. Cummins, G. Roth and D. Cornish, Community impacts of the Guide to the proposed Murray-Darling Basin Plan. Volume 1: Executive Summary. Report to the Murray-Darling Basin Authority, May.

- Hayman Peter, Thomas Dane, Alexander Bronya, and Nidumolu Uday (2011). Climate Change Scenarios Information. Milestone 2 Report. A report prepared by prepared by SARDI Climate Applications for The Environment Institute, The University of Adelaide, as part of the Strengthening basin communities program – Planning Component Consultancy SBC033A.1/2, 48 pages.

- Kellett, Bart M. (2010). Options for farmers to adapt to change in the Riverland of South Australia. Executive Summary Report. University of Adelaide, Environment Institute, Landscape Futures Program, 11 pages.

- Kellett , Bart M. and Banerjee, Onil (2010) Reconfiguration scenarios and data needs. Executive Summary Report. University of Adelaide, Environment Institute, Landscape Futures Program, 11 pages.

- Kellett, B., Summers, D., Barnett, K., Siebentritt, M., Meyer, W., Spoehr, J. (2011). Adaptation and emerging opportunities for the SA Murray-Darling region. Milestone 2 Report. A report prepared by SARDI Climate Applications for The Environment Institute, The University of Adelaide, as part of the Strengthening basin communities program – Planning Component Consultancy SBC033A.1/2, 54 pages.

- Kellett, B. (2010) Developing Landholder Capacity to adapt to Climate Risks and Variable Resource Availability in the Bookpurnong and Pyap to Kingston On Murray Regions of the Riverland South Australia Options for farmers to adapt to change in the Riverland of South Australia. Executive Summary Report. The Environment Institute, The University of Adelaide.

- Kellett, B. (2010) Developing landholder capacity to adapt to climate risks and variable resource availability in the Loxton to Bookpurnong and Pyap to Kingston on Murray Regions of the Riverland SA. Executive Summary Report. Reconfiguration scenarios and data needs.The Environment Institute, The University of Adelaide. Onil Banerjee CSIRO.

- Lucy, Schapel (2011) Climate Change, Communities and Environment (SA Murray-Darling Basin) Planning for Outcomes – short term and long term. Report from Rural Solutions, 24 pages.

- Lucy, Schapel (2010). Climate Change, Communities and Environment Research Project (Eyre Peninsula NRM Region): Plan for Outcomes and Key Actions. Report from Rural Solutions SA, 26 pages.

- Lyle, Greg (2010). Eyre Peninsula Spatial Datasets. The University of Adelaide, Environment Institute, Landscape Futures Program, 33 pages.

- Lyle, G. (March 2011). Eyre Peninsula Climate Regionalisation. The University of Adelaide, Environment Institute, Landscape Futures Program, 34 pages.

- Meyer, W., Siebentritt, M., Hayman, P., Alexander, B., Kellett, B., Summers, D., Bryan, B., Connor, J., Spoehr, J., Sharma, V., Sharley, T. and Lyle, G. (2010). Climate change impact assessment, adaptation and emerging opportunities for the SA Murray-Darling basin. Literature Review. Milestone 1 Report. A report prepared by The Environment Institute, The

University of Adelaide, as part of the Strengthening basin communities program – Planning Component Consultancy SBC033A.1/2, 68 pages.

- Meyer, Wayne S. (2010). Building research capability to identify climate change vulnerability and adaptation options for South Australian landscapes. Year 1 Report. The University of Adelaide, Environment Institute, Landscape Futures Program, 7 pages.
- Meyer, Wayne S. (2011). Building research capability to identify climate change vulnerability and adaptation options for South Australian landscapes. Year 2 Report. The University of Adelaide, Environment Institute, Landscape Futures Program, 10 pages.
- Meyer, Wayne S.(2012). Building research capability to identify climate change vulnerability and adaptation options for South Australian landscapes. The Premiers Science Research Fund Final Report. The Environment Institute, The University of Adelaide, ? pages.
- Meyer, W., Bryan, B., Summers, D., Lyle, G., Crossman, N., Moon, T., Gonzales, R., Turner, D., Hayman, P., Lewis, M. (2012). Climate Change, Community and Environment: Technical Report (with an emphasis on Eyre Peninsula), 246 pages.
- Siebentritt, M.A. and Sharley, T. (2011). Outcomes of Stakeholder Engagement. Milestone 2 Report. A report prepared by SARDI Climate Applications for The Environment Institute, The University of Adelaide, as part of the Strengthening basin communities program – Planning Component Consultancy SBC033A.1/2, 59 pages.
- Siebentritt, M., Meyer, W. And Spoehr, J. (2011). Adaptation and Emerging Opportunities plan for the SA Murray-Darling region. Milestone 4 Report. A report prepared by The Environment Institute, The University of Adelaide, as part of the Strengthening basin communities program – Planning Component Consultancy SBC033A.1/2, 70 pages.
- Summers, David and Lyle, Greg. (2010). South Australian Murray Darling Basin NRM Region Datasets. University of Adelaide, Environment Institute, Landscape Futures Program, 16 pages.
- Summers, D., Siebentritt, M., Sharley, T., Meyer, W., Bryan, B., Connor, J. and Spoehr, J. 2011. Climate change impact assessment report for the SA marray-darling region. Milestone 3 report, A report prepared by The Environment Institute, The University of Adelaide, as part of the Strengthening basin communities program – Planning Component Consultancy SBC033A.1/2, 57 pages.

Conference Presentations

- Bryan, B., Meyer, W. and Summers, D. (2009). Climate change vulnerability and adaptation options for southern Australian landscapes. *In:* Spatial Diversity: Surveying & Spatial Sciences Institute Biennial International Conference, 28 September - 2 October 2009. Adelaide, South Australia.

- Foster, B. (2012). Title of paper. *In:* Planet under Pressure: New Knowledge towards Solutions, 26th -29th March, 2012, London, U.K.

- Hayman, P.T. and McCarthy, M.G. (2010). Irrigation and drought in a southern Australian climate that is arid, variable and changing. *In:* International Drought Symposium, May 2010. Water Science and Policy Centre, University of California, Riverside.

- Lyle, G. (2012). NRM – land use and sustainable agricultural production. Paper and oral presentation as an invited speaker for the SPAA Precision Agriculture Australia Expo, 15th February 2012. Port Lincoln, Eyre Peninsula, South Australia.

- Meyer, W., Bryan, B., Fisher, A., Crossman, N. & Lewis, M. (2009). Applying landscape science to natural resource management. *In:* SSSI Conference, Place & Purpose Symposium, Sept/Oct 2009. Adelaide, South Australia .

- Siebentritt, M., Meyer, W. And Spoehr, J. 2012. Climate Change impact assessment, adaptation and emerging opportunities for the SA Murray-Darling region. *In:* Climate Adaptation in Action 2012: Sharing Knowledge to Adapt, 26-28 June 2012. National Climate Change Adaptation Research Facility, Melbourne, Victoria.

- Summers, D., Bryan, B., Crossman, N. D. and Meyer, W. 2012. Conservation planning and vulnerable species. *In:* Climate Adaptation in Action 2012: Sharing Knowledge to Adapt, 26-28 June 2012. National Climate Change Adaptation Research Facility, Melbourne, Victoria.

- Summers, D., Crossman, N. D. and Bryan, B. 2010. Modelling tools to better target priority area. *In:* NRM Authorised Officer Conference, 7-8 June 2010. Adelaide, South Australia.

Brochures and Articles

- Kellett, Bart M. and Meyer, Wayne S. (2010) Lower Murray Landscape Futures Project (www.landscapefutures.com.au) KEY MESSAGES. University of Adelaide, Environment Institute, Landscape Futures Program, 2 pages.

- Meyer, Wayne S. (2009). Climate Change, Communities and Environment: Building research capability to identify climate change vulnerability and adaptation options for South Australian landscapes. PREMIER'S SCIENCE AND RESEARCH FUND 2009, 1 page.

- Meyer, Wayne S. and Bryan, Brett (2011). Productive and healthy landscapes for a changing environment. Submitted to SA NRM Newsletter.

- Wahlquist, A. (2011). Agricultural landscapes for a changing environment. ECOS, Issue 141, 4 July 2011.

- Wahlquist, A. (2011) Science helps SA farm communities adapt to change. ECOS Issue 161, 4 July 2011.

Website and Podcasts

- Environment Institute: Landscape Futures Program - website
  http://www.adelaide.edu.au/environment/lfp/

- Landscape Science Cluster - website
  http://landscapescience.org/
  Climate Change, Community and Environment is listed under "Projects".

- Project Launch (2009) - available on podcast
  http://www.adelaide.edu.au/environment/lfp/news/2009/psrf-launch.html

- Place and Purpose Symposium (2009) - key papers available on podcast
  http://www.adelaide.edu.au/environment/lfp/news/2009/pandp/run.html

- Eyre Peninsula Inaugural meeting (2009) - presentations available online at
  http://landscapescience.org/index.php?id=38

- SA MDB Inaugural meeting (2009) - presentations available online at
  http://landscapescience.org/index.php?id=39

Appendix 3: Meetings, Consultations, Presentations and Workshops

General

- 26 Sep - 2 Oct 2009 – Brett Bryan presented at 'Spatial Diversity', the Surveying and Spatial Sciences Institute Biennial International Conference, held in Adelaide.
- 22 Oct 2009 - The Premier's Science and Research Fund - Climate Change, Communities and Environment research project was officially launched in Adelaide.
  Podcasts of this event can be downloaded at
  http://www.adelaide.edu.au/environment/lfp/news/2009/psrf-launch.html
- 30 Sep – 1 Oct 2009 - Convening of the Place and Purpose Symposium as part of the Surveying and Spatial Science Institutes (SSSI) biennial conference held in Adelaide in October 2009. The partners in this project, through the Landscape Science Cluster organised the Symposium at which three papers highlighting the foundational concepts and work we presented to a National audience. Podcasts of some of the key papers can be downloaded at http://www.adelaide.edu.au/environment/lfp/news/2009/pandp/run.html
- 18 Dec 2009 – Initial meeting of the Advisory Group
- 15 Mar 2010 – 2nd Advisory Group meeting
- 14-16 Mar 2010 – P. Hayman and M. Mc Carthy gave a presentation at the International Drought Symposium, Water Science and Policy Centre, University of California
- 7-8 June 2010 – Dave Summers presented at 'Modelling tools to better target priority area', the NRM Authorised Officer Conference, held in Adelaide
- 26 Jul 2010 – 3rd Advisory Group meeting
- 21 Feb 2011 – 4th Advisory Group meeting
- 18 Jul 2011 – 5th Advisory Group meeting
- 7-11 Nov 2011 - Transformational change of regional landscapes: Navigating planetary limits and resource constraints over the next five decades. ACEAS workshop, Byron Bay, NSW.
- 21 Nov 2011 - 6th Advisory Group meeting
- 26 -29 Mar 2012, Brian Foster presented at 'Planet under Pressure: New Knowledge towards Solutions', held in London, U.K.
- 16 – 19 April 2012 – National NRM Knowledge Conference, Adelaide
- 23 Apr 2012 - 7th Advisory Group meeting
- 4 Jun 2012 - PSRF Final Report workshop
- 18 Jun 2012 - 8th Advisory Group meeting

- 26-28 June 2012 - Dave Summers and Mark Siebentritt both presented at the ‘Climate Adaptation in Action 2012: Sharing Knowledge to Adapt’ conference, at the National Climate Change Adaptation Research Facility, Melbourne
- TBA - 9th Advisory Group meeting. Final wrap-up

Eyre Peninsula NRM Region

- 24 Nov 2009 - An inaugural meeting and project establishment workshop were run on Eyre Peninsula. Contributions to this meeting are available on the Landscape Science Cluster web site http://landscapescience.org/index.php?id=38
- 24-26 Feb 2010 - A visit by Wayne Meyer, Greg Lyle and David Summers was made to Port Lincoln, where they met with EPNRM, DENR, and Rural Solutions SA staff
- With the retention of a Rural Solutions SA Officer (David Davenport) to act as a research officer for the project on Eyre Peninsula we had a program of raising the project profile and increasing regional industry links. In conjunction with the grower’s review meetings he introduced the growers to the concept and construct of the project.
- 16 Mar 2010 – Greg Lyle made a visit to a local meeting of far west growers involved with the Agricultural Advisory Board and Minnipa Agricultural Research Centre end of season review at Charra
- 20 Jul 2010 – Presentation to EP Climate Change Sector Agreement Committee Meeting
- 10 Aug 2010 – Presentation to grower meeting Cleve field day
- 16 Sep 2010 - Program logic meeting, Port Lincoln
- 18 Nov 2010 - Presentation to EP NRM Board Staff, North Shields, Port Lincoln
- 10 Feb 2011 – Project presentation to EP NRM Board, Port Lincoln
- Apr 2011 – Rodolphe met with stakeholders regarding social modelling
- 1 Sep 2011 – Meeting between the research team and EP NRM Board at Port Lincoln to help guide the CCCE project outputs to be most useful in EP regional planning
- 1-7 Nov 2011 – Rodolphe carried out social surveys with 15 stakeholders on Eyre Peninsula
- Nov 2011-2012 – Rodolphe continued with online surveys
- Nov 2011 - Greg talked with Minnipa group who gave more yield data information from the upper EP
- 15 Feb 2012 – Greg Lyle presented gave an oral presentation as an invited speaker for the SPAA Precision Agriculture Australia Expo in Port Lincoln
- Mar 2012 – Dave Davenport met with farmers to validate wheat yield figures from APSIM modelling

- Associated with a series of forums held to launch the Future Farm Landscape program on the Eyre Peninsula, Wayne Meyer held three meetings incorporating updates on modelling
  - 19 Mar 2012 at Cleve
  - 20 Mar 2012 Streaky Bay
  - 21 Mar 2012 Cummins
- April 2012 – Validation of ASPIM Crop Modelling and Soil Characterisation through Dave Davenport who talked to growers and consultants to see if the actual model is how they expected it

SA MDB NRM Region

- 26 Nov 2009 - An inaugural meeting and project establishment workshop were run in the SA MDB region. Contributions to this meeting are available on the Landscape Science Cluster web site http://landscapescience.org/index.php?id=39
- 15 Apr 2010 - SBC Steering Committee meeting, Murray Bridge Council Office
- 20 Apr 2010 – (SA MDB) SBC - CCAP project inception meeting, Karoonda Local Government Office
- 12 May 2010 – Meeting with community and SA MDB NRM Board, Berri
- 23 May 2010 – Meeting with community and SA MDB NRM Board, Berri
- 2 Jul 2010 - SBC Steering Committee meeting, Murray Bridge Council Office
- 23 Jul 2010 – Meeting with community and SA MDB NRM Board, Berri
- 19 Aug 2010 – Carbon Forum, Murray Bridge
- Sep 2010 - Survey #1 – Introductory survey (September 2010) – the 17 Consultation Reference Panel (CRP) members were given no reading material prior to the survey which was conducted in person with either 1 or 2 members of the project team taking 1-1.5 hours per interview. The aim of this survey was to understand ingoing awareness. Held at each person’s office or local town
- 1 Sep 2010 - Briefing of SBC Integrated Water Management Plan consultants, Adelaide
- Oct 2010 - Survey #2 – Conditioned responses – CRP members were given two documents for background reading prior to conducting an online survey. The documents were the Milestone 1 report from the project team and the summary of survey #1. The purpose of this survey was to further explore issues raised during the first survey after having provided the CRP members with more information about the potential impacts of climate change as well as adaptation measures and opportunities. Phone based survey.
- Nov 2010 - Meeting of the CRP. The purpose of the meeting was to provide an opportunity to further explore specific issues that had been raised in either survey 1 or 2, but in a group

format which provided the opportunity for discussion and exchange of views amongst CRP members. Held at the Karoonda Football Club

- 4 Nov 2010 – Meeting with SA MDB NRM Board
- 10 Nov 2010 - Local Government planners forum, Murray Bridge NRM Centre
- 16 Nov 2010 - Bookpurnong to Lock 4 Land & Water Management Planning Group, Loxton Hotel
- 17 Nov 2010 - Pyap to Kingston Land & Water Management Planning Group, Moorook Bowling Club
- 2 Feb 2011 - Program logic meeting for the SA MDB NRM region, Waite Campus, Adelaide
- 7 Apr 2011 - SA MDB NRM Board's Mayors' Forum
- Adaptation and Emerging Opportunities Plan Workshops
    - 13 Oct 2011 - Murray Bridge - Tourism, renewable energy, industry and manufacturing
    - 14 Oct 2011 – Loxton - Primary production- sustaining irrigated horticulture and dryland farming including diversification
- Nov 2011 - A show-and-tell was given in Berri of the user interface of the ILSA optimisation modelling tool, which is available at http://www.fieldobs.com.au:8081/ils/
- A consultative group set up in the SA MDB NRM region associated with the SBC – CCAP project has been particularly helpful in providing a wide range of views and perceptions about climate change and its effects from land holders and special interest groups.

Appendix 4: Program Logic

Figure A4-1: Program Logic flow diagram – Eyre Peninsula NRM Region

Source: (Lucy, 2010)

See next page

Figure A4-2: Program Logic flow diagram – SA MDB NRM Region

Source: (Lucy, 2011)

See page after next

Figure A4-1: Climate Change, Communities and Environment Research Project – Eyre Peninsula NRM Region

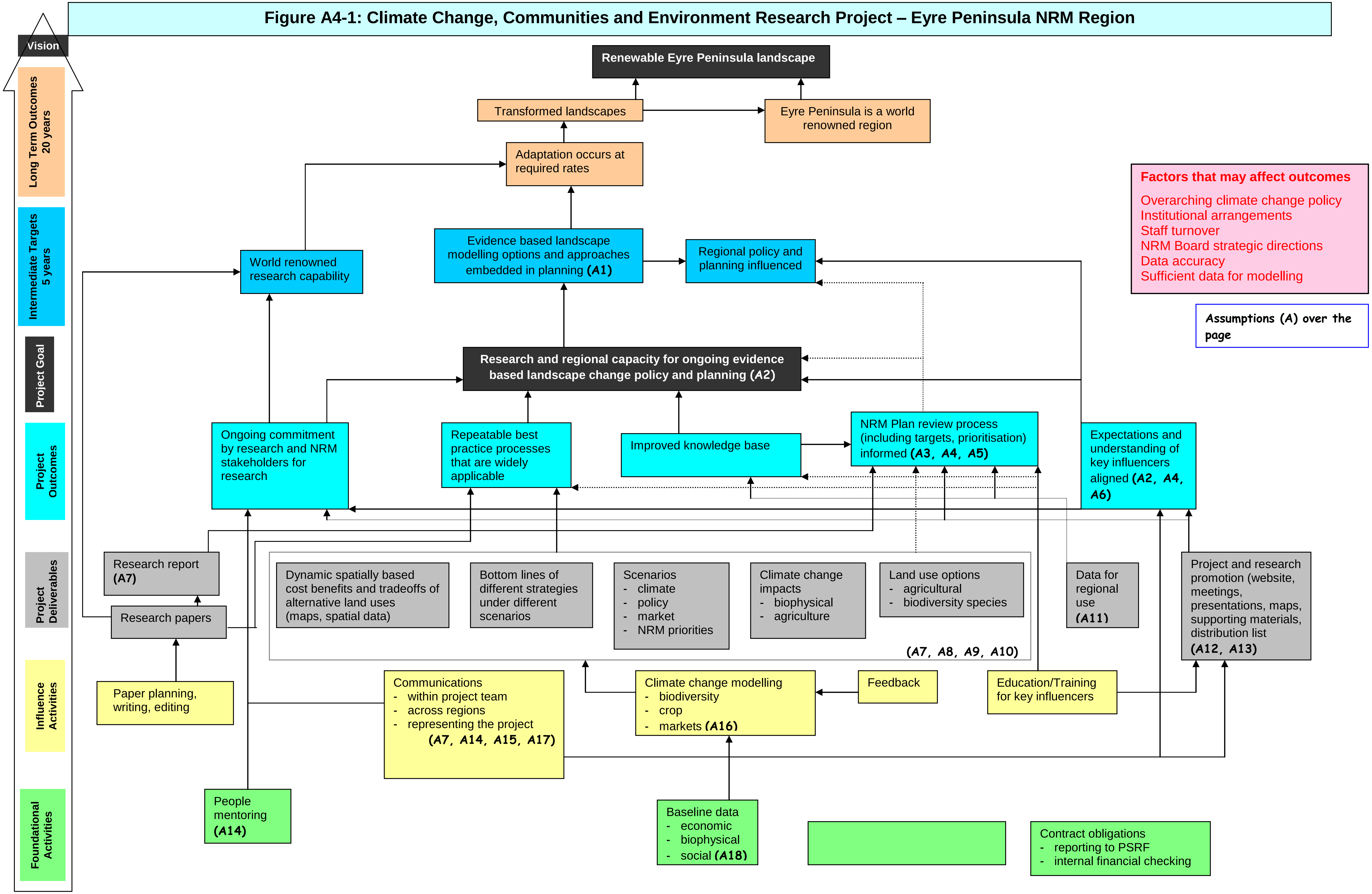
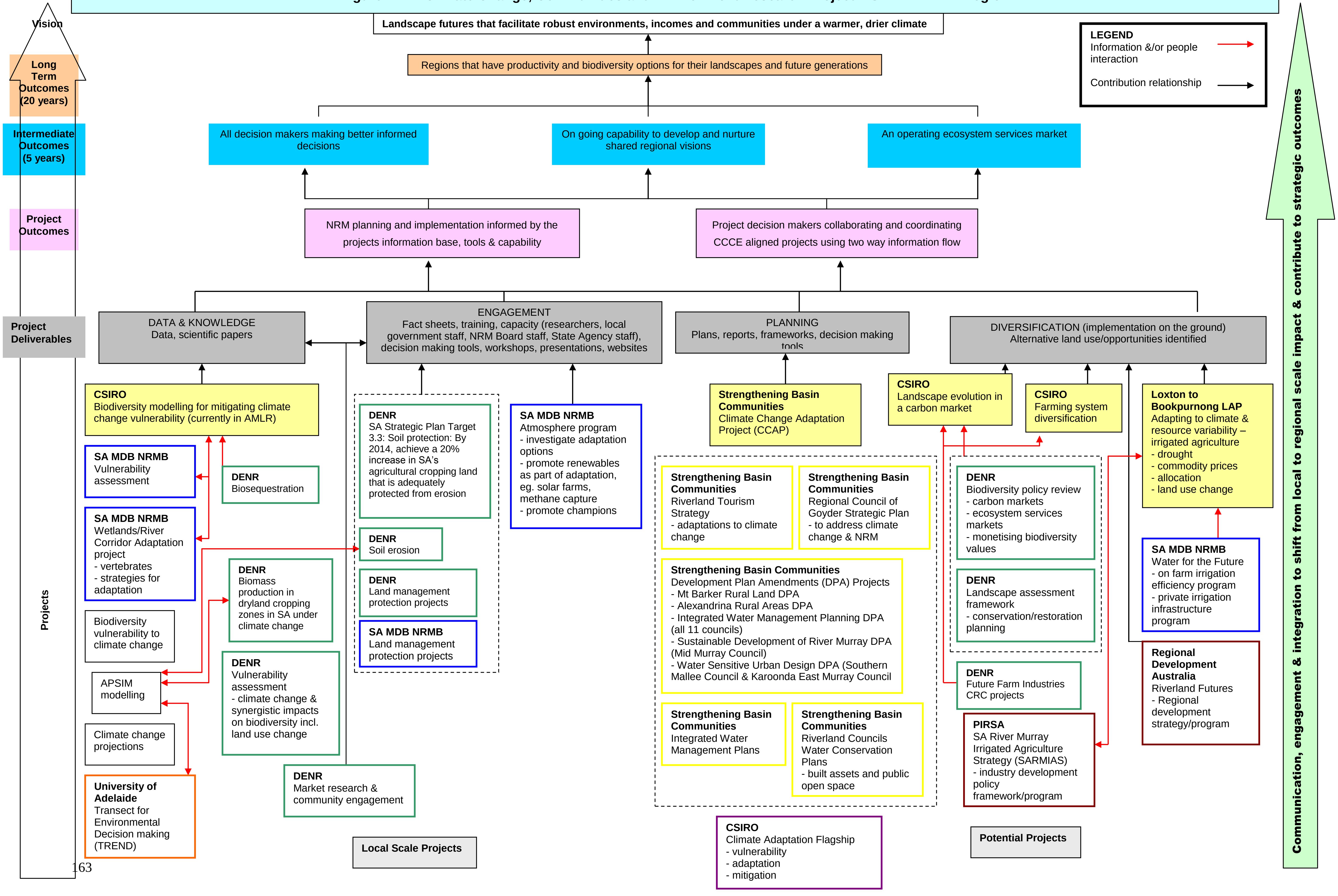


Figure A4-2: Climate Change, Communities and Environment Research Project – SA MDB NRM Region



Vision

Landscape futures that facilitate robust environments, incomes and communities under a warmer, drier climate

Long Term Outcomes (20 years)

Regions that have productivity and biodiversity options for their landscapes and future generations

Intermediate Outcomes (5 years)

All decision makers making better informed decisions

On going capability to develop and nurture shared regional visions

An operating ecosystem services market

Project Outcomes

NRM planning and implementation informed by the projects information base, tools & capability

Project decision makers collaborating and coordinating CCCE aligned projects using two way information flow

Project Deliverables

DATA & KNOWLEDGE
Data, scientific papers

ENGAGEMENT
Fact sheets, training, capacity (researchers, local government staff, NRM Board staff, State Agency staff), decision making tools, workshops, presentations, websites

PLANNING
Plans, reports, frameworks, decision making tools

DIVERSIFICATION (implementation on the ground)
Alternative land use/opportunities identified

Projects

CSIRO
Biodiversity modelling for mitigating climate change vulnerability (currently in AMLR)

SA MDB NRMB
Vulnerability assessment

DENR
Biosequestration

SA MDB NRMB
Wetlands/River Corridor Adaptation project
- vertebrates
- strategies for adaptation

Biodiversity vulnerability to climate change

APSIM modelling

Climate change projections

University of Adelaide
Transect for Environmental Decision making (TREND)

DENR
Biomass production in dryland cropping zones in SA under climate change

DENR
Vulnerability assessment
- climate change & synergistic impacts on biodiversity incl. land use change

DENR
Market research & community engagement

DENR
SA Strategic Plan Target 3.3: Soil protection: By 2014, achieve a 20% increase in SA's agricultural cropping land that is adequately protected from erosion

DENR
Soil erosion

DENR
Land management protection projects

SA MDB NRMB
Land management protection projects

SA MDB NRMB
Atmosphere program
- investigate adaptation options
- promote renewables as part of adaptation, eg. solar farms, methane capture
- promote champions

Local Scale Projects

Strengthening Basin Communities
Climate Change Adaptation Project (CCAP)

Strengthening Basin Communities
Riverland Tourism Strategy
- adaptations to climate change

Strengthening Basin Communities
Regional Council of Goyder Strategic Plan
- to address climate change & NRM

Strengthening Basin Communities
Development Plan Amendments (DPA) Projects
- Mt Barker Rural Land DPA
- Alexandrina Rural Areas DPA
- Integrated Water Management Planning DPA (all 11 councils)
- Sustainable Development of River Murray DPA (Mid Murray Council)
- Water Sensitive Urban Design DPA (Southern Mallee Council & Karoonda East Murray Council

Strengthening Basin Communities
Integrated Water Management Plans

Strengthening Basin Communities
Riverland Councils Water Conservation Plans
- built assets and public open space

CSIRO
Climate Adaptation Flagship
- vulnerability
- adaptation
- mitigation

CSIRO
Landscape evolution in a carbon market

CSIRO
Farming system diversification

DENR
Biodiversity policy review
- carbon markets
- ecosystem services markets
- monetising biodiversity values

DENR
Landscape assessment framework
- conservation/restoration planning

DENR
Future Farm Industries CRC projects

PIRSA
SA River Murray Irrigated Agriculture Strategy (SARMIAS)
- industry development policy framework/program

Potential Projects

Loxton to Bookpurnong LAP
Adapting to climate & resource variability – irrigated agriculture
- drought
- commodity prices
- allocation
- land use change

SA MDB NRMB
Water for the Future
- on farm irrigation efficiency program
- private irrigation infrastructure program

Regional Development Australia
Riverland Futures
- Regional development strategy/program

LEGEND
Information &/or people interaction →
Contribution relationship →

Communication, engagement & integration to shift from local to regional scale impact & contribute to strategic outcomes

Table A4-1: Assumptions and factors for the CCCE research project – Eyre Peninsula NRM Region
Source: (Lucy, 2010)

Assumptions	
A1	We can optimise a landscape
A2	Aligning expectations and understanding will embed landscape modelling in planning
A3	Land use change will occur without a crisis – that is we change before we absolutely have to
A4	There is sufficient capacity in the regional community to address the topic
A5	There will be economic drivers for change
A6	Stakeholder expectations can be managed
A7	The research project can effectively communicate its findings
A8	Cost benefits and tradeoffs, scenarios and climate impacts can be developed and presented in a way that is useful to policy and planning
A9	Scenarios recognise component (climate, policy, market, NRM priorities) realities
A10	Change to world markets for resource needs
A11	Meaningful data is produced for decision making
A12	NRM Board and other research project stakeholders really want to promote transformational land use
A13	Communicating will align expectations and understanding
A14	We have the right expertise delivering the project
A15	Key stakeholders will take time to listen/engage
A16	Modelling assumptions are representative of economic, biophysical and social components
A17	Stakeholders are actually interested
A18	We have sufficient rigorous data to drive models
Factors (internal and external)	
Overarching climate change policy	
Institutional arrangements	
NRM Board strategic directions	
Data accuracy	
Sufficient data for modelling	
Staff turnover	

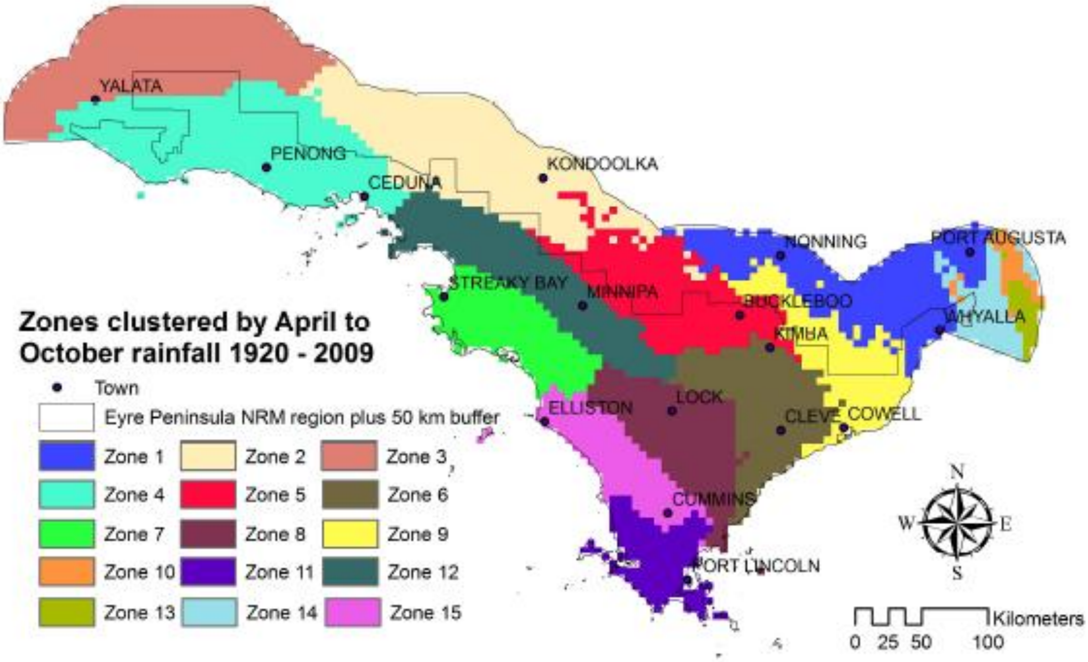
Assumptions are expectations. They are based on current knowledge and experience about what is important for a project to succeed. Internal and external factors can hinder the project from proceeding as planned. Both are inherent in the CCCE research project and key assumptions and factors have been identified and listed above (Table A4-1). These can be monitored and managed for the project to be successful in achieving its outcomes. The assumptions and factors are also recorded as part of the program logic (refer Figure A4-1).

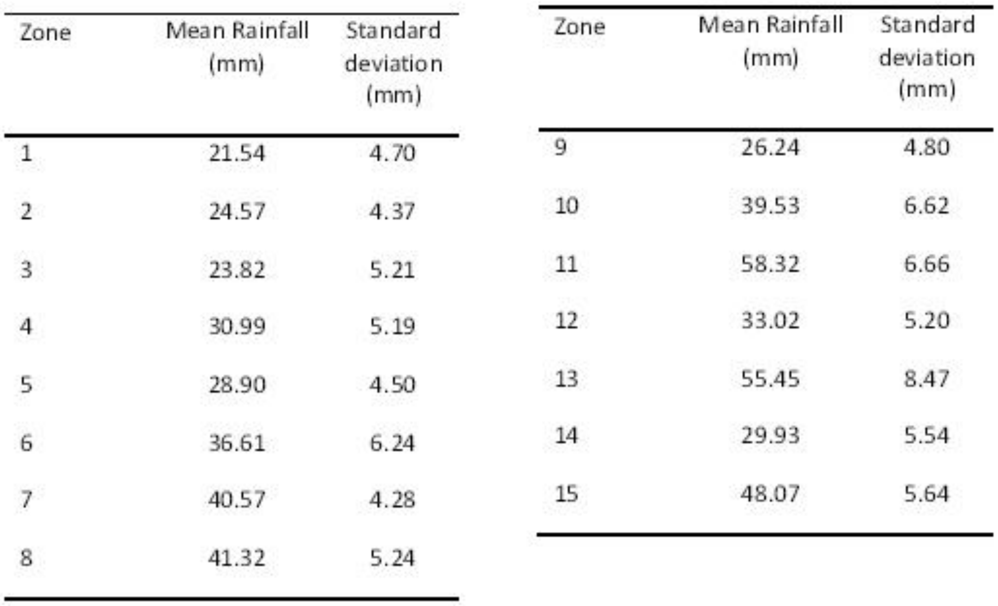
Table A4-2: Assumptions and factors for the CCCE research project – SA MDB NRM Region

Source: (Lucy, 2011)

Assumptions	
A1	Key stakeholders will take time to listen/engage – relevant for projects with engagement
A2	Land managers seek/require information on land management changes required to manage climate change – relevant for projects increasing awareness/knowledge of land managers
A3	There is sufficient capacity in the regional community to address the topic – relevant for projects working with community
A4	We have sufficient rigorous data to drive models - relevant for modelling exercises in projects
A5	Modelling assumptions are representative of economic, biophysical and social components – relevant for modelling based projects/activities
A6	The CCCE (SA MDB) research project is integrated with other initiatives/organisations across the region – relevant for the CCCE (SA MDB) research project umbrella
A7	Information on the impacts of climate change to primary production and changes to land class can be collected and collated – relevant for projects identifying alternative land use/opportunities
A8	Meaningful data is produced for decision making - relevant for projects creating data/information & projects aiming to inform decision making processes
A9	Data & knowledge in a format meaningful for stakeholder decision making – relevant for projects delivering data and knowledge deliverables
A10	Cost benefits and tradeoffs, scenarios and climate impacts can be developed and presented in a way that is useful to policy and planning - relevant for projects aiming to inform decision making processes
A11	We have the right expertise delivering the project – relevant for the CCCE (SA MDB) research project umbrella
A12	The research project can effectively communicate its findings – relevant for project outcomes
A13	Information and demonstration sites relating to climate change adaptation will result in changes to land management practices – relevant for project outcomes
A14	Land use change will occur without a crisis, i.e. is we change before we absolutely have to – relevant for projects identifying alternative land use/opportunities, intermediate and long term outcomes
A15	The NRM Board and other research project stakeholders really want to promote transformational land use – relevant for projects identifying alternative land use/opportunities, intermediate and long term outcomes
A16	There are key strategies for an ecologically & economically diverse region – relevant for projects identifying alternative land use/opportunities, intermediate and long term outcomes
A17	The project can influence ecosystem services market development - relevant for intermediate outcomes
A18	Decision makers understand implications of risk, tradeoffs & public responsibility – relevant for intermediate outcomes
A19	There will be economic drivers for change – relevant for relevant for projects identifying alternative land use/opportunities, intermediate and long term outcomes
A20	There is capability to develop and sustain a regional vision – relevant for intermediate outcomes
A21	Planning and implementation frameworks support a building and maintaining a diverse region – relevant for long term outcomes
A22	We can optimise a landscape – relevant for the vision

Appendix 5: APSIM Modelling: Technical Report





Zone	Mean Rainfall (mm)	Standard deviation (mm)
1	21.54	4.70
2	24.57	4.37
3	23.82	5.21
4	30.99	5.19
5	28.90	4.50
6	36.61	6.24
7	40.57	4.28
8	41.32	5.24

Zone	Mean Rainfall (mm)	Standard deviation (mm)
9	26.24	4.80
10	39.53	6.62
11	58.32	6.66
12	33.02	5.20
13	55.45	8.47
14	29.93	5.54
15	48.07	5.64

Figure A5-1: Rainfall cluster zones in Eyre Peninsula NRM region plus a 50 km inland buffer
Cluster zones and the associated mean rainfall and standard deviation (SD) for
the aggregated dataset - April to October rainfall over the 1920 to 2009 time period

Put in ascending order and colour code for low, medium, high?

Below is the summary of soil attributes from South Australian State Land and Soil Information Framework' generated from the South Australian State Land and Soil mapping program (Hall et al., 2009).

Cona and U values by soil texture used in the APSIM model;

Soil texture	Description	Cona	U
A	More than 60% sand	2.00	2.00
AF	More than 30% sand	2.18	2.36
B	More than 60% loamy sand	2.45	2.91
C	More than 60% sandy loam	2.73	3.45
CC	More than 30% sandy loam - Coarser	3.09	4.18
CF	More than 30% sandy loam - Finer	3.18	4.36
D	More than 60% loam	3.27	4.55
E	More than 60% sandy clay loam	3.36	4.73
EC	More than 30% sandy clay laom	3.82	5.64
F	More than 60% clay loam	3.91	5.82
FC	More than 30% clay loam	4	6

Table XX Initial nitrogen and ammonium values (kg/ha) across rainfall zones, rooting depth and texture variables

		Nitrogen (kg/ha)						Ammonium (kg/ha)					
		Texture						Texture					
Rainfall zone	Root Depth (cm)	More than 60% sand	More than 60% loamy sand	More than 60% sandy loam	More than 60% loam	More than 60% sandy clay loam	More than 60% clay loam	More than 60% sand	More than 60% loamy sand	More than 60% sandy loam	More than 60% loam	More than 60% sandy clay loam	More than 60% clay loam
Low	0-100	32	36	42	50	58	58	10.56	11.88	13.86	16.5	19.14	19.14
Medium	0-100	42	48	58	62	64	64	13.86	15.84	19.14	20.46	21.12	21.12
High	0-100	48	54	64	74	82	82	15.84	17.82	21.12	24.42	27.06	27.06
Low	0-60	24	28	34	40	46	46	7.92	9.24	11.22	13.2	15.18	15.18
Medium	0-60	32	38	45	50	52	54	10.56	12.54	14.85	16.5	17.16	17.82
High	0-60	40	46	54	62	70	80	13.2	15.18	17.82	20.46	23.1	26.4
Low	0-40	16	20	24	28	32	34	5.28	6.6	7.92	9.24	10.56	11.22
Medium	0-40	30	32	36	38	44	48	9.9	10.56	11.88	12.54	14.52	15.84
High	0-40	36	42	48	54	60	66	11.88	13.86	15.84	17.82	19.8	21.78
Low	0-20	12	14	16	20	24	24	3.96	4.62	5.28	6.6	7.92	7.92
Medium	0-20	16	18	22	26	30	32	5.28	5.94	7.26	8.58	9.9	10.56
High	0-20	24	28	32	36	40	44	7.92	9.24	10.56	11.88	13.2	14.52

Table XX Values of applied nitrogen (kg/ha) at sowing and at certain phenological stage (Zaddock stage 30-32) for the low, medium and high rainfall zone

Rainfall Zone	Nitrogen at Sowing (kg/ha)	Nitrogen at Zaddock stage 30-32 (kg/ha)
Low	10	0
Medium	13	12
High	16	34

Soil Group and sub groups ‘soils’

The soils of the Eyre Peninsula can be categorised into 333 groups form the South Australian State Land and Soil Information Framework. These classifications are based on over 28,000 (conducted according to McDonald et al., 1990))individual soil profiles. Profile descriptions were used as a basis for developing the central concepts of group and sub groups and included information on profile, site and landform descriptions as well as limited chemical analyses of selected samples. A strong knowledge of soil behaviour, limitations and potential across this area assisted the development of these categories (Hall, et al., 2009)

Soil data sheets were available for each soil characterisation site. These include soil profile and landscape photographs, soil profile descriptions, details chemical analysis of each soil layer and interpretations of these in terms of natural resource management and land use and management limitation and potential.

The South Australian system of soil categorisation was constructed so that there would be sufficient classes to enable meaningful description between different soils. Of the 61 sub groups defined for the SA agricultural region, 33 were evident across the Eyre Peninsula. This system of categorisation is a simple way of arranging SA soils in terms of their most significant profile features. Individual soil profiles encompassed by a soil concept are not identical, but fall within a specified range of variation. However, as expected, some soil profiles fit the relevant central concept better than others.

Soil Classification	Description
A	**Calcareous soils**
A1	Highly calcareous sandy loam
A2	Calcareous loam on rock
A3	Moderately calcareous loam
A4	Calcareous loam
A5	Calcareous loam on clay
A6	Calcareous gradational clay loam
A8	Gypseous calcareous loam
B	**Shallow soil on calcrete or limestone**
B1	Shallow highly calcareous sandy loam on calcrete
B2	Shallow calcareous loam on calcrete
B3	Shallow sandy loam on calcrete
C	**Gradational soils with highly calcareous lower subsoil**
C3	Friable gradational clay loam
C4	Hard gradational clay loam
D	**Hard red-brown texture-contrast soils with alkaline subsoil**
D1	Loam over clay on rock
D2	Loam over red clay
D3	Loam over poorly structured red clay
D5	Hard loamy sand over red clay
D6	Ironestone gravelly sandy loam over red clay
F	**Deep loamy texture-contrast soils with brown or dark subsoil**
F1	Loam over brown or dark clay
F2	Sandy loam over poorly structured brown or dark clay
G	**Sand over clay soils**
G1	Sand over sandy clay loam
G2	Bleached sand over sandy clay loam
G3	Thick sand over clay
G4	Sand over poorly structured clay
H	**Deep sands**

H1	Carbonate sand
H2	Siliceous sand
H3	Bleached siliceous sand
J	**Ironstone soils**
J1	Ironstone soil with alkaline lower subsoil
J2	Ironstone soil
L	**Shallow soils on rock**
L1	Shallow soil on rock
M	**Deep uniform to gradational soils**
M2	Deep friable gradational clay loam
M3	Deep gravelly soil
M4	Deep hard gradational sandy loam
N	**Wet soils**
N2	Saline soil

Seven physical and chemical constraints

Average depth to hard pan and hard rock

Hardpan is cemented material in or below the soil. Calcrete is the most common, in the Eyre Peninsula. Depth to hard material is routinely measured during field survey where it occurs within a metre of the surface. Depth to hard rock defined as material too hard to dig with hand tools. Hard rock is basement or country rock which generally occurs at or near the surface for hilly country. Depths are defined for the range of soils occurring within a landscape map unit. Each soil landscape unit is categorised into six categories according to the estimated average depth to hardpan, on a proportional basis representing an average depth value only.

Legend category	Average depth to hard rock
A	More than 150cm
B	100-150cm
C	50-100cm
D	25-50cm
E	10-25cm
X	Not applicable

Legend category	Average depth to hardpan
A	More than 150cm
B	100-150cm
C	50-100cm
D	25-50cm
E	10-25cm
F	Less than 10cm
X	Not applicable

Acidity

Soil acidity varies across the landscape with management practices having a greater influence than soil type. However, there are broad trends across landscapes so the acidity assessment is intended to highlight land where acidity is or could become a significant problem. Assessments are based on an interpretation of soil landscape units. Soil landscape units are characterised into legend categories according to most acidic component provide that it makes up 30% of the area of the map unit. Categories account for surface ans subsoil acidity and surface buffering capacity (i.e. capacity of surface soil to resist acidification). Acidic soils have a PHcacl2 of 5.4 or less, or a PHh20 of 6.4 or less.

Legend category	Soil acidity	Surface buffering capacity
A	Negligible	Any
B	10-30% of soils acidic	Any
C	Surface soil only	Moderate to high
D	Surface soil only	Low
E	Surface and subsoil	Moderate to high
F	Surface and subsoil	Low
X	Not applicable	

Depth to sodium toxicity

Soils in the drier parts of southern Australia have very high levels of deep subsoil sodicity (exchangeable sodium percentages (ESP) exceeding 25) generally at depths of between 50 and 100cm, but sometimes shallower. Conditions associated with high pH moderate salinity and high boron concentrations. High levels of sodicity are toxic to the plant. Each soil landscape map unit assessed according to the estimated depth to toxic sodium concentration. Legend categories are determined by rating the most severely affected landscape component, provided it occupies at least 30% of the area of the soil landscape unit.

Legend category	Depth to ESP exceeding 25
A	None present or deeper than 100cm
B	50-100cm
C	25-50cm
D	10-25cm
E	Less than 10cm
X	Not applicable

Depth to toxic levels (15mg/kg) of boron (boron toxicity)

At high concentrations boron is toxic to plants. Because boron is slightly soluble, they are leached out of the root zone in higher rainfall areas, but in lower rainfall areas or on land where impermeable clay layers at depth prevent leaching, Boron concentrations can be high. Assessments are made from soil test results and extrapolation between similar soil materials and environments. Each soil landscape map unit is assessed according to the average estimated depth to toxic boron concentration.

Legend category	Depth to boron concentration exceeding 15mg/kg
A	None present or deeper than 100cm
B	50-100cm

C	25-50cm
D	10-25cm
E	Less than 10cm
X	Not Applicable

Proportion of land with high or moderate aluminum toxicity

Aluminium toxicity generally occurs in strongly acidic soils of the Eyre Peninsula. Plants vary in their susceptibility to aluminium toxicity. Toxicity can vary extensively with a soil landscape unit. Each map unit is categorised into generalised legend categories according to various proportions of high and moderate toxicity.

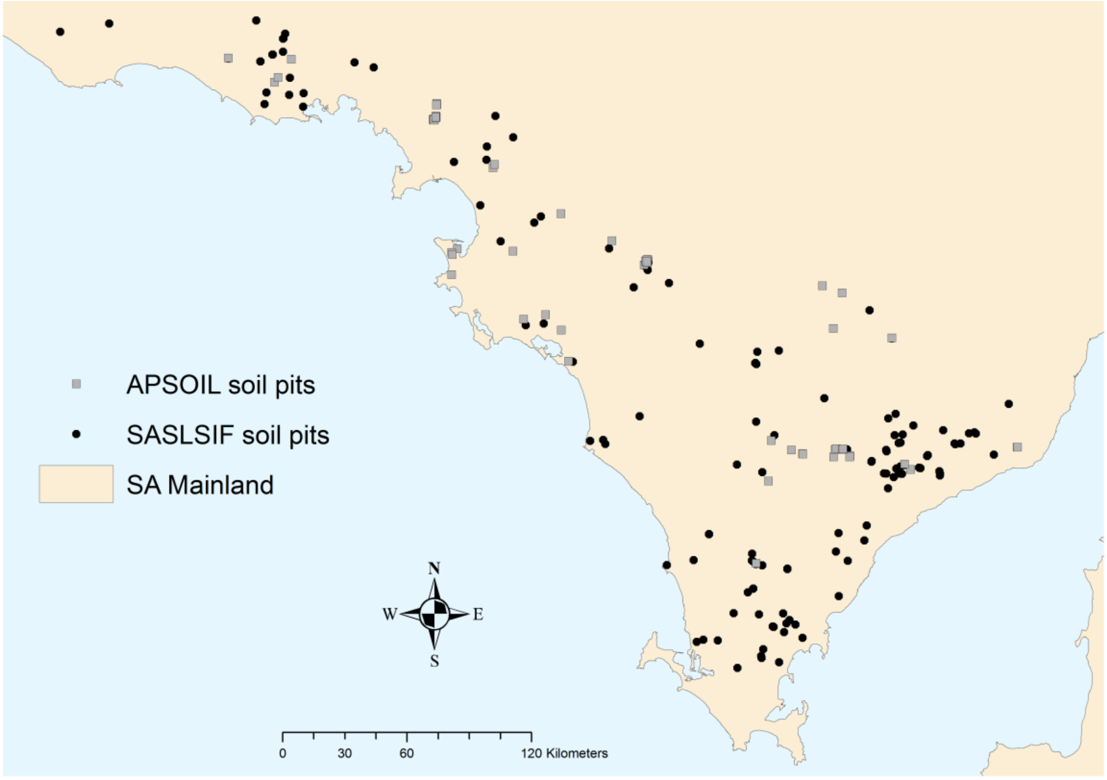
Legend category	Proportion of land with potentially high or moderate aluminium toxicity
A	Negligible to minor
B	10-30% moderately toxic and/or 1-10% highly toxic
C	30-60% moderately toxic
D	More than 60% moderately toxic
E	10-30% highly toxic
F	10-30% highly toxic and more than 60% moderately toxic
G	30-60% highly toxic
H	60-90% highly toxic
I	More than 90% highly toxic
X	Not applicable

Dry Saline Land

Dry saline land is classified according to the level of soil salinity, qualified where relevant with an estimate of the proportion of land affected by highly saline ‘magnesia’ patches.

Salinity category	Classification criteria (depth below surface)		Land class
	Indicative ECe (dS/m)	Vegetative indicators	
Low	Surface < 2 Subsoil<4	No apparent effects	1v
Moderately low	Surface 2-4 Subsoil 4-8	Some wheat yield depression but no vegetative indication	2v
Moderate	Surface 4-8 Subsoil 8-16	Halophytes usually evident	3v
Moderately high	Surface > 8 Subsoil > 16	Halophytes predominate	4v
High	Any	>50% bare (‘magnesia’) ground	7v

Spatial distribution of APSOIL and SASLSIF soil pits across the Eyre Peninsula



Available Water Holding Capacity

The effective depth of a soil, as determined by the physical and chemical constraints, together with the clay content of the soil within that depth, determine the water holding capacity of the profile and how much water is available. Available water holding capacity attribute classes are estimated from soil texture, structure and stone content within the potential root zone of a wheat plant. The features affecting AWHC vary substantially across the landscape and within soil landscape map units. Capacities are estimates for the characteristic soil of each map unit based on morphological properties, not laboratory analysis. Each soil landscape map unit is categorised into five legend categories according to the estimate average available water capacity of its soils, on a proportional basis.

Legend category	Average available water holding capacity

A	High	More than 100mm
B	Moderate	70-100mm
C	Moderate low	40-70mm
D	Low	20-40mm
E	Very low	<20mm
X	Not applicable	

Land is classified with respect to water holding capacity on the basis that yield potential decreases with decreasing storage capacity, all things being equal. Classes are based on estimates of the total AWHC of the root zone with wheat being used as the benchmark in this classification. Water storage capacity is not considered to be limiting if the available storage in the root zone is more than 100mm. Soils with less than 20mm capacity are not generally arabale under natural rainfall due to the poor capacity of the soil to supply sufficient water long enough for crops to mature.

Categories of Soil texture

Soil texture refers to the relative proportions of sand, silt, and clay size particles within the soil layer. Besides clay mineralogy, the content of clay-size particles is the most important determinant of soil behaviour. Texture values are based on grades given by McDonald et al., 1990. Base texture grades have been aggregated into 11 key classes for land and soil description, mapping and classification purposes in South Australia. Soil landscape map units are categorised into legend categories according to their most common surface texture where this accounts for less than 60% of the map unit, and a qualifier is in other cases to indicate whether the majority of other soils have coarser (more sandy) or finer (more clayey) textured surfaces.

Legend category	Dominant surface texture	Subdominant surface texture (mainly coarser or mainly finer)
A	More than 60% sand	
AF	More than 30% sand	Finer
B	More than 60% loamy sand	
C	More than 60% sandy loam	
CC	More than 30% sandy loam	Coarser

CF	More than 30% sandy loam	Finer
D	More than 60% loam	
E	More than 60% sandy clay loam	
EC	More than 30% sandy clay loam	Coarser
F	More than 60% clay loam	
FC	More than 30% clay loam	Coarser

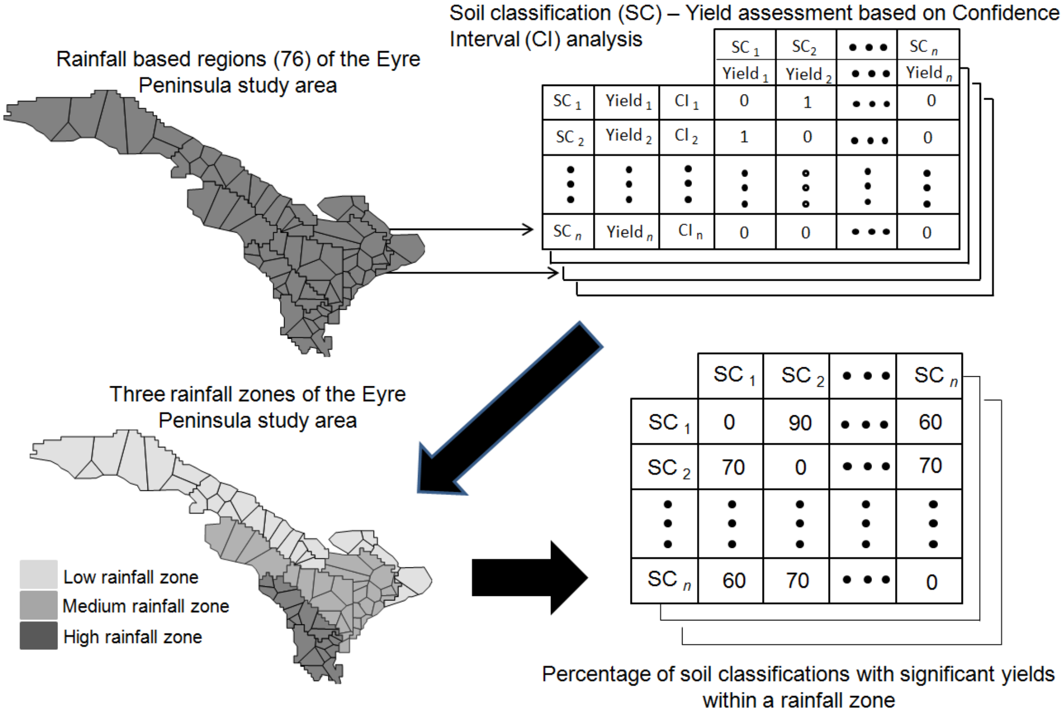
Yield comparisons

We test whether changing PAWC in defined rooting depth and texture characterisations produce statistically significant differences in simulated mean yields. Secondly we test whether changing rooting depth in defined PAWC and texture characterisations produce statistically significant differences in simulated mean yields. Thirdly, we test whether changing rooting depth and PAWC in defined texture characterisations produce statistically significant differences in simulated mean yields. Finally, we test whether within defined root zone depth and PAWC category does the texture classification produce statistically significant differences in simulated mean yields.

Comparison of soil characterisations

In order to reflect the variability of yield across a region we have typified for crop modelling purposes the potential soil types based on rooting depth, PAWC and texture through measured field observations. We expect that simulating yield for each of the 41 soil types would create different yield distributions due to these soil characterisation differences. If the yields simulated by crop modelling do not simulate different yield distributions then a range of specific field measurements may not be needed.

Figure X shows a two-step approach to determine if yields generated across the 41 soil characterisations are statistically significant. This approach is highlighted in the next two sections.



			SC_1 $Yield_1$	SC_2 $Yield_2$	• • •	SC_n $Yield_n$
SC_1	$Yield_1$	CI_1	0	1	• • •	0
SC_2	$Yield_2$	CI_2	1	0	• • •	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮
SC_n	$Yield_n$	CI_n	0	0	• • •	0

	SC_1	SC_2	• • •	SC_n
SC_1	0	90	• • •	60
SC_2	70	0	• • •	70
⋮	⋮	⋮	⋮	⋮
SC_n	60	70	• • •	0

Figure XX Two step approach to determine if simulated yields are statistically different. First Step involves a confidence interval analysis of the simulated yields for each rooting depth, plant available water capacity and texture category. The second step involves deriving the percentage of soil classification with significant yields within each rainfall zone.

Within region analysis

For each of the 76 regions, simulated wheat yields over 110 years for the 41 soil characteristics were sorted into their classified physical attributes of rooting depth, PAWC and texture (from “sand” to “clay loam”).

A matrix was created listing yield and its corresponding 95%confidence interval (alpha=0.05) calculated for each soil characterisation based on the standard deviation and number of years of simulation in the down the first vertical row elements. Yield values for each of the soil characterisations were listed within the column elements across the top of the matrix (Figure X). Element by element yields comparisons were made to test whether the simulated yield means come from the same population of values. This involved comparing the differences between the yield means relative to the size of their associated confidence intervals (Masson and Loftus, 2003—**add this reference**). Loftus and Masson , 1994 **add this reference** showed that two means will be significantly different by t-test if and only if the absolute difference between the means is at least as large as √2 multiplied by the confidence interval (CI), where CI is the 100(1-α)% confidence interval (Equation 1)

$$|\text{MEAN}_{\text{yield mean 1}} - \text{MEAN}_{\text{yield mean 2}}| > \sqrt{2}\ \text{X CI} \qquad (\textit{Equation 1})$$

Where differences fell outside the confidence interval a value of 1 was assigned to highlight that the yields differences between the two soil characterisation comparisons were statistically significant. A value of zero was assigned where non-significance occurred or where the same soils characteristics were compared along the matrix diagonal. The comparison across all 41 soil types within each rainfall region provides a statistical assessment of the yield differences between variations in root zone depths, PAWC values and texture categories. This provides evidence to determine the importance of breaking up the study region into a range of rooting depth, PAWC and texture soil attributes.

Across region comparison

Each regional yield assessment was assigned to their corresponding rainfall zone in order to compare regions with similar soil and crop fertilisation rates. A matrix was created for the low, medium and high rainfall zone with the soil characteristics variables along the row and column axes (figure xx). The percentage ratio of regions with yield significance for each soil characteristic was then calculated by totalling the regional values of significance across each rainfall zone and dividing by the number of regions within the classified rainfall zone. This index for each soil characteristic represented the magnitude of significant yield differences across the three rainfall zones.

Results

Changing PAWC with root zone depth and texture held constant (TEXTURE within RZ)

Figure xx shows the percentage of regions where simulated yields are statistically different when PAWC levels are changed and rooting zone depth and texture are held constant. Each row element signifies a particular soil characterisation, simulated yields for this element are compared to the simulated yields of soil characterisations in the same rooting depth and texture characterisation but with changes in PAWC level (the column elements).

No comparisons for the 0-20cm root zone.

Two groups of three comparisons can be made across the sand and sandy-loam textured soils for the 20-40cm root zone depth category.

For the 0-40cm rooting depth and sand texture characterisation changing PAWC values showed very high significance across the 0-20mm and 20-40mm PAWC values in all rainfall regions. Comparison between the yields simulated from the 40-70mm and the 70-100mm PAWC show low yield differences in the low, medium and high rainfall zones.

For the 0-40cm rooting depth sandy-loam, all PAWC categories are show statistically significant yield differences across the low rainfall zone. For the medium and high rainfall zone the comparison of the yields simulated by the 20-40mm PAWC category were statistically significant. For the medium rainfall zone, a low to moderate number of regions showed statistical yield differences when the 40-70mm and 70-100mm PAWC categories were compared. No difference was found between 40-70mm and 70-100mm PAWC in the high rainfall zone.

For the 0-40cm sandy-clay-loam the comparison across PAWC magnitudes showed no difference in yields in the low and medium rainfall zone. For the high rainfall zone, comparison showed moderate yield differences.

For the 0-60cm sand, comparison between the 20-40mm and 40-70mm showed low statistical yield differences while comparisons between 70-100mm PAWC were statistically significant in the low rainfall zone. For the medium and high rainfall zone, yield differences were in the high to very high categories for the majority of comparisons.

For the 0-60cm sandy-loam, comparison of yield differences across PAWC values in the low rainfall zone shows low significance between in the 20-40mm and 40-70mm PAWC as well as the 70-100mm and 100+mm PAWC categories. Comparisons across these categories showed very high significance. In the medium rainfall zone, low yield differences were found between the 70-100mm and 100+mm PAWC categories while other cross comparisons generated very high statistically significant yield differences. For high rainfall zones, high significant differences existed between simulated yields for the 20-40mm and 40-70mm PAWC soil characterisations. Less significant differences were found for the 70-100mm and 100+mm PAWC soils while other cross comparisons showed very high number of regions had statistically significant yield differences.

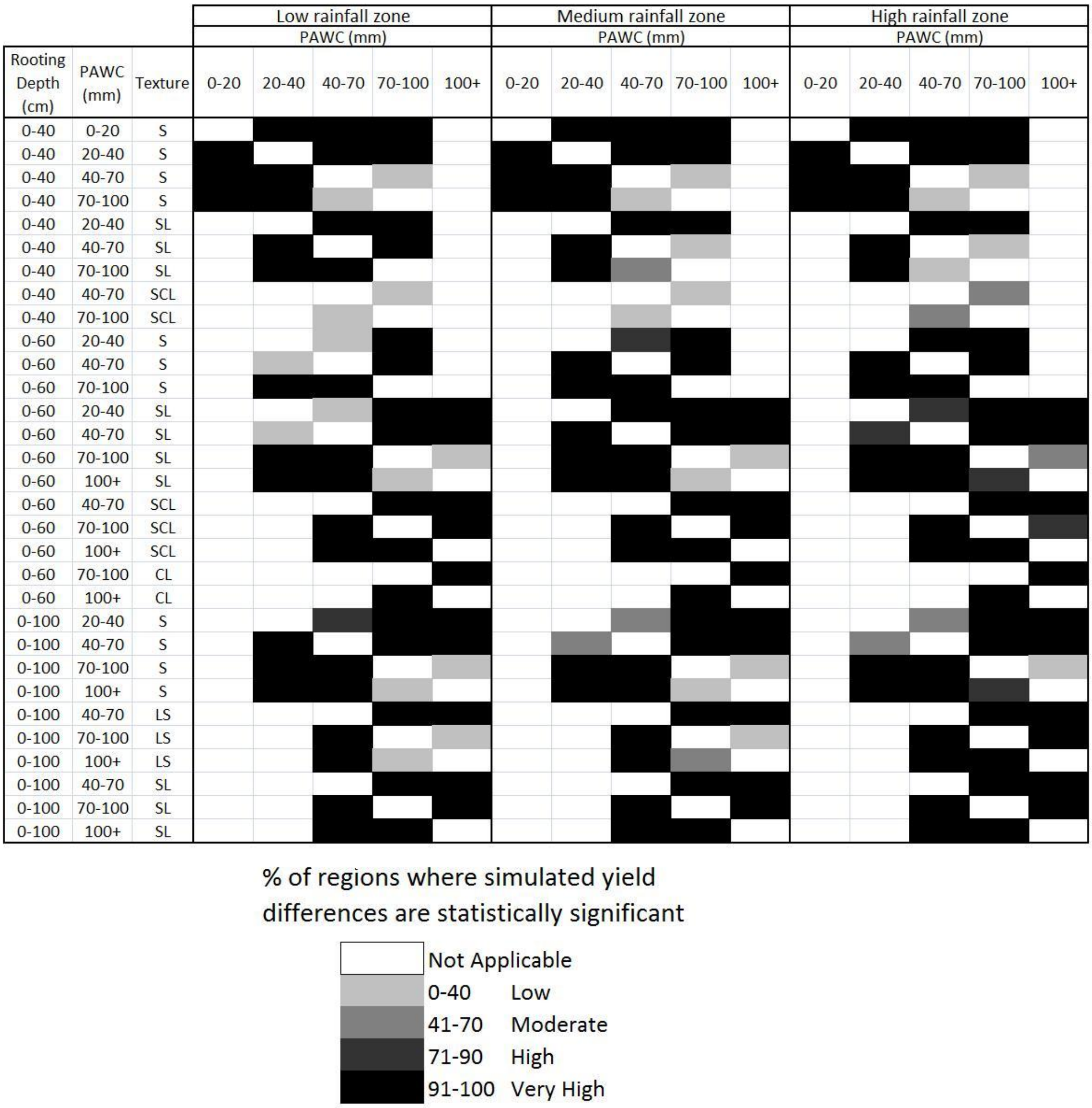
For the 0-60cm rooting depth sandy-clay-loam comparisons across the all rainfall regions showed the majority of regions showed very high significant yield differences. The exception was in the high rainfall region where a high rate was recorded in the 70-100mm and 100+mm PAWC comparison.

For the 0-60cm rooting depth, clay loam soil category showed very high significant yield differences in the low, medium and high rainfall zones.

For the 0-100cm root zone and sand texture type showed moderate to high yield differences were found between the 20-40cm and 40-70cm PAWC categories in the low rainfall zones. The yield significance for these categories was moderate in the medium and high rainfall zones. Cross comparisons between the 20-40mm and 40-70mm PAWC values with the 70-100mm and 100+mm PAWC showed very high significance in yield differences. Comparison between the 70-100mm and 100+mm PAWC categories showed low yield significance in the low and medium rainfall zones with low to moderate significance in the high rainfall zone.

For the 0-60cm loamy-sand, changes in PAWC showed significant yield in the 40-70mm PAWC in the low and medium rainfall zones. No difference were found between the 70-100mm and 100mm +PAWC levels in the low rainfall zone while only moderate yield differences were shown in the medium rainfall zone. All PAWC comparisons showed very high yield differences in the high rainfall zones.

For the 0-100cm root zone sandy-loam category changes in PAWC showed very high significant yield differences across all PAWC levels in the low, medium and high rainfall zones.



			Low rainfall zone					Medium rainfall zone					High rainfall zone				
			PAWC (mm)					PAWC (mm)					PAWC (mm)				
Rooting Depth (cm)	PAWC (mm)	Texture	0-20	20-40	40-70	70-100	100+	0-20	20-40	40-70	70-100	100+	0-20	20-40	40-70	70-100	100+
0-40	0-20	S		█	█	█			█	█	█			█	█	█	
0-40	20-40	S	█		█	█		█		█	█		█		█	█	
0-40	40-70	S	█	█		░		█	█		░		█	█		░	
0-40	70-100	S	█	█	░			█	█	░			█	█	░		
0-40	20-40	SL			█	█				█	█				█	█	
0-40	40-70	SL		█		█			█		░			█		░	
0-40	70-100	SL		█	█				█	▒				█	░		
0-40	40-70	SCL				░					░					▒	
0-40	70-100	SCL			░					░					▒		
0-60	20-40	S			░	█				▓	█				█	█	
0-60	40-70	S		░		█			█		█			█		█	
0-60	70-100	S		█	█				█	█				█	█		
0-60	20-40	SL			░	█	█			█	█	█			▓	█	█
0-60	40-70	SL		░		█	█		█		█	█		▓		█	█
0-60	70-100	SL		█	█		░		█	█		░		█	█		▒
0-60	100+	SL		█	█	░			█	█	░			█	█	▓	
0-60	40-70	SCL				█	█				█	█				█	█
0-60	70-100	SCL			█		█			█		█			█		▓
0-60	100+	SCL			█	█				█	█				█	█	
0-60	70-100	CL					█					█					█
0-60	100+	CL				█					█					█	
0-100	20-40	S			▓	█	█			▒	█	█			▒	█	█
0-100	40-70	S		█		█	█		▒		█	█		▒		█	█
0-100	70-100	S		█	█		░		█	█		░		█	█		░
0-100	100+	S		█	█	░			█	█	░			█	█	▓	
0-100	40-70	LS				█	█				█	█				█	█
0-100	70-100	LS			█		░			█		░			█		█
0-100	100+	LS			█	░				█	▒				█	█	
0-100	40-70	SL				█	█				█	█				█	█
0-100	70-100	SL			█		█			█		█			█		█
0-100	100+	SL			█	█				█	█				█	█	

% of regions where simulated yield differences are statistically significant

□	Not Applicable	
░	0-40	Low
▒	41-70	Moderate
▓	71-90	High
█	91-100	Very High

Figure XX Percentage of regions where simulated yield differences are statistically significant with changes in PAWC across variations in rooting depth (cm), PAWC (mm) and texture characterisations within the low, medium and high rainfall zones.

Changing root zone depth with PAWC and texture held constant (Across RZ)

Figure xx shows the percentage of regions where simulated yields are statistically different when rooting depth levels are changed and PAWC magnitudes and texture are held constant. Each row element signifies a particular soil characterisation; simulated yields for this element are compared to the simulated yields of soil characterisations in the same PAWC levels and texture characterisation but with changes in rooting depth (the column elements).

Yields for all the soil characterisation for the 0-20cm root zone showed significant differences across all root zones and rainfall zones within the constant PAWC and texture parameters.

For the 0-20mm PAWC sand soil type change in rooting depth showed very high statistical yield differences. Comparison between the 20-40mm PAWC category showed very high significance for the comparisons between 0-40cm and 0-60 and 0-100cm. Comparison between the 0-60 and 0-100cm showed low significant yield differences in the low rainfall region. Similar results were found for the medium rainfall zone except that comparisons between the 0-60cm and 0-40cm and the 0-60cm and 0-100cm showed moderate rate of significant yield differences. For the high rainfall zone comparisons across rooting zones have high (0-60cm to 0-40cm comparison) and very high rates of yield significance.

For the 40-70mm PAWC and sand texture changing rooting depth showed high to very high yield differences in the low rainfall zone. In the medium rainfall zone comparisons varied from moderate to very high while all comparison showed very high yield differences in the high rainfall zone.

For the 70-100 PAWC and sand texture changing rooting depth showed very high statistical differences when different rooting zone depths were compared t the 0-40cm characterisation. Comparisons between the 0-60 and 0-100cm rooting depth showed the greatest variation with moderate to very high yield differences in the low, moderate differences in the medium and low differences in the high rainfall zones

For the yields simulated for the 20-40mm PAWC sandy-loam only the 0-20cm showed statistically significant yield differences, comparisons between the 0-40 and 0-60cm rooting depths showed low statistical significance.

For the sandy-loam 40-70mm PAWC comparisons, changes in rooting depth showed very high significant differences between the 0-40cm and 0-60cm rooting depths. Comparison between the 0-100cm to the two other rooting depths showed low yield differences in the low and medium rainfall zones. In the high rainfall zones these comparison increased from moderate to high significant yield differences.

For the yields simulated for the 70-100mm PAWC sandy-loam comparisons with the 0-40cm rooting depth showed very high statistical significance. Comparison between the 0-60cm and 0-100cm rooting depths showed low levels of statistical significance.

For the 100+mm PAWC and sandy-loam comparisons in the 0-60cm and 0-100cm rooting depths showed very high rates of yield differences.

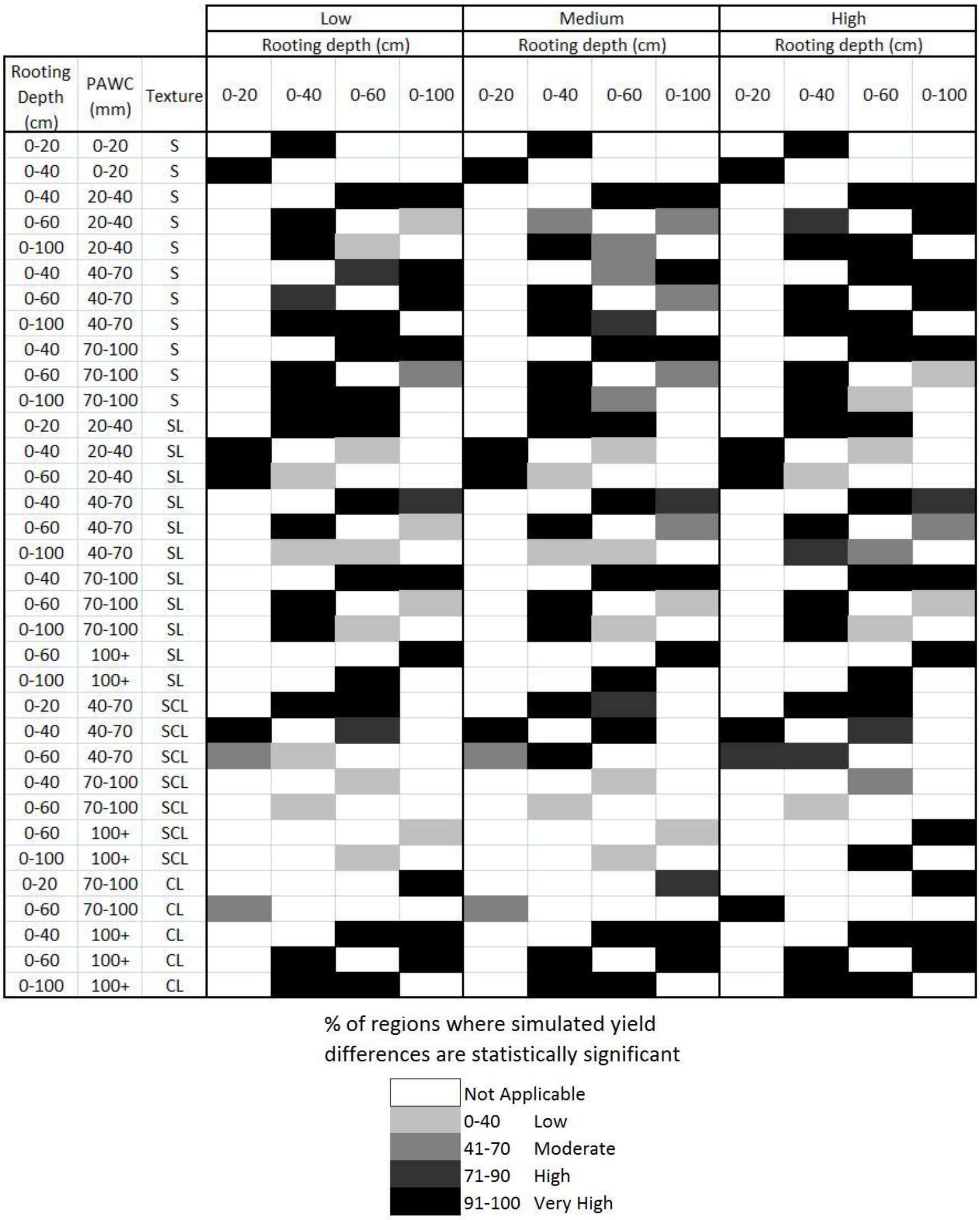
For sandy-clay-loam in the 40-70mm PAWC category determining the number of regions with yield differences showed very high rates between 0-20cm and 0-40cm rooting depths. Cross comparisons with the yields simulated by the 0-60cm rooting depth soil characterisation showed moderate to low yield differences while the 0-40cm comparison to the 0-60cm showed high yield differences in the low rainfall zone. Within the medium rainfall zone the majority of yield differences were within the very high category except the comparisons between the 0-20cm and 0-60cm rooting depths which were in the moderate to high category. Yield differences for the high rainfall zones ranged from high to very high yield significance.

For the sandy-clay-loam 70-100mm PAWC category comparing across the two root zones showed differences in yields were mainly in the low category in the low, medium and high rainfall zones. Within the high rainfall zone, the comparison between the 0-40cm and 0-60cm showed a low to moderate yield differences.

For the sandy-clay-loam 100+mm PAWC category comparing yield differences across the 0-60cm and 0-100cm rooting depths resulted in low rates of significance in the low and medium rainfall zone. For the high rainfall, cross comparisons showed very high yield differences.

For the 70-100mm PAWC clay-loam soil characterisation comparison between the 0-20cm and 0-60cm rooting depth showed moderate to very high rates of yield significance in the low and medium rainfall zones. Both comparisons for the high rainfall zone were within the very high significance category.

For the 100+mm PAWC clay-loam very high significant differences are highlighted across all rooting depths for the low, medium and high rainfall zones.



			Low				Medium				High			
			Rooting depth (cm)				Rooting depth (cm)				Rooting depth (cm)			
Rooting Depth (cm)	PAWC (mm)	Texture	0-20	0-40	0-60	0-100	0-20	0-40	0-60	0-100	0-20	0-40	0-60	0-100
0-20	0-20	S	□	█	□	□	□	█	□	□	□	█	□	□
0-40	0-20	S	█	□	□	□	█	□	□	□	█	□	□	□
0-40	20-40	S	□	□	█	█	□	□	█	█	□	□	█	█
0-60	20-40	S	□	█	□	░	□	▒	□	▒	□	▓	□	█
0-100	20-40	S	□	█	░	□	□	█	▒	□	□	█	█	□
0-40	40-70	S	□	□	▓	█	□	□	▒	█	□	□	█	█
0-60	40-70	S	□	▓	□	█	□	█	□	▒	□	█	□	█
0-100	40-70	S	□	█	█	□	□	█	▓	□	□	█	█	□
0-40	70-100	S	□	□	█	█	□	□	█	█	□	□	█	█
0-60	70-100	S	□	█	□	▒	□	█	□	▒	□	█	□	░
0-100	70-100	S	□	█	█	□	□	█	▒	□	□	█	░	□
0-20	20-40	SL	□	█	█	□	□	█	█	□	□	█	█	□
0-40	20-40	SL	█	□	░	□	█	□	░	□	█	□	░	□
0-60	20-40	SL	█	░	□	□	█	░	□	□	█	░	□	□
0-40	40-70	SL	□	□	█	▓	□	□	█	▓	□	□	█	▓
0-60	40-70	SL	□	█	□	░	□	█	□	▒	□	█	□	▒
0-100	40-70	SL	□	░	░	□	□	░	░	□	□	▓	▒	□
0-40	70-100	SL	□	□	█	█	□	□	█	█	□	□	█	█
0-60	70-100	SL	□	█	□	░	□	█	□	░	□	█	□	░
0-100	70-100	SL	□	█	░	□	□	█	░	□	□	█	░	□
0-60	100+	SL	□	□	□	█	□	□	□	█	□	□	□	█
0-100	100+	SL	□	□	█	□	□	□	█	□	□	□	█	□
0-20	40-70	SCL	□	█	█	□	□	█	▓	□	□	█	█	□
0-40	40-70	SCL	█	□	▓	□	█	□	█	□	█	□	▓	□
0-60	40-70	SCL	▒	░	□	□	▒	█	□	□	▓	▓	□	□
0-40	70-100	SCL	□	□	░	□	□	□	░	□	□	□	▒	□
0-60	70-100	SCL	□	░	□	□	□	░	□	□	□	░	□	□
0-60	100+	SCL	□	□	□	░	□	□	□	░	□	□	□	█
0-100	100+	SCL	□	□	░	□	□	□	░	□	□	□	█	□
0-20	70-100	CL	□	□	□	█	□	□	□	▓	□	□	□	█
0-60	70-100	CL	▒	□	□	□	▒	□	□	□	█	□	□	□
0-40	100+	CL	□	□	█	█	□	□	█	█	□	□	█	█
0-60	100+	CL	□	█	□	█	□	█	□	█	□	█	□	█
0-100	100+	CL	□	█	█	□	□	█	█	□	□	█	█	□

% of regions where simulated yield differences are statistically significant

□	Not Applicable	
░	0-40	Low
▒	41-70	Moderate
▓	71-90	High
█	91-100	Very High

Figure XX Percentage of regions where simulated yield differences are statistically significant with changes in rooting depth across variations in rooting depth (cm), PAWC (mm) and texture characterisations within the low, medium and high rainfall zones. <need to change rainfall titles>

Changing root zone depth and PAWC with texture held constant

For the sand to clay loam texture, comparing root zone depth 0-20 cm with all other root zone depths showed significant difference in simulated yield across all rainfall zones. For the finer textured soils within this root zone depth, the majority of soil characterisations simulate significant yields across all root zones and rainfall zones.

Two exception were found with the first comparing the “sandy clay loam” to the corresponding textured soil in the 0-60cm rooting depth and 40-70mm PAWC where regions ranged from 93%, 73%,95% across the low, medium and high rainfall zones. The second showed that the “clay” produced 93% and 90% significant yields across the region in the low and medium rainfall zones when compared to the corresponding texture within the 0-60cm rooting depth and 70-100mm category.

For “sand” texture in 20-40mm PAWC across all rooting depth and PAWC showed the majority was significant except for the 0-100cm and 40-70mm PAWC where only 15%, 73% of simulated yields were significant in the low and medium rainfall zone. All were significant in the high rainfall zone.

For 20-40cm rooting zone and 40-70mm PAWC “sand” texture in low rainfall zone 0-60cm and 60-100cm 20-40mm PAWC had 37% and 70% agreement others all significant. In medium rainfall zone, 60-100cm 20-40mm and 96% and 95% for the medium and high rainfall zone while 40-70mm PAWC the medium zone had 93% agreement. All other comparison between “sands” and varying root depths and PAWC were significant.

For “sands” 70-100mm PAWC 52% and 96% of yields were significant when compared to 40-60cm and 60-100cm 20-40mm PAWC in low rainfall zone. Yields for the medium and high rainfall zones as well as others not mentioned above in the low rainfall simulate yields.

For the “sandy loam” 0-40cm 20-40mm PAWC comparison with the 0-60cm 40-70mm PAWC showed 33% and 57% agreement and 89% and 100% agreement for the 0-100cm 40-70mm category in the low and medium rainfall zone.

For the sandy loam” 0-40cm 40-70mm PAWC 93% of significant yields when compared 0-60cm and 0-100cm rooting depths and 70-100mm PAWC in the low rainfall zone. In the medium rainfall zone, 87% for the 0-60cm and 70-100cm PAWC, **80% for the 0-60cm and 100+PAWC**, 93% for the 0-100cm and 70-100mm. For the high rainfall zone, **68% yield significance rate for 0-60cm and 100+ PAWC** and 94% for the 0-100cm and 70-100mm PAWC.

In the low rainfall zone, the sandy loam 0-40cm 70-100mm PAWC , 93% of the regions show different yields with 0-60cm and 20-40mm, 52% for the 0-60cm 40-70mm PAW and 22% for the 0-100cm 40-70mm. Yields for the 0-60cm and 0-100cm root zone depths, the 70-100 and 100+ PAWC are all significant. In the medium rainfall zone, 77% and 47% of the regions had significant yields when compared to the 0-60cm and 0-100cm rooting depth and 40-70mm PAWC category. In the high rainfall zone, 94%, 79% of the yields were statistically significant in the 0-60cm 20-40mm and 40-70mm PAWC. Within the 0-100cm root depth and 40-70mm PAWC 53% of the regions produced statistically significant yields. **Lower PAWC in the high rainfall area ...**

In the low rainfall region, for the “sandy clay loam” in the 0-40cm 40-70mm PAWC comparison between the 0-60cm 70-100mm PAWC showed only 48% of the regions had statistical significance. These two categories are close increasing PAWC and root depth. Increasing the PAWC to 100+ and increasing the root zone showed 100% of regions with significant yield differences. In the medium and high rainfall region, only difference across rooting depths and PAWC was 37% and 95% of region had 0-60cm rooting depth and 70-100mm PAWC.

In the low rainfall region, for the “sandy clay loam” in the 0-40cm 70-100mm PAWC, 96% 0-60cm and 40-70mm PAWC all other significant in the 0-60cm and 0-100cm 100+ PAWC category on the low rainfall zones. For the medium and high rainfall zone all categories changes provided significantly different yields.

For the 0-60cm 20-40mm PAWC “sand” in the low rainfall zone results show that 11%, 18% yield difference in 0-40cm and 40-70mm and 70-100mm PAWC. Comparison with 0-100cm shows 88% of regions have significant yields for the 40-70mm PAWC while all yields are significant for the 70-100 and 100+PAWC for this rooting zone. In the medium and high rainfall zone, shows yields significance in the 0-40cm root zones and 40-70mm and 70-100mm PAWC. Comparison between the 0-100cm and 40-70mm PAWC show 10% and 74% of regions yield differences while increasing PAWC show significant yield differences across the medium and high rainfall zones.

For the 0-60cm 40-70mm PAWC “sand” yields were statistically significant for the 0-40cm in the low, medium . Comparison to the 0-100cm and 20-40mm showed no statistical difference, 20% and 63% while statistical differences were found with PAWC values of between 70-100 mm and 100+mm for the low, medium and high rainfall zones.

For the 0-60cm 70-100mm PAWC “sand” comparison with the 0-40cm across all PAWC categories are all significant in all rainfall area. Comparison between 0-100cm rooting depth and PAWC of 20-40mm, 40-70mm and 100+ saw results of 100%, 100% and 94% in the low rainfall zone. All yields were significant for the medium and

For the 0-60cm 20-40mm PAWC “sandy loam” comparison across root zones and PAWC values showed 96% and 85% yield significance comparing to the 0-40cm 40-70mm and 70-100mm, 96%, 100% and 100% for the 0-100cm 40-70mm, 70-100mm and 100+mm PAWC in the low rainfall zone. All yields were significant for the medium and high rainfall zones across rooting depths and PAWC categories.

For the 0-60cm 40-70cm PAWC “sandy loam” comparison across root zones and PAWC categories shows 19%, 53% of regions have statistical significance for the 0-40cm and 20-40mm PAWC category. For the 0-40cm 70-100mm PAWC 15%, 73%, show significant yields in low rainfall zones. Increasing rooting depth and PAWC values to 70-100mm PAWC and 100+ mm PAWC show significant yields differences in the low, medium rainfall zone. In the high rainfall zone, all yields across variations in root zone depth and PAWC were significant.

For the 0-60cm 70-100 cm PAWC “sandy loam” comparison across root zones and PAWC categories showed 93%, 67% and 94% yield significance across the 0-40cm 40-70mm PAWC in the low, medium and high rainfall zones. All other yields were significant across rooting zone depths and PAWC values.

For the 0-60cm 100+mm PAWC “sandy loam” across root zones and PAWC categories showed 93%, 57% and 10% of regions had yield differences in 0-40cm 40-70mm PAWC and 59%, 47%, 53% in the 0-100cm 70-100mm all other provided significant yields.

For the 0-60cm 40-70 mm PAWC “sandy clay loam” shows 70% ratio for the 0-40cm 70-100mm PAWC in the low rainfall zone. Increasing root zone and PAWC level generates statistically significant yield differences. Yields differences for the medium ad high rainfall were all statistically significant.

For the 0-60cm 70-100 mm PAWC “sandy clay loam” shows 11%, 13% and 89% of region in the low, medium and high rainfall zone while the 0-100cm rooting depth and 100+mm PAWC had statistically significant yield differences in all rainfall zones. For the 0-60cm 100+ mm PAWC “sandy clay loam” shows statistical significance when compared to the 0-40cm and lower PAWC categories in the low, medium and high rainfall zones.

No comparison can be made for the 0-60cm 100+ mm PAWC “clay loam” soil characterisations.

Yields for the 0-100cm 20-40mm PAWC “sand” show statistical significance when compared to the 0-40cm 0-20mm PAWC and 0-60cm 70-100mm PAWC in the low, medium and high. Comparison with the 0-40cm 40-70mm showed 78% and 70-100mm 56% in the low rainfall zone only. No difference was found in the low and medium rainfall zones in the 0-60cm 40-70mm PAWC. For this soil characterisation 53% of regions in the high rainfall zone had significant yields. For the medium and high rainfall zone, all comparisons were significant in the 0-40cm root depth.

Yields for the 0-100cm 40-70 mm PAWC “sand” in the low rainfall region significant yield differences in the 0-40cm 0-20mm 19%, 73%, and 94% in the 0-40cm 20-40mm in the low, medium and high rainfall zones. Comparison with the 0-60cm 20-40mm 93%, 17%, 73% in the low, medium and high rainfall zones. Indicates that these yields may be higher for the 0-60cm or lower for the 0-100cm soil characterisation.

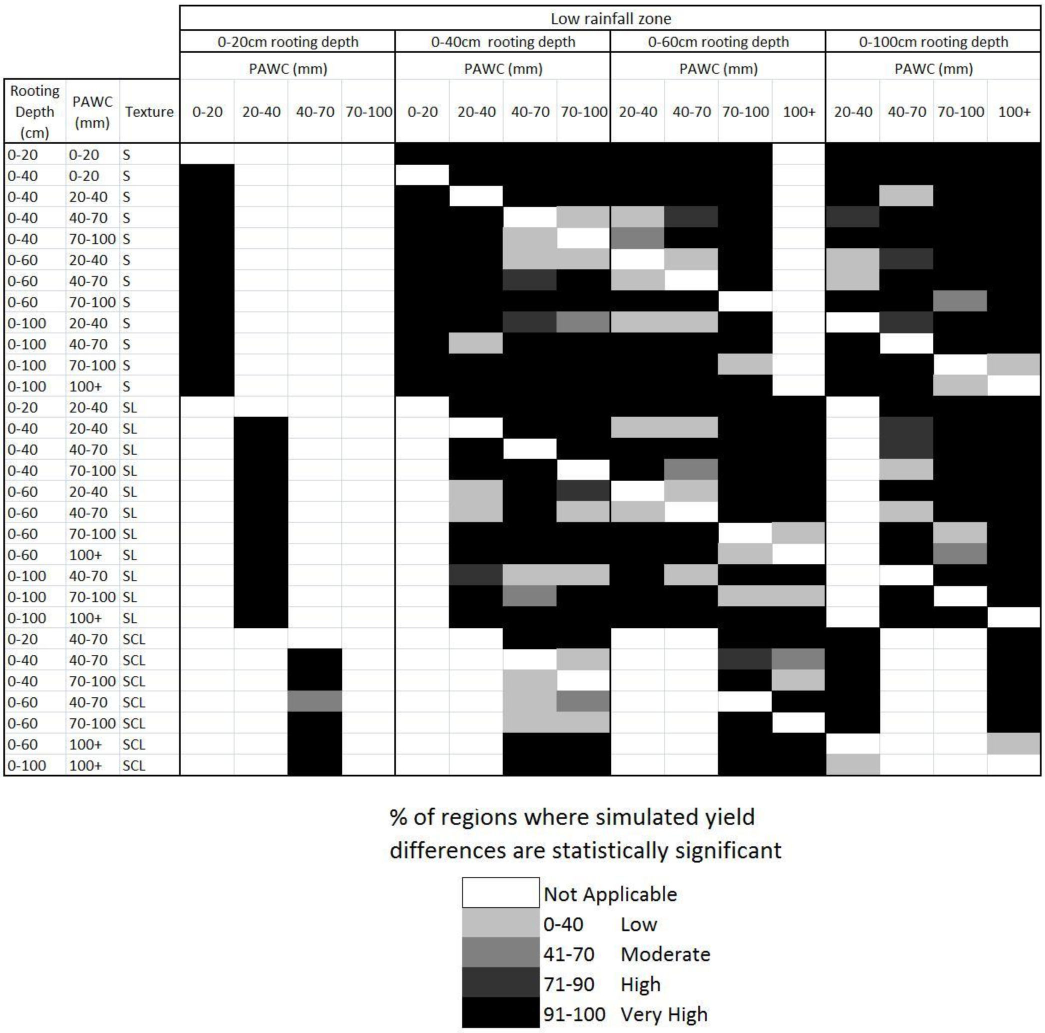
Yields for the 0-100cm 70-100 mm PAWC “sand” all yields were significant across the root zone depth and PAWC combinations in the low, medium and high rainfall zones.

Yields for the 0-100cm 40-70mm PAWC “sandy loam ” comparison with 0-40cm 20-40mm PAWC show 70% while the 70-100mm PAWC 7% in the low rainfall region. Comparisons across the 0-60cm and variations in PAWC show statistical significance with 96% being the lowest for the 20-40mm PAWC.

Yields for the 0-100cm 70-100mm PAWC “sandy loam” comparison with PAWC in the 0-40cm root zone range shows 89%, 70%, 84% and yield significance for the 40-70mm PAWC values in the low medium and high rainfall zones. Comparison with the 0-60cm and PAWC variations show significant yield differences in the 20-40 and 40-70mm PAWC categories but only no difference in the 70-100mm in the low, medium and high rainfall zones. For the low, medium and high rainfall zone 22%, 23% and 42% of the regions showed yield significance when compared to the in the 0-60cm 100+ PAWC category.

Yields for the 0-100cm 100+mm PAWC “sandy loam” were significant across the variations in root zone depth and PAWC variations across the low, medium and high rainfall zones.

Yields for the 0-100cm 100+mm PAWC “sandy clay loam” show significance across all root zones and PAWC values in the low, medium and high rainfall zones.

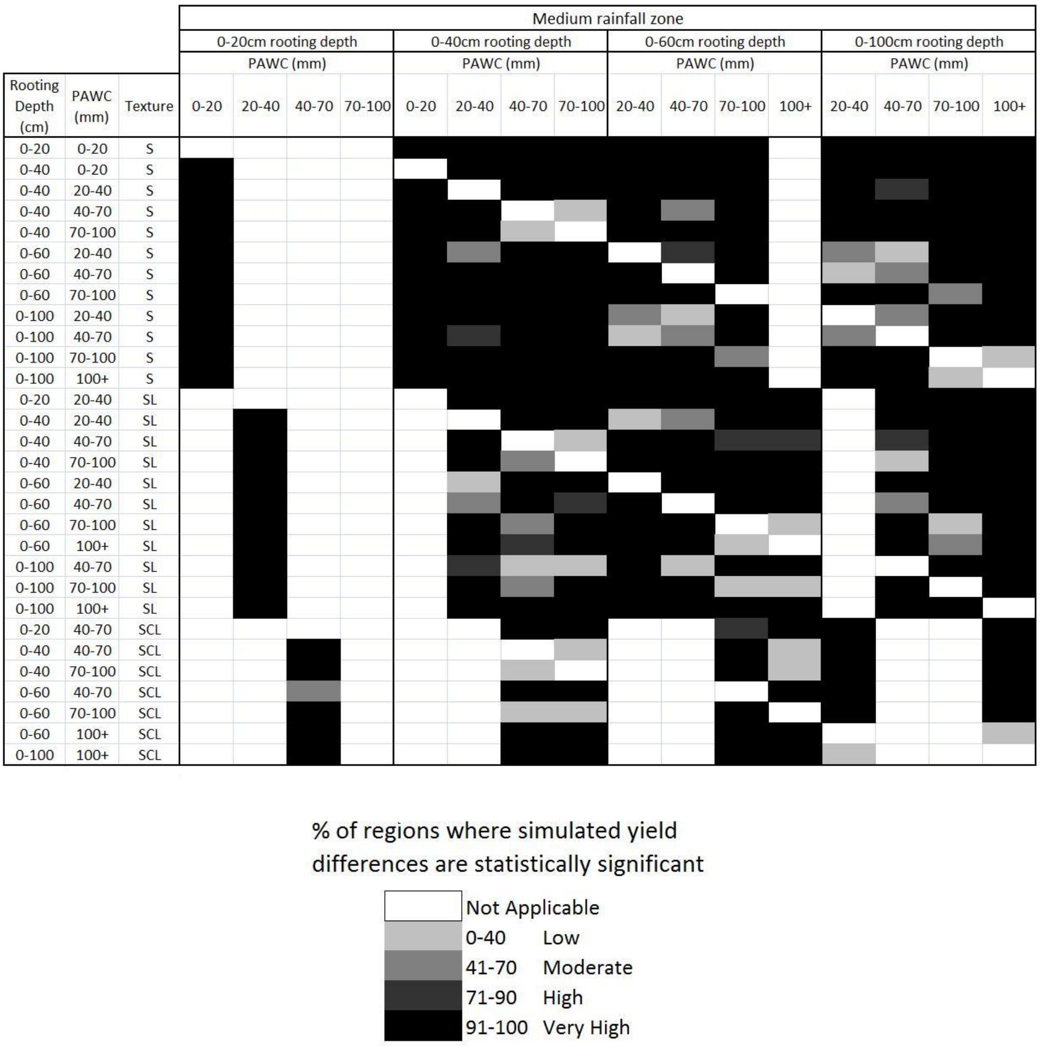


			Low rainfall zone															
			0-20cm rooting depth				0-40cm rooting depth				0-60cm rooting depth				0-100cm rooting depth			
			PAWC (mm)				PAWC (mm)				PAWC (mm)				PAWC (mm)			
Rooting Depth (cm)	PAWC (mm)	Texture	0-20	20-40	40-70	70-100	0-20	20-40	40-70	70-100	20-40	40-70	70-100	100+	20-40	40-70	70-100	100+
0-20	0-20	S	□	□	□	□	■	■	■	■	■	■	■	□	■	■	■	■
0-40	0-20	S	■	□	□	□	□	■	■	■	■	■	■	□	■	■	■	■
0-40	20-40	S	■	□	□	□	■	□	■	■	■	■	■	□	■	░	■	■
0-40	40-70	S	■	□	□	□	■	■	□	░	░	▓	■	□	▓	■	■	■
0-40	70-100	S	■	□	□	□	■	■	░	□	▒	■	■	□	■	■	■	■
0-60	20-40	S	■	□	□	□	■	■	░	░	□	░	■	□	░	▓	■	■
0-60	40-70	S	■	□	□	□	■	■	▓	■	░	□	■	□	░	■	■	■
0-60	70-100	S	■	□	□	□	■	■	■	■	■	■	□	□	■	■	▒	■
0-100	20-40	S	■	□	□	□	■	■	▓	▒	░	░	■	□	□	▓	■	■
0-100	40-70	S	■	□	□	□	■	░	■	■	■	■	■	□	■	□	■	■
0-100	70-100	S	■	□	□	□	■	■	■	■	■	■	░	□	■	■	□	░
0-100	100+	S	■	□	□	□	■	■	■	■	■	■	■	□	■	■	░	□
0-20	20-40	SL	□	□	□	□	□	■	■	■	■	■	■	■	□	■	■	■
0-40	20-40	SL	□	■	□	□	□	□	■	■	░	░	■	■	□	▓	■	■
0-40	40-70	SL	□	■	□	□	□	■	□	■	■	■	■	■	□	▓	■	■
0-40	70-100	SL	□	■	□	□	□	■	■	□	■	▒	■	■	□	░	■	■
0-60	20-40	SL	□	■	□	□	□	░	■	▓	□	░	■	■	□	■	■	■
0-60	40-70	SL	□	■	□	□	□	░	■	░	░	□	■	■	□	░	■	■
0-60	70-100	SL	□	■	□	□	□	■	■	■	■	■	□	░	□	■	░	■
0-60	100+	SL	□	■	□	□	□	■	■	■	■	■	░	□	□	■	▒	■
0-100	40-70	SL	□	■	□	□	□	▓	░	░	■	░	■	■	□	□	■	■
0-100	70-100	SL	□	■	□	□	□	■	▒	■	■	■	░	░	□	■	□	■
0-100	100+	SL	□	■	□	□	□	■	■	■	■	■	■	■	□	■	■	□
0-20	40-70	SCL	□	□	□	□	□	□	■	■	□	□	■	■	■	□	□	■
0-40	40-70	SCL	□	□	■	□	□	□	□	░	□	□	▓	▒	■	□	□	■
0-40	70-100	SCL	□	□	■	□	□	□	░	□	□	□	■	░	■	□	□	■
0-60	40-70	SCL	□	□	▒	□	□	□	░	▒	□	□	□	■	■	□	□	■
0-60	70-100	SCL	□	□	■	□	□	□	░	░	□	□	■	□	■	□	□	■
0-60	100+	SCL	□	□	■	□	□	□	■	■	□	□	■	■	□	□	□	░
0-100	100+	SCL	□	□	■	□	□	□	■	■	□	□	■	■	░	□	□	□

% of regions where simulated yield differences are statistically significant

□	Not Applicable	
░	0-40	Low
▒	41-70	Moderate
▓	71-90	High
■	91-100	Very High

Figure XX Percentage of regions where simulated yield differences are statistically significant with changes in rooting depth and PAWC categories across variations in rooting depth (cm), PAWC (mm) and texture characterisations within the low rainfall zone.

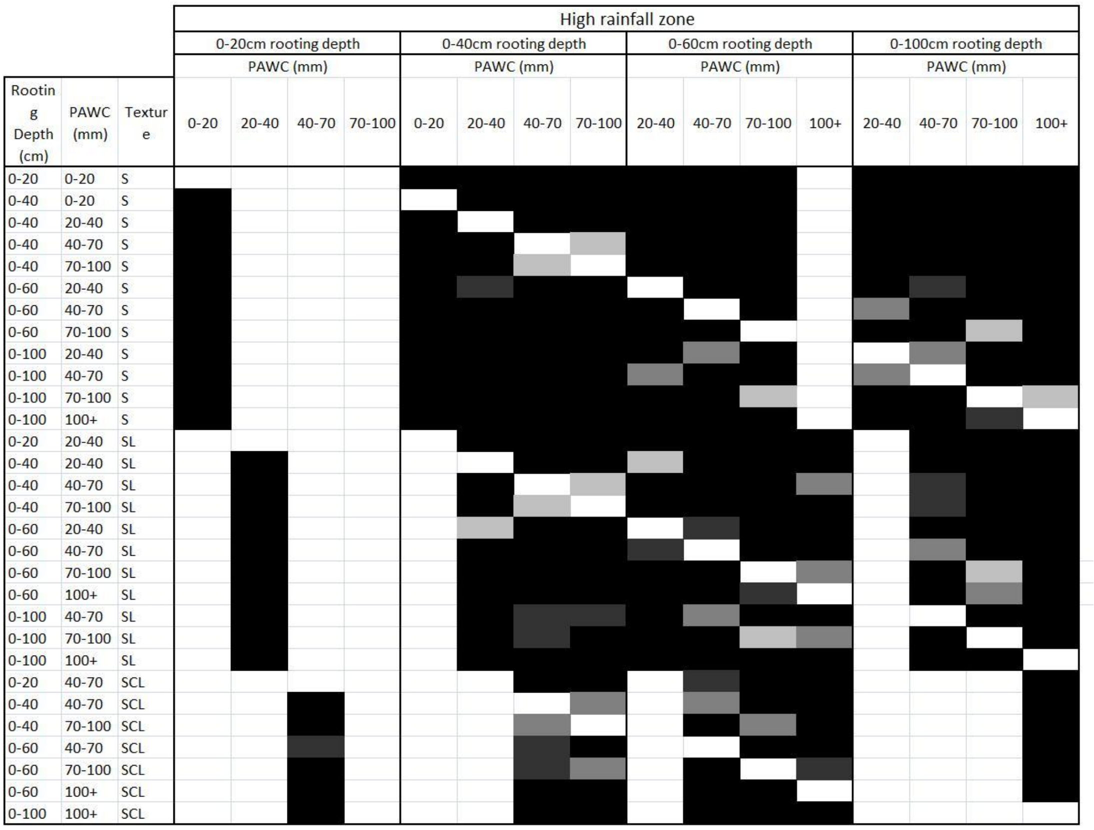


			Medium rainfall zone															
			0-20cm rooting depth				0-40cm rooting depth				0-60cm rooting depth				0-100cm rooting depth			
			PAWC (mm)				PAWC (mm)				PAWC (mm)				PAWC (mm)			
Rooting Depth (cm)	PAWC (mm)	Texture	0-20	20-40	40-70	70-100	0-20	20-40	40-70	70-100	20-40	40-70	70-100	100+	20-40	40-70	70-100	100+
0-20	0-20	S	□	□	□	□	█	█	█	█	█	█	█	□	█	█	█	█
0-40	0-20	S	█	□	□	□	□	█	█	█	█	█	█	□	█	█	█	█
0-40	20-40	S	█	□	□	□	█	□	█	█	█	█	█	□	█	▓	█	█
0-40	40-70	S	█	□	□	□	█	█	□	░	█	▒	█	□	█	█	█	█
0-40	70-100	S	█	□	□	□	█	█	░	□	█	█	█	□	█	█	█	█
0-60	20-40	S	█	□	□	□	█	▒	█	█	□	▓	█	□	▒	░	█	█
0-60	40-70	S	█	□	□	□	█	█	█	█	█	□	█	□	░	▒	█	█
0-60	70-100	S	█	□	□	□	█	█	█	█	█	█	□	□	█	█	▒	█
0-100	20-40	S	█	□	□	□	█	█	█	█	▒	░	█	□	□	▒	█	█
0-100	40-70	S	█	□	□	□	█	▓	█	█	░	▒	█	□	▒	□	█	█
0-100	70-100	S	█	□	□	□	█	█	█	█	█	█	▒	□	█	█	□	░
0-100	100+	S	█	□	□	□	█	█	█	█	█	█	█	□	█	█	░	□
0-20	20-40	SL	□	□	□	□	□	█	█	█	█	█	█	█	□	█	█	█
0-40	20-40	SL	□	█	□	□	□	□	█	█	░	▒	█	█	□	█	█	█
0-40	40-70	SL	□	█	□	□	□	█	□	░	█	█	▓	▓	□	▓	█	█
0-40	70-100	SL	□	█	□	□	□	█	▒	□	█	█	█	█	□	░	█	█
0-60	20-40	SL	□	█	□	□	□	░	█	█	□	█	█	█	□	█	█	█
0-60	40-70	SL	□	█	□	□	□	▒	█	▓	█	□	█	█	□	▒	█	█
0-60	70-100	SL	□	█	□	□	□	█	▒	█	█	█	□	░	□	█	░	█
0-60	100+	SL	□	█	□	□	□	█	▓	█	█	█	░	□	□	█	▒	█
0-100	40-70	SL	□	█	□	□	□	▓	░	░	█	░	█	█	□	□	█	█
0-100	70-100	SL	□	█	□	□	□	█	▒	█	█	█	░	░	□	█	□	█
0-100	100+	SL	□	█	□	□	□	█	█	█	█	█	█	█	□	█	█	□
0-20	40-70	SCL	□	□	□	□	□	□	█	█	□	□	▓	█	█	□	□	█
0-40	40-70	SCL	□	□	█	□	□	□	□	░	□	□	█	░	█	□	□	█
0-40	70-100	SCL	□	□	█	□	□	□	░	□	□	□	█	░	█	□	□	█
0-60	40-70	SCL	□	□	▒	□	□	□	█	█	□	□	□	█	█	□	□	█
0-60	70-100	SCL	□	□	█	□	□	□	░	░	□	□	█	□	█	□	□	█
0-60	100+	SCL	□	□	█	□	□	□	█	█	□	□	█	█	□	□	□	░
0-100	100+	SCL	□	□	█	□	□	□	█	█	□	□	█	█	░	□	□	□

% of regions where simulated yield differences are statistically significant

□	Not Applicable	
░	0-40	Low
▒	41-70	Moderate
▓	71-90	High
█	91-100	Very High

Figure XX Percentage of regions where simulated yield differences are statistically significant with changes in rooting depth and PAWC categories across variations in rooting depth (cm), PAWC (mm) and texture characterisations within the medium rainfall zone.



			High rainfall zone															
			0-20cm rooting depth				0-40cm rooting depth				0-60cm rooting depth				0-100cm rooting depth			
			PAWC (mm)				PAWC (mm)				PAWC (mm)				PAWC (mm)			
Rooting Depth (cm)	PAWC (mm)	Texture	0-20	20-40	40-70	70-100	0-20	20-40	40-70	70-100	20-40	40-70	70-100	100+	20-40	40-70	70-100	100+
0-20	0-20	S	□	□	□	□	■	■	■	■	■	■	■	□	■	■	■	■
0-40	0-20	S	■	□	□	□	□	■	■	■	■	■	■	□	■	■	■	■
0-40	20-40	S	■	□	□	□	■	□	■	■	■	■	■	□	■	■	■	■
0-40	40-70	S	■	□	□	□	■	■	□	░	■	■	■	□	■	■	■	■
0-40	70-100	S	■	□	□	□	■	■	░	□	■	■	■	□	■	■	■	■
0-60	20-40	S	■	□	□	□	■	▓	■	■	□	■	■	□	■	▓	■	■
0-60	40-70	S	■	□	□	□	■	■	■	■	■	□	■	□	▒	■	■	■
0-60	70-100	S	■	□	□	□	■	■	■	■	■	■	□	□	■	■	░	■
0-100	20-40	S	■	□	□	□	■	■	■	■	■	▒	■	□	□	▒	■	■
0-100	40-70	S	■	□	□	□	■	■	■	■	▒	■	■	□	▒	□	■	■
0-100	70-100	S	■	□	□	□	■	■	■	■	■	■	░	□	■	■	□	░
0-100	100+	S	■	□	□	□	■	■	■	■	■	■	■	□	■	■	▓	□
0-20	20-40	SL	□	□	□	□	□	■	■	■	■	■	■	■	□	■	■	■
0-40	20-40	SL	□	■	□	□	□	□	■	■	░	■	■	■	□	■	■	■
0-40	40-70	SL	□	■	□	□	□	■	□	░	■	■	■	▒	□	▓	■	■
0-40	70-100	SL	□	■	□	□	□	■	░	□	■	■	■	■	□	▓	■	■
0-60	20-40	SL	□	■	□	□	□	░	■	■	□	▓	■	■	□	■	■	■
0-60	40-70	SL	□	■	□	□	□	■	■	■	▓	□	■	■	□	▒	■	■
0-60	70-100	SL	□	■	□	□	□	■	■	■	■	■	□	▒	□	■	░	■
0-60	100+	SL	□	■	□	□	□	■	■	■	■	■	▓	□	□	■	▒	■
0-100	40-70	SL	□	■	□	□	□	■	▓	▓	■	▒	■	■	□	□	■	■
0-100	70-100	SL	□	■	□	□	□	■	▓	■	■	■	░	▒	□	■	□	■
0-100	100+	SL	□	■	□	□	□	■	■	■	■	■	■	■	□	■	■	□
0-20	40-70	SCL	□	□	□	□	□	□	■	■	□	▓	■	■	□	□	□	■
0-40	40-70	SCL	□	□	■	□	□	□	□	▒	□	▒	■	■	□	□	□	■
0-40	70-100	SCL	□	□	■	□	□	□	▒	□	□	■	▒	■	□	□	□	■
0-60	40-70	SCL	□	□	▓	□	□	□	▓	■	□	□	■	■	□	□	□	■
0-60	70-100	SCL	□	□	■	□	□	□	▓	▒	□	■	□	▓	□	□	□	■
0-60	100+	SCL	□	□	■	□	□	□	■	■	□	■	■	□	□	□	□	■
0-100	100+	SCL	□	□	■	□	□	□	■	■	□	■	■	■	□	□	□	□

Figure XX Percentage of regions where simulated yield differences are statistically significant with changes in rooting depth and PAWC categories across variations in rooting depth (cm), PAWC (mm) and texture characterisations within the high rainfall zone.

Texture with root zone depth and PAWC held constant

Figure xx shows the percentage of regions where simulated yields are statistically different when soil texture characterisations are changed and rooting depth levels and PAWC magnitudes are held constant. Each row element signifies a particular soil characterisation, simulated yields for this element are compared to the simulated yields of soil characterisations in the same rooting depth level and PAWC magnitude but with changes in soil texture (the column elements).

Comparisons were made where there were texture progression through the defined root zone depth and PAWC categories. Figure XX shows the matrix of comparison for soil texture categories for the defined root zone depth and PAWC. Four categories are constructed to highlight the percentage of regions where the texture characterisation has a statistically significant impact or difference in simulated yields. These categories range from low (0-40%), moderate (41-70%), high (71-90%) and very high (91-100%).

Through spatial cluster analysis (Lyle, 2012) 76 regions have been differentiated based on monthly rainfall datasets. These regions were then grouped into three rainfall zones where the low rainfall zone had 27 regions, the medium rainfall zone 30 regions and the high rainfall zone 19 regions. Based on this analysis we assume that within a rainfall zone, each region has a significantly different rainfall distribution. Therefore comparisons of soil characterisation on simulated yields across regions will mix the distributions of rainfall as well as the soil characterisation effects. We remove this influence by looking at the statistical significance differences within a region and total the results across the rainfall zone to understand the effect on simulated yield based on soil properties only.

A low number (or low percentage) of regions implies that there is low statistical significance for the soil texture characterisation in those regions to simulated statistically significant yields across a rainfall zone. While this implies that some regions produce statistically significant yields, a low significance level suggests that there is minimal benefit to its application or differentiation for a regional analysis.

Simulated wheat yields for the 0-20cm rooting depth and 20-40mm PAWC categories showed all regions had statistically significance yield differences across the three texture characterisations in the medium and high rainfall zones. In the low rainfall zone, comparison between the loamy-sand and sandy-loam soil showed only moderate to low results. Comparison of these soil types with the sandy-clay-loam showed statistical significant differences.

For the 20-40cm 20-40mm PAWC texture changes across the range showed low, medium and high rainfall zone had significant yields.

For the 20-40cm 40-70 mm PAWC texture changes showed high and very high number of regions showing statistically significant differences between the sand compared to the other texture values in the three rainfall zones. A low number of regions had statistically significant yield differences when comparisons were made between the sandy-loam and sandy-clay-loam in the three rainfall zones. These low results suggest that the crop model fails to identify significant yield differences in this PAWC category and finer texture range in this root zone depth and PAWC range.

For the 20-40 cm 70-100mm PAWC category, the low rainfall zone differences between sand and the sandy-loam shows moderate to low number of the regions have significantly different yields in the low rainfall region. This trend continues for the medium rainfall zone while in the high rainfall region both textural comparisons provide significant yield differences. Comparing the two texture categories to the sandy-clay-loam show yields had a high to very high significance in the low rainfall region, moderate to high significance in the medium and a very high significance in the high rainfall zone.

For the 0-60cm rooting depth 20-40mm PAWC comparison between the sand and the sandy-loam show low significance in the low and medium rainfall zones. High significance levels were recorded in the high rainfall zone for these soil characteristics.

For the 0-60cm 40-70mm PAWC yield differences between the sand and the sandy-loam ranged between low to moderate in the low and medium rainfall zones. This changed to moderate and high in the high rainfall zone. Simulated yields for the sand and sandy-clay-loam remained in the moderate to high significance level in the low and medium rainfall zones but became very high in the high rainfall zone. Difference in the sandy-loam and the sandy-clay-loam was low in both the low and medium rainfall zones becoming high to very high significance in the high rainfall zone.

The percentage rates of statistically significant yield differences for the 0-60cm 70-100mm PAWC showed low significance rates between the range of texture categories between the sand and sandy clay loam across the low and medium rainfall zones. These results were similar for the sand and loamy-sand in the high rainfall zone while increasing texture showed high to very high statistical significance in the sandy loam and sandy-clay-loam comparisons. As highlighted in the methods section we should expect simulated yields for clay soil characterisations to decrease in the low and medium rainfall zones. The difference in clay soil texture to the other soil textures was evident in the low and medium rainfall zones but was less significant in the high rainfall zone. This can be seen in Figure XX where the drop in average yields was not as great in the high rainfall zones when compared to the low and medium rainfall zones.

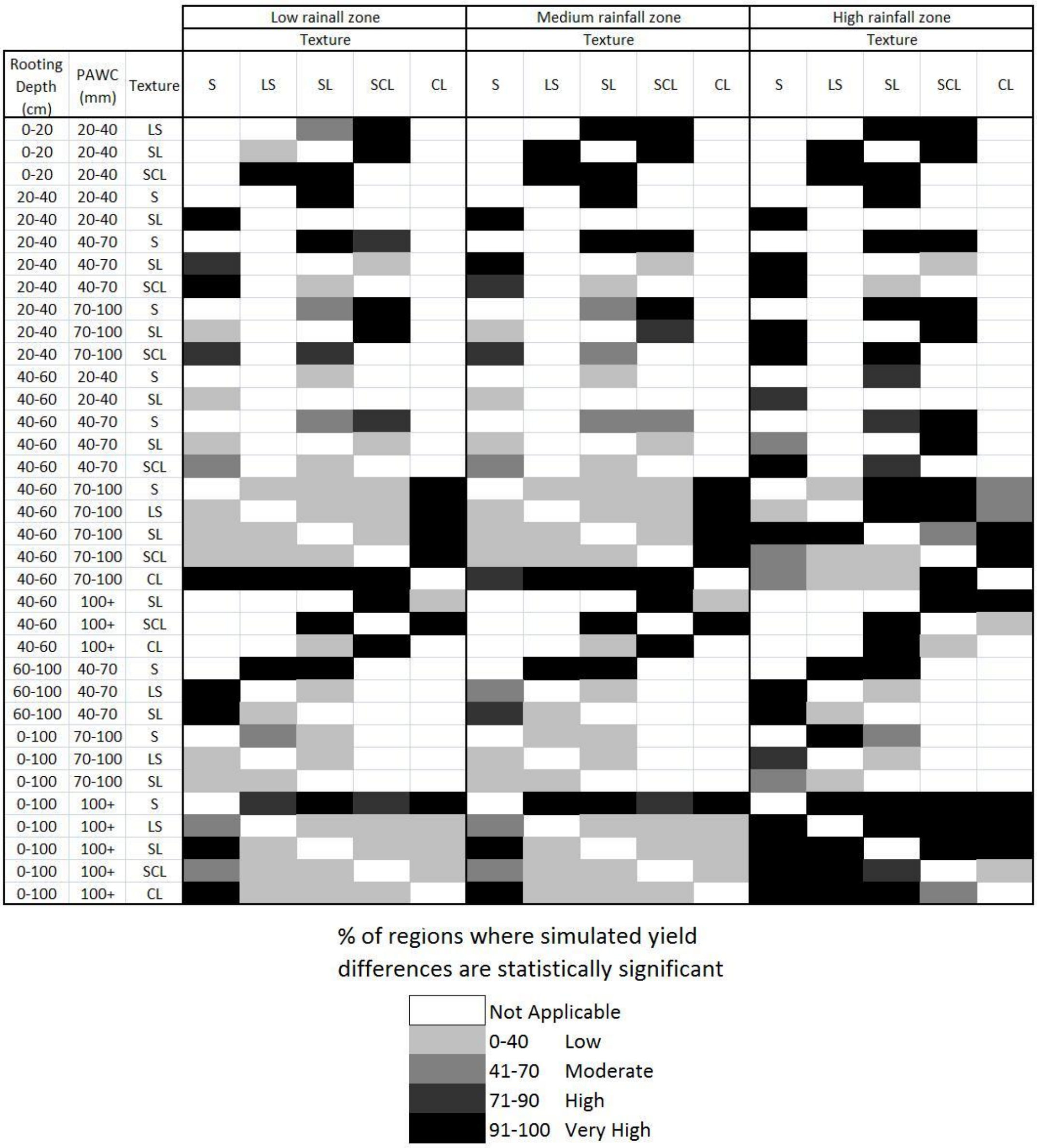
Soil characterisations in the low rainfall region increasing textures at this root zone depth showed limited explanatory power up until the clay-loam textured soil. However, in high the movement from “sand” to “sandy loam” and “sandy clay loam” showed a high proportion of statistical difference. Identifying finer textured soils in the high rainfall zones showed less significant yield differences.

Comparison with the 0-60cm 100+ PAWC textures shows very high significant yield differences between the sandy-loam and sandy-clay-loam in all rainfall zones. Low statistical difference was found when comparing the sandy-loam to the clay-loam in the low and medium rainfall zones while very high levels were found in the high rainfall zone. In the low and medium rainfall area, simulated yields for the sandy-clay-loam were all significant (very high) when compared to the other soil textures. In the high rainfall region comparison between the sandy-clay-loam and the clay-loam showed low significance.

Comparison of the 0-100cm 40-70mm PAWC shows very high rate of statistically significant yield differences between the sand and the loamy-sand in the low, very high and moderate in the medium and very high to high in the high rainfall zone. These rates were very similar when the sand and sandy-loam soil characterisations were compared. Low yield differences were seen when the loamy-sand and the sandy-loam were compared across all rainfall regions.

Comparison of the 0-100cm 70-100 mm PAWC showed a low number of regions with statistical differences across the texture categories in the low rainfall areas. Moderate to low yield differences were seen comparing the sand to the loamy sand soil characterisation in the low and medium rainfall zones. Moderate to very high yield differences were shown in the high rainfall region. No differences were apparent for the comparison between the loamy-sand and sandy-loam texture types in the low, medium and high rainfall zones.

For the 0-100cm 100+ mm PAWC showed the sand texture class showed moderate to very high significance when compared across the soil texture classes in the low and medium rainfall regions. Comparison with the loamy-sand to other finer textured soil types showed a low number of regions with significant yield differences in the low and medium rainfall zones. In the high rainfall zone, textural differences are were apparent with very high significant differences in yields for the majority of texture comparisons. Comparison of yields simulated by the sandy-clay-loam and the clay-loam showed low and moderate differences across the high rainfall zones.



			Low rainall zone					Medium rainfall zone					High rainfall zone				
			Texture					Texture					Texture				
Rooting Depth (cm)	PAWC (mm)	Texture	S	LS	SL	SCL	CL	S	LS	SL	SCL	CL	S	LS	SL	SCL	CL
0-20	20-40	LS	☐	☐	▒	█	☐	☐	☐	█	█	☐	☐	☐	█	█	☐
0-20	20-40	SL	☐	░	☐	█	☐	☐	█	☐	█	☐	☐	█	☐	█	☐
0-20	20-40	SCL	☐	█	█	☐	☐	☐	█	█	☐	☐	☐	█	█	☐	☐
20-40	20-40	S	☐	☐	█	☐	☐	☐	☐	█	☐	☐	☐	☐	█	☐	☐
20-40	20-40	SL	█	☐	☐	☐	☐	█	☐	☐	☐	☐	█	☐	☐	☐	☐
20-40	40-70	S	☐	☐	█	▓	☐	☐	☐	█	█	☐	☐	☐	█	█	☐
20-40	40-70	SL	▓	☐	☐	░	☐	█	☐	☐	░	☐	█	☐	☐	░	☐
20-40	40-70	SCL	█	☐	░	☐	☐	▓	☐	░	☐	☐	█	☐	░	☐	☐
20-40	70-100	S	☐	☐	▒	█	☐	☐	☐	▒	█	☐	☐	☐	█	█	☐
20-40	70-100	SL	░	☐	☐	█	☐	░	☐	☐	▓	☐	█	☐	☐	█	☐
20-40	70-100	SCL	▓	☐	▓	☐	☐	▓	☐	▒	☐	☐	█	☐	█	☐	☐
40-60	20-40	S	☐	☐	░	☐	☐	☐	☐	░	☐	☐	☐	☐	▓	☐	☐
40-60	20-40	SL	░	☐	☐	☐	☐	░	☐	☐	☐	☐	▓	☐	☐	☐	☐
40-60	40-70	S	☐	☐	▒	▓	☐	☐	☐	▒	▒	☐	☐	☐	▓	█	☐
40-60	40-70	SL	░	☐	☐	░	☐	░	☐	☐	░	☐	▒	☐	☐	█	☐
40-60	40-70	SCL	▒	☐	░	☐	☐	▒	☐	░	☐	☐	█	☐	▓	☐	☐
40-60	70-100	S	☐	░	░	░	█	☐	░	░	░	█	☐	░	█	█	▒
40-60	70-100	LS	░	☐	░	░	█	░	☐	░	░	█	░	☐	█	█	▒
40-60	70-100	SL	░	░	☐	░	█	░	░	☐	░	█	█	█	☐	▒	█
40-60	70-100	SCL	░	░	░	☐	█	░	░	░	☐	█	▒	░	░	☐	█
40-60	70-100	CL	█	█	█	█	☐	▓	█	█	█	☐	▒	░	░	█	☐
40-60	100+	SL	☐	☐	☐	█	░	☐	☐	☐	█	░	☐	☐	☐	█	█
40-60	100+	SCL	☐	☐	█	☐	█	☐	☐	█	☐	█	☐	☐	█	☐	░
40-60	100+	CL	☐	☐	░	█	☐	☐	☐	░	█	☐	☐	☐	█	░	☐
60-100	40-70	S	☐	█	█	☐	☐	☐	█	█	☐	☐	☐	█	█	☐	☐
60-100	40-70	LS	█	☐	░	☐	☐	▒	☐	░	☐	☐	█	☐	░	☐	☐
60-100	40-70	SL	█	░	☐	☐	☐	▓	░	☐	☐	☐	█	░	☐	☐	☐
0-100	70-100	S	☐	▒	░	☐	☐	☐	░	░	☐	☐	☐	█	▒	☐	☐
0-100	70-100	LS	░	☐	░	☐	☐	░	☐	░	☐	☐	▓	☐	░	☐	☐
0-100	70-100	SL	░	░	☐	☐	☐	░	░	☐	☐	☐	▒	░	☐	☐	☐
0-100	100+	S	☐	▓	█	▓	█	☐	█	█	▓	█	☐	█	█	█	█
0-100	100+	LS	▒	☐	░	░	░	▒	☐	░	░	░	█	☐	█	█	█
0-100	100+	SL	█	░	☐	░	░	█	░	☐	░	░	█	█	☐	█	█
0-100	100+	SCL	▒	░	░	☐	░	▒	░	░	☐	░	█	█	▓	☐	░
0-100	100+	CL	█	░	░	░	☐	█	░	░	░	☐	█	█	█	▒	☐

% of regions where simulated yield
differences are statistically significant

☐ Not Applicable
░ 0-40 Low
▒ 41-70 Moderate
▓ 71-90 High
█ 91-100 Very High

Figure XX Percentage of regions where simulated yield differences are statistically significant with changes in texture across variations in rooting depth (cm), PAWC (mm) and texture characterisations within the low, medium and high rainfall zones.

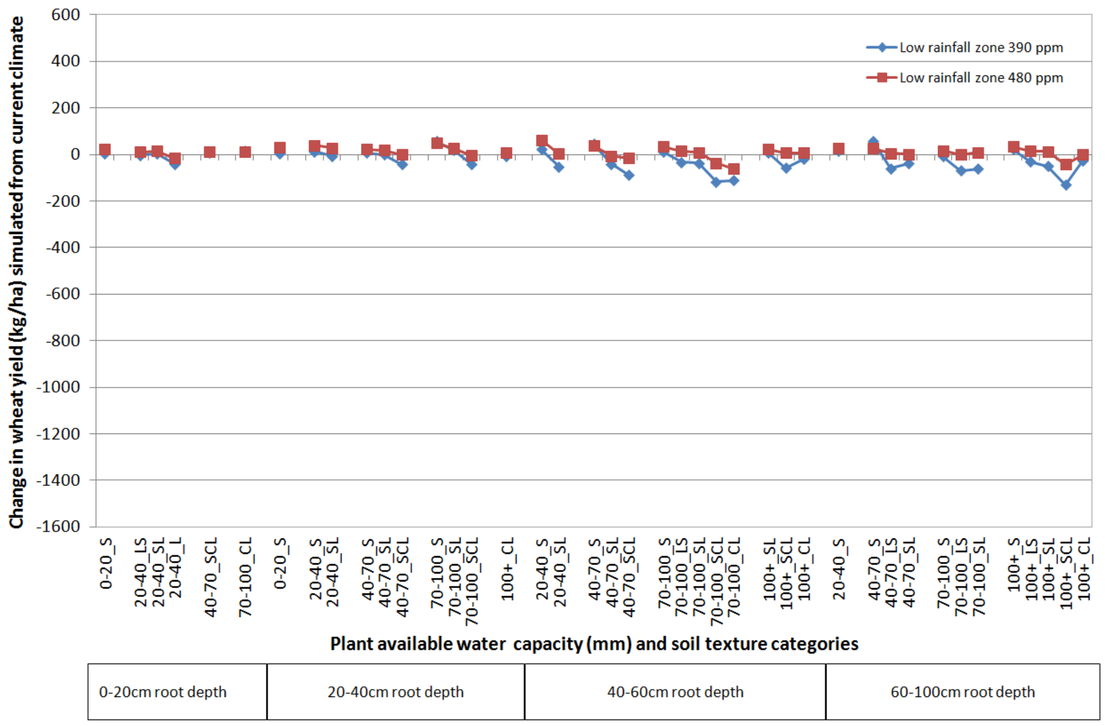


Figure XX Change in wheat simulated from current climate to scenario S1 over the rooting depth, PAWC and soil texture classifications for the low rainfall zone

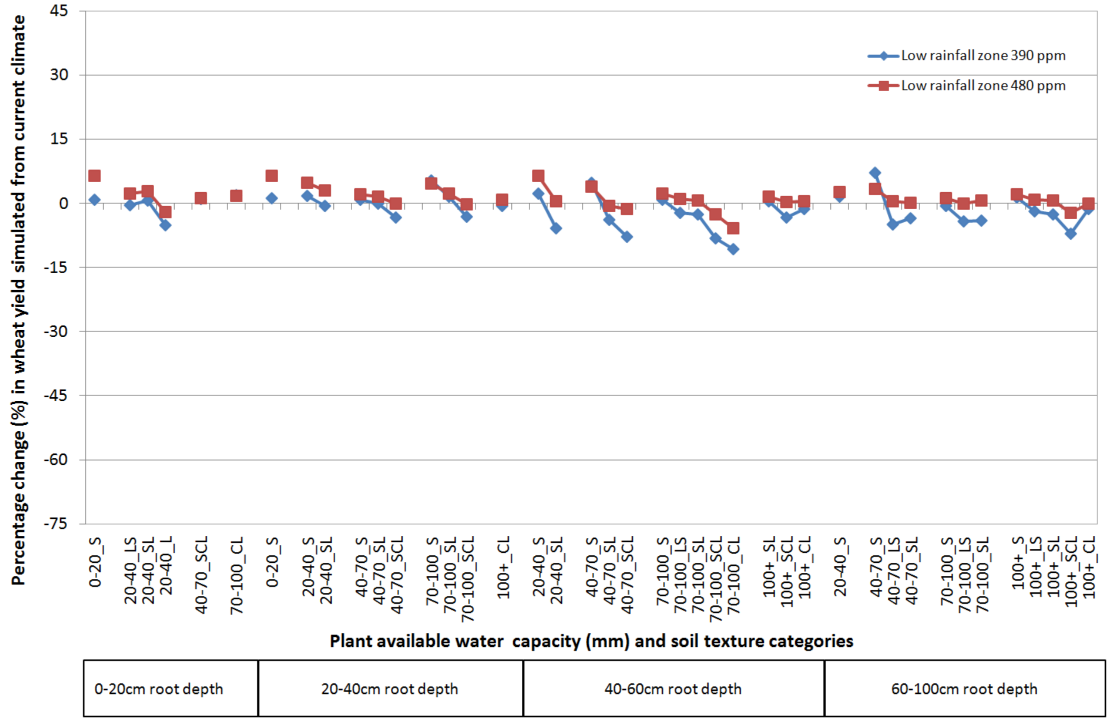


Figure XX Percentage change (%) in wheat simulated from current climate to scenario S1 over the rooting depth, PAWC and soil texture classifications for the low rainfall zone

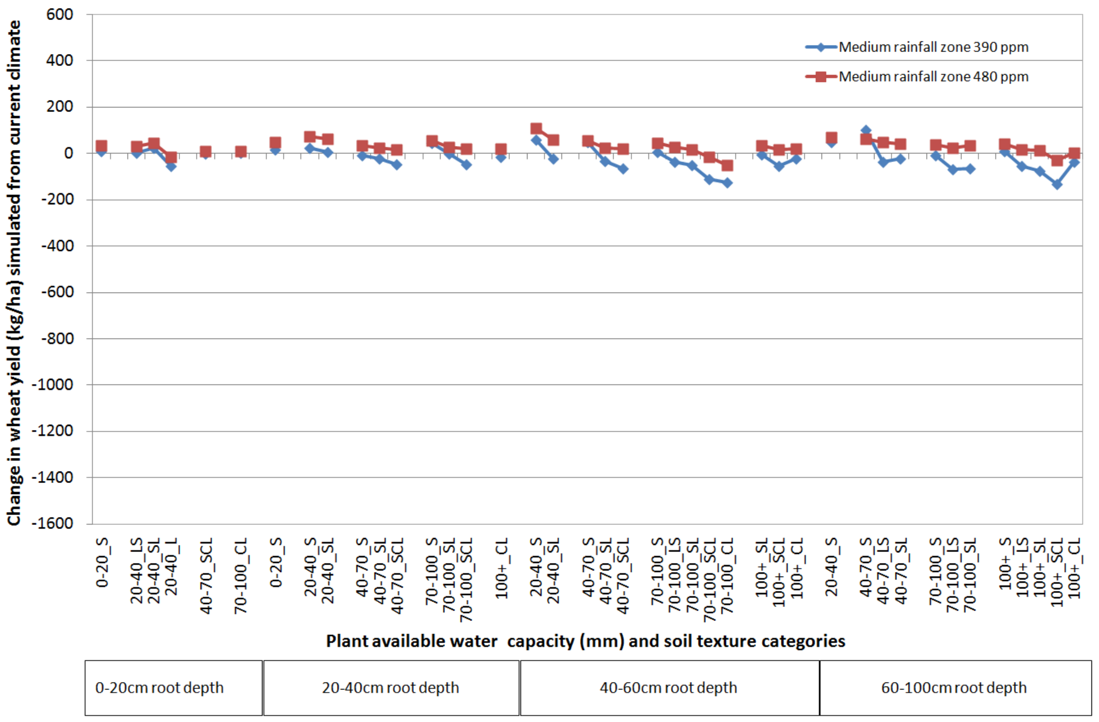


Figure XX Change in wheat simulated from current climate to scenario S1 over the rooting depth, PAWC and soil texture classifications for the medium rainfall zone

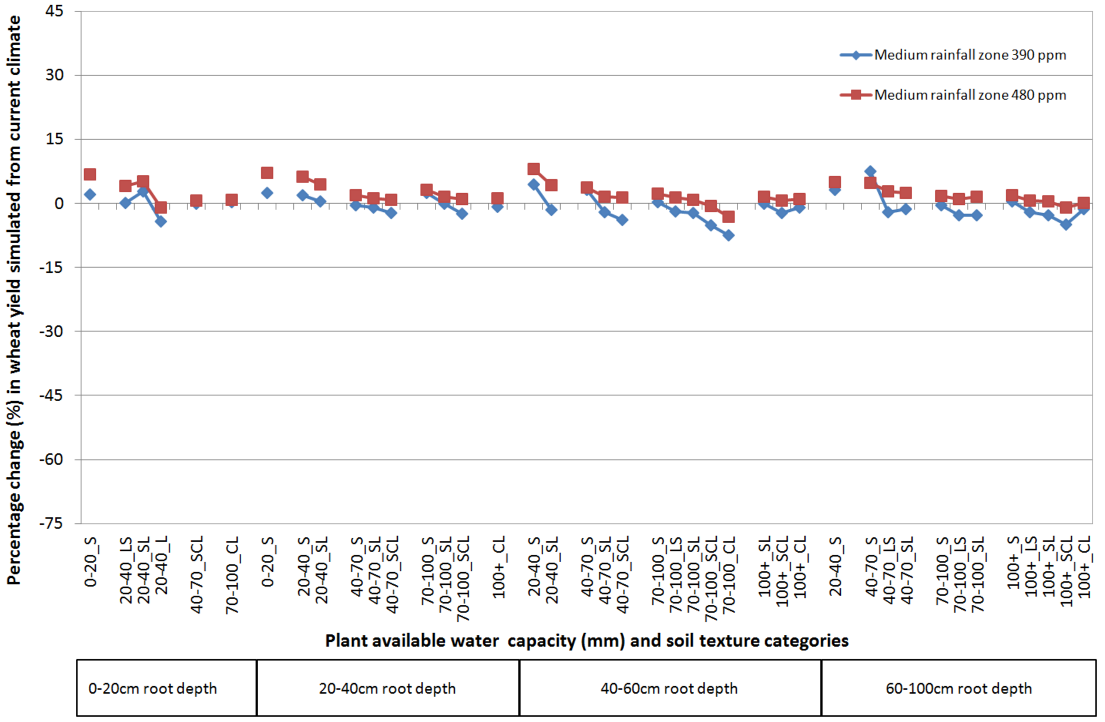


Figure XX Percentage change (%) in wheat simulated from current climate to scenario S1 over the rooting depth, PAWC and soil texture classifications for the medium rainfall zone

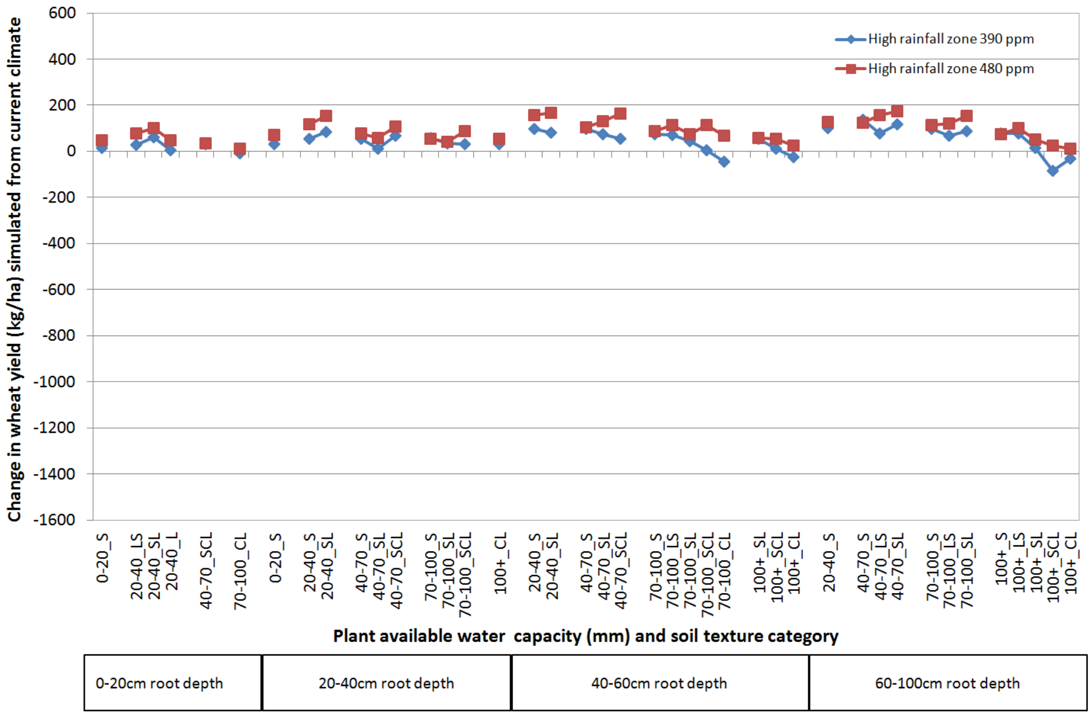


Figure XX Change in wheat simulated from current climate to scenario S1 over the rooting depth, PAWC and soil texture classifications for the high rainfall zone

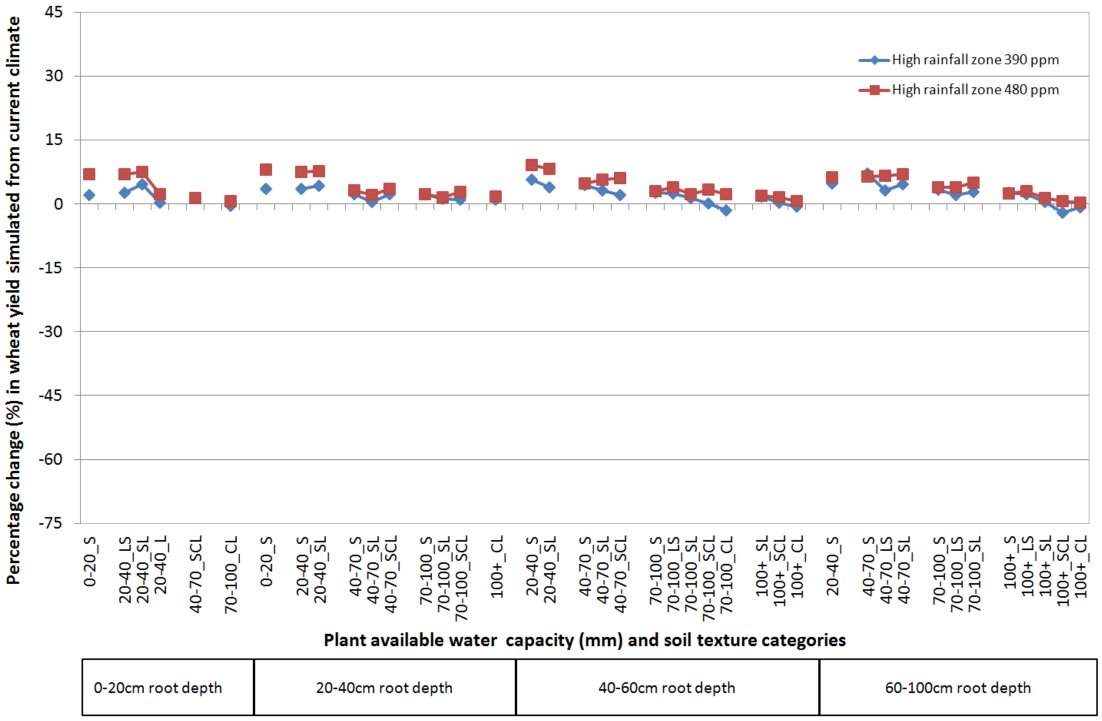


Figure XX Percentage change (%) in wheat simulated from current climate to scenario S1 over the rooting depth, PAWC and soil texture classifications for the high rainfall zone

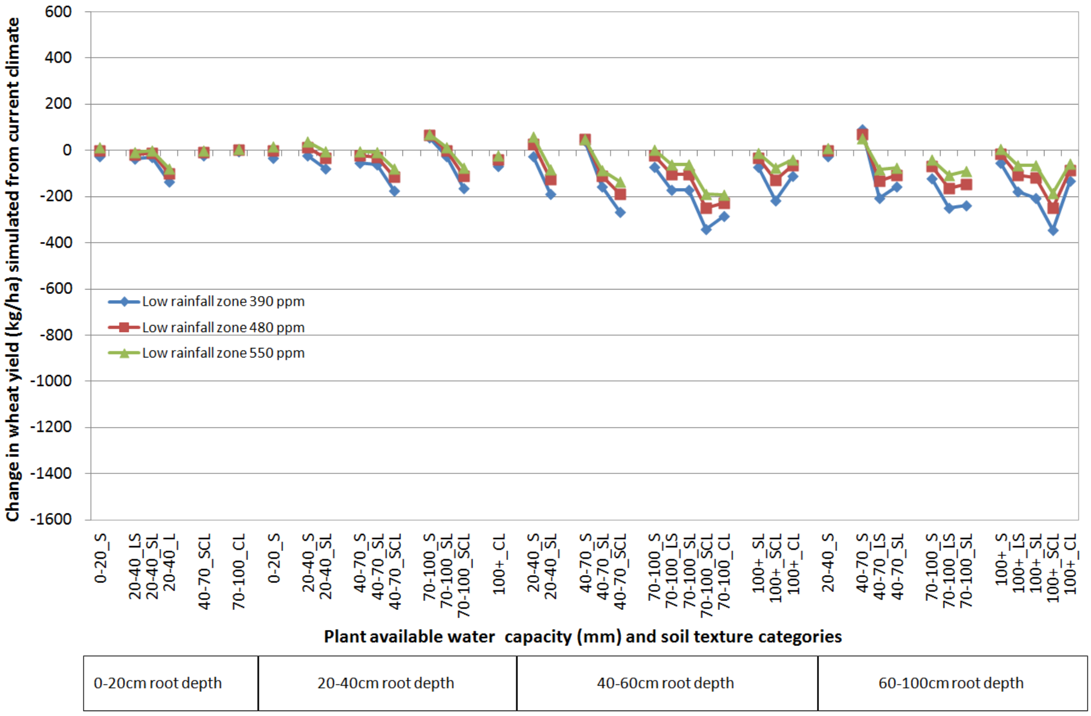


Figure XX Change in wheat simulated from current climate to scenario S5 over the rooting depth, PAWC and soil texture classifications for the low rainfall zone

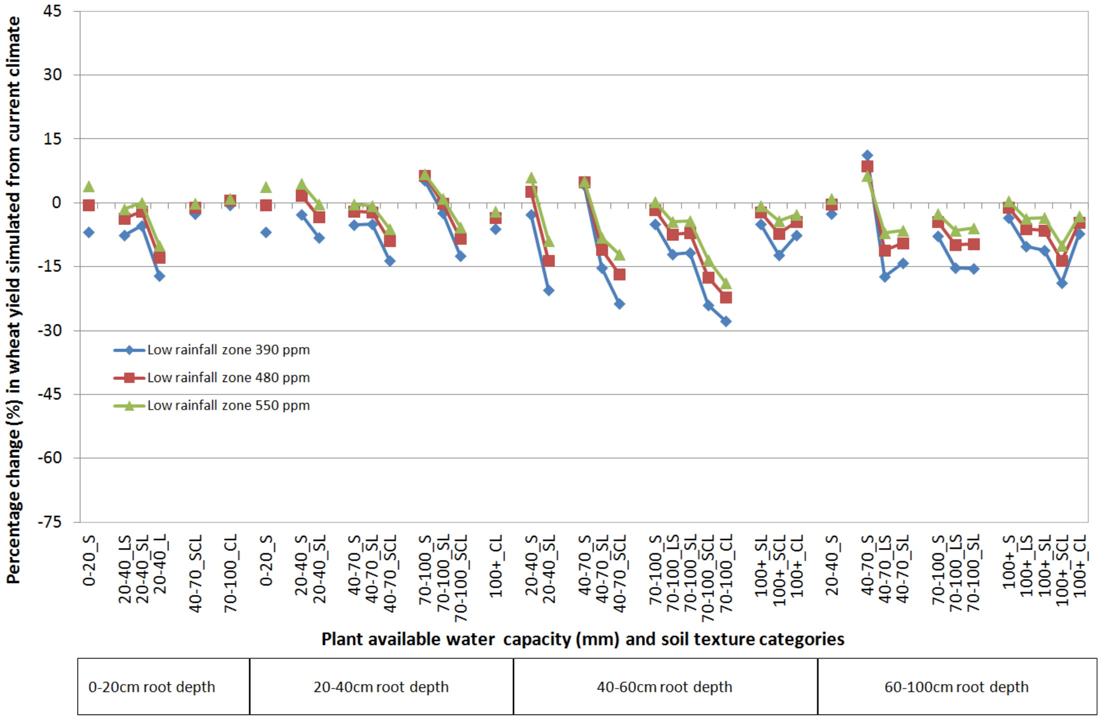


Figure XX Percentage change (%) in wheat simulated from current climate to scenario S5 over the rooting depth, PAWC and soil texture classifications for the low rainfall zone

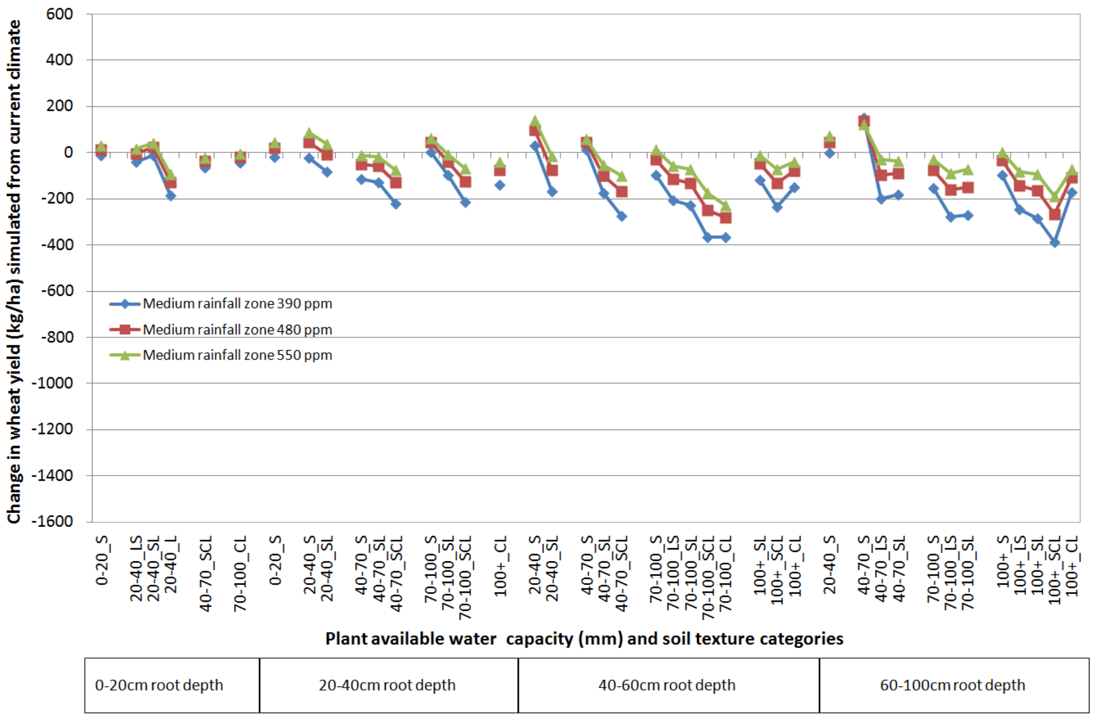


Figure XX Change in wheat simulated from current climate to scenario S5 over the rooting depth, PAWC and soil texture classifications for the medium rainfall zone

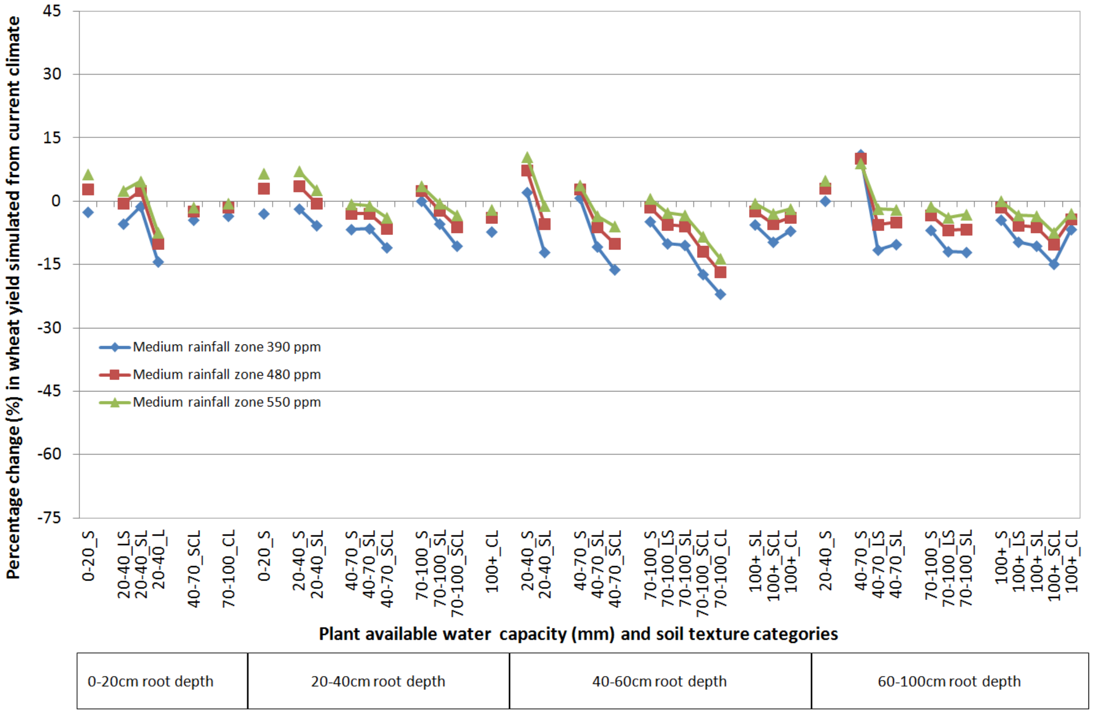


Figure XX Percentage change (%) in wheat simulated from current climate to scenario S5 over the rooting depth, PAWC and soil texture classifications for the medium rainfall zone

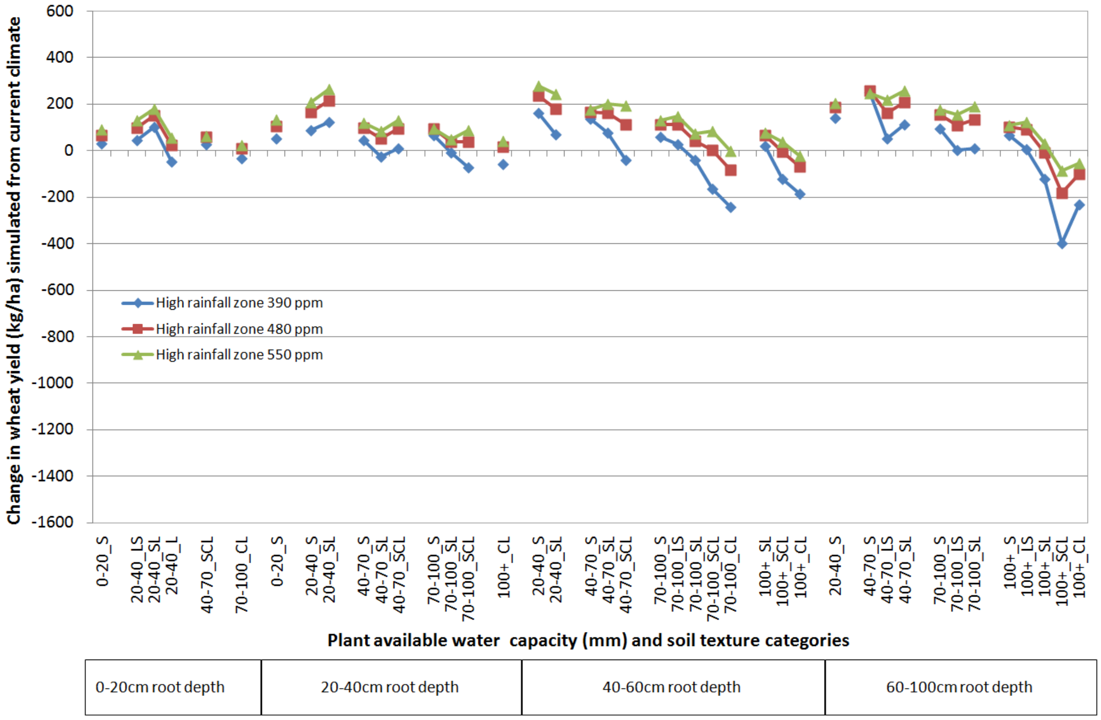


Figure XX Change in wheat simulated from current climate to scenario S5 over the rooting depth, PAWC and soil texture classifications for the high rainfall zone

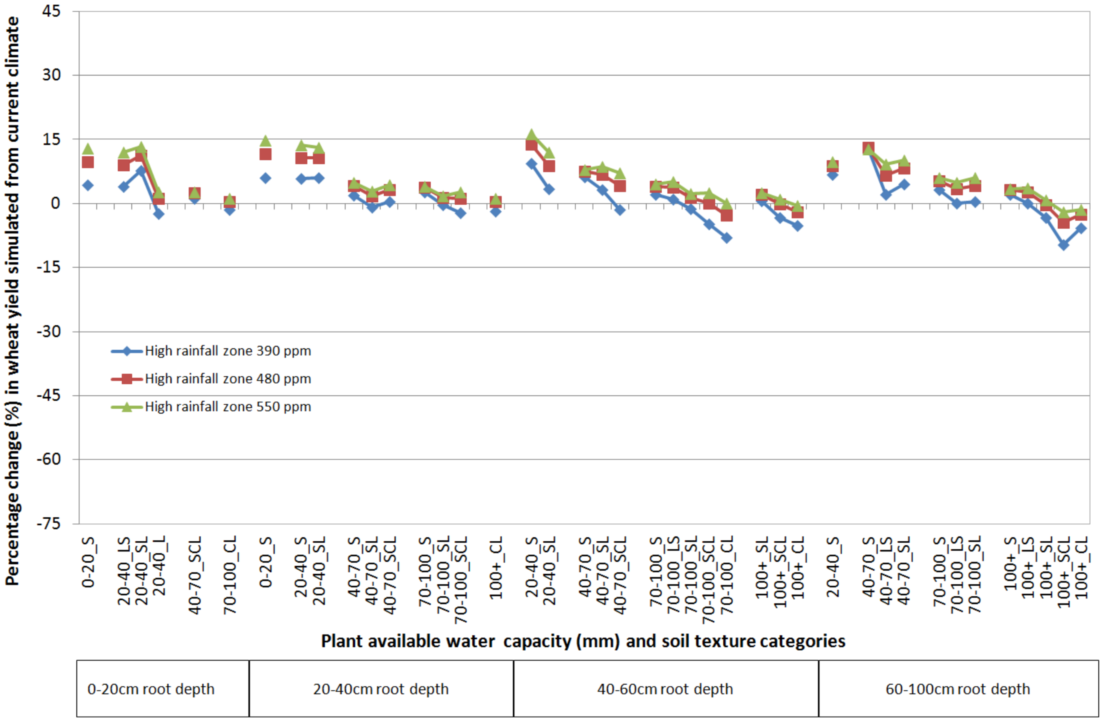


Figure XX Percentage change (%) in wheat simulated from current climate to scenario S5 over the rooting depth, PAWC and soil texture classifications for the high rainfall zone

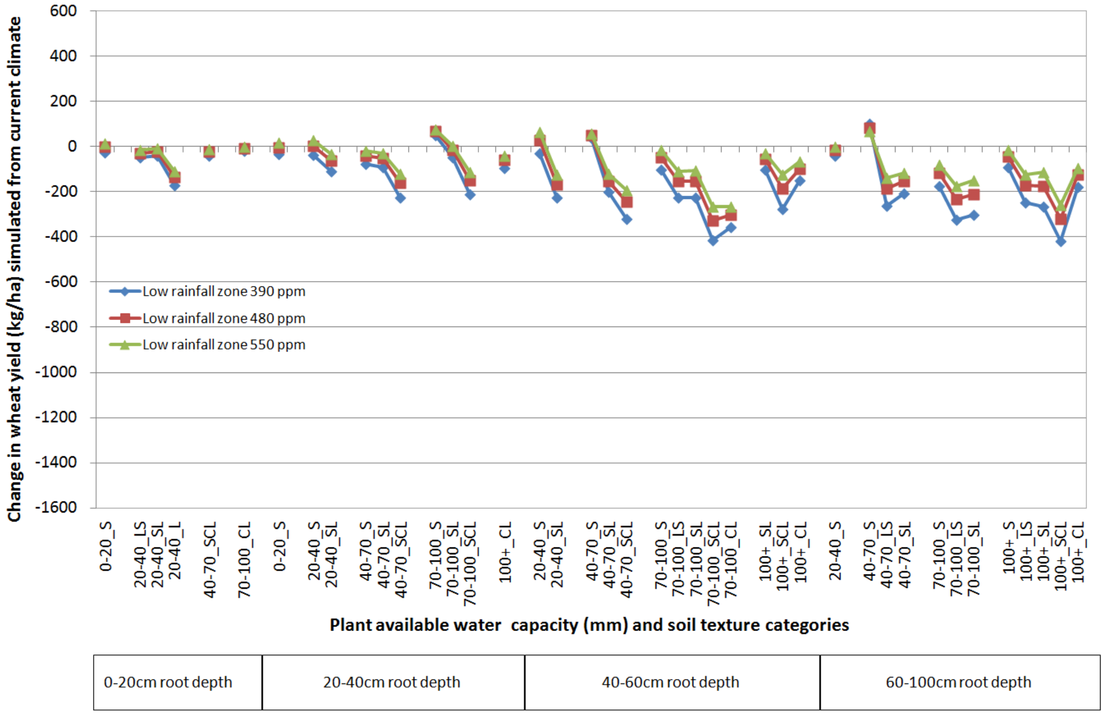


Figure XX Change in wheat simulated from current climate to scenario S2 over the rooting depth, PAWC and soil texture classifications for the low rainfall zone

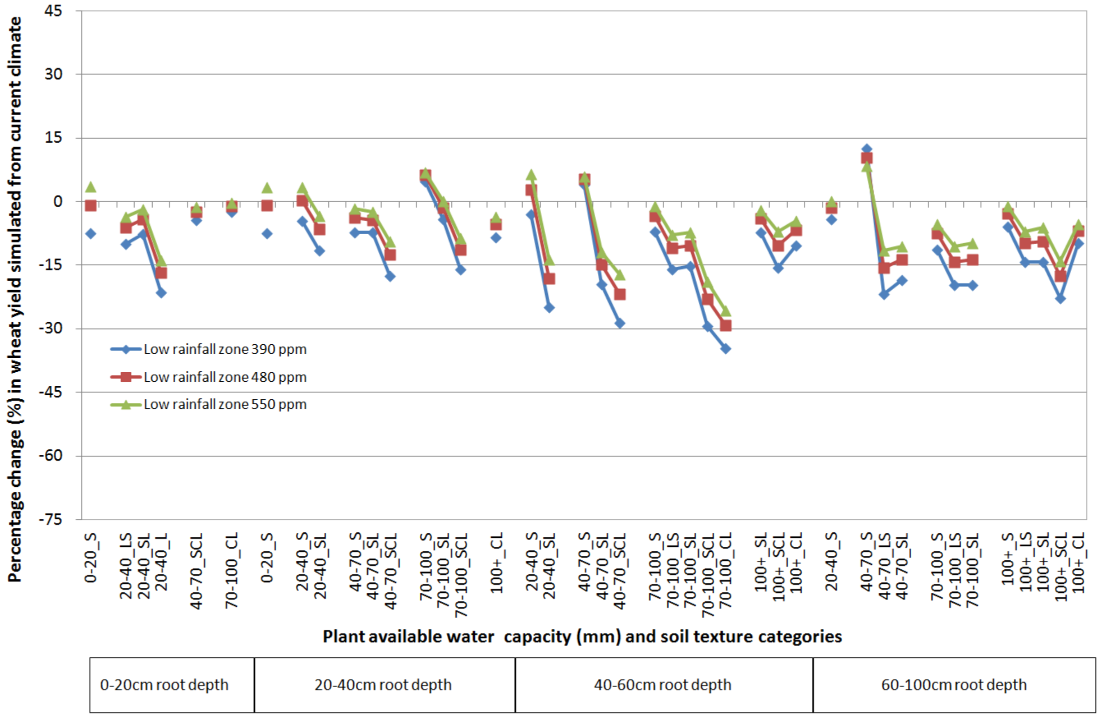


Figure XX Percentage change (%) in wheat simulated from current climate to scenario S2 over the rooting depth, PAWC and soil texture classifications for the low rainfall zone

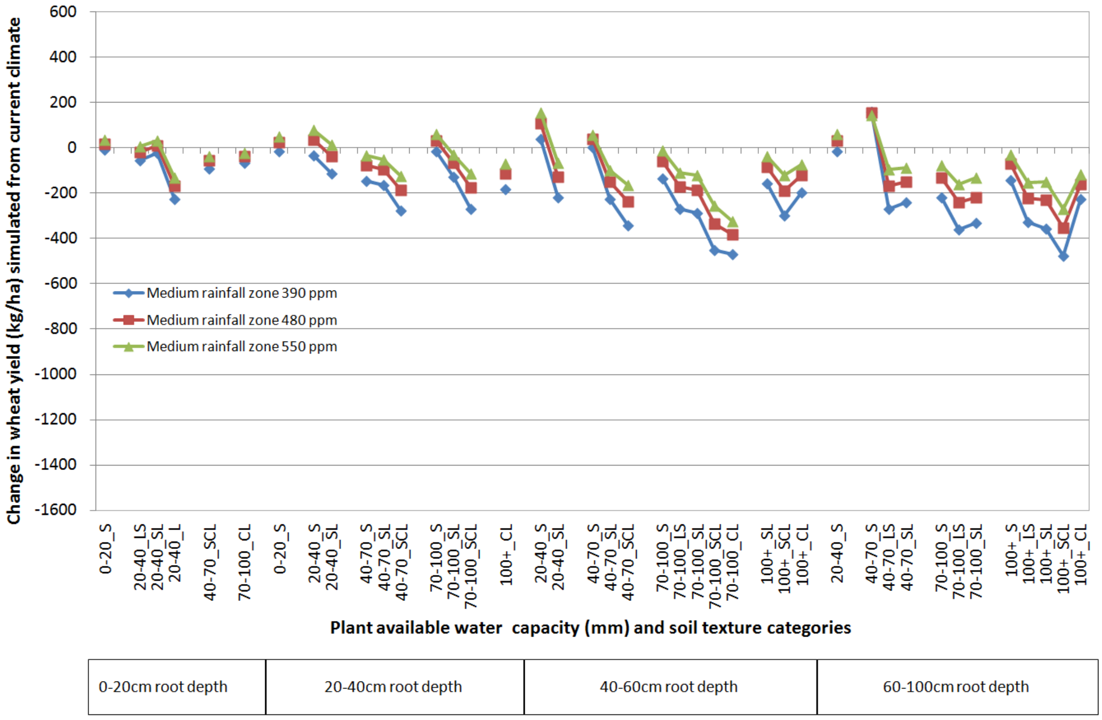


Figure XX Change in wheat simulated from current climate to scenario S2 over the rooting depth, PAWC and soil texture classifications for the medium rainfall zone

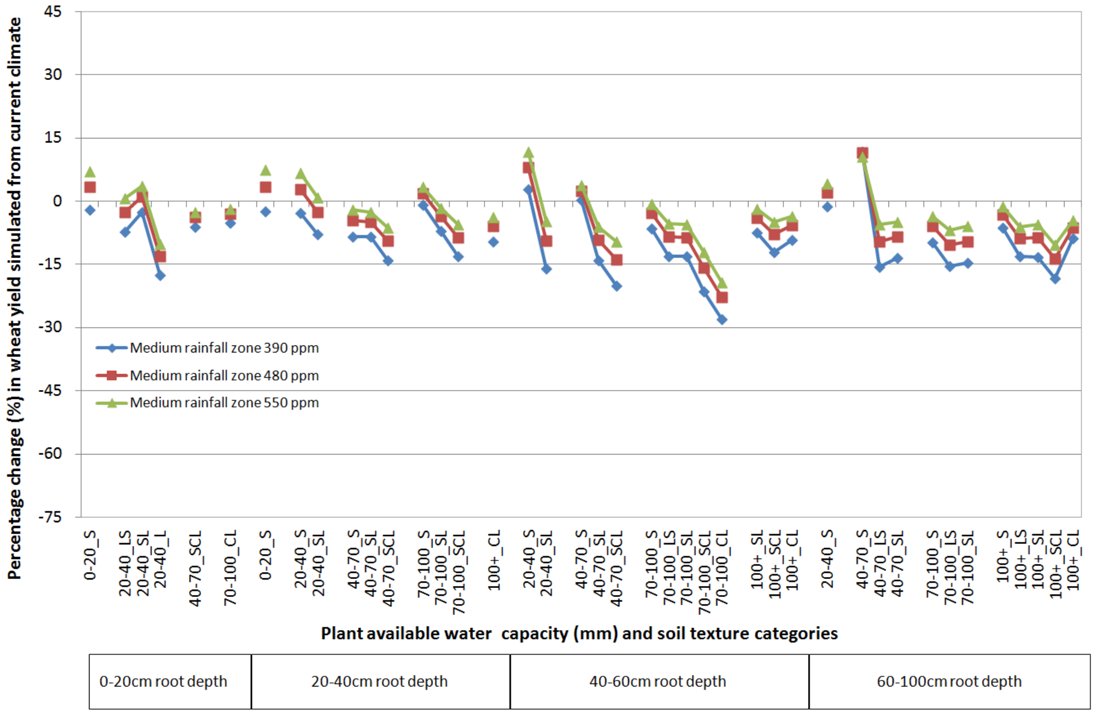


Figure XX Percentage change (%) in wheat simulated from current climate to scenario S2 over the rooting depth, PAWC and soil texture classifications for the medium rainfall zone

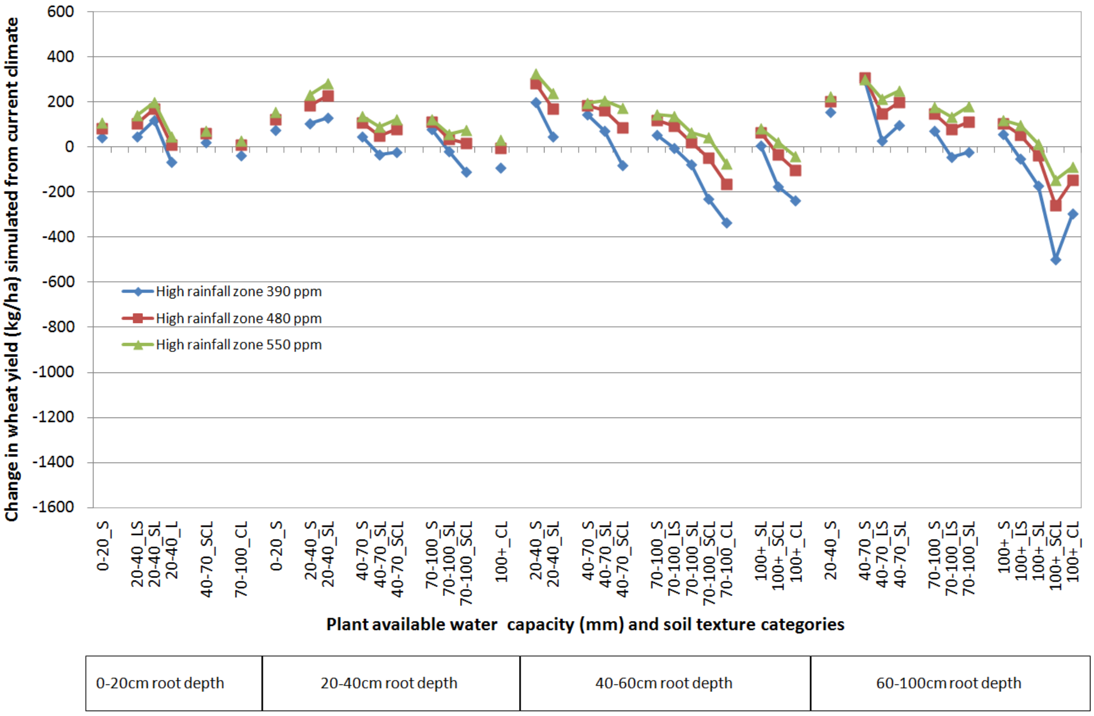


Figure XX Change in wheat simulated from current climate to scenario S2 over the rooting depth, PAWC and soil texture classifications for the high rainfall zone

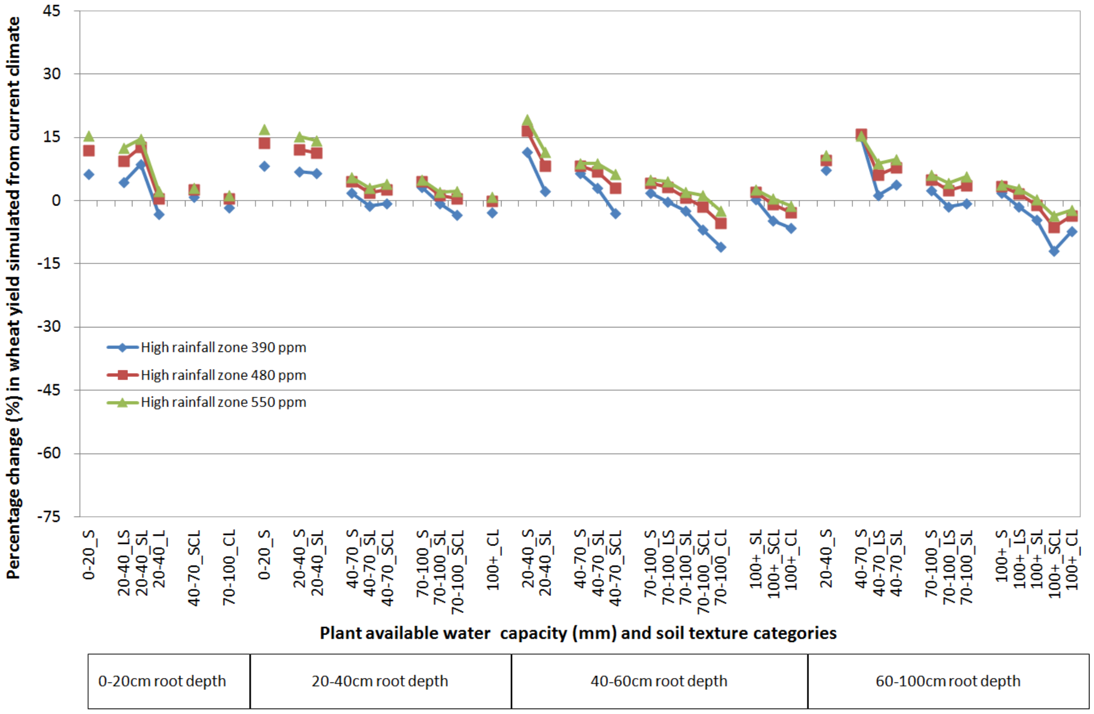


Figure XX Percentage change (%) in wheat simulated from current climate to scenario S2 over the rooting depth, PAWC and soil texture classifications for the high rainfall zone

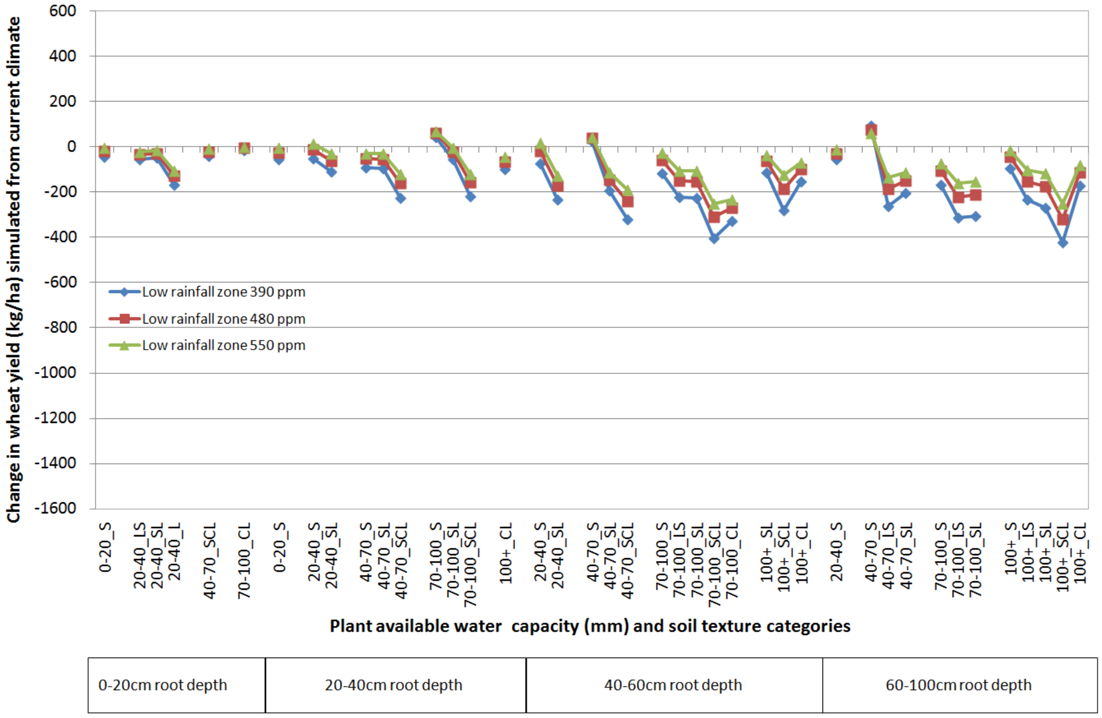


Figure XX Change in wheat simulated from current climate to scenario S6 over the rooting depth, PAWC and soil texture classifications for the low rainfall zone

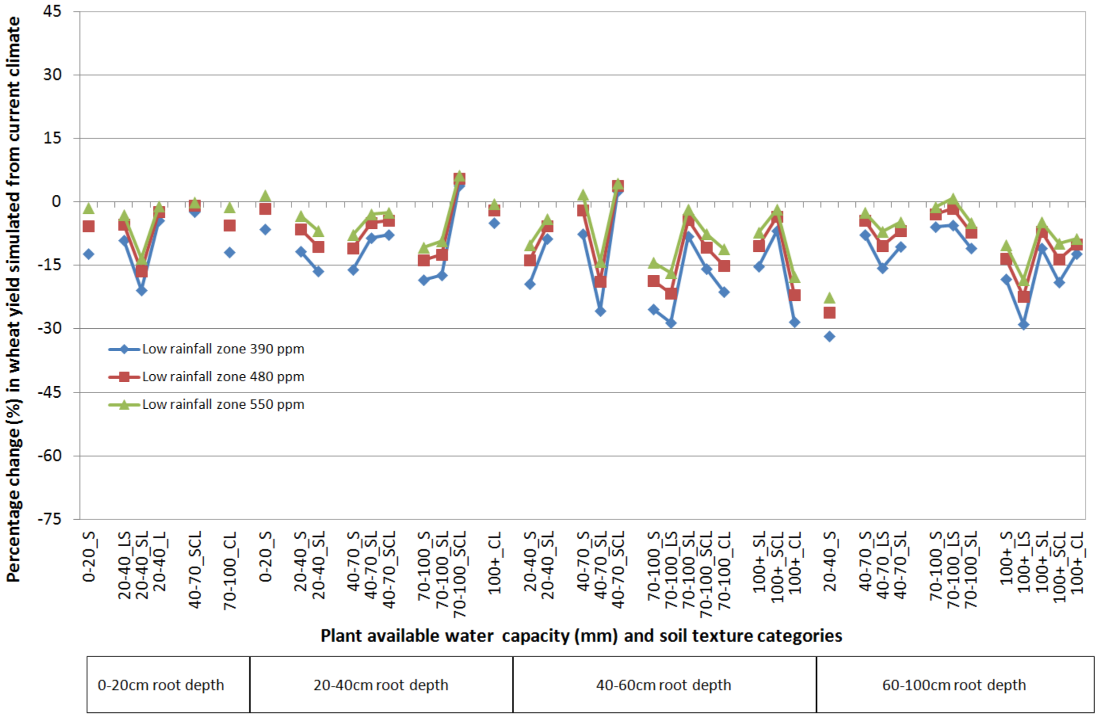


Figure XX Percentage change (%) in wheat simulated from current climate to scenario S6 over the rooting depth, PAWC and soil texture classifications for the low rainfall zone

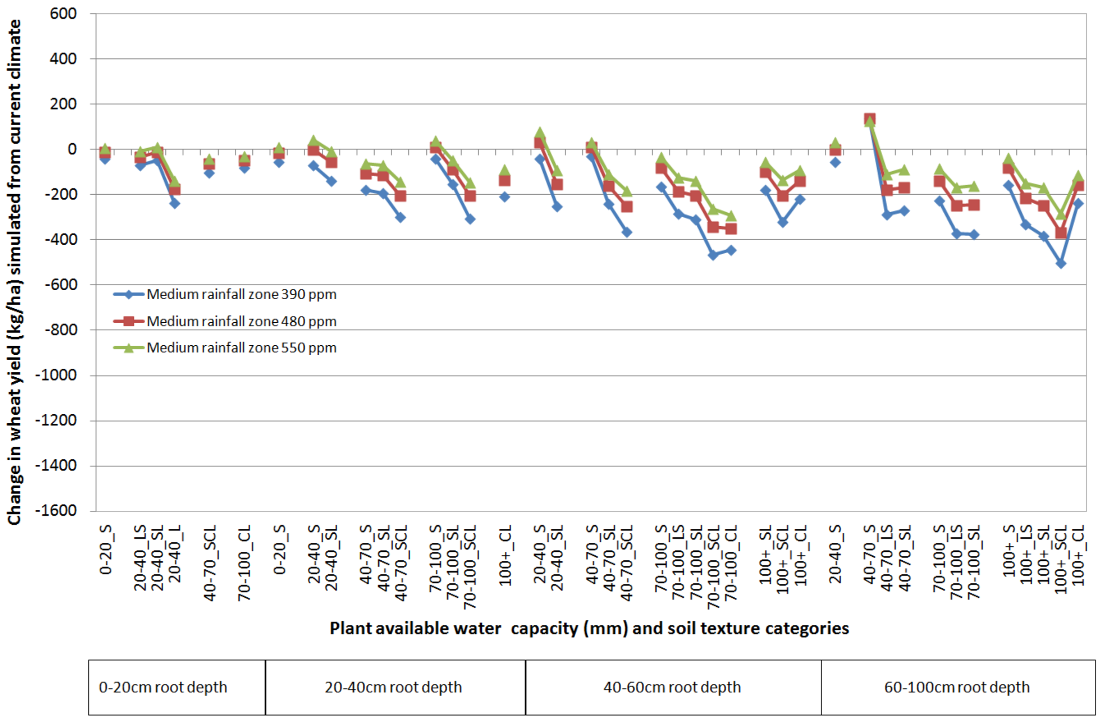


Figure XX Change in wheat simulated from current climate to scenario S6 over the rooting depth, PAWC and soil texture classifications for the medium rainfall zone

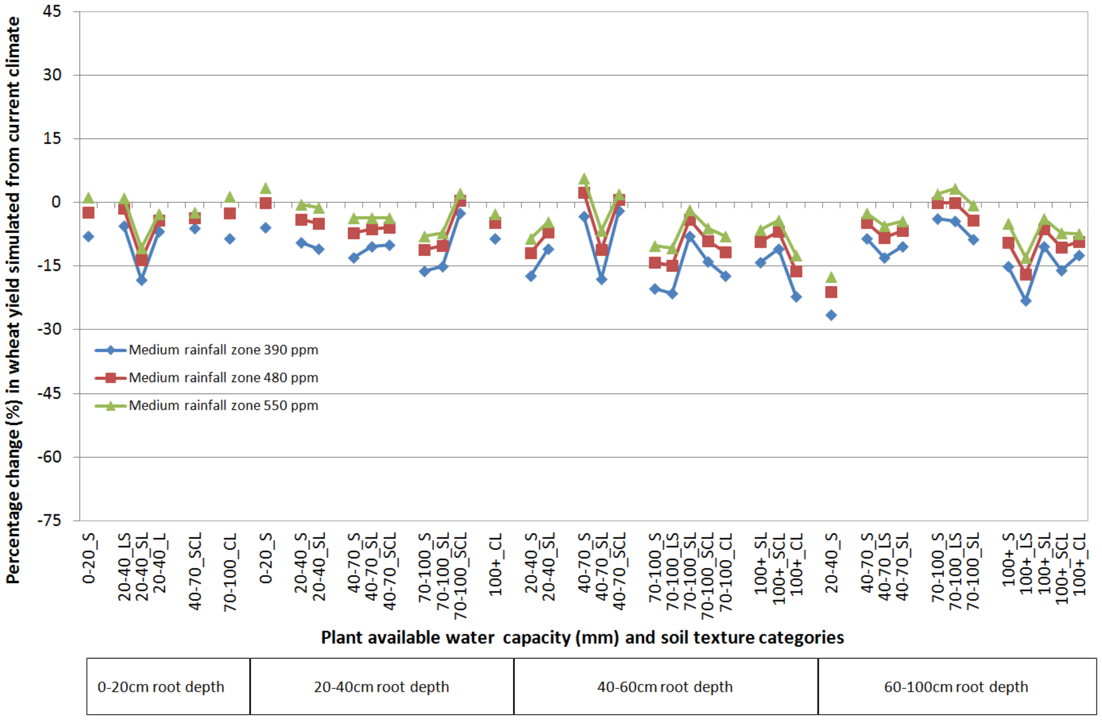


Figure XX Percentage change (%) in wheat simulated from current climate to scenario S6 over the rooting depth, PAWC and soil texture classifications for the medium rainfall zone

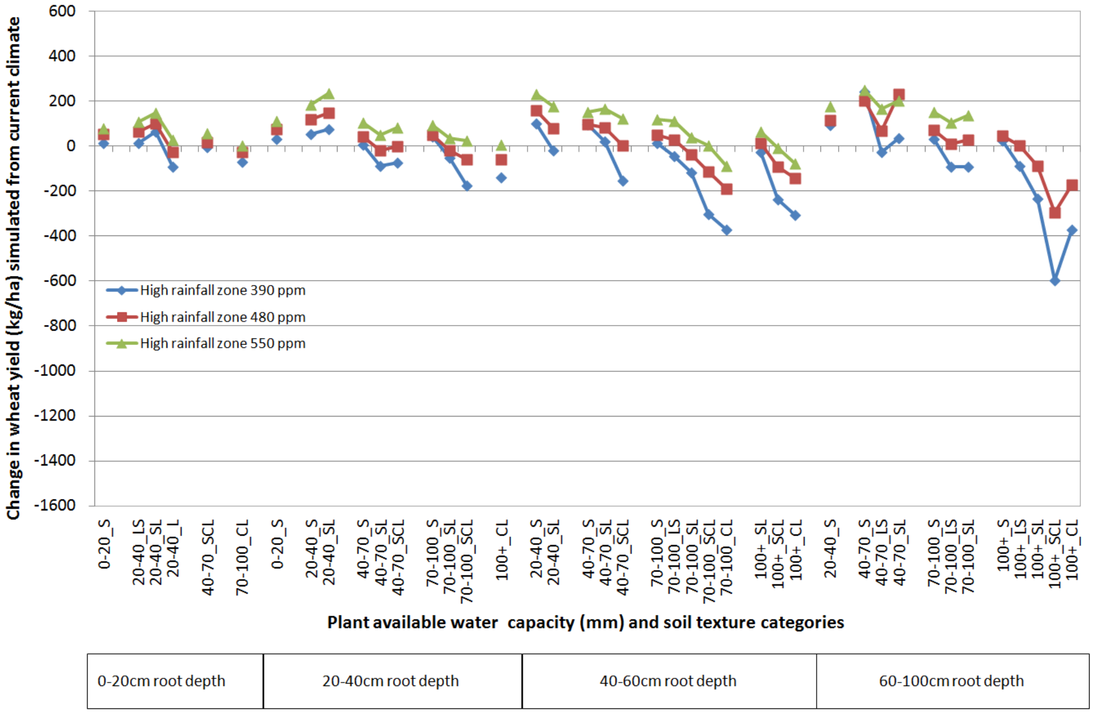


Figure XX Change in wheat simulated from current climate to scenario S6 over the rooting depth, PAWC and soil texture classifications for the high rainfall zone

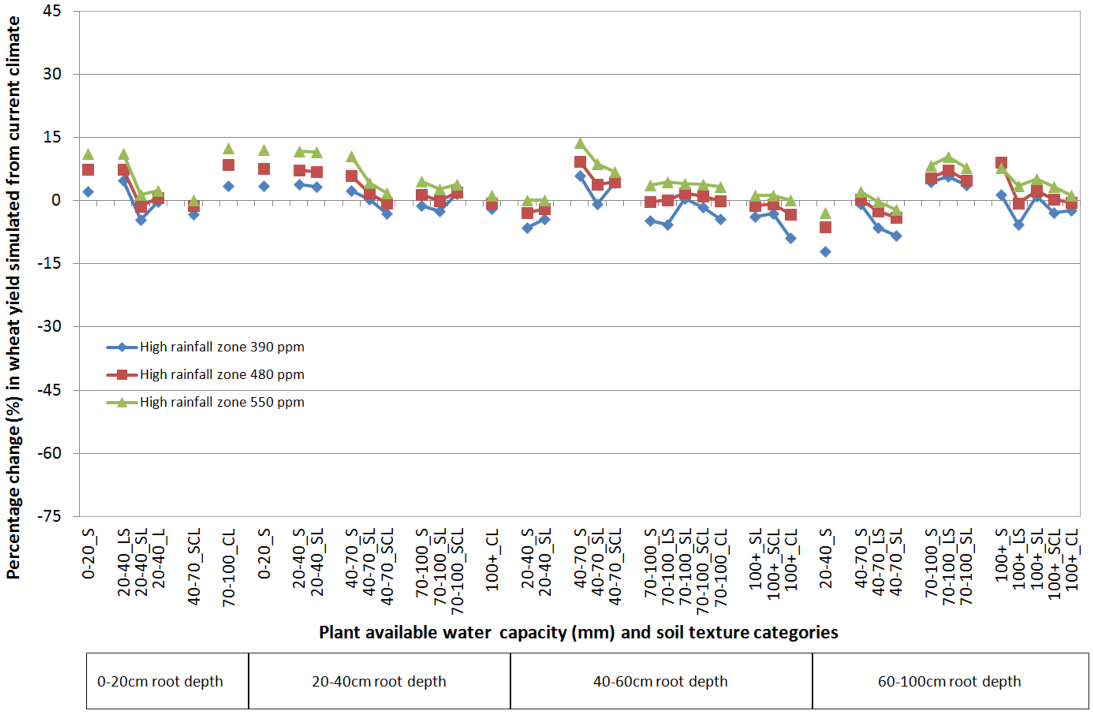


Figure XX Percentage change (%) in wheat simulated from current climate to scenario S6 over the rooting depth, PAWC and soil texture classifications for the high rainfall zone

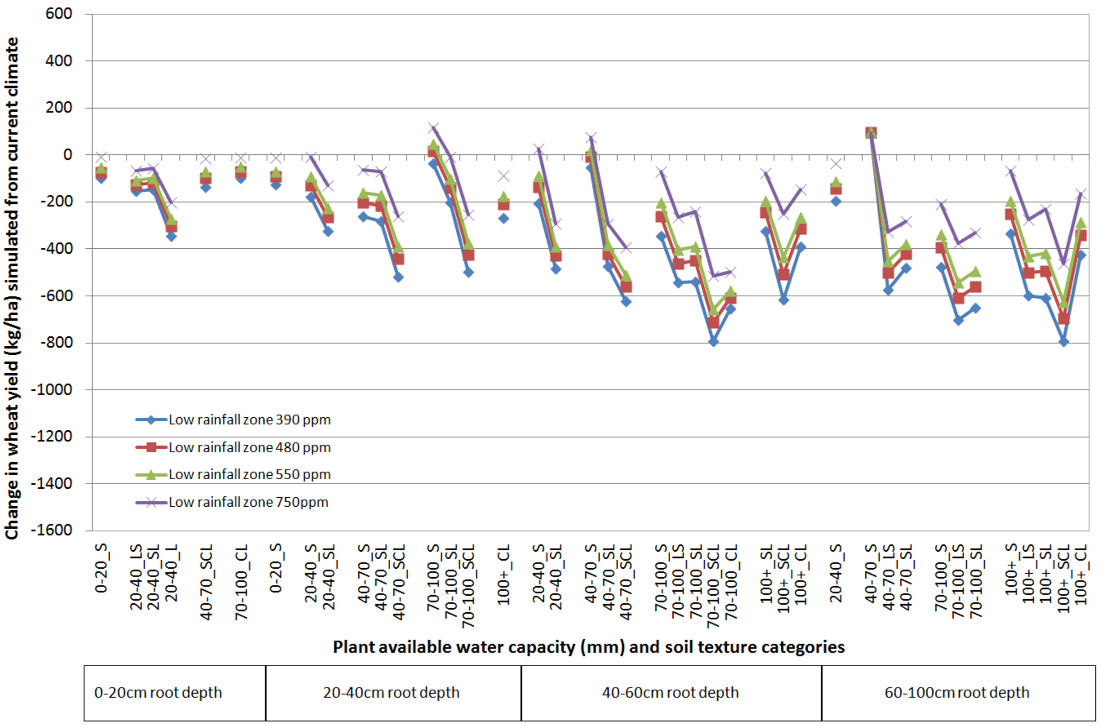


Figure XX Change in wheat simulated from current climate to scenario S3 over the rooting depth, PAWC and soil texture classifications for the low rainfall zone

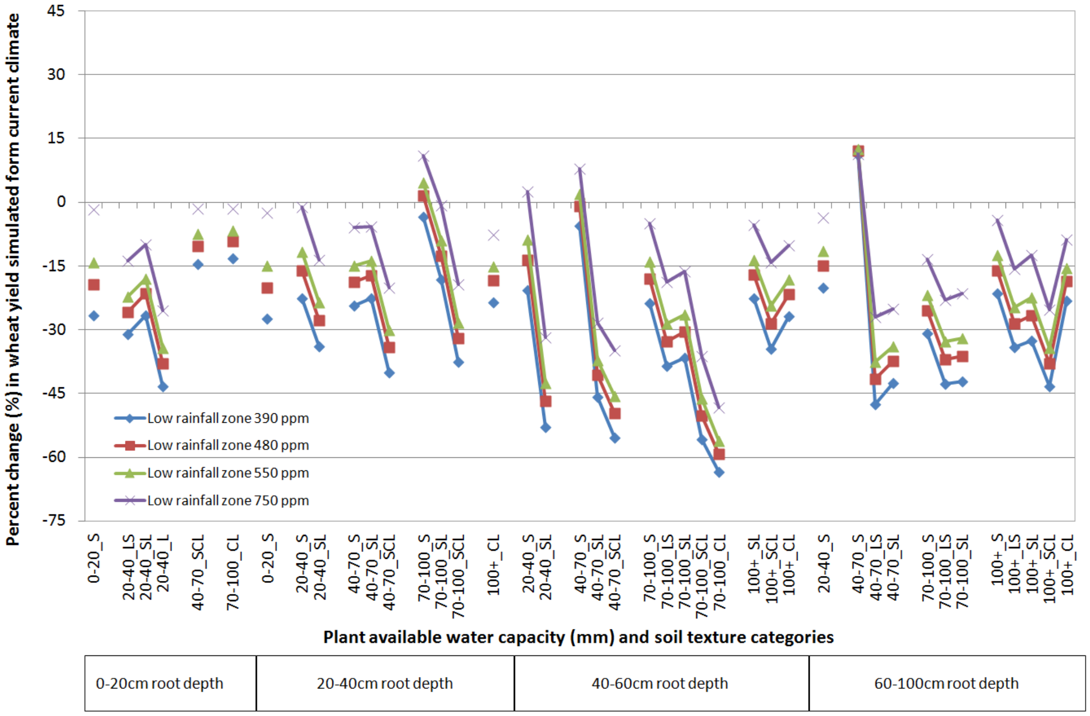


Figure XX Percentage change (%) in wheat simulated from current climate to scenario S3 over the rooting depth, PAWC and soil texture classifications for the low rainfall zone

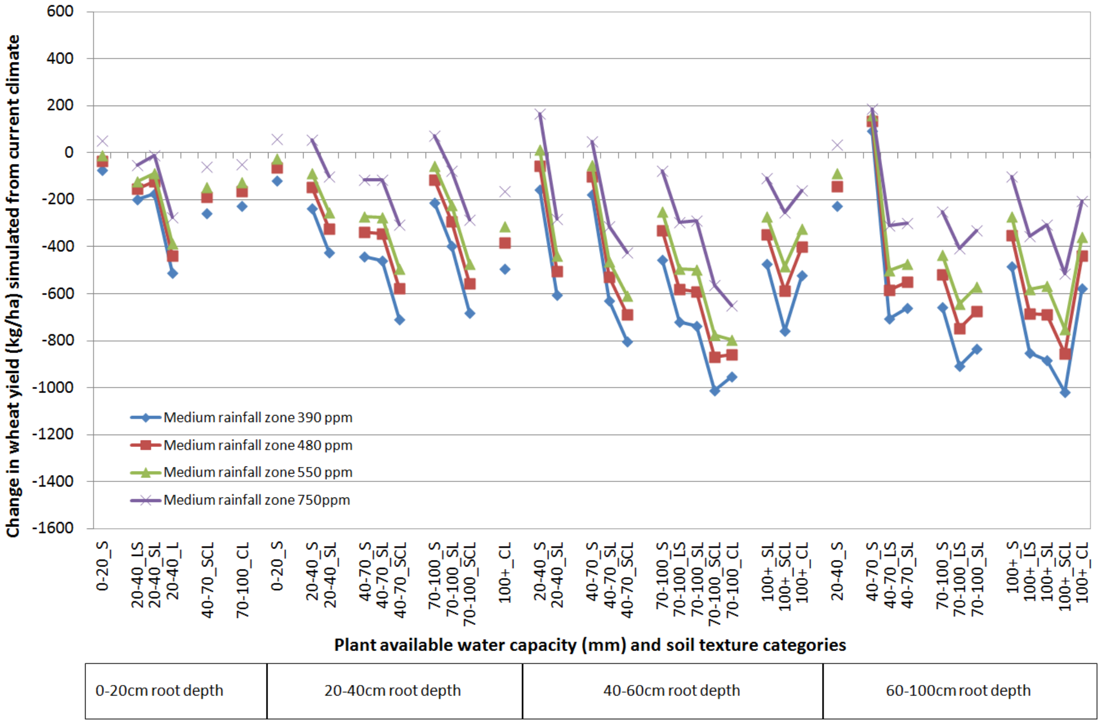


Figure XX Change in wheat simulated from current climate to scenario S3 over the rooting depth, PAWC and soil texture classifications for the medium rainfall zone

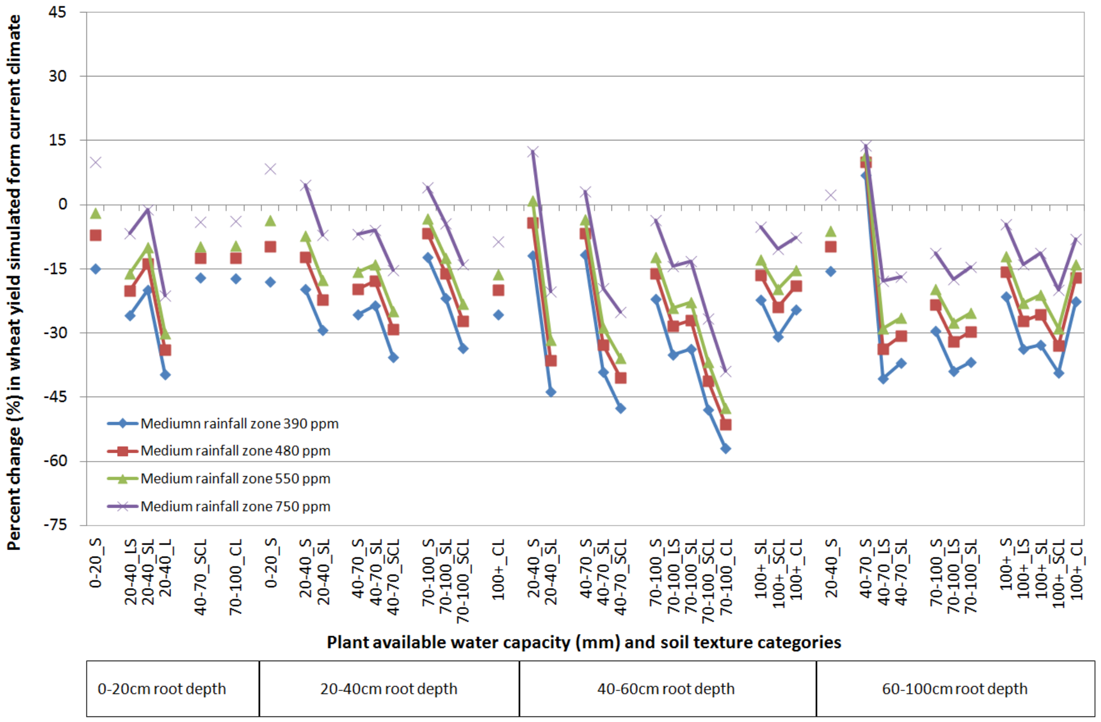


Figure XX Percentage change (%) in wheat simulated from current climate to scenario S2 over the rooting depth, PAWC and soil texture classifications for the medium rainfall zone

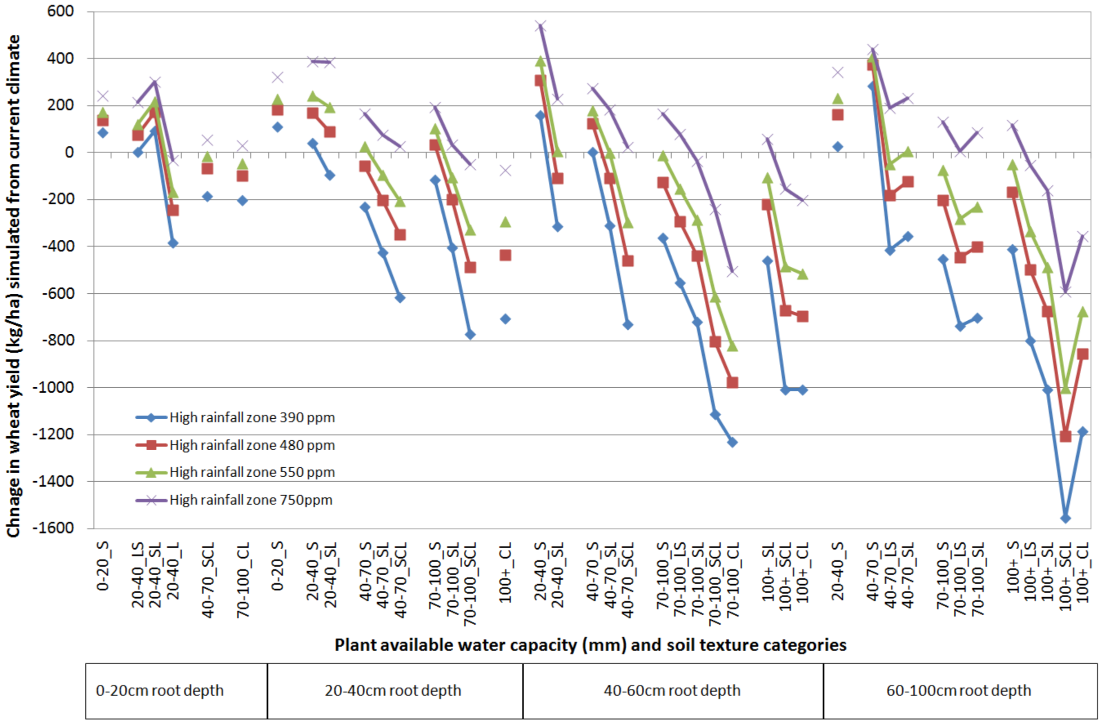


Figure XX Change in wheat simulated from current climate to scenario S3 over the rooting depth, PAWC and soil texture classifications for the high rainfall zone

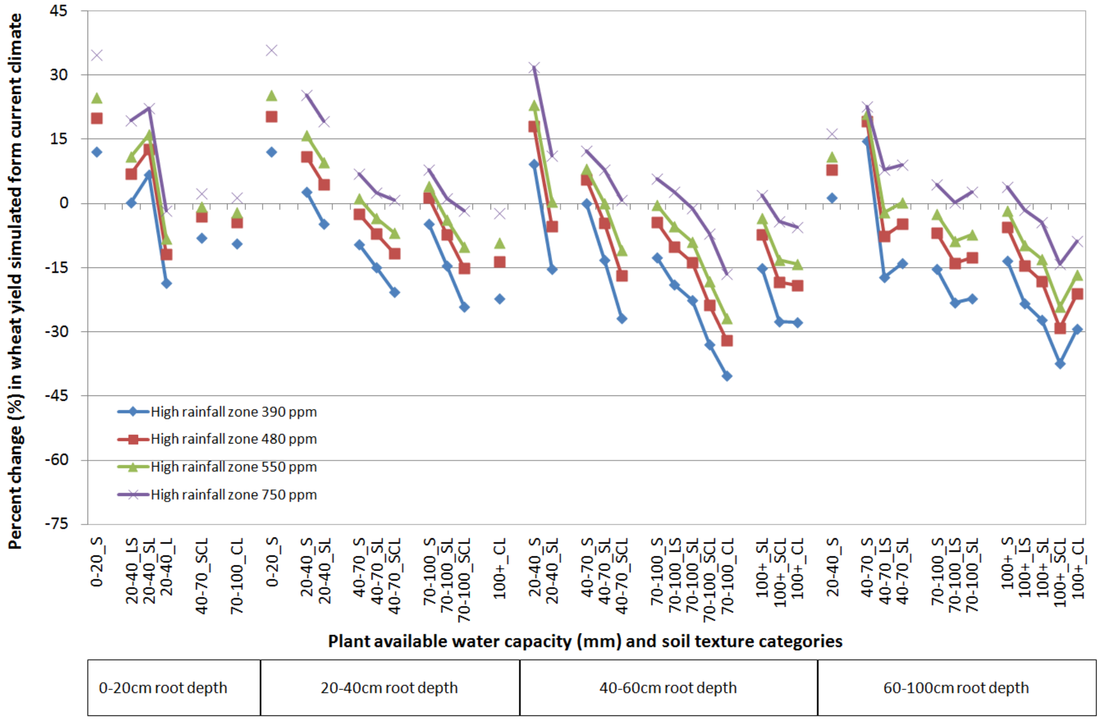
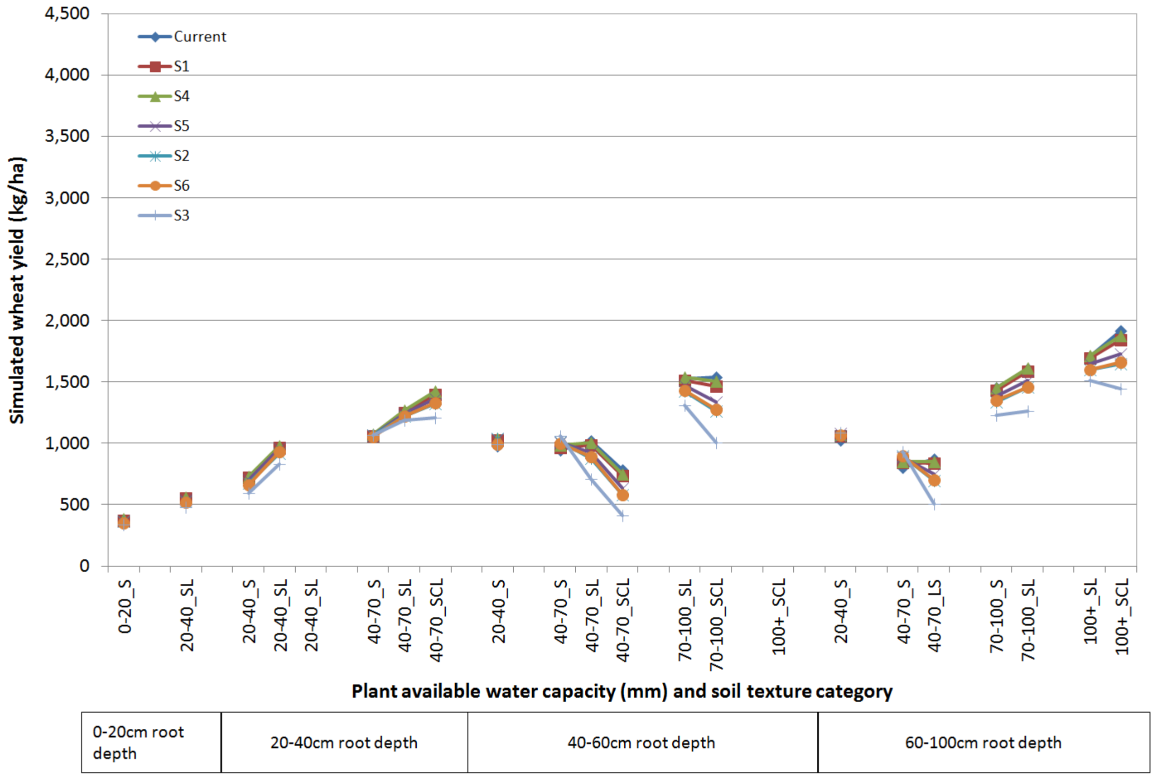
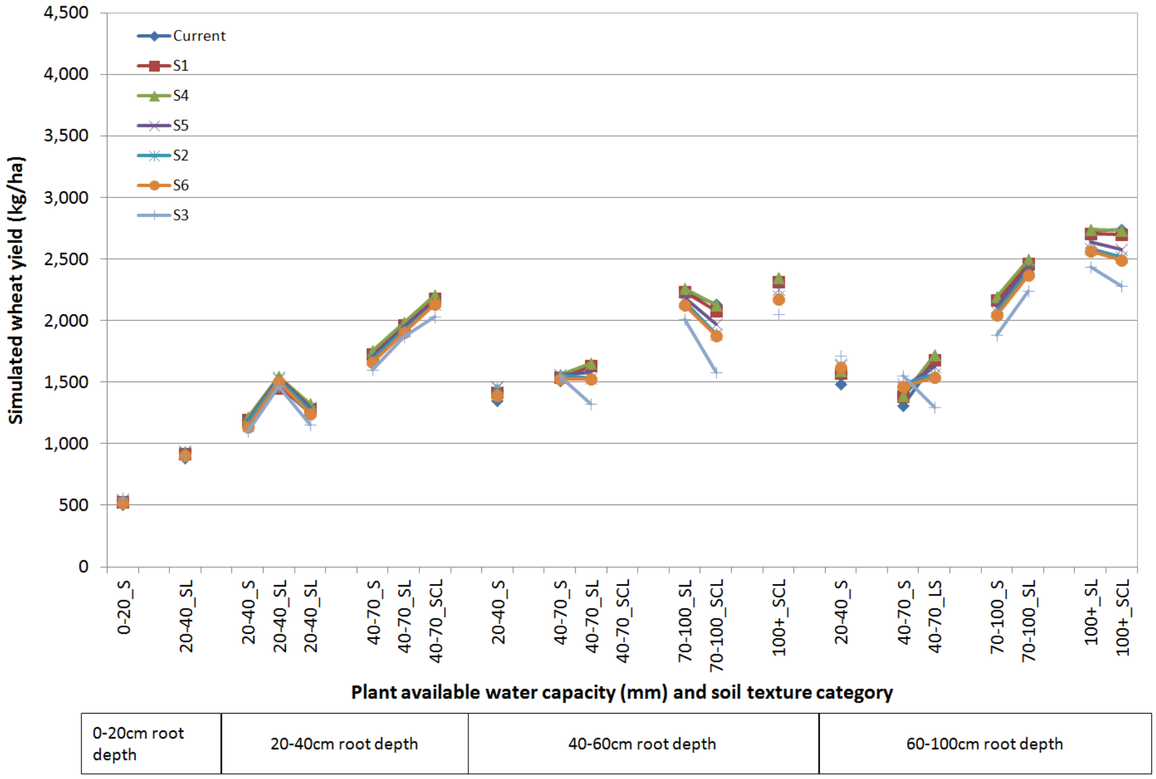


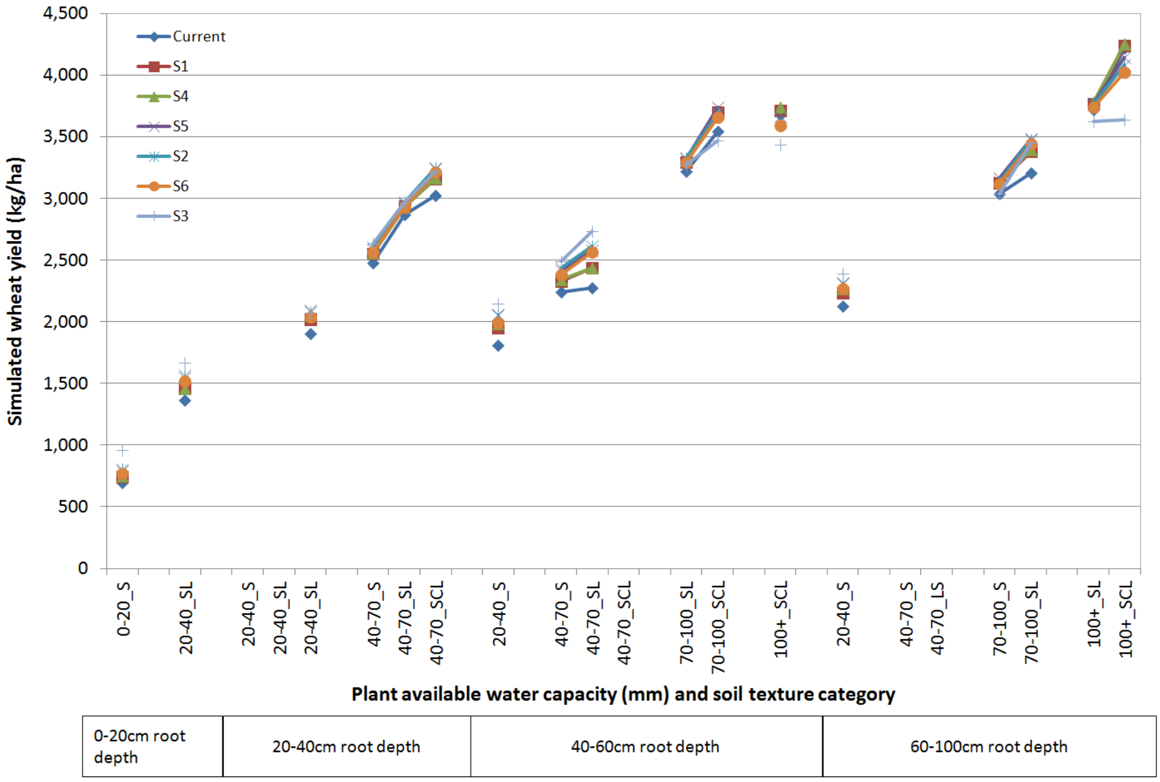
Figure XX Percentage change (%) in wheat simulated from current climate to scenario S3 over the rooting depth, PAWC and soil texture classifications for the low rainfall zone



Climate change impacts on simulated yields by rooting depth, plant available water capacity and soil texture for the low rainfall zone



Climate change impacts on simulated yields by rooting depth, plant available water capacity and soil texture for the medium rainfall zone



Climate change impacts on simulated yields by rooting depth, plant available water capacity and soil texture for the high rainfall zone

Variable Costs to calculate Profit at Full equity by rainfall zone

Cost	Low rainfall zone ($/ha)	Medium rainfall zone ($/ha)	High rainfall zone ($/ha)
Seed	12.3	16.4	17.43
Seed treatment	2.76	3.68	3.91
Levies			
GRDC	3	5	7
EPR and state levies	3.45	5.75	8.05
Fertiliser			
18:20:0 @ $750 /tonne (rate)	37.5 (50)	45 (60)	56.25 (75)
Urea @ $530 /tonne (rate)	10.6 (20)	26.5 (50)	53 (100)
Chemicals			
Pre-emergent herbicides	10.6	40.6	40.6
Post-emergent herbicides	4.63	5.67	5.67
Fungicides	0	7	7
Operations			
Fuel and oil	9.28	11.14	13
Repairs and maintenance	9.03	10.84	12.64
Freight			
Grain	24	40	56
Fertiliser	0.64	1.44	2.4
Contract work			
Aerial spraying	0	12.5	25
Insurance	2.55	4.25	6
Administration	4	4	4
Contracts	7	7	7
Handling and marketing	6	6	6

Hired labour	3	3	3
Interest	13	13	13
Less depreication	26	26	26
Less inputted cost of family labour	21	21	21

Table XX Profit at full equity values for current, S1 and S4 CC scenarios at a grain price of $200 per tonne for the low rainfall zone.

Rooting depth (cm)	PAWC and texture category	Hectares	Percent Area (%)	Current PFE	S1 CC scenario PFE	Difference S1 and Current	Percent change (%)	S4 CC scenario	Difference S4 and Current	Percent change (%)
0-20	0-20_S	29,696.39	2.3	-4,100,222	-3,967,648	132,575	3.2	-4,026,173	74,049	1.8
0-20	20-40_SL	6,775.92	0.5	-679,856	-663,893	15,963	2.3	-671,815	8,042	1.2
20-40	20-40_S	13,191.47	1.0	-885,015	-841,251	43,764	4.9	-868,479	16,536	1.9
20-40	20-40_SL	13,487.84	1.1	-299,849	-198,504	101,345	33.8	-232,837	67,012	22.3
20-40	20-40_SL									
20-40	40-70_S	1,636.72	0.1	1,207	8,481	7,274	602.7	3,134	1,927	159.7
20-40	40-70_SL	256,731.27	20.1	10,237,246	11,195,092	957,846	9.4	10,257,509	20,263	0.2
20-40	40-70_SCL	21,787.47	1.7	1,561,555	1,620,305	58,750	3.8	1,506,164	-55,391	-3.5
40-60	20-40_S	72,869.85	5.7	-1,061,135	-173,363	887,773	83.7	-370,434	690,701	65.1
40-60	40-70_S	25,704.12	2.0	-556,767	-346,222	210,545	-37.8	-434,246	122,521	-22.0
40-60	40-70_SL	598,491.27	46.8	-3,655,774	-5,321,654	-1,665,880	-45.6	-7,464,613	-3,808,839	-104.2
40-60	40-70_SCL	9,672.67	0.8	-513,387	-584,714	-71,326	-13.9	-602,809	-89,422	-17.4
40-60	70-100_SL	133,083.15	10.4	12,593,945	12,943,755	349,810	2.8	12,289,517	-304,428	-2.4
40-60	70-100_SCL	1,407.23	0.1	136,941	127,214	-9,728	-7.1	117,404	-19,537	-14.3
40-60	100+_SCL		0.0							
60-100	20-40_S	2,182.78	0.2	-11,197	10,929	22,126	197.6	5,456	16,653	148.7
60-100	40-70_S	451.94	0.0	-22,026	-18,135	3,891	17.7	-18,385	3,641	16.5
60-100	40-70_LS	11.36	0.0	-407	-448	-41	-10.0	-492	-85	-20.8
60-100	70-100_S	10,899.28	0.9	879,515	878,231	-1,284	-0.1	832,734	-46,782	-5.3
60-100	70-100_SL	72,938.26	5.7	8,095,934	8,167,986	72,052	0.9	7,773,901	-322,033	-4.0
60-100	100+_SL	5,499.61	0.4	725,278	732,587	7,309	1.0	704,766	-20,512	-2.8
60-100	100+_SCL	1,840.35	0.1	319,527	304,250	-15,276	-4.8	292,527	-26,999	-8.4

Table XX Profit at full equity values for current, S5, S2 and S6 CC scenarios at a grain price of $200 per tonne for the low rainfall zone.

Rooting depth (cm)	PAWC and texture category	Hectares	Percent Area (%)	Current PFE	S5 CC scenario PFE	Difference S5 and Current	Percent change (%)	S2 CC scenario PFE	Difference S2 and Current	Percent change (%)	S6 CC scenario PFE	Difference S6 and Current	Percent change (%)
0-20	0-20_S	29,696.39	2.3	-4,100,222	-4,055,676	44,546	1.1	-4,061,090	39,132	1.0	-4,168,828	-68,606	-1.7
0-20	20-40_SL	6,775.92	0.5	-679,856	-691,323	-11,467	-1.7	-710,485	-30,629	-4.5	-720,895	-41,039	-6.0
20-40	20-40_S	13,191.47	1.0	-885,015	-927,086	-42,071	-4.8	-991,397	-106,382	-12.0	-1,028,374	-143,359	-16.2
20-40	20-40_SL	13,487.84	1.1	-299,849	-255,571	44,278	14.8	-351,917	-52,068	-17.4	-319,259	-19,410	-6.5
20-40	20-40_SL												
20-40	40-70_S	1,636.72	0.1	1,207	6,333	5,127	424.8	4,928	3,721	308.3	1,520	313	25.9
20-40	40-70_SL	256,731.27	20.1	10,237,246	9,878,800	-358,445	-3.5	8,793,087	-1,444,158	-14.1	8,651,249	-1,585,997	-15.5
20-40	40-70_SCL	21,787.47	1.7	1,561,555	1,352,574	-208,981	-13.4	1,190,074	-371,481	-23.8	1,204,123	-357,432	-22.9
40-60	20-40_S	72,869.85	5.7	-1,061,135	-217,852	843,284	79.5	-115,172	945,964	89.1	-856,951	204,184	19.2
40-60	40-70_S	25,704.12	2.0	-556,767	-241,448	315,319	56.6	-201,464	355,303	63.8	-276,337	280,430	50.4
40-60	40-70_SL	598,491.27	46.8	-3,655,774	-15,139,089	-11,483,314	314.1	-20,373,631	-16,717,857	457.3	-19,194,424	-15,538,650	425.0
40-60	40-70_SCL	9,672.67	0.8	-513,387	-802,536	-289,149	-56.3	-914,312	-400,925	-78.1	-907,358	-393,971	-76.7
40-60	70-100_SL	133,083.15	10.4	12,593,945	11,204,907	-1,389,038	-11.0	9,992,281	-2,601,664	-20.7	10,117,705	-2,476,240	-19.7
40-60	70-100_SCL	1,407.23	0.1	136,941	80,897	-56,044	-40.9	59,761	-77,180	-56.4	63,232	-73,709	-53.8
40-60	100+_SCL		0.0										
60-100	20-40_S	2,182.78	0.2	-11,197	11,578	22,776	203.4	4,811	16,008	143.0	5,815	17,012	151.9
60-100	40-70_S	451.94	0.0	-22,026	-14,707	7,319	33.2	-13,825	8,201	37.2	-13,883	8,143	37.0
60-100	40-70_LS	11.36	0.0	-407	-681	-275	-67.5	-801	-394	-96.8	-792	-386	-94.8
60-100	70-100_S	10,899.28	0.9	879,515	728,221	-151,295	-17.2	621,748	-257,768	-29.3	646,547	-232,969	-26.5
60-100	70-100_SL	72,938.26	5.7	8,095,934	6,760,399	-1,335,535	-16.5	5,930,707	-2,165,227	-26.7	5,939,134	-2,156,800	-26.6
60-100	100+_SL	5,499.61	0.4	725,278	659,386	-65,892	-9.1	606,889	-118,389	-16.3	603,056	-122,223	-16.9
60-100	100+_SCL	1,840.35	0.1	319,527	249,701	-69,825	-21.9	219,260	-100,267	-31.4	225,225	-94,302	-29.5

Table XX Profit at full equity values for current, S6 CC scenarios at a grain price of $200 per tonne for the low rainfall zone.

Rooting depth (cm)	PAWC and texture category	Hectares	Percent Area (%)	Current PFE	S3 CC scenario PFE	Difference S3 and Current	Percent change (%)
0-20	0-20_S	29,696.39	2.3	-4,100,222	-4,247,340	-147,118	-3.6
0-20	20-40_SL	6,775.92	0.5	-679,856	-776,451	-96,595	-14.2
20-40	20-40_S	13,191.47	1.0	-885,015	-1,209,826	-324,812	-36.7
20-40	20-40_SL	13,487.84	1.1	-299,849	-596,328	-296,479	-98.9
20-40	20-40_SL						
20-40	40-70_S	1,636.72	0.1	1,207	5,705	4,498	372.7
20-40	40-70_SL	256,731.27	20.1	10,237,246	6,898,029	-3,339,217	-32.6
20-40	40-70_SCL	21,787.47	1.7	1,561,555	698,386	-863,169	-55.3
40-60	20-40_S	72,869.85	5.7	-1,061,135	-873,408	187,727	17.7
40-60	40-70_S	25,704.12	2.0	-556,767	47,730	604,497	-108.6
40-60	40-70_SL	598,491.27	46.8	-3,655,774	-40,876,778	-37,221,004	-1,018.1
40-60	40-70_SCL	9,672.67	0.8	-513,387	-1,232,471	-719,084	-140.1
40-60	70-100_SL	133,083.15	10.4	12,593,945	6,968,957	-5,624,988	-44.7
40-60	70-100_SCL	1,407.23	0.1	136,941	-12,436	-149,377	-109.1
40-60	100+_SCL						
60-100	20-40_S	2,182.78	0.2	-11,197	14,865	26,063	232.8
60-100	40-70_S	451.94	0.0	-22,026	-10,829	11,197	50.8
60-100	40-70_LS	11.36	0.0	-407	-1,229	-822	-202.0
60-100	70-100_S	10,899.28	0.9	879,515	387,561	-491,955	-55.9
60-100	70-100_SL	72,938.26	5.7	8,095,934	3,115,299	-4,980,635	-61.5
60-100	100+_SL	5,499.61	0.4	725,278	504,182	-221,096	-30.5
60-100	100+_SCL	1,840.35	0.1	319,527	145,028	-174,498	-54.6

Table XX Profit at full equity values for current, S1 and S4 CC scenarios at a grain price of $250 per tonne for the low rainfall zone.

Rooting depth (cm)	PAWC and texture category	Hectares	Percent Area (%)	Current PFE	S1 CC scenario PFE	Difference S1 and Current	Percent change (%)	S4 CC scenario PFE	Difference S4 and Current	Percent change (%)
0-20	0-20_S	29,696.39	2.32	-3,566,217	-3,400,499	165,718	4.6	-3,473,656	92,561	2.6
0-20	20-40_SL	6,775.92	0.53	-494,085	-474,131	19,954	4.0	-484,033	10,052	2.0
20-40	20-40_S	13,191.47	1.03	-413,716	-359,012	54,704	13.2	-393,046	20,670	5.0
20-40	20-40_SL	13,487.84	1.06	333,300	459,982	126,682	38.0	417,065	83,765	25.1
20-40	20-40_SL									
20-40	40-70_S	1,636.72	0.13	87,437	96,529	9,092	10.4	89,845	2,409	2.8
20-40	40-70_SL	256,731.27	20.08	26,274,949	27,472,256	1,197,307	4.6	26,300,277	25,328	0.1
20-40	40-70_SCL	21,787.47	1.70	3,095,786	3,169,223	73,437	2.4	3,026,547	-69,238	-2.2
40-60	20-40_S	72,869.85	5.70	2,499,248	3,608,964	1,109,716	44.4	3,362,625	863,377	34.5
40-60	40-70_S	25,704.12	2.01	653,507	916,688	263,181	40.3	806,659	153,152	23.4
40-60	40-70_SL	598,491.27	46.82	26,851,074	24,768,725	-2,082,349	-7.8	22,090,025	-4,761,049	-17.7
40-60	40-70_SCL	9,672.67	0.76	-133,919	-223,077	-89,158	66.6	-245,696	-111,777	83.5
40-60	70-100_SL	133,083.15	10.41	22,729,297	23,166,559	437,263	1.9	22,348,762	-380,535	-1.7
40-60	70-100_SCL	1,407.23	0.11	245,056	232,896	-12,159	-5.0	220,634	-24,421	-10.0
40-60	100+_SCL									
60-100	20-40_S	2,182.78	0.17	100,599	128,257	27,658	27.5	121,416	20,817	20.7
60-100	40-70_S	451.94	0.04	-3,805	1,058	4,864	127.8	745	4,551	119.6
60-100	40-70_LS	11.36	0.00	88	37	-51	-58.2	-18	-106	-121.0
60-100	70-100_S	10,899.28	0.85	1,671,607	1,670,001	-1,605	-0.1	1,613,129	-58,477	-3.5
60-100	70-100_SL	72,938.26	5.71	13,949,176	14,039,241	90,065	0.6	13,546,635	-402,541	-2.9
60-100	100+_SL	5,499.61	0.43	1,195,327	1,204,464	9,136	0.8	1,169,687	-25,640	-2.1
60-100	100+_SCL	1,840.35	0.14	496,027	476,931	-19,095	-3.8	462,278	-33,749	-6.8

Table XX Profit at full equity values for current, S5, S2 and S6 CC scenarios at a grain price of $250 per tonne for the low rainfall zone.

Rooting depth (cm)	PAWC and texture category	Hectares	Percent Area (%)	Current PFE	S5 CC scenario PFE	Difference S5 and Current	Percent change (%)	S2 CC scenario PFE	Difference S2 and Current	Percent change (%)	S6 CC scenario PFE	Difference S6 and Current	Percent change (%)
0-20	0-20_S	29,696.39	2.32	-3,566,217	-3,510,534	55,683	1.6	-3,517,302	48,915	1.4	-3,651,975	-85,757	-2.4
0-20	20-40_SL	6,775.92	0.53	-494,085	-508,418	-14,333	-2.9	-532,371	-38,286	-7.7	-545,384	-51,299	-10.4
20-40	20-40_S	13,191.47	1.03	-413,716	-466,305	-52,589	-12.7	-546,694	-132,978	-32.1	-592,915	-179,199	-43.3
20-40	20-40_SL	13,487.84	1.06	333,300	388,647	55,347	16.6	268,215	-65,085	-19.5	309,038	-24,262	-7.3
20-40	20-40_SL												
20-40	40-70_S	1,636.72	0.13	87,437	93,845	6,408	7.3	92,087	4,651	5.3	87,828	391	0.4
20-40	40-70_SL	256,731.27	20.08	26,274,949	25,826,892	-448,057	-1.7	24,469,751	-1,805,198	-6.9	24,292,453	-1,982,496	-7.5
20-40	40-70_SCL	21,787.47	1.70	3,095,786	2,834,559	-261,226	-8.4	2,631,434	-464,351	-15.0	2,648,996	-446,790	-14.4
40-60	20-40_S	72,869.85	5.70	2,499,248	3,553,353	1,054,105	42.2	3,681,703	1,182,455	47.3	2,754,478	255,230	10.2
40-60	40-70_S	25,704.12	2.01	653,507	1,047,656	394,149	60.3	1,097,636	444,129	68.0	1,004,045	350,537	53.6
40-60	40-70_SL	598,491.27	46.82	26,851,074	12,496,931	-14,354,143	-53.5	5,953,753	-20,897,321	-77.8	7,427,761	-19,423,313	-72.3
40-60	40-70_SCL	9,672.67	0.76	-133,919	-495,355	-361,436	-269.9	-635,075	-501,156	-374.2	-626,383	-492,464	-367.7
40-60	70-100_SL	133,083.15	10.41	22,729,297	20,993,000	-1,736,297	-7.6	19,477,217	-3,252,080	-14.3	19,633,997	-3,095,300	-13.6
40-60	70-100_SCL	1,407.23	0.11	245,056	175,001	-70,055	-28.6	148,581	-96,475	-39.4	152,919	-92,137	-37.6
40-60	100+_SCL												
60-100	20-40_S	2,182.78	0.17	100,599	129,069	28,470	28.3	120,610	20,010	19.9	121,865	21,265	21.1
60-100	40-70_S	451.94	0.04	-3,805	5,343	9,149	240.4	6,446	10,251	269.4	6,374	10,179	267.5
60-100	40-70_LS	11.36	0.00	88	-256	-343	-391.5	-404	-492	-561.3	-394	-482	-549.8
60-100	70-100_S	10,899.28	0.85	1,671,607	1,482,488	-189,119	-11.3	1,349,397	-322,209	-19.3	1,380,396	-291,211	-17.4
60-100	70-100_SL	72,938.26	5.71	13,949,176	12,279,757	-1,669,419	-12.0	11,242,642	-2,706,534	-19.4	11,253,176	-2,696,000	-19.3
60-100	100+_SL	5,499.61	0.43	1,195,327	1,112,963	-82,365	-6.9	1,047,341	-147,986	-12.4	1,042,549	-152,778	-12.8
60-100	100+_SCL	1,840.35	0.14	496,027	408,745	-87,282	-17.6	370,694	-125,333	-25.3	378,150	-117,877	-23.8

Table XX Profit at full equity values for current and S3 CC scenarios at a grain price of $250 per tonne for the low rainfall zone.

Rooting depth (cm)	PAWC and texture category	Hectares	Percent Area (%)	Current PFE	S3 CC scenario PFE	Difference S3 and Current	Percent change (%)
0-20	0-20_S	29,696.39	2.32	-3,566,217	-3,750,114	-183,897	-5.2
0-20	20-40_SL	6,775.92	0.53	-494,085	-614,829	-120,744	-24.4
20-40	20-40_S	13,191.47	1.03	-413,716	-819,731	-406,015	-98.1
20-40	20-40_SL	13,487.84	1.06	333,300	-37,298	-370,599	-111.2
20-40	20-40_SL						
20-40	40-70_S	1,636.72	0.13	87,437	93,060	5,623	6.4
20-40	40-70_SL	256,731.27	20.08	26,274,949	22,100,928	-4,174,021	-15.9
20-40	40-70_SCL	21,787.47	1.70	3,095,786	2,016,824	-1,078,962	-34.9
40-60	20-40_S	72,869.85	5.70	2,499,248	2,733,907	234,659	9.4
40-60	40-70_S	25,704.12	2.01	653,507	1,409,129	755,621	115.6
40-60	40-70_SL	598,491.27	46.82	26,851,074	-19,675,181	-46,526,255	-173.3
40-60	40-70_SCL	9,672.67	0.76	-133,919	-1,032,774	-898,855	-671.2
40-60	70-100_SL	133,083.15	10.41	22,729,297	15,698,062	-7,031,235	-30.9
40-60	70-100_SCL	1,407.23	0.11	245,056	58,335	-186,721	-76.2
40-60	100+_SCL						
60-100	20-40_S	2,182.78	0.17	100,599	133,178	32,578	32.4
60-100	40-70_S	451.94	0.04	-3,805	10,190	13,996	367.8
60-100	40-70_LS	11.36	0.00	88	-940	-1,027	-1,171.7
60-100	70-100_S	10,899.28	0.85	1,671,607	1,056,663	-614,943	-36.8
60-100	70-100_SL	72,938.26	5.71	13,949,176	7,723,382	-6,225,794	-44.6
60-100	100+_SL	5,499.61	0.43	1,195,327	918,957	-276,371	-23.1
60-100	100+_SCL	1,840.35	0.14	496,027	277,904	-218,123	-44.0

Table XX Profit at full equity values for current, S1 and S4 CC scenarios at a grain price of $300 per tonne for the low rainfall zone.

Rooting depth (cm)	PAWC and texture category	Hectares	Percent Area (%)	Current PFE	S1 CC scenario PFE	Difference S1 and Current	Percent change (%)	S4 CC scenario PFE	Difference S4 and Current	Percent change (%)
0-20	0-20_S	29,696	2.32	-3,032,212	-2,833,350	198,862	6.6	-2,921,139	111,073	3.7
0-20	20-40_SL	6,776	0.53	-308,313	-284,369	23,945	7.8	-296,251	12,063	3.9
20-40	20-40_S	13,191	1.03	57,582	123,228	65,645	114.0	82,386	24,804	43.1
20-40	20-40_SL	13,488	1.06	966,450	1,118,467	152,018	15.7	1,066,968	100,518	10.4
20-40	20-40_SL									
20-40	40-70_S	1,637	0.13	173,666	184,577	10,911	6.3	176,557	2,891	1.7
20-40	40-70_SL	256,731	20.08	42,312,652	43,749,421	1,436,769	3.4	42,343,046	30,394	0.1
20-40	40-70_SCL	21,787	1.70	4,630,016	4,718,141	88,125	1.9	4,546,931	-83,086	-1.8
40-60	20-40_S	72,870	5.70	6,059,632	7,391,290	1,331,659	22.0	7,095,683	1,036,052	17.1
40-60	40-70_S	25,704	2.01	1,863,782	2,179,599	315,817	16.9	2,047,564	183,782	9.9
40-60	40-70_SL	598,491	46.82	57,357,922	54,859,103	-2,498,819	-4.4	51,644,664	-5,713,258	-10.0
40-60	40-70_SCL	9,673	0.76	245,549	138,560	-106,989	-43.6	111,416	-134,133	-54.6
40-60	70-100_SL	133,083	10.41	32,864,648	33,389,364	524,715	1.6	32,408,007	-456,642	-1.4
40-60	70-100_SCL	1,407	0.11	353,170	338,579	-14,591	-4.1	323,865	-29,306	-8.3
40-60	100+_SCL									
60-100	20-40_S	2,183	0.17	212,396	245,586	33,189	15.6	237,376	24,980	11.8
60-100	40-70_S	452	0.04	14,415	20,251	5,836	40.5	19,876	5,461	37.9
60-100	40-70_LS	11	0.00	582	521	-61	-10.5	455	-127	-21.9
60-100	70-100_S	10,899	0.85	2,463,698	2,461,772	-1,926	-0.1	2,393,525	-70,173	-2.8
60-100	70-100_SL	72,938	5.71	19,802,418	19,910,496	108,078	0.5	19,319,369	-483,050	-2.4
60-100	100+_SL	5,500	0.43	1,665,377	1,676,340	10,963	0.7	1,634,608	-30,768	-1.8
60-100	100+_SCL	1,840	0.14	672,527	649,612	-22,915	-3.4	632,028	-40,499	-6.0

Table XX Profit at full equity values for current, S5,S2 and S6 CC scenarios at a grain price of $300 per tonne for the low rainfall zone.

Rooting depth (cm)	PAWC and texture category	Hectares	Percent Area (%)	Current PFE	S5 CC scenario PFE	Difference S5 and Current	Percent change (%)	S2 CC scenario PFE	Difference S2 and Current	Percent change (%)	S6 CC scenario PFE	Difference S6 and Current	Percent change (%)
0-20	0-20_S	29,696	2.32	-3,032,212	-2,965,393	66,820	2.2	-2,973,514	58,698	1.9	-3,135,121	-102,909	-3.4
0-20	20-40_SL	6,776	0.53	-308,313	-325,513	-17,200	-5.6	-354,257	-45,943	-14.9	-369,872	-61,558	-20.0
20-40	20-40_S	13,191	1.03	57,582	-5,524	-63,106	-109.6	-101,991	-159,574	-277.1	-157,456	-215,039	-373.4
20-40	20-40_SL	13,488	1.06	966,450	1,032,866	66,416	6.9	888,347	-78,102	-8.1	937,335	-29,115	-3.0
20-40	20-40_SL												
20-40	40-70_S	1,637	0.13	173,666	181,356	7,690	4.4	179,247	5,581	3.2	174,136	470	0.3
20-40	40-70_SL	256,731	20.08	42,312,652	41,774,983	-537,668	-1.3	40,146,414	-2,166,238	-5.1	39,933,657	-2,378,995	-5.6
20-40	40-70_SCL	21,787	1.70	4,630,016	4,316,545	-313,472	-6.8	4,072,795	-557,222	-12.0	4,093,869	-536,148	-11.6
40-60	20-40_S	72,870	5.70	6,059,632	7,324,557	1,264,926	20.9	7,478,577	1,418,946	23.4	6,365,908	306,276	5.1
40-60	40-70_S	25,704	2.01	1,863,782	2,336,761	472,979	25.4	2,396,737	532,955	28.6	2,284,427	420,645	22.6
40-60	40-70_SL	598,491	46.82	57,357,922	40,132,951	-17,224,971	-30.0	32,281,137	-25,076,786	-43.7	34,049,947	-23,307,975	-40.6
40-60	40-70_SCL	9,673	0.76	245,549	-188,174	-433,724	-176.6	-355,838	-601,387	-244.9	-345,407	-590,956	-240.7
40-60	70-100_SL	133,083	10.41	32,864,648	30,781,092	-2,083,557	-6.3	28,962,153	-3,902,496	-11.9	29,150,288	-3,714,360	-11.3
40-60	70-100_SCL	1,407	0.11	353,170	269,104	-84,066	-23.8	237,401	-115,770	-32.8	242,606	-110,564	-31.3
40-60	100+_SCL												
60-100	20-40_S	2,183	0.17	212,396	246,560	34,164	16.1	236,408	24,012	11.3	237,915	25,518	12.0
60-100	40-70_S	452	0.04	14,415	25,394	10,979	76.2	26,717	12,302	85.3	26,630	12,215	84.7
60-100	40-70_LS	11	0.00	582	170	-412	-70.7	-8	-590	-101.4	4	-578	-99.3
60-100	70-100_S	10,899	0.85	2,463,698	2,236,756	-226,942	-9.2	2,077,047	-386,651	-15.7	2,114,245	-349,453	-14.2
60-100	70-100_SL	72,938	5.71	19,802,418	17,799,115	-2,003,303	-10.1	16,554,577	-3,247,841	-16.4	16,567,218	-3,235,200	-16.3
60-100	100+_SL	5,500	0.43	1,665,377	1,566,539	-98,838	-5.9	1,487,793	-177,584	-10.7	1,482,043	-183,334	-11.0
60-100	100+_SCL	1,840	0.14	672,527	567,789	-104,738	-15.6	522,127	-150,400	-22.4	531,074	-141,453	-21.0

Table XX Profit at full equity values for current, S3 CC scenarios at a grain price of $300 per tonne for the low rainfall zone.

Rooting depth (cm)	PAWC and texture category	Hectares	Percent Area (%)	Current PFE	S3 CC scenario PFE	Difference S3 and Current	Percent change (%)
0-20	0-20_S	29,696	2.32	-3,032,212	-3,252,889	-220,676	-7.3
0-20	20-40_SL	6,776	0.53	-308,313	-453,206	-144,893	-47.0
20-40	20-40_S	13,191	1.03	57,582	-429,635	-487,217	-846.1
20-40	20-40_SL	13,488	1.06	966,450	521,731	-444,718	-46.0
20-40	20-40_SL						
20-40	40-70_S	1,637	0.13	173,666	180,414	6,748	3.9
20-40	40-70_SL	256,731	20.08	42,312,652	37,303,827	-5,008,825	-11.8
20-40	40-70_SCL	21,787	1.70	4,630,016	3,335,262	-1,294,754	-28.0
40-60	20-40_S	72,870	5.70	6,059,632	6,341,222	281,591	4.6
40-60	40-70_S	25,704	2.01	1,863,782	2,770,528	906,746	48.7
40-60	40-70_SL	598,491	46.82	57,357,922	1,526,417	-55,831,506	-97.3
40-60	40-70_SCL	9,673	0.76	245,549	-833,076	-1,078,626	-439.3
40-60	70-100_SL	133,083	10.41	32,864,648	24,427,167	-8,437,482	-25.7
40-60	70-100_SCL	1,407	0.11	353,170	129,105	-224,065	-63.4
40-60	100+_SCL						
60-100	20-40_S	2,183	0.17	212,396	251,490	39,094	18.4
60-100	40-70_S	452	0.04	14,415	31,210	16,795	116.5
60-100	40-70_LS	11	0.00	582	-650	-1,233	-211.7
60-100	70-100_S	10,899	0.85	2,463,698	1,725,766	-737,932	-30.0
60-100	70-100_SL	72,938	5.71	19,802,418	12,331,466	-7,470,952	-37.7
60-100	100+_SL	5,500	0.43	1,665,377	1,333,732	-331,645	-19.9
60-100	100+_SCL	1,840	0.14	672,527	410,779	-261,748	-38.9

Table XX Profit at full equity values for current, S1 and S4 CC scenarios at a grain price of $200 per tonne for the medium rainfall zone.

Rooting depth (cm)	PAWC and texture category	Hectares	Percent Area (%)	Current PFE	S1 CC scenario PFE	Difference S1 and Current	Percent change (%)	S4 CC scenario PFE	Difference S4 and Current	Percent change (%)
0-20	0-20_S	24,779.27	2.10	-5,336,677	-5,161,165	175,512	3.3	-5,227,220	109,457	2.1
0-20	20-40_SL	30,615.53	2.60	-4,262,876	-3,959,597	303,279	7.1	-4,051,372	211,504	5.0
20-40	20-40_S	21,509.71	1.82	-1,849,368	-1,584,052	265,316	14.3	-1,663,116	186,252	10.1
20-40	20-40_SL	698.47	0.06	-15,069	-4,445	10,624	70.5	-18,506	-3,437	-22.8
20-40	20-40_SL	11,025.21	0.93	-733,735	-569,753	163,982	22.3	-656,942	76,794	10.5
20-40	40-70_S	48,021.41	4.07	1,314,408	1,642,786	328,378	25.0	1,417,437	103,030	7.8
20-40	40-70_SL	53,155.96	4.51	4,144,259	4,327,694	183,435	4.4	4,092,412	-51,846	-1.3
20-40	40-70_SCL	17,319.28	1.47	2,022,463	2,164,162	141,699	7.0	2,076,630	54,166	2.7
40-60	20-40_S	54,534.79	4.62	-2,534,837	-1,472,393	1,062,444	41.9	-1,755,153	779,684	30.8
40-60	40-70_S	156,366.56	13.26	-2,073,321	-566,913	1,506,408	72.7	-1,277,055	796,266	38.4
40-60	40-70_SL	245,603.02	20.82	2,497,382	3,626,853	1,129,471	45.2	2,502,379	4,997	0.2
40-60	40-70_SCL									
40-60	70-100_SL	165,482.57	14.03	21,620,683	22,620,366	999,683	4.6	21,583,956	-36,727	-0.2
40-60	70-100_SCL	36,182.73	3.07	3,980,060	3,947,797	-32,263	-0.8	3,613,080	-366,980	-9.2
40-60	100+_SCL	33,866.48	2.87	5,130,471	5,182,115	51,644	1.0	4,992,046	-138,425	-2.7
60-100	20-40_S	742.15	0.06	-13,675	2,246	15,921	116.4	-1,387	12,288	89.9
60-100	40-70_S	63,955.92	5.42	-3,432,223	-2,438,357	993,866	29.0	-2,540,472	891,751	-26.0
60-100	40-70_LS	3,945.94	0.33	68,147	113,439	45,293	66.5	81,381	13,234	19.4
60-100	70-100_S	41,791.12	3.54	4,909,643	5,138,945	229,302	4.7	4,901,979	-7,664	-0.2
60-100	70-100_SL	38,585.11	3.27	6,465,599	7,079,616	614,017	9.5	6,817,720	352,121	5.4
60-100	100+_SL	48,972.56	4.15	11,196,164	11,329,732	133,568	1.2	11,000,848	-195,316	-1.7
60-100	100+_SCL	82,430.01	6.99	19,159,634	19,021,690	-137,944	-0.7	18,403,486	-756,148	-3.9

Table XX Profit at full equity values for current, S5,S2 and S6 CC scenarios at a grain price of $200 per tonne for the medium rainfall zone.

Rooting depth (cm)	PAWC and texture category	Hectares	Percent Area (%)	Current PFE	S5 CC scenario PFE	Difference S5 and Current	Percent change (%)	S2 CC scenario PFE	Difference S2 and Current	Percent change (%)	S6 CC scenario PFE	Difference S6 and Current	Percent change (%)
0-20	0-20_S	24,779.27	2.10	-5,336,677	-5,138,972	197,706	3.7	-5,121,919	214,758	4.0	-5,267,441	69,237	1.3
0-20	20-40_SL	30,615.53	2.60	-4,262,876	-3,939,601	323,275	7.6	-3,977,464	285,412	6.7	-4,125,794	137,082	3.2
20-40	20-40_S	21,509.71	1.82	-1,849,368	-1,675,931	173,437	9.4	-1,755,950	93,418	5.1	-1,920,896	-71,528	-3.9
20-40	20-40_SL	698.47	0.06	-15,069	-5,370	9,699	64.4	-7,425	7,644	50.7	-10,876	4,193	27.8
20-40	20-40_SL	11,025.21	0.93	-733,735	-626,950	106,786	14.6	-684,053	49,682	6.8	-750,969	-17,234	-2.3
20-40	40-70_S	48,021.41	4.07	1,314,408	1,229,493	-84,914	-6.5	1,056,678	-257,730	-19.6	747,139	-567,268	-43.2
20-40	40-70_SL	53,155.96	4.51	4,144,259	3,947,772	-196,486	-4.7	3,614,666	-529,593	-12.8	3,436,872	-707,387	-17.1
20-40	40-70_SCL	17,319.28	1.47	2,022,463	2,011,648	-10,815	-0.5	1,910,179	-112,284	-5.6	1,913,861	-108,602	-5.4
40-60	20-40_S	54,534.79	4.62	-2,534,837	-1,332,866	1,201,971	47.4	-1,247,360	1,287,477	50.8	-2,039,611	495,226	19.5
40-60	40-70_S	156,366.56	13.26	-2,073,321	-650,835	1,422,486	68.6	-683,007	1,390,314	67.1	-1,633,990	439,332	21.2
40-60	40-70_SL	245,603.02	20.82	2,497,382	-25,830	-2,523,212	-101.0	-2,400,439	-4,897,820	-196.1	-2,575,167	-5,072,549	-203.1
40-60	40-70_SCL												
40-60	70-100_SL	165,482.57	14.03	21,620,683	20,170,703	-1,449,980	-6.7	18,894,599	-2,726,084	-12.6	18,023,584	-3,597,098	-16.6
40-60	70-100_SCL	36,182.73	3.07	3,980,060	2,817,779	-1,162,281	-29.2	2,251,497	-1,728,563	-43.4	2,152,126	-1,827,935	-45.9
40-60	100+_SCL	33,866.48	2.87	5,130,471	4,561,784	-568,687	-11.1	4,210,234	-920,237	-17.9	4,021,486	-1,108,985	-21.6
60-100	20-40_S	742.15	0.06	-13,675	8,005	21,680	158.5	9,491	23,166	-169.4	5,851	19,526	-142.8
60-100	40-70_S	63,955.92	5.42	-3,432,223	-1,572,396	1,859,827	54.2	-1,255,111	2,177,112	63.4	-1,504,826	1,927,397	-56.2
60-100	40-70_LS	3,945.94	0.33	68,147	35,207	-32,940	-48.3	-11,967	-80,114	-117.6	-34,474	-102,620	-150.6
60-100	70-100_S	41,791.12	3.54	4,909,643	4,451,245	-458,397	-9.3	4,088,609	-821,034	-16.7	3,889,737	-1,019,906	-20.8
60-100	70-100_SL	38,585.11	3.27	6,465,599	6,623,359	157,759	2.4	6,328,795	-136,805	-2.1	6,082,343	-383,256	-5.9
60-100	100+_SL	48,972.56	4.15	11,196,164	10,359,007	-837,157	-7.5	9,839,097	-1,357,066	-12.1	9,655,228	-1,540,936	-13.8
60-100	100+_SCL	82,430.01	6.99	19,159,634	16,498,653	-2,660,981	-13.9	15,454,854	-3,704,779	-19.3	15,008,926	-4,150,708	-21.7

Table XX Profit at full equity values for current, S3 CC scenarios at a grain price of $200 per tonne for the medium rainfall zone

Rooting depth (cm)	PAWC and texture category	Hectares	Percent Area (%)	Current PFE	S3 CC scenario PFE	Difference S3 and Current	Percent change (%)
0-20	0-20_S	24,779.27	2.10	-5,336,677	-5,055,188	281,490	5.3
0-20	20-40_SL	30,615.53	2.60	-4,262,876	-4,135,814	127,062	3.0
20-40	20-40_S	21,509.71	1.82	-1,849,368	-2,076,940	-227,572	-12.3
20-40	20-40_SL	698.47	0.06	-15,069	-15,735	-666	-4.4
20-40	20-40_SL	11,025.21	0.93	-733,735	-934,957	-201,221	-27.4
20-40	40-70_S	48,021.41	4.07	1,314,408	164,680	-1,149,728	-87.5
20-40	40-70_SL	53,155.96	4.51	4,144,259	3,058,778	-1,085,481	-26.2
20-40	40-70_SCL	17,319.28	1.47	2,022,463	1,555,123	-467,341	-23.1
40-60	20-40_S	54,534.79	4.62	-2,534,837	-1,292,179	1,242,658	-49.0
40-60	40-70_S	156,366.56	13.26	-2,073,321	-1,089,492	983,830	-47.5
40-60	40-70_SL	245,603.02	20.82	2,497,382	-12,572,184	-15,069,565	-603.4
40-60	40-70_SCL						
40-60	70-100_SL	165,482.57	14.03	21,620,683	14,249,613	-7,371,069	-34.1
40-60	70-100_SCL	36,182.73	3.07	3,980,060	11,065	-3,968,995	-99.7
40-60	100+_SCL	33,866.48	2.87	5,130,471	3,170,643	-1,959,828	-38.2
60-100	20-40_S	742.15	0.06	-13,675	20,339	34,014	-248.7
60-100	40-70_S	63,955.92	5.42	-3,432,223	-371,668	3,060,555	-89.2
60-100	40-70_LS	3,945.94	0.33	68,147	-225,467	-293,613	-430.9
60-100	70-100_S	41,791.12	3.54	4,909,643	2,541,348	-2,368,295	-48.2
60-100	70-100_SL	38,585.11	3.27	6,465,599	5,113,319	-1,352,280	-20.9
60-100	100+_SL	48,972.56	4.15	11,196,164	8,377,549	-2,818,614	-25.2
60-100	100+_SCL	82,430.01	6.99	19,159,634	11,507,213	-7,652,421	-39.9

Table XX Profit at full equity values for current, S1 and S4 CC scenarios at a grain price of $250 per tonne for the medium rainfall zone.

Rooting depth (cm)	PAWC and texture category	Hectares	Percent Area (%)	Current PFE	S1 CC scenario PFE	Difference S1 and Current	Percent change (%)	S4 CC scenario PFE	Difference S4 and Current	Percent change (%)
0-20	0-20_S	24,779.27	2.10	-4,713,284	-4,493,894	219,390	4.7	-4,576,463	136,821	2.9
0-20	20-40_SL	30,615.53	2.60	-2,909,968	-2,530,870	379,098	13.0	-2,645,589	264,379	9.1
20-40	20-40_S	21,509.71	1.82	-612,443	-280,798	331,645	54.2	-379,628	232,815	38.0
20-40	20-40_SL	698.47	0.06	36,343	49,624	13,280	36.5	32,047	-4,296	11.8
20-40	20-40_SL	11,025.21	0.93	-46,178	158,800	204,978	443.9	49,814	95,992	207.9
20-40	40-70_S	48,021.41	4.07	5,436,701	5,847,174	410,473	7.6	5,565,488	128,787	2.4
20-40	40-70_SL	53,155.96	4.51	9,379,645	9,608,939	229,294	2.4	9,314,837	-64,808	-0.7
20-40	40-70_SCL	17,319.28	1.47	3,896,302	4,073,426	177,124	4.5	3,964,010	67,708	1.7
40-60	20-40_S	54,534.79	4.62	1,139,702	2,467,758	1,328,055	116.5	2,114,307	974,605	85.5
40-60	40-70_S	156,366.56	13.26	9,761,307	11,644,316	1,883,010	19.3	10,756,639	995,333	10.2
40-60	40-70_SL	245,603.02	20.82	22,524,366	23,936,205	1,411,839	6.3	22,530,612	6,247	0.0
40-60	40-70_SCL									
40-60	70-100_SL	165,482.57	14.03	40,098,976	41,348,580	1,249,604	3.1	40,053,067	-45,908	-0.1
40-60	70-100_SCL	36,182.73	3.07	7,833,511	7,793,181	-40,329	-0.5	7,374,786	-458,725	-5.9
40-60	100+_SCL	33,866.48	2.87	9,088,541	9,153,096	64,555	0.7	8,915,509	-173,031	-1.9
60-100	20-40_S	742.15	0.06	41,536	61,437	19,901	47.9	56,896	15,360	37.0
60-100	40-70_S	63,955.92	5.42	762,239	2,004,572	1,242,333	163.0	1,876,928	1,114,689	146.2
60-100	40-70_LS	3,945.94	0.33	396,912	453,528	56,616	14.3	413,455	16,542	4.2
60-100	70-100_S	41,791.12	3.54	9,438,552	9,725,179	286,627	3.0	9,428,972	-9,580	-0.1
60-100	70-100_SL	38,585.11	3.27	11,130,223	11,897,744	767,521	6.9	11,570,373	440,151	4.0
60-100	100+_SL	48,972.56	4.15	17,864,037	18,030,997	166,960	0.9	17,619,892	-244,145	-1.4
60-100	100+_SCL	82,430.01	6.99	30,461,513	30,289,083	-172,429	-0.6	29,516,328	-945,185	-3.1

Table XX Profit at full equity values for current, S5,S2 and S6 CC scenarios at a grain price of $250 per tonne for the medium rainfall zone.

Rooting depth (cm)	PAWC and texture category	Hectares	Percent Area (%)	Current PFE	S5 CC scenario PFE	Difference S5 and Current	Percent change (%)	S2 CC scenario PFE	Difference S2 and Current	Percent change (%)	S6 CC scenario PFE	Difference S6 and Current	Percent change (%)
0-20	0-20_S	24,779.27	2.10	-4,713,284	-4,466,152	247,132	5.2	-4,444,836	268,448	5.7	-4,626,738	86,546	1.8
0-20	20-40_SL	30,615.53	2.60	-2,909,968	-2,505,874	404,094	13.9	-2,553,203	356,765	12.3	-2,738,615	171,353	5.9
20-40	20-40_S	21,509.71	1.82	-612,443	-395,647	216,796	35.4	-495,670	116,773	19.1	-701,853	-89,410	-14.6
20-40	20-40_SL	698.47	0.06	36,343	48,467	12,124	33.4	45,899	9,555	26.3	41,584	5,241	14.4
20-40	20-40_SL	11,025.21	0.93	-46,178	87,304	133,482	289.1	15,925	62,102	134.5	-67,720	-21,542	46.7
20-40	40-70_S	48,021.41	4.07	5,436,701	5,330,558	-106,143	-2.0	5,114,539	-322,162	-5.9	4,727,615	-709,085	-13.0
20-40	40-70_SL	53,155.96	4.51	9,379,645	9,134,037	-245,608	-2.6	8,717,654	-661,991	-7.1	8,495,411	-884,234	-9.4
20-40	40-70_SCL	17,319.28	1.47	3,896,302	3,882,783	-13,519	-0.3	3,755,947	-140,355	-3.6	3,760,550	-135,752	-3.5
40-60	20-40_S	54,534.79	4.62	1,139,702	2,642,166	1,502,464	131.8	2,749,049	1,609,347	141.2	1,758,734	619,032	54.3
40-60	40-70_S	156,366.56	13.26	9,761,307	11,539,414	1,778,108	18.2	11,499,199	1,737,893	17.8	10,310,471	549,165	5.6
40-60	40-70_SL	245,603.02	20.82	22,524,366	19,370,351	-3,154,015	-14.0	16,402,090	-6,122,276	-27.2	16,183,679	-6,340,686	-28.2
40-60	40-70_SCL												
40-60	70-100_SL	165,482.57	14.03	40,098,976	38,286,501	-1,812,474	-4.5	36,691,371	-3,407,604	-8.5	35,602,603	-4,496,373	-11.2
40-60	70-100_SCL	36,182.73	3.07	7,833,511	6,380,659	-1,452,851	-18.5	5,672,807	-2,160,704	-27.6	5,548,592	-2,284,918	-29.2
40-60	100+_SCL	33,866.48	2.87	9,088,541	8,377,682	-710,859	-7.8	7,938,245	-1,150,296	-12.7	7,702,309	-1,386,232	-15.3
60-100	20-40_S	742.15	0.06	41,536	68,636	27,100	65.2	70,493	28,957	69.7	65,944	24,408	58.8
60-100	40-70_S	63,955.92	5.42	762,239	3,087,022	2,324,783	305.0	3,483,629	2,721,390	357.0	3,171,485	2,409,246	316.1
60-100	40-70_LS	3,945.94	0.33	396,912	355,738	-41,175	-10.4	296,770	-100,142	-25.2	268,637	-128,275	-32.3
60-100	70-100_S	41,791.12	3.54	9,438,552	8,865,555	-572,997	-6.1	8,412,260	-1,026,292	-10.9	8,163,669	-1,274,883	-13.5
60-100	70-100_SL	38,585.11	3.27	11,130,223	11,327,422	197,199	1.8	10,959,217	-171,006	-1.5	10,651,152	-479,070	-4.3
60-100	100+_SL	48,972.56	4.15	17,864,037	16,817,591	-1,046,446	-5.9	16,167,704	-1,696,333	-9.5	15,937,867	-1,926,170	-10.8
60-100	100+_SCL	82,430.01	6.99	30,461,513	27,135,287	-3,326,226	-10.9	25,830,539	-4,630,974	-15.2	25,273,128	-5,188,385	-17.0

Table XX Profit at full equity values for current and S3 CC scenarios at a grain price of $250 per tonne for the medium rainfall zone.

Rooting depth (cm)	PAWC and texture category	Hectares	Percent Area (%)	Current PFE	S3 CC scenario PFE	Difference S3 and Current	Percent change (%)
0-20	0-20_S	24,779.27	2.10	-4,713,284	-4,361,422	351,862	7.5
0-20	20-40_SL	30,615.53	2.60	-2,909,968	-2,751,142	158,827	5.5
20-40	20-40_S	21,509.71	1.82	-612,443	-896,908	-284,465	-46.4
20-40	20-40_SL	698.47	0.06	36,343	35,511	-832	-2.3
20-40	20-40_SL	11,025.21	0.93	-46,178	-297,704	-251,527	-544.7
20-40	40-70_S	48,021.41	4.07	5,436,701	3,999,541	-1,437,160	-26.4
20-40	40-70_SL	53,155.96	4.51	9,379,645	8,022,794	-1,356,851	-14.5
20-40	40-70_SCL	17,319.28	1.47	3,896,302	3,312,126	-584,176	-15.0
40-60	20-40_S	54,534.79	4.62	1,139,702	2,693,025	1,553,322	136.3
40-60	40-70_S	156,366.56	13.26	9,761,307	10,991,094	1,229,787	12.6
40-60	40-70_SL	245,603.02	20.82	22,524,366	3,687,409	-18,836,956	-83.6
40-60	40-70_SCL						
40-60	70-100_SL	165,482.57	14.03	40,098,976	30,885,139	-9,213,836	-23.0
40-60	70-100_SCL	36,182.73	3.07	7,833,511	2,872,266	-4,961,244	-63.3
40-60	100+_SCL	33,866.48	2.87	9,088,541	6,638,755	-2,449,785	-27.0
60-100	20-40_S	742.15	0.06	41,536	84,054	42,518	102.4
60-100	40-70_S	63,955.92	5.42	762,239	4,587,932	3,825,693	501.9
60-100	40-70_LS	3,945.94	0.33	396,912	29,896	-367,017	-92.5
60-100	70-100_S	41,791.12	3.54	9,438,552	6,478,183	-2,960,369	-31.4
60-100	70-100_SL	38,585.11	3.27	11,130,223	9,439,873	-1,690,350	-15.2
60-100	100+_SL	48,972.56	4.15	17,864,037	14,340,769	-3,523,268	-19.7
60-100	100+_SCL	82,430.01	6.99	30,461,513	20,895,987	-9,565,526	-31.4

Table XX Profit at full equity values for current, S1 and S4 CC scenarios at a grain price of $300 per tonne for the medium rainfall zone.

Table XX Profit at full equity values for current, S5, S2 and S6 CC scenarios at a grain price of $300 per tonne for the medium rainfall zone.

Table XX Profit at full equity values for current and S3 CC scenarios at a grain price of $300 per tonne for the medium rainfall zone

Table XX Profit at full equity values for current, S1 and S4 CC scenarios at a grain price of $200 per tonne for the medium rainfall zone.

Table XX Profit at full equity values for current, S5, S2 and S6 CC scenarios at a grain price of $200 per tonne for the medium rainfall zone.

Table XX Profit at full equity values for current and S3 CC scenarios at a grain price of $200 per tonne for the high rainfall zone

Table XX Profit at full equity values for current, S1 and S4 CC scenarios at a grain price of $250 per tonne for the high rainfall zone.

Table XX Profit at full equity values for current, S5 and S2 and S6 CC scenarios at a grain price of $250 per tonne for the high rainfall zone.

Table XX Profit at full equity values for current and S3 CC scenarios at a grain price of $250 per tonne for the high rainfall zone.

Table XX Profit at full equity values for current, S1 and S4 CC scenarios at a grain price of $300 per tonne for the high rainfall zone.

Table XX Profit at full equity values for current, S5, S2 and S6 CC scenarios at a grain price of $300 per tonne for the high rainfall zone.

Table XX Profit at full equity values for current and S3 CC scenarios at a grain price of $300 per tonne for the high rainfall zone

Appendix 6: 3PG Modelling: Technical Data

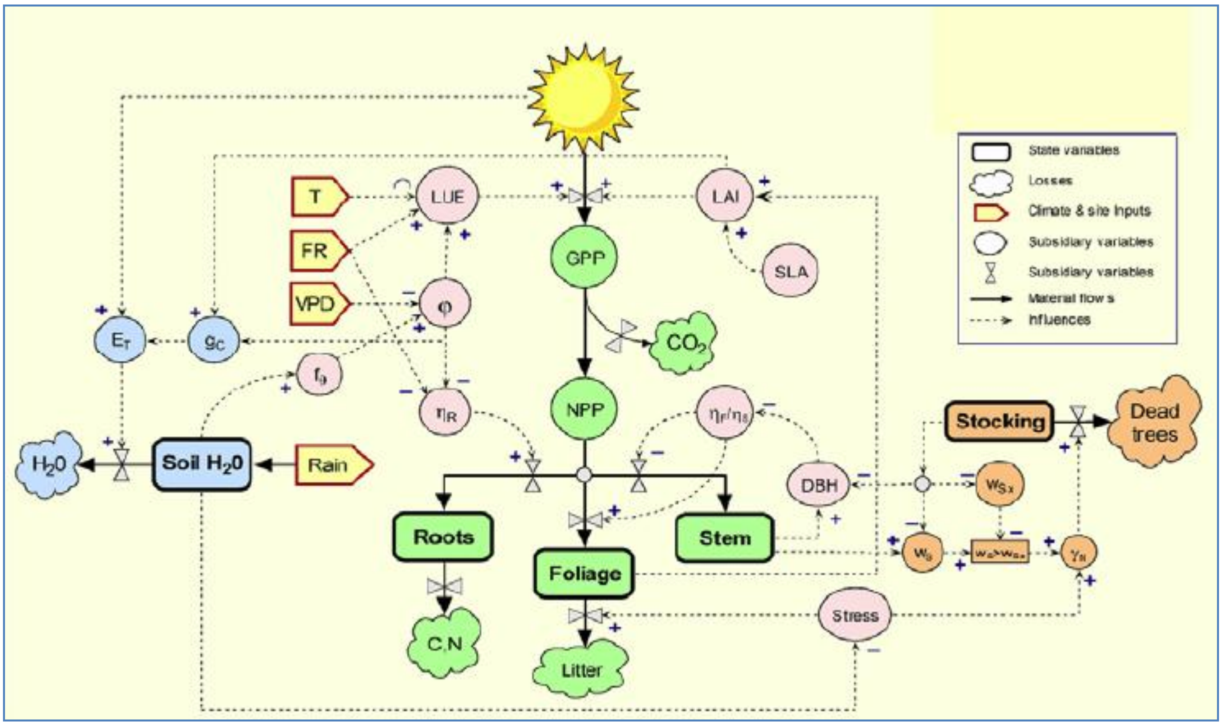


Figure A6-1: Basic structure of 3-PG and the causal influences of its variables and processes

Source: (Paul et al., 2007; Sands, 2004)

Symbols used stand for gross primary production (GPP), net primary production (NPP), site fertility rating (FR), air temperature (T), vapour pressure deficit (VPD), rate of evapotranspiration (ET), canopy conductance (gc), mass of stem including branches and bark (wS), maximum stem mass per tree at 1000 trees/ha (wSx), rate of mortality (γN), leaf area index (LAI), specific leaf area (SLA), light use efficiency (LUE), physiological modifier of canopy conductance (ϕ), soil water modifier (fθ), fraction of NPP allocated to roots (ηR), and ratio of fraction of NPP allocated to foliage relative to the stem (ηF/ηS).

Table A6-1: Standard 3PG species parameters (3PGxl vsn 3 beta, 3PG2 beta)

Meaning/comments	Name	Units	E. Cladocalyx	Environmental Planting	Oil Mallee
Biomass partitioning and turnover					
Allometric relationships & partitioning					
Foliage:stem partitioning ratio @ D=2 cm	pFS2	-	1	1	1
Foliage:stem partitioning ratio @ D=20 cm	pFS20	-	0.15	0.3	0.4
Constant in the stem mass v. diam. relationship	aWS	-	0.074	0.148	0.03
Power in the stem mass v. diam. relationship	nWS	-	2.6834	2.565	2.57
Maximum fraction of NPP to roots	pRx	-	0.8	0.8	0.9
Minimum fraction of NPP to roots	pRn	-	0.25	0.2	0.4
Volum of soil accessed by 1 kg of root DM	spRootVol	m3/kg soil	3.8	3.8	3.8
Litterfall & root turnover					
Maximum litterfall rate	gammaF1	1/month	0.008	0.005	0.015
Litterfall rate at t = 0	gammaF0	1/month	0.001	0.001	0.001
Age at which litterfall rate has median value	tgammaF	months	10	10	12
Average monthly root turnover rate	gammaR	1/month	0.015	0.001	0.015
NPP & conductance modifiers					
Temperature modifier (gmTemp)					
Minimum temperature for growth	Tmin	deg. C	1	10	10
Optimum temperature for growth	Topt	deg. C	30	18	30
Maximum temperature for growth	Tmax	deg. C	34	40	45
Frost modifier (gmFrost)					
Days production lost per frost day	kF	days	0	0	0
Fertitlity effects (gmNutr)					
Value of 'm' when FR = 0	m0	-	0	0	0
Value of 'fNutr' when FR = 0	fN0	-	0.6	0.6	0.6
Power of (1-FR) in gmNutr	fNn	-	1	1	1

mospheric CO2 effects					
xRatio of alpha at 700 and 350 ppm	gmCalpha700	-	1.4	1.4	1.4
xRatio of canopy conductance at 700 and 350 ppm	gmCg700	-	0.7	0.7	0.7
Salinity effects (gmSalt)					
Salinty beow which no effects of salt on growth	EC0	dS/m	999	999	999
Salinty above whichgrowth ceases	EC1	dS/m	999	999	999
Power of EC in gmSalt	ECn	-	1	1	1
Age modifier (gmAge)					
Maximum stand age used in age modifier	MaxAge	years	65	60	65
Power of relative age in function for fAge	nAge	-	4	20	2
Relative age at fAge = 0.5	rAge	-	0.95	0.8	0.95
Stem mortality & self-thinning					
Mortality rate for large t	gammaN1	%/year	0	0	0
Seedling mortality rate (t = 0)	gammaN0	%/year	0	0	0
Age at which mortality rate has median value	tgammaN	years	0	0	0
Shape of mortality response	ngammaN	-	1	1	1
Max. stem mass per tree @ 1000 trees/hectare	wSx1000	kg/tree	300	300	300
Power in self-thinning rule	thinPower	-	1.5	1.5	1.5
Fraction mean single-tree foliage biomass lost per dead tree	mF	-	0	0	0
Fraction mean single-tree root biomass lost per dead tree	mR	-	0.2	0.2	0.2
Fraction mean single-tree stem biomass lost per dead tree	mS	-	0.2	0.2	0.2
Canopy structure and processes					
Specific leaf area					
Specific leaf area at age 0	SLA0	m^2/kg	4.72	5	4
Specific leaf area for mature leaves	SLA1	m^2/kg	4.72	5	2.5
Age at which specific leaf area = (SLA0+SLA1)/2	tSLA	years	2.5	1	4
Light interception & VPD attenuation					
Extinction coefficient for absorption of PAR by canopy	k	-	0.5	0.5	0.5

Age at canopy cover	fullCanAge	years	3	3	3
LAI for 50% reduction of VPD in canopy	cVPD0		5	5	5
Rainfall interception					
Maximum thickness of water retained on leaves	tWaterMax	mm	0.15	0.1	0.2
Maximum proportion of rainfall evaporated from canopy	MaxIntcptn	-	0.15	0.15	0.15
LAI for maximum rainfall interception	LAImaxIntcptn	-	3	3	3
Production and respiration					
Canopy quantum efficiency	alphaCx	molC/molPAR	0.06	0.06	0.06
Edge tree growth % enhancement	edgeEffect	-	20	20	20
Ratio NPP/GPP	Y	-	0.47	0.47	0.47
Conductance					
Maximum stomatal conductance	gSx	m/s	0.008	0.008	0.008
Radiation for gS = gSx/2	IgS	W/m2	100	100	100
Minimum canopy conductance	MinCond	m/s	0	0	0
Maximum canopy conductance	MaxCond	m/s	0.02	0.03	0.015
LAI for maximum canopy conductance	LAIgcx	-	3.33	3.33	3.33
Defines stomatal response to VPD	CoeffCond	1/mBar	0.05	0.025	0.05
Canopy aerodynamic conductance	gAc	m/s	0.15	0.03	0.22
Soil aerodynamic conductance	gAs	m/s	0	0.01	0.005
Wood and stand properties					
Branch and bark fraction (fracBB)					
Branch and bark fraction at age 0	fracBB0	-	0.63	0.55	0.8
Branch and bark fraction for mature stands	fracBB1	-	0.42	0.44	0.4
Age at which fracBB = (fracBB0+fracBB1)/2	tBB	years	7.102	7	5.5
Basic Density					
Minimum basic density - for young trees	rho0	t/m3	0.6	0.63	0.7
Maximum basic density - for older trees	rho1	t/m3	0.82	0.42	0.8
Age at which rho = (rhoMin+rhoMax)/2	tRho	years	5	7	4

Stem height					
Constant in the stem height relationship	aH	-	0	0	0
Power of DBH in the stem height relationship	nHB	-	0	0	0
Power of stocking in the stem height relationship	nHN	-	0	0	0
Stem volume					
Constant in the stem volume relationship	aV	-	0	0	0
Power of DBH in the stem volume relationship	nVB	-	0	0	0
Power of stocking in the stem volume relationship	nVN	-	0	0	0
Conversion factors					
Intercept of net v. solar radiation relationship	Qa	W/m2	0	0	0
Slope of net v. solar radiation relationship	Qb	-	0.8	0.8	0.8
Molecular weight of dry matter	gDM_mol	gDM/mol	24	24	24
Conversion of solar radiation to PAR	molPAR_MJ	mol/MJ	2.3	2.3	2.3

Appendix 7: Biodiversity Modelling: Technical Data

Exposure

We selected three diverse models to quantify species exposure in this study:

- logistic regression (Márcia Barbosa et al., 2003; Schussman et al., 2006) uses a logistic function to predict the species distributions
- the generalised additive model (GAM) (Elith et al., 2006; Guisan et al., 2002; Luoto et al., 2007) uses a non-parametric smooth function
- the maximum entropy method (MaxEnt) (Phillips et al., 2006) uses a machine-learning method which finds the distribution of maximum entropy (distribution that is closest to uniform) subject to the constraint that the expected value of each environmental variable under the estimated distribution matches its empirical average

For each model run, the validation data set (created through a a random 70/30 split of the presence and absence species records) was used to assess the predictive accuracy of individual models under the baseline climate using area under the curve (AUC) statistics from threshold-independent Receiver Operating Characteristic (ROC) plots (Fielding and Bell, 1997). The mean AUC was calculated over the ten runs of each model.

The ensemble model combined the outputs of the three models into a single prediction of species distribution $\mathbf{P}_i$ for each species *i* under each climate scenario using the AUC accuracy statistics (Carvalho et al., 2010):

$$\mathbf{P}_i = \frac{AUC_{LRi}\mathbf{P}_{LRi} + AUC_{Gi}\mathbf{P}_{Gi} + AUC_{Mi}\mathbf{P}_{Mi}}{AUC_{LRi} + AUC_{Gi} + AUC_{Mi}} \qquad (1)$$

where $\mathbf{P}_{LRi}$, $\mathbf{P}_{Gi}$, and $\mathbf{P}_{Mi}$ represent species distribution layers (probability of species presence) calculated by logistic regression, generalised additive model, and maximum entropy model, respectively. *AUC* is the mean Area Under the Curve accuracy statistic for each model. Finally, AUC was calculated for each ensemble forecast for baseline climate to enable a comparison of accuracy with the three individual models.

Species sensitivity

The sensitivity of species to climate change was specified as a scalar sensitivity weight (w_{is}) calculated as the ratio of the change in species distribution to the extent of species distribution under each climate change scenario (*s*) for each species (*i*) (Crossman et al., 2012). The change in species distribution was calculated as the sum of the absolute value of the probability of occurrence layer under climate change $\mathbf{P}_{ick}$ subtracted from the probability of occurrence layer under the current climate $\mathbf{P}_{ick}$ over all grid cells m for k = 1, 2, …, m. The extent of species distribution under future climate was calculated as the sum over all grid cells m of the layer $\mathbf{P}_{isk}$ for k = 1, 2, …, m. Species sensitivity weights were calculated as (after (Crossman et al., 2012)):

$$w_{is} = \frac{\sum_{k=1}^{m} |\mathbf{P}_{ick} - \mathbf{P}_{isk}|}{\sum_{k=1}^{m} \mathbf{P}_{isk}} \qquad (2)$$

Higher sensitivity weights are assigned to those species whose spatial distribution was projected to contract or shift, particularly if their geographic range is already limited. Species with an extensive distribution receive lower sensitivity weights, especially where distributions are projected to increase under climate change (Crossman et al., 2012).

Adaptive capacity

The dispersal potential $\mathbf{D}_i$ for each species was calculated to provide a measure of adaptive capacity. This was calculated using a negative exponential dispersal kernel based on the distance layer $\mathbf{d}_i$ quantifying the Euclidean distance to the nearest known location of each species (Portnoy and Willson, 1993):

$$\mathbf{D}_i = e^{(-\theta \mathbf{d}_i)} \qquad (3)$$

The negative exponential function creates a dispersal potential layer with values ranging between zero (cells that are far away) and one (cells that are close by). Thus, a higher potential dispersal score is assigned to areas closer to known species locations.

Crossman et al. (2012) demonstrated that the coefficient value within the dispersal kernel significantly affects the adaptive capacity layers and subsequent prioritisation. Here, we used a coefficient value of $\vartheta = 0.0001$ to represent generalised dispersal and migration processes of plant species over multiple generations.

Calculating and evaluating spatial priorities for mitigating species vulnerability

The conservation planning software package Zonation (Moilanen and Kujala, 2008b) was used to create continuous layers ranking the conservation priority $\mathbf{Z}_{skL}$ of each grid cell k, level of analysis L, and climate change scenario s. Values closer to zero indicate those cells of least conservation value, through to 1 indicating greatest conservation value. We modified the Zonation outputs such that $\mathbf{Z}'_{skL} = 1 - \mathbf{Z}_{skL}$ to provide an indicator of conservation priority that more intuitively relates to the level of representation of species distributions. In this formulation, areas with value of $\mathbf{Z}'_{skL} \leq \delta/100$ in the Zonation spatial conservation priority layers capture roughly $\delta\%$ of the spatial distribution of each species.

We then used correlation analysis to compare spatial conservation priority layers calculated using the four levels of analysis above. To minimise spatial autocorrelation we extracted 200 random points, then calculated Pearson's *r* pairwise correlation coefficients between spatial priority layers. This was repeated 1,000 times and the mean and standard deviation of the correlation statistics presented.

We also quantified the level of representation R_{isLj} of each species *i* as the sum, over all grid cells *m* for *k* = 1, 2, …, *m*, of ensemble-model-predicted probability of occurrence $\mathbf{P}_{isk}$ multiplied by the dispersal potential layer $\mathbf{D}_i$ captured by the modified Zonation layers $\mathbf{Z'}_{skL}$ under each climate change scenario *s* and level of analysis *L*. Species representation R_{isLj} was calculated for each increment of conservation priority $j \in J\{0.005, 0.015, 0.025, \ldots, 0.995\}$ and graphed as *species representation curves*:

$$R_{isLj} = \frac{\sum_{k=1}^{m} \mathbf{P}_{isk} \mathbf{D}_i \mathbf{X}_{skLj}}{\sum_{k=1}^{m} \mathbf{P}_{isk}\, \mathbf{D}_i} \qquad (4)$$

$$\text{where } \mathbf{X}_{skLj} = \begin{cases} 0, & \text{if } (1 - \mathbf{Z'}_{skL}) > j \\ 1, & otherwise \end{cases} \quad \text{for } \forall\, j \text{ in } J$$

AUC statistics were calculated based on species representation curves (which have similar characteristics to ROC plots (Fawcett, 2006)); to quantify a threshold-independent measure of species representation by priority areas for each level of analysis and scenario. AUC was calculated by summing, over all priority levels $j \in J$, the level of species representation R_{isLj} captured at priority level *j*, multiplied by the marginal gain in conservation priority $1/|J|$.

$$AUC_{isL} = \sum_{j \in J} \frac{1}{|J|} R_{isLj} \qquad (4)$$

Species whose representation tracks the conservation priority level perfectly (i.e. where $R_{isLj} = j \text{ for } \forall\, j \text{ in } J$), then AUC_{isL} = 0.5. Where species are exhibit better than average representation by conservation priority areas $0.5 < AUC_{isL} \leq 1$, whilst $0.5 > AUC_{isL} \geq 0$ reflects below-average species representation in spatial conservation priorites.

To evaluate the impact of including components of vulnerability, the mean level of representation R_{isLj} was graphed and the mean AUC_{sL} calculated for three indicators: all species; the 50 most-sensitive species, and; the five worst-performing species, under each climate change scenario *s* and level of analysis *L*.