Climate change, wheat production and erosion risk in South Australia's cropping zone:

Linking crop simulation modelling to soil landscape mapping

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Abstract

The prospect of a drying, warming climate trend is cause for concern within South Australia's cropping zone, with potential to decrease grain production and increase the risk of soil erosion. These issues have been investigated through a novel modelling approach that links the crop simulation model APSIM (Agricultural Production Systems Simulator) to regionally representative soil and climate datasets. The loss of precious topsoil through erosion has significant impacts on the long-term productivity of agricultural soils and the condition of the environment (through degradation of soil fertility, carbon content and waterholding capacity as well as off-site impacts). In cropping areas, erosion risk is already a focus for monitoring and improving management. With potential for less crop biomass available to protect soils, climate change represents a further threat to sustainable land management. In addition, if declining rainfall reduces average grain yields this will have important implications for farm businesses, land management and land use strategies in affected areas. The modelling involved a developmental process. Early APSIM investigations to build understanding of the primary drivers of wheat crop performance underpinned the design of generalised 'modelling soil profile' groups and selection of representative climate datasets, appropriate for a regional scale analysis. Soil variability was taken into account by categorising mapped soils (from the State Land & Soil Information Framework) based on existing estimates for 'surface soil clay content' and 'plant available waterholding capacity'. Sixteen 'modelling soil profile' groups were established, each represented by a single APSIM soil file. A relatively streamlined modelling approach was favoured to provide greater clarity in interpreting results (less confounding between variables) as well as constraining a potentially huge modelling task. At the regional scale, simulated historic average wheat yields were comparable to observed wheat yields across SA, which provided confidence in the approach. The mapped attributes 'water erosion potential' and 'wind erosion potential' provided a basis for specifying 'critical cover levels' required for protection against erosion and hence a means to assess potential changes in the frequency and severity of erosion risk (corresponding to seasons when critical cover levels were not met). The modelling results offer further information to guide potential policy responses, and help plan and prioritise regional adaptation activities, as well as providing a focus for monitoring of potential climate change impacts. The modelling approach presented here also offers an efficient, transparent, consistent and adaptable framework for finer scale crop simulation modelling (using more localised information within APSIM), or subsequent regional economic or social modelling of potential climate change impacts across the agricultural zone of SA.

Executive Summary

Introduction

Projections for a warming and drying climate[1] represent a dual threat to natural resource management and production levels across South Australia's dryland (rain-fed) cropping regions. Within an already largely moisture limited environment, a further decline in rainfall has potential to bring (i) less reliable grain production and (ii) increasing incidence of soil erosion risk due to reduced crop biomass levels.

Soils are an important natural resource, requiring good management to protect their productive capacity and vital ecosystem services (including storage and cycling of carbon, water and nutrients). This is underscored by the fact that we are witnessing ever-increasing pressures on the natural resource base. A key issue is the protection of soils from wind and water erosion, which is seen as critical to the long-term sustainability of agricultural land, farming businesses and the condition of the environment. Loss of precious topsoil degrades soil fertility, carbon content and waterholding capacity, as well as causing off-site impacts. There has been a major improvement in the protection of soil from erosion over the last 10 years due to the widespread adoption of no-till farming, stubble retention and improved grazing management. However, if declining rainfall reduces average grain yields and crop biomass available to protect soils, this will have important implications for farm businesses, land management and land use strategies in affected areas. It is also recognised that adverse impacts to farm businesses will reduce the capacity of land managers to deliver a range of important natural resource management (NRM) outcomes in regional areas.

A crop simulation modelling exercise was conceived to address the need for better information about potential climate change impacts on both production and NRM across the dryland cereal cropping zone of Southern South Australia. Ultimately, this will contribute to the body of knowledge informing future decisions by a range of stakeholders involved with climate change adaptation planning and policy development (e.g. policy, industry, community, and regional NRM groups).

Approach

A novel crop simulation modelling approach has been developed which accounts for key factors driving crop growth across different regions, while avoiding high levels of complexity. A relatively streamlined modelling approach was favoured in order to achieve greater clarity when interpreting results (avoiding confounding between potentially large numbers of soil and climate variables) and to contain the modelling task to something manageable. The investigation focussed on wheat grain yields and erosion risk (related to levels of residual crop biomass available to protect soils) in recognition of the important links between production and sustainable land management outcomes.

In essence, the modelling links the crop simulation model APSIM (Agricultural Production Systems Simulator, Keating et al. 2003) to South Australia's comprehensive soil and land attribute spatial datasets (available from the State Land & Soil Information Framework or SL&SIF[2]), as well as spatial and long-term time series climate datasets. Given that rainfall is the most uncertain parameter within future climate projections, climate change scenarios were selected which focus on different levels of rainfall decline (-5%, -10% and -20% compared to historic 1900-2009 climate records), while keeping constant levels of warming (+1.5°C compared to historic records) and constant CO_2 increase (to 480 ppm, compared to 390 ppm used in historic scenario). These scenarios are consistent with the projected envelope of likely change by 2030.

Soil variability was taken into account by categorising mapped soils (from the SL&SIF) based on existing estimates for 'surface soil clay content' and 'plant available waterholding capacity' (PAWC[3]), which were seen as critical parameters influencing soil-plant-water relations. Sixteen 'modelling soil profile' groups were established (see Table 3), with each group represented by a single custom-built APSIM soil characterisation

[1] Climate change projections for the dryland agricultural regions of SA indicate that annual average temperatures will increase by 0.4°C to 1.8°C by the year 2030, and between 0.8°C and 5.5°C by 2070. Average annual rainfall may decrease by as much as 15% by 2030 and by 45% by 2070 (Suppiah et al. 2006).

[2] http://www.environment.sa.gov.au/Knowledge_Bank/Information_data/soil-and-land

[3] PAWC values have been derived using quantitative estimates for a number of mapped attributes. This includes consideration of subsoil constraints in the form of physical or chemical barriers to root growth (via the attribute 'depth to impeding layer for annual crops and pastures') and 'coarse fragment content'.

file. Parameters for each of the sixteen APSIM soil files were defined with a level of generalisation appropriate for this type of regional scale analysis. However they lack the degree of differentiation required for close analysis of specific soils or distinct local areas. This innovative use of APSIM soil files was guided by earlier investigations to better understand the key drivers of wheat crop performance. The approach took account of all soil areas used for cropping while drastically reducing the potential number of APSIM modelling runs required.

A further key innovation in this regional scale analysis has been the extension of an approach used by SARDI Climate Applications (Hayman et al. 2010b) which has significantly streamlined the use of climate files in APSIM. This involves adjusting the daily climate record from a selected quality long-term file to mimic the average climate conditions of other locations. This approach was based on the understanding (developed from studying many sites across SA) that long-term yield probability (percentile) distributions will often be closely matched among sites with equivalent average growing season rainfall, even though season by season outcomes can vary greatly. The reliability of rainfall (in terms of the relative occurrence of poor, average and good growing seasons) is also recognised as an important factor in predicting crop performance. Initial plans to use an array of actual regional representative climate station records were changed when the more streamlined approach (using a suite of adjusted climate records derived from a limited selection of quality sites) was seen to offer sufficient simulation accuracy, while dramatically improving efficiencies and avoiding gaps in data quality and availability. An external review of the APSIM modelling approach (including the application of soils and climate data) identified some key issues where further clarification has been necessary, as summarised in Appendix A.

Mapped attributes of 'wind erosion potential' and 'water erosion potential' were used as a basis for the establishment of critical (residual stubble) cover requirements. These critical cover levels provided benchmarks to compare seasonal crop simulation outcomes of post-harvest biomass, providing an indicator of potential changes in erosion risk (due to low crop biomass) in response to climate change. Other mapped soil and land attributes (such as slope, drainage, rockiness, salinity) together with land use and climatic information were used to limit analyses only to those areas suited to dryland cereal cropping.

Previous broadscale crop simulation modelling exercises of this kind in South Australia have typically not accounted for all the available soil and land information. The usual approach has been to consider 'most common' (or dominant) soil types while ignoring the remaining sub-dominant soils. The issue here is that 'most common' soils often account for less than 50% of a map unit (Soil & Land Program 2007a). By contrast, this study has used the standardised data handling conventions developed for use with the SL&SIF (Section 2.5) which allow all mapped soils to contribute information (in proportion to their areal extent within each map unit) within a GIS modelling framework. As such, this study is the first crop simulation modelling exercise to be based on such consistent and comprehensive soil and land attribute data over such a large area.

Key findings

Modelling results generally support field observations that some soil types outperform others across a range of climatic conditions. Shallow clayey soils are found to be most vulnerable to poor yields and low stubble cover in dry years. In low rainfall environments, higher rates of evaporation and higher wilting point moisture levels in clay surface soils increases the risk of moisture stress and terminal drought, compared to sandy surface soils. Sandy surface soils combined with large PAWC (e.g. deep sands or some sandy surfaced texture-contrast soils) are found to be the most resilient for cropping in drier environments.

Model results for potential climate change impacts on production and erosion risk indicators are presented in the form of maps and tabulated areal statistics (for crop reporting districts and NRM Regions). Simulated results display a relatively close association with recent historic wheat grain yield data obtained from the Australian Bureau of Statistics and Primary Industries and Regions SA (PIRSA) Crop and Pasture reports. Based on the PIRSA crop report yield values (although these are regional estimates, they are considered the most reliable dataset) a root mean square error of 0.52 t/ha was achieved, comparing simulated long-term historic wheat grain yields with 10 year average crop reporting district records from across the State. Feedback from regional farming systems and soil and land management consultants indicates that, in general terms, the modelling is reasonably close to expected grain yield results, although a number of local discrepancies have been noted (with both low and high predictions). A range of assumptions (detailed within this report) were made in order to deliver an efficient yet meaningful modelling process. It is important that these assumptions, and the associated model limitations, are recognised when interpreting the results.

Low rainfall cropping environments appear most vulnerable to reducing grain yields and increasing erosion risk, if rainfall declines. In some areas of the State, impacts from low to moderate level climate change (see 5-10% rainfall reduction scenarios) on grain yields appear to be subdued, or in some cases grain yield is boosted slightly. This contrasts with a more pronounced impact on post-harvest biomass and erosion risk for these climate change scenarios. This appears to be linked to the modelling assumption of a single medium maturing wheat variety and the influence of warming which will bring flowering and grain production earlier (leaving less time for the crops to grow vegetative biomass). While, in reality, farmers will make different variety selections to optimise crop performance (including the need to avoid frosts), the modelling does suggest (for some areas) there will be a general trade-off between grain yield and residual crop biomass (available to protect soils) under declining rainfall. Meanwhile, cropping systems in the wetter parts of the State are likely to benefit from a warming, drying climate. In these situations, where moisture is not a limiting factor, the increased CO_2 and temperature (in historically cool regions) have the opportunity to boost plant and crop production levels. New opportunities may also arise in areas that have been historically too wet and cold for cereal cropping, although this was not investigated in this study.

The erosion risk modelling indicates that erosion risk is a gradational problem, increasing in extent with poorer seasons and increasing in frequency with a drying climate. The modelling provides a guide to areas that might first show increased erosion risk due to low biomass growth in poorer seasons. The erosion risk maps highlight a patchwork of areas that will need to be monitored if projections of a drying climate become a reality, to identify any emerging and recurrent erosion risk issues.

DEWNR will continue to work in partnership with industry and NRM stakeholder groups to examine the potential regional implications and support adaptation responses to climate change. It is anticipated that this will include further discussions around the findings of this study. This study has provided more detailed information to assist with future adaptation planning and priority setting. For example, it provides a focus for identifying areas where alternative sustainable land management, land use or farming business strategies may need to be considered across the State's cropping zone.

> Important note – The climate change scenarios depicted in this report represent hypothetical, 'what if' scenarios used to examine the potential impacts of a warming, drying climate. While being consistent with the envelope of possible change over the next 2-3 decades (Suppiah et al. 2006), they should not be taken as definitive predictions of future climate.

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The vision for this project followed previous work examining potential climate change impacts to the inherent wind erosion potential of soil across the State's NRM Regions (DWLBC 2009a), undertaken as a case study within DEWNR's (formerly DWLBC) 2006-08 'Regional climate change decision framework' project. The crop simulation modelling project summarised in this report arose from inter-agency discussions on the next step towards better understanding the potential impacts of climate change on sustainable land management throughout the State's cropping zone.

Through the pilot and State-wide (cropping-zone) projects, valuable contributions have also been made by regional soils, land management and farming systems consultants Mary-Anne Young, Michael Wurst, Barry Mudge, David Davenport, Brian Hughes and Richard Saunders (from Rural Solutions SA); and technical advisors Giles Forward and Tim Herrmann (from DEWNR). Bertram Ostendorf from The University of Adelaide offered valuable early guidance to focus our methodologies for modelling and mapping. Special thanks to Neal Dalgliesh (CSIRO Ecosystem Sciences) and Dennis van Gool (Department of Agriculture and Food, Government of Western Australia) for their review comments and suggestions which (although not included in full) have led to important improvements in the report. Some key issues requiring further clarification with the APSIM modelling were identified through this review process and these are summarised in Appendix A.

4 DAFF Australia's Farming Future: Developing Climate Change Resilient cropping and mixed cropping/grazing businesses in Australia.

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1. Introduction

1.1 Rationale

The need for better information on the potential impacts of climate change on agriculture to support short and long term adaptation decisions is widely appreciated. For many years, successful land managers in low rainfall zones have been developing and undertaking appropriate adaptations in farming and business systems in response to climate risks (Doudle et al. 2008, CSIRO 2008, PIRSA 2009, Rebbeck & Duffield 2008, Liddicoat et al. 2009). However if a warming, drying trend continues, the impact of climate variability on farming systems and natural resources is expected to increase (see Section 2.1). With climate change, current strategies may not be enough and more transformational changes may be required (CSIRO 2008, PIRSA 2009). This may also include traditionally reliable higher rainfall areas, where land managers will need to look more broadly for appropriate risk management and adaptation strategies.

In recent years a number of projects have investigated impacts and adaptive options for dryland agriculture in a more variable and changing climate. These include those examining agronomic adaptations such as plant species selection, maximising water use efficiency or modifying sowing times; through to landscape analyses with perennial vegetation systems (Hobbs 2009; Bryan et al. 2007, 2010) and farm business planning (Doudle et al. 2008). A number of projects have also looked at climate change impacts on natural resources (Bardsley 2006, AMLR & DWLBC 2007, DWLBC 2009a, Sweeney 2010).

However there has been a scarcity of studies investigating the interaction of potential climate change impacts on farm productivity and impacts on land condition such as erosion risk (e.g. Bryan et al. 2007, 2010). The interaction is important not only because future productivity relies on the sustainable management of soils, but also because increased incidence of poor crop and pasture growth is likely to lead to land degradation through increased wind or water erosion. Erosion and loss of topsoil reduces nutrient levels, soil carbon content, plant-available waterholding capacity (PAWC) and hence the productive capacity of our soils. At the national level, wind and water erosion are seen as major threats, with many soils eroding faster than they are forming (Leys et al. 2008). Loss of valuable topsoil is a critical issue considering forecasts for increasing population and associated growing pressure on agricultural land to produce more food and fibre.

To inform planning for potential climate risks, this project examines the link between crop production and risk of land degradation by soil erosion (from wind or water) under different climate change scenarios. Erosion is a particular concern in cropping regions where soil disturbance and periods of bare ground are a common feature of traditional tillage-based cropping systems. The first half of the 20th century witnessed extreme erosion events; and while improved management practices since that time have markedly reduced average rates of soil loss, they still exceed rates of soil formation and therefore remain unsustainable (McCord and Payne 2004, Forward and Dutkiewicz 2012).

Large areas of the State have sufficient potential (or inherent susceptibility) for erosion that require special management measures to avoid unacceptable soil loss. Considering land not under native vegetation, this includes 2.9 million ha with moderately low to moderately high water erosion potential and 5.9 million ha with moderately low to moderately high wind erosion potential (according to data from the State Land & Soil Information Framework, see Appendix B). In cleared, non-arable areas there is a further 359,700 ha of land with high to extreme water erosion potential, and 250,600 ha of land with high to extreme wind erosion potential.

The importance of soil erosion as an NRM issue is reflected in Target 70 of the South Australian Strategic Plan, which states that by 2020, SA aims to achieve a 25% increase in the protection of agricultural cropping land from soil erosion (baseline: 2002-03). Soil erosion has also been chosen as a key issue for this study due to its strong links to climate and plant production and the availability of good quality soil and land attribute spatial data.

This project recognises the current work being undertaken by a range of organisations (in particular SARDI, CSIRO, DEWNR, Future Farm Industries Cooperative Research Centre [FFI CRC] and Rural Solutions SA) in the field of production agriculture and land use, and seeks to fill a 'niche gap' by including investigations into the impact of climate change on our natural resources.

1.2 Aims

The ultimate aims of this work are to better inform land managers, help conserve our precious natural resources and assist with higher level NRM planning activities under future climate change. Key questions being addressed include:

- How might a warming, drying climate impact on cereal cropping, in particular:
    - Wheat grain yields?
    - Residual crop biomass available to protect soils from erosion?
- What are the influences of soil type and regional climate?
- What are potential implications for land management and land use?

Detailed objectives established for this study were:

(1) To explore and evaluate the use of the APSIM (Agricultural Production Systems Simulator) crop simulation tool together with landscape modelling frameworks to provide indicators of the vulnerability of wheat cropping to climate change (from a production and land management perspective).

(2) To investigate combinations of available spatial data describing soil attributes, vegetation, climate, current land use, land cover, and wind and water erosion risk to inform planning and policy for land use and land management under climate change.

It is expected that outcomes from the project will contribute information to the work of stakeholder organisations including policy, industry, research and regional NRM groups: DEWNR, PIRSA, SARDI, FFICRC, SANTFA, Upper North Farming Systems, Mallee Sustainable Farming Inc, YP Alkaline Soils Group, Advisory Board of Agriculture, Ag Excellence Alliance and NRM Regions (NY, EP, SAMDB, AMLR and KI), who are involved in managing the impacts of climate change. It will be another step in the process of refining predictions to assist land managers to build 'adaptive capacity' and develop long term plans in response to climate change.

Model outputs should not be seen as providing the absolute answer, in attempting to show areas under imminent threat of land degradation from climate change. Instead, map products will help provide a focus for:

- prioritising adaptation activities in regional areas
- identifying areas to monitor for future vulnerability and erosion impacts if a warming, drying climate trend continues to emerge in line with scientific projections.

It is envisaged that follow up work will be undertaken, in partnership with stakeholder groups, to discuss the findings of this work and support ongoing adaptation efforts. This may include exploration of potential alternative sustainable land management or land use options (particularly on low return land), investigating alternative business strategies, and the extension of currently successful risk management approaches.

2. Background

2.1 Potential impacts of climate change

Climate change projections for the dryland agricultural regions of SA indicate that annual average temperatures will increase by 0.4°C to 1.8°C by the year 2030, and between 0.8°C and 5.5°C by 2070. Average annual rainfall may decrease by as much as 15% by 2030 and by 45% by 2070 (Suppiah et al. 2006).

Because rainfall is already a limiting factor across the majority of South Australia's agricultural zone, if climate change brings further climatic warming and drying the impact is expected to be primarily negative, and exacerbated on the drier fringe (e.g. in already marginal and low return cropping land). Under such a trend, impacts are likely to include, but are not limited to (Suppiah et al. 2006, McInnes et al. 2003 , CSIRO & BoM 2007, CSIRO 2008 , PIRSA 2009 , Stokes & Howden 2010 , Sweeney 2010, Ludwig & Asseng 2006 , Hennessy et al. 2008)[5]:

- Less growing season rainfall (with predicted declines mostly in winter and spring)
- Increased frequency of low rainfall years
- Increased evaporative water loss combined with reduced water availability
- Longer dry spells between rainfall events
- Higher frequency and severity of droughts
- Increase in bush fire risk (20-30% increase by 2050)
- Accelerated crop growth due to warmer temperatures
- The need for different crop variety selections to adapt to changing conditions (e.g. warming and/or potential declines in spring rainfall)
- Reduced viability for crops sensitive to dry conditions (e.g. canola and some pulses)
- Restricted options and times for crop rotation
- Reduced crop and pasture yields in warmer, low rainfall areas (where reductions in rainfall are expected to outweigh any benefits from increased CO_2 concentrations)
- Possible yield increases (due to increased CO_2) where rainfall or soil constraints are not limiting; this may also occur with faster crop development (with warmer temperatures) shifting the grain filling period into a wetter part of the season
- Production may increase in cooler or wetter areas due to (i) warmer winter temperatures and (ii) reduced waterlogging and reduced nutrient leaching
- Reduced grain and pasture protein quality resulting from increased nitrogen use efficiency under higher CO_2 levels
- Reduced maturation time prior to harvest (under hotter and drier conditions) which may affect grain quality, e.g. grain cracking or small grains
- Where rainfall is limiting, farms dominated by fine textured (more clayey) soils are likely to see much stronger negative effects of declining rainfall than farms dominated by more sandy soils
- Possible higher vulnerability of sandy soil types to reduced crop yields under high temperatures (although in low rainfall settings, moisture stress in heavy soils is likely to be a bigger problem)
- Increased rainfall intensity, which may increase opportunities for water harvesting, but also lead to higher incidences of flooding, erosion and storm damage
- More intense and frequent heatwaves (however for cropping the risk of heat stress will tend to be offset by faster crop development with flowering and grain fill during cooler periods)
- Increased heat stress in livestock due to heatwaves
- Reduced availability and quality of water for livestock
- Migration and changes in the competitiveness of pest plants, animals and diseases
- Problems with changed timing and/or strength of climatic indicators (or triggers) used by plant and animal species, and potential mis-matches in the development of synergistic species – which may impact on 'ecosystem services' such as pollination, pest control, etc.
- Reduced ground cover protection for erosion control
- Salinity increases in soils and groundwater resulting from warmer, drier conditions and less flushing by rainfall
- Potential reduction in watertable-induced salinity due to lowering of watertables
- Reduced recharge to groundwater and aquifers.

[5] Note: while potential impacts include greater climate extremes (e.g. droughts, heatwaves, bushfires) – these have not been examined within the modelling approach described in this report.

DWLBC 2009a suggests further potential influences from climate change on plant and soil interactions:

- Less plant canopy as a consequence of reduced plant biomass associated with decreasing soil moisture
- Changes in litter cover in response to changes in organic decomposition rates caused by soil microbial activity which is driven by temperature and soil moisture
- Reduced soil moisture as a consequence of increased evapotranspiration rates and projected reduced rainfall, longer dry spells and increased rainfall intensity (resulting in less infiltration and more runoff particularly on low permeability soils)
- Increased soil erodibility as a result of lower organic matter levels causing poorer soil structure

With a drying climate, the frequency of low rainfall years is expected to increase. Greater likelihood of reduced biomass due to poor seasons (and hence reduced ground cover) will add to the challenge of managing erosion risk. Soil organic carbon also plays an important role in boosting soil structure and water-holding capacity. Under declining rainfall and increased temperatures we could expect reduced organic matter inputs, potentially higher microbial decomposition rates (with higher temperatures, provided moisture is not limiting) and hence a declining soil organic carbon balance. Over time this would lead to declines in soil structure and water retention properties. Both declining soil carbon and increasing erosion have potential for enhancing negative impacts – resulting in a loss of soil fertility and waterholding capacity which in turn leads to a further decline in plant growth.

Wind erosion prone soils are a particular problem in very low rainfall situations when seed heads set early and crops do not grow high enough to act as an effective barrier to wind (M-A Young Rural Solutions SA 2010, pers. comm.). Where it is still economic to harvest, the header combs must be set low enough to reap the crop. In low rainfall years this is an issue as stubble height is a major factor in protecting against wind erosion.

2.2 The role of management in addressing climate risk

Management will play a critical role in overcoming any future climate challenges – whether to cropping production or the sustainability of natural resources (including soils). Existing climate risk management strategies developed in low rainfall, less reliable country, will provide a valuable foundation for short and long term climate change adaptation across the State (e.g. Doudle et al. 2008, PIRSA 2009). In the medium to long term this may include 'incremental' changes (involving small progressive steps) and/or 'transformational' changes (taking a predominantly different approach) in farming systems. Potential changes may involve new ways of managing current and emerging issues; developing new farming systems, species, varieties and technologies; and re-locating farming enterprises to more favourable climatic zones (PIRSA, 2009). Adaptation responses may also be planned (in anticipation of future change) or autonomous (reacting to climate pressures as they emerge) (Allen Consulting Group 2005, Rebbeck & Duffield 2008). Climate risk management strategies make an important distinction between 'short-term' and 'long-term' decision making (based on particular indicators, benchmarks or trigger points) and this provides a useful approach for considering potential risks associated with climate change (M Rebbeck SARDI & B Mudge Rural Solutions SA 2009, pers. comm.). Any of these potential changes will need to be underpinned by increased knowledge by farmers and their advisers of their farming system and its drivers (e.g. available soil moisture, soil characteristics) (N Dalgliesh CSIRO Ecosystem Sciences 2012, pers. comm.).

Within current farming systems, land managers are increasingly adopting a flexible approach where management responses are driven by seasonal indicators. Through short-term or tactical responses, farmers aim to minimise their exposure to poor seasons and maximise benefits in good seasons. Examples of this in cropping systems can include: adjusting crop area and crop type; flexible, incremental nitrogen applications depending on how the season is progressing and knowledge of available resources (e.g. monitoring or modelling water and nitrogen); and crop canopy management (e.g. through control of sowing density, fertiliser timing, early crop grazing) to avoid excessive evapo-transpiration and subsequent low soil moisture during the critical grain filling period. Multi-purpose crops with minimal early inputs are another way to leave options open for either grazing by livestock or eventual harvesting if the season progresses well.

Longer term or strategic responses have included different crop variety selection, tailoring management and alternative land use to soil type, breeding new varieties, and adoption of conservation farming techniques (no or zero-till and stubble retention). The latter practice is being increasingly adopted (Llewellyn & D'Emden 2010) for the multiple benefits of conserving soil moisture, soil structure, organic matter and hence waterholding capacity. For many farmers, the move towards no-till and increasing summer weed control (with chemical control rather than soil tillage) has been a response to drier winters and lower productivity, and this has had positive flow on effects in helping to retain more surface cover and providing greater erosion protection (B Mudge Rural Solutions SA 2010, pers. comm.).

Investment in technology such as precision agriculture systems which allow inter-row sowing and controlled traffic can offer significant input and water use efficiency benefits, enabling farmers to work with higher levels of stubble cover and protect large paddock areas from soil compaction. Such moves can be of benefit for production, financial viability and soil protection in moisture challenged environments. Strategic management responses such as these aim to build robust and resilient farming businesses (ie. better adaptive capacity) able to withstand the increasing challenges associated with climate change.

Livestock are considered a useful risk management tool in a variable climate and marketplace. Management strategies can include forward planning of stocking (and de-stocking) rates based on forecasts of available feed. Breed selection also plays a role in addressing potential climate risks. On the other hand, livestock have a significant impact in reducing surface cover from grazing, trampling and pulling out stubbles. In many cases where failed crops occur, erosion will not be an issue if grazing is eliminated (B Hughes & B Mudge Rural Solutions SA 2010, pers. comm.). The use of 'feed lots' (dedicated low erodibility farm areas for livestock containment and supplementary feeding) during low rainfall periods when feed is scarce, also provide a means to retain vegetative cover and protect farm land from erosion.

Even with the best of climate conditions, management can have detrimental impacts on erosion risk. Following good rainfall years in higher rainfall areas, it can be difficult seeding into very thick stubbles. In these conditions there is often increased burning of stubbles. Rather than delaying burning until just before seeding, land managers will often burn early to get a 'clean' burn (before conditions become too cold), therefore increasing the number of days that soils are unprotected, and increasing the risk of exposure to a significant erosion event (M-A Young Rural Solutions SA 2010, pers. comm.). Higher market prices for grain legumes can also impact on erosion risk particularly in moderate to high rainfall areas (where grain legumes are mostly grown). Larger areas sown to grain legumes (influenced by higher prices; above levels that might be expected from good crop rotation practice for managing disease and weed issues) can present an increased erosion risk, as stubbles are often thin and easily degraded, offering limited soil protection.

2.3 Management decisions and issues for this simulation modelling

As outlined above, management decisions can play a critical role in matters of relevance to this study including: seasonal crop outcomes, how well farming systems may cope with climate change, and control of erosion risk.

However, the difficulty for a high level modelling exercise such as this study is trying to account for the variety of management decisions that farmers might use to cope with climate variability and uncertainty – particularly as they try to mitigate losses and land degradation in poor years while trying to capitalise on good years. A simple example of this is the level and timing of nitrogen application(s) to crops. For our State's largely nutrient limited soils, extra nitrogen can potentially have a dramatic influence on seasonal outcomes, depending on moisture availability.

> Management factors are important but complex. To investigate the fundamental climate issues, simplified management assumptions have been made.
>
> This avoids confounding the study with differing management decisions.

To focus this investigation on the influences of climate and soil type interactions we decided to take a simplified approach to management decisions, whereby certain fixed management assumptions have been made. In trying to cover such a large study area it is inevitable that the modelling assumptions won't necessarily match individual or local experience in a large number of situations. In making set assumptions (e.g. nitrogen application, crop variety, row spacing) the modelling may under-estimate (or over-estimate) cropping production in comparison to local farmer experience. Accordingly, the model assumptions need to be recognised as constraints which influence simulated levels of production. In some cases, if taken out of context, the modelling may lead to incorrect perceptions about the sustainability of wheat production in certain areas. The modelling assumes modern practices (with minimal soil disturbance) and does not take into account any improvements in varieties or agronomic techniques.

It is not the intention of this work to model the variety of different management approaches that farmers successfully utilise across the spectrum from higher rainfall, more reliable areas, through to the drier, more marginal areas. While the absolute simulation results need to be viewed in the context of model assumptions, for communication with stakeholders it may be of greater value to focus on the relative differences between scenarios results.

2.4 Potential crop simulation modelling frameworks

Basic relationships between crop growth and climate

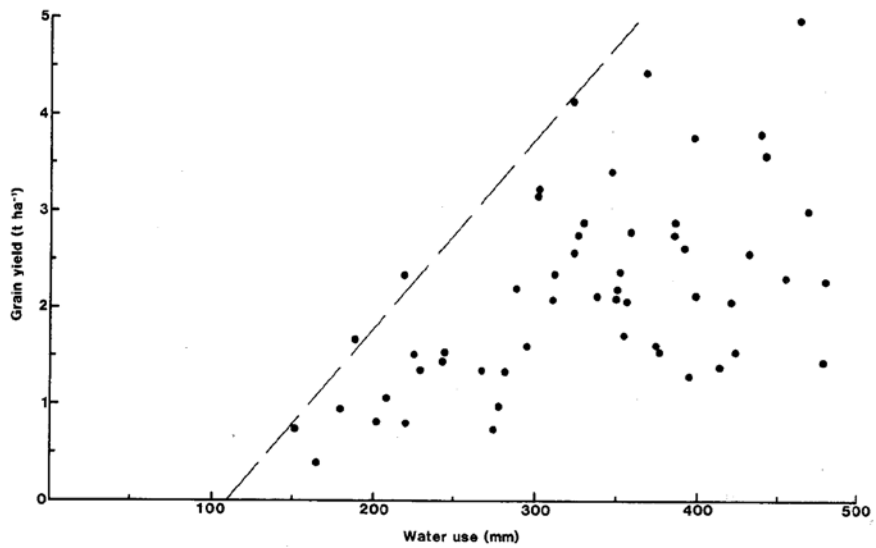
Work by French and Schultz during the 1970s-80s in South Australia, quantified the relationship between water use and crop performance indicators such as grain yield and biomass. This is encapsulated in the concept of water-use efficiency (WUE), which is a measure of grain production per mm of available water. French and Schultz (1984a) proposed upper limits to water use efficiency, potential yield and potential biomass, suggesting that the most efficient wheat crops, after allowing a loss of 110 mm (as a threshold rainfall before crops would yield owing to evaporation), were able to produce 20 kg of grain per hectare for every mm of water transpired by the crop, and 55 $kg.ha^{-1}.mm^{-1}$ of dry matter or total above-ground biomass production.

These simple estimates of an upper limit to crop productivity can be expressed in the form of linear equations, or plotted as graphs (see below):

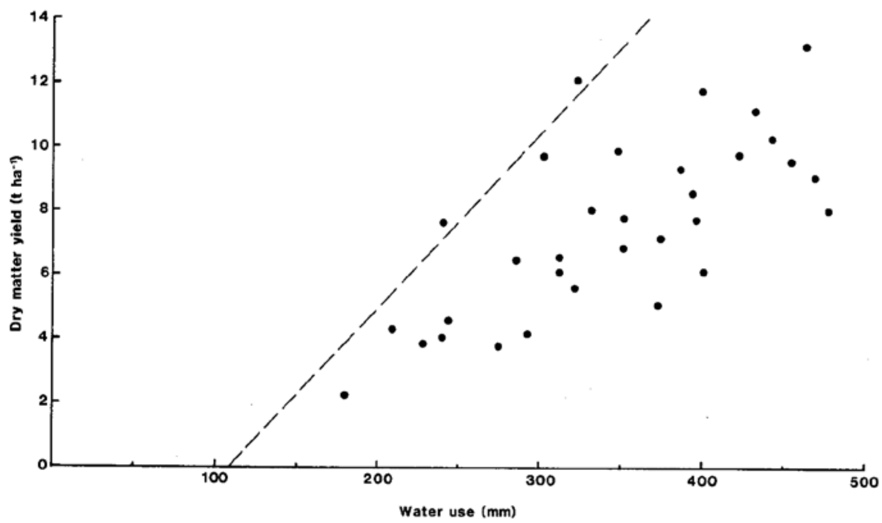
Potential wheat grain yield (kg/ha) = (GSR – WL + S) x WUE_{yield} (Fig 1a)

Dry matter production (kg/ha) = (GSR – WL + S) x $WUE_{dry\ matter}$ (Fig 1b)

where GSR = growing season rainfall (mm),
WL = water loss (threshold evapotranspiration) =110 mm for GSR > 150 mm,
S = decrease in stored soil moisture (mm),
WUE_{yield} = 20 $kg.ha^{-1}.mm^{-1}$
$WUE_{dry\ matter}$ = 55 $kg.ha^{-1}.mm^{-1}$



(a)



(b)

Figure 1. Plots of potential upper limit production for (a) grain yield, and (b) total dry matter, for wheat as described by French and Schultz 1984a.

A number of factors can limit actual crop yields including: soil type, rainfall patterns, stored soil moisture at sowing, time of sowing, cultivation practices, nutrient availability, crop variety genetic properties, waterlogging, pests, weeds and diseases (French and Schultz 1984a,b). Work to better understand crop water use efficiency and factors affecting production in different climatic and soil type settings is ongoing (GRDC 2009, CSIRO & GRDC 2011).

Review of alternative modelling approaches and tools

Since the proposal by French and Schultz of this upper limit concept for crop yield and biomass production, a number of modified and improved models along similar lines (e.g. van Gool & Vernon 2005, Oliver et al. 2009) and more complex models that use weather files to simulate a daily soil moisture budget and crop growth (e.g. APSIM) have been developed to investigate, predict and better explain crop performance and the underlying causal factors. Different models are underpinned by varying levels of complexity and input information, with quite variable predictive accuracy.

APSIM has been adopted by many researchers to investigate influences on crop performance. A number of studies have utilised APSIM to investigate the potential impacts of climate change and climate variability on cereal crop production in southern Australia (e.g. Ludwig & Asseng 2006, Luo et al. 2005a, Luo et al. 2005b, Bryan et al. 2007, Alexander et al. 2008, Hayman et al. 2010ab, Nidumolu et al. 2012). Modelled impacts due to changing climate factors, and their interaction (e.g. temperature, rainfall and CO_2), can be quite complex and non-linear, indicating that climate change has the potential to bring negative or positive changes to crop production and gross economic margins across different annual rainfall and temperature zones and soil types.

While they cannot perfectly mimic the real world with all its complexity, these crop simulation models provide a framework to explore the major potential impacts of climate change. There is generally a trade off between levels of data input, model design and predictive accuracy. The better a model takes account of factors that influence crop growth, with quality input data to match, the better it will perform. When coupled with available spatial information on soil properties and regional climate data, there is the opportunity to investigate and map the potential impacts for different regions and soil types.

A selection of alternative modelling frameworks and tools were reviewed to gain a better perspective on previous approaches used to investigate climate impacts on production and soil erosion risk (or erosion potential) within southern Australia (Table 1). From a review of these alternative modelling approaches it is apparent that appropriately parameterised APSIM models remain the benchmark for accuracy in simulating crop performance. Models using monthly data (e.g. modified French & Schultz models) are disadvantaged in that they cannot account for extreme or short-lived climate events (e.g. heatwaves or heavy rainfall events) which can impact significantly on yields, or result in runoff or drainage where growing season rainfall does not contribute to yield. Crop suitability type spatial modelling using land and soil attribute data combined with average annual rainfall can provide a general indication of long-term crop performance but does not simulate season-by-season production.

Remote sensing techniques also offer promise for cost-effective, high resolution monitoring (and potentially prediction) of crop growth, ground cover and climate interactions but require availability of long-term, good quality imagery covering the area of interest. Long-term datasets are required to average out year-to-year variability in the distribution of rainfall. Peak crop biomass will generally vary in time across the State (due to different moisture and temperature conditions), which has implications for optimum image capture dates across different regions.

A number of previous studies have utilised the State Land & Soil Information Framework (Soil & Land Program 2007a,b) in a limited capacity by only considering data from the most common land and soil component of each mapped soil landscape area. This approach has been widely used by modellers attempting to incorporate the State's comprehensive soil and land spatial data, but overlooks the available quantitative and semi-quantitative data on sub-dominant components of soil landscape map units which often occupy large areas of the landscape (this is explained further in Section 2.5).

Table 1. Examples of alternative modelling frameworks for investigating climate impacts on crop (or pasture) production and erosion risk (or potential)

Studies/ References	Main tool used in modelling	Study area	Investigates: Crop production	Erosion risk (or potential)
French & Schultz 1984a,b	French & Schultz	SA cropping areas	✓	
Luo et al. 2005b	APSIM	Mid-lower north SA	✓	
Bryan et al. 2007; Bryan et al. 2010	APSIM	Lower Murray-Darling Basin (SA & Victoria)	✓	✓
Van Gool & Vernon 2005	Modified French & Schultz	WA cropping areas	✓	
Oliver et al. 2009	Modified French & Schultz (x17), APSIM	SA and WA	✓	
Lyle et al. 2009	Remote sensing	SA cropping areas	✓	
Clarke et al. 2011	Remote sensing	SA cropping areas		✓
Hughes et al. 2009	Qualitative vulnerability scoring	EP study areas	✓	✓
Wurst et al. 2003	Hybrid French & Schultz / APSIM	Farm-scale assessments	✓	
WA DAF & Landgate 2010 ('Pastures from Space')	Remote sensing	Multi-scale assessments	✓	
Qld DERM 2010 ('Aussie Grass')	Remote sensing	Multi-scale assessments	✓	
DWLBC 2009a	Rule-based assessment of changes to erosion potential classes	SA agricultural zone		✓
Soil & Land Program crop suitability spatial modelling	Rule-based assessment based on land and soil attributes and average annual rainfall	SA agricultural zone	✓	

2.5 The State Land & Soil Information Framework

An overview of the State Land & Soil Information Framework (SL&SIF, www.environment.sa.gov.au/Knowledge_Bank/Information_data/soil-and-land) is provided at this point because the structure and data residing in this framework are significant within the context of this study. Figure 2 provides a brief conceptual overview of the various information resources that make up the SL&SIF. While the Framework is based upon data developed via the State Land & Soil Mapping Program (1986 to 2012), it also incorporates derived data (e.g. from conceptual landscape modelling utilising base land and soil attribute data as well as external spatial data such as climate or vegetation) and is updated as new data, techniques and understanding are developed and incorporated. Further background information is available from Soil & Land Program 2007a,b, Maschmedt 2002, and Hall et al. 2009. Key characteristics of the SL&SIF of importance to this study are discussed further below.

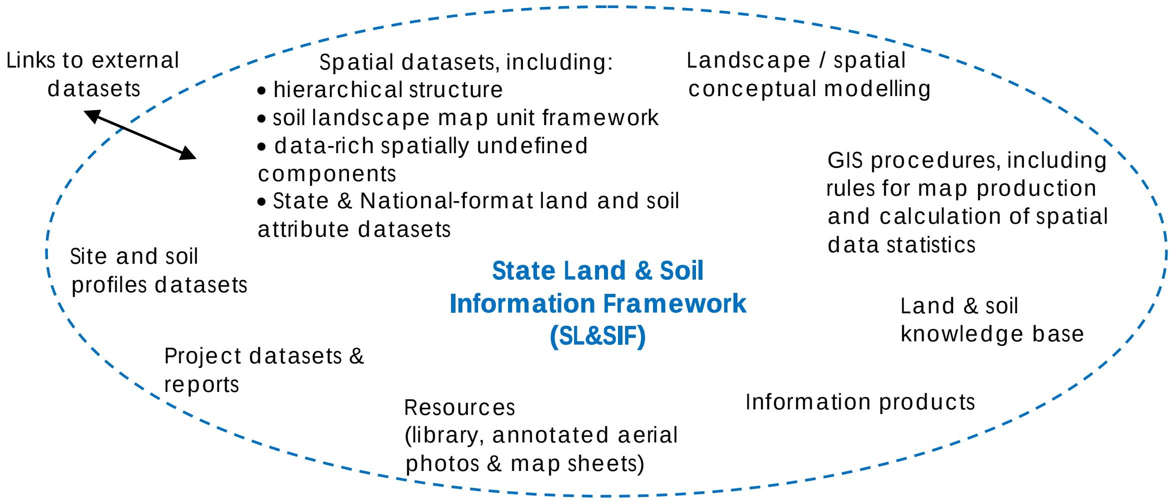


Figure 2. Overview of the State Land & Soil Information Framework (J Hall DEWNR, 2011, pers. comm.)

Spatial datasets

Spatial data are arranged within a nested hierarchy of map units from (in order of decreasing size): biophysical regions, biophysical sub-regions, land zones, land systems and soil landscapes. Mapping was undertaken at a scale of 1:100,000, except for higher rainfall and more intensively used areas which are mapped at 1:50,000 (Hall et al. 2009). The smallest map units, soil landscapes, are tracts of land formed on a limited range of geological materials, having recognisable topographic features, and with a defined association of soils. At the scale of mapping, soil landscapes may contain spatially undefined facets (land or soil components). Information for these spatially undefined components (including areal proportion and quantitative to semi-quantitative descriptions of various land and soil attributes) are recorded in data tables (see Figure 3). Attribute data within the SL&SIF have been developed from a combination of extensive field survey work, laboratory test results, stereoscopic air photo interpretation, previous existing mapping information and expert judgement.

The SA State Land & Soil Information Framework utilises a soil landscape map unit framework to capture comprehensive information about our heterogenous landscapes that otherwise cannot be displayed at regional mapping scales.

Key features of this system include:

- proportional contributions from spatially undefined map unit components can be retained in modelling, ensuring all relevant data is taken into account
- information can be grouped or summarised to suit the scale of the issue being investigated
- a large range of quantitative and semi-quantitative attribute data is available to suit various needs.

The SL&SIF contains two key data formats, termed the (i) 'SA-format', and (ii) 'National-format' soil and land attribute datasets. Both datasets have been developed by the DEWNR Soil & Land Program, following standards and criteria outlined in Maschmedt 2002 (for SA-format data) and McKenzie et al. 2005 (for National-format data, as used in the Australian Soil Resource Information System or ASRIS).

Within the 'SA-format' dataset, over 40 attributes of importance for land use and natural resource management are described. This includes the soil type attribute of 'subgroup soil', for which sixty-one conceptual classes encompass all known soils within Southern South Australia (Hall et al. 2009). For the SA-format dataset, spatially undefined components are based on distinct elements in the landscape (e.g. flats, rises, swales, sandhills, etc.). Attribute conditions (including associated subgroup soils) are ascribed to these landscape components. Multiple subgroup soils can occur within a landscape component and estimates of their areal proportion (within each landscape component and cumulatively across the total map unit) are also recorded.

In recent years the DEWNR Soil & Land Program has also developed 'National-format' land and soil attribute datasets, which are defined for each soil component of each soil landscape map unit. In the National-format datasets, spatially undefined components are representative of soil profile types based on the SA-format subgroup soils. However soil component attribution varies according to conditions found within each land system, resulting in approximately 1,500 subgroup soil variants being described. National-format attribute datasets have been developed according to protocols designed for the Australian Soil Resource Information System (McKenzie et al. 2005), and encompass (i) landscape characteristics (e.g. slope, drainage, etc.) and (ii) information for five key layers corresponding to increasing depth down the soil profile.

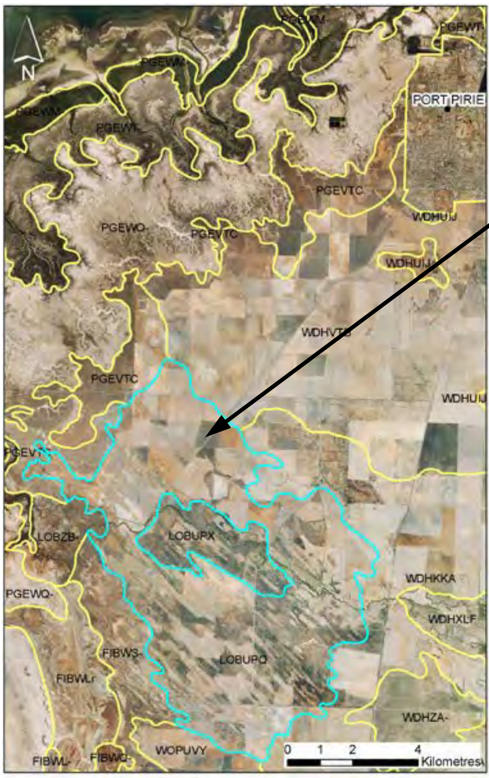
GIS procedures

The State Land & Soil Mapping Program required the associated development of specialised GIS procedures and programming. Within the SL&SIF, a particular combination of land system and soil landscape is given a unique 'LANSLU' identifier code. The areal proportion and associated attributes of each spatially undefined landscape or soil component within a LANSLU map unit can either be (i) presented in a simplified format for mapping, or (ii) analysed via LANSLU-linked data tables (containing 'analysis data') to obtain summary spatial data statistics.

Procedures have been developed through the evolution of the SL&SIF to provide access to the large range of available information for use in a variety of formats (e.g. standard attribute mapping, spatial data statistics, and customised modelling and mapping). 'Spatial data statistics' provide a summary of the areas of land within each attribute class using the primary 'analysis data', rather than the simplified (or secondary / derived) 'mapping data' and map legend categories. In calculating spatial data statistics for a study area this incorporates proportional contributions from each (spatially undefined) land or soil component within every map unit, within the study area.

Landscape / spatial modelling

The map units and linked land and soil attribute data tables provide the basis for a wide range of potential landscape models. SA-format datasets have been used in past modelling activities undertaken by the Soil & Land Program, including State-wide assessments of salinity risk (due to rising watertables), suitability for specific crop types and potential for soil carbon improvement – to name a few examples. Knowledge of soil and land processes are incorporated into modelling via conceptualisations and the formulation of soil and land attribute based rules. Linkage to 3rd party datasets (e.g. climate, digital elevation models, etc.) is also possible within the GIS environment. This particular study mostly uses National-format attribute datasets, and also links to external climate and land use datasets.



Example data table for highlighted map unit (LANSLU = LOBUPQ)

LANSLU identifier code	Soil components (National / ASRIS format)	Soil % Area [Total 5651 ha]	Soil component (basic description)	*Surface clay content	*Depth to (chemical or physical) impeding layer for annual crop & pasture roots
LOBUPQ	H2C	45%	Siliceous sand	5%	1.0m
	A4PS	25%	Calcareous loam	15%	0.3m
	C1BS	15%	Gradational sandy loam	7%	0.25m
	A6SS	5%	Calcareous gradational clay loam	30%	0.3m
	D4BS	5%	Loam over pedaric red clay	18%	0.1m
	E2BS	5%	Red cracking clay	40%	0.35m

Spatially undefined soil component areas sum up to 100% of the LANSLU map unit

Figure 3. An example *soil landscape map unit* (or LANSLU) and linked data table describing spatially undefined soil components (of known areal proportions) and selected attributes(*). Each soil component is described with respect to a range of National-format attributes including, for example, estimates at five depth layers for: clay content, coarse fragment content, bulk density, pH, organic carbon content, wilting point and field capacity moisture contents, etc.

Typical map products

Map products based on soil and land attribute data need to account for the spatially undefined components residing within each soil landscape map unit, but as this information cannot all be displayed at once, maps present a carefully considered simplification of the available data. This requires mapping rules to be developed which highlight features of interest for each particular issue or investigation. Common examples of map presentations are listed below (while Appendix C contains a general disclaimer outlining limitations associated with SL&SIF map products):

i. most common, or dominant attribute class or value occurring within a map unit
ii. most limiting attribute condition(s) occurring within a map unit
iii. prevalence of an attribute class or value (or selected combinations of classes) occurring within a map unit, often expressed as "proportion of the landscape with …"
iv. selected combinations of attribute classes or values occurring within a map unit by proportion (e.g. "30% high salinity and 70% low salinity")
v. area-weighted average values calculated across all components in a map unit (for quantitative data).

2.6 The 'APSIM' crop simulation model

APSIM (Keating et al. 2003) is a crop simulation tool used by agricultural systems researchers, leading farmers and farm advisors (through the 'Yield Prophet' online interface: www.yieldprophet.com.au) to investigate influences on cropping systems and assist with management decisions. A brief overview of APSIM is provided at this point as it is important to understand the nature of model inputs and outputs (illustrated in Figures 4 & 5). The APSIM model offers a powerful tool for investigation, but to a degree constrains the methodology used in this study[6]. While APSIM can simulate a number of crop species, wheat has been chosen for this study as it is the principal crop across South Australia's cereal cropping zone and makes a useful reference for comparison.

APSIM is essentially a point-based model which requires detailed information for:

(1) Soil characterisation – which captures important physical and chemical properties. Critically this includes moisture-holding properties of the soil profile down to the maximum rooting depth of annual crops.

(2) Starting conditions – such as soil moisture content, residual fertility and organic matter, etc.

(3) Agronomic assumptions – such as levels of fertiliser applied, farming systems/ technologies (relating to levels of soil disturbance), sowing rates, and rules to dictate when sowing will occur.

(4) Climate information – daily climate data (rainfall and temperature), preferably from a long-term, quality, representative monitoring station.

Seasonal crop growth is simulated in daily time steps through to maturity, for each year within the climate record. Long-term climate records are valuable for generating meaningful summary statistics. If 100 years of climate station data is provided for the 'APSIM run' this produces 100 years of variable seasonal outcomes (see Figure 4). Useful outputs for our work are grain yield and total shoot (above-ground) biomass at maturity, provided in t/ha on a dry matter basis. For a particular soil x climate scenario, simulated grain yield or biomass outcomes can be ranked from highest to lowest. All the results from such a long-term APSIM run can be considered equivalent to 100% of the possible outcomes from that particular soil x climate scenario. Simple descriptive statistics (e.g. percentiles) can be used to assess the probability (or frequency) of getting above or below a particular biomass or yield. The spread of seasonal results provided by a single APSIM run can be presented in the form of a probability distribution curve (see Figure 5).

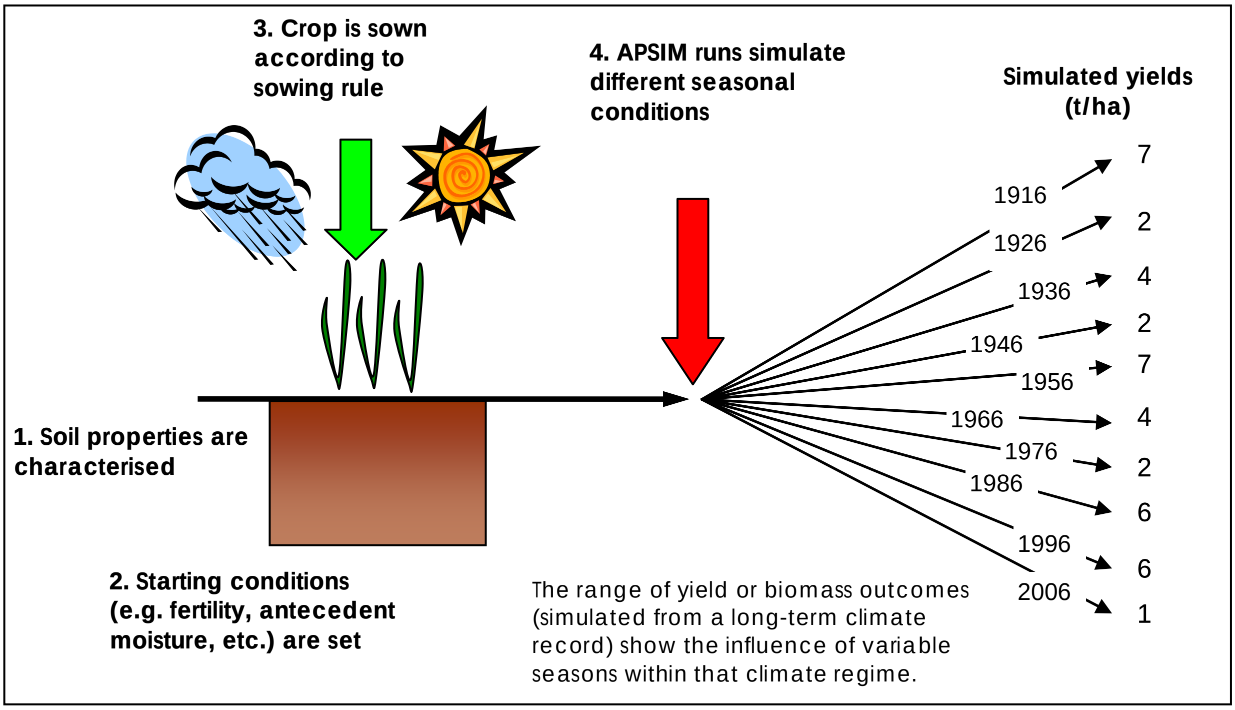


Figure 4. Overview of the APSIM crop simulation model (adapted from T McClelland BCG 2009 pers. comm.)

[6] This is because APSIM produces point-based outputs in tonnes/ha, but cannot model specific parameters that are considered important in field assessments of erosion risk (see Section 2.7)

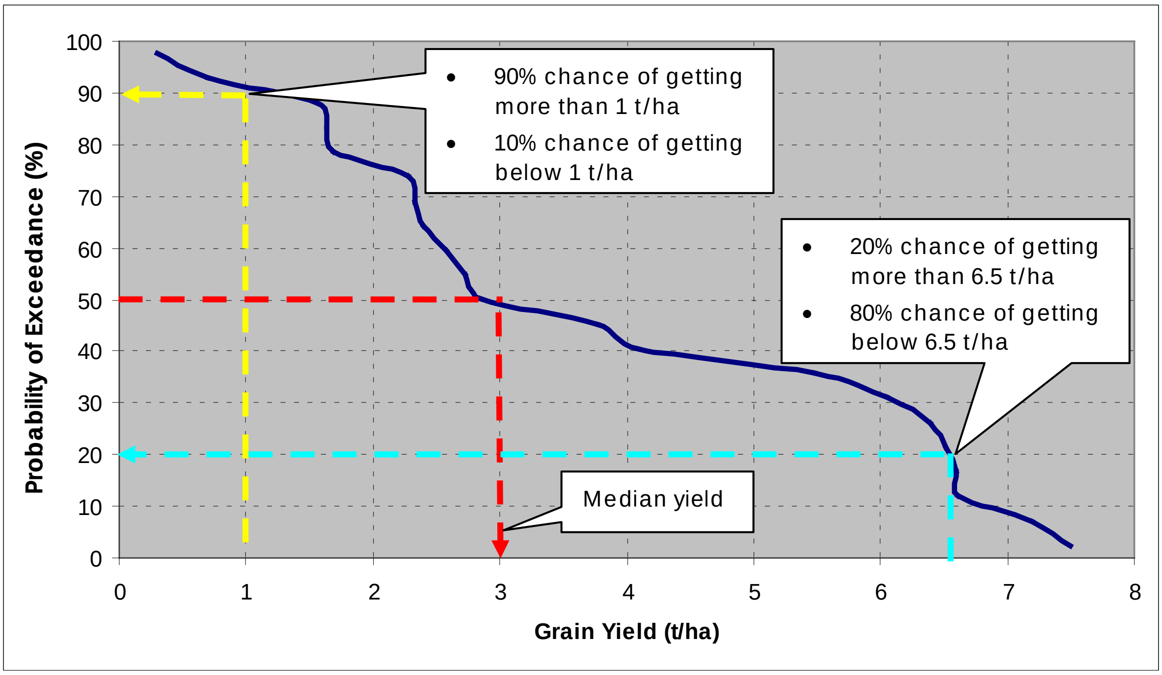


Figure 5. Example of a probability distribution curve output (dark blue line) from an APSIM crop simulation run (adapted from T McClelland BCG 2009 pers. comm.)

The example 'probability distribution curve' above results from a single APSIM crop simulation run (ie. from one soil type and one long-term climate record) and can provide a large amount of information. Some example observations are listed below to help with interpreting this curve:

- The maximum yield (7.5 t/ha in Figure 5) is the 'best season on record' or 99th percentile[7].
- The lowest yield (0.3 t/ha in this example) is the 'worst season on record' or 1st percentile. Across the long-term record, there is a 99% probability that this value will be exceeded.
- The median yield (or 50th percentile), 3 t/ha in this example, has 50% of observations above and 50% below it. (Note this is different to the average, or arithmetic mean of all outcomes.)
- The 20th percentile (or decile 2 [8]) value is around 1.6 t/ha in this example, and is representative of a poor year. Across the long-term record there is an 80% probability that this value will be exceeded.
- The 80th percentile (or decile 8) value is around 6.5 t/ha in this example, and is representative of a good year. Across the long-term record there is only a 20% probability that this value will be exceeded.

'Upscaling' across space and time

APSIM is a point-based tool that needs to be run separately for each combination of soil and climate data. An upscaling method is required to provide information at a regional scale, which considers spatial variation in soil types and climatic conditions. Further details of the approach taken are provided in the 'Method' section.

For this study, the APSIM model was re-initialised (in terms of soil moisture, nutrients, organic matter, etc.) so that each season is treated independently, rather than attempting to model cumulative effects of (for example) declining stubble levels, soil erosion and resultant long-term changes in soil condition (e.g. organic matter levels, fertility and PAWC).

[7] A 'percentile' is the value of a variable below which a certain percent of observations fall. For example the 20th percentile is the value below which 20 percent of the observations may be found.

[8] To calculate deciles, values are ranked in ascending order then split into 10 equally sized groups. The first group contains the lowest 10% of values and is termed the 'decile 1 range' (or decile range 1). The highest value in this group is termed 'decile 1'. This naming convention continues for decile ranges and decile values 1 to 9. Decile range 10 contains the highest 10% of values and has an upper limit being the highest on record. (Also see Fairbanks et al. 2011.)

2.7 Factors influencing erosion risk

Significant wind and water erosion events in the agricultural zone of SA are usually very sporadic in time and place, associated with infrequent weather events. As these events are spatially variable and difficult to measure directly, 'erosion risk' is typically monitored as a surrogate indicator of actual erosion. Changes in erosion risk over the longer term will inevitably result in changes in the actual amounts of erosion (McCord and Payne 2004, Forward 2011).

Monitoring of wind and water erosion risk has been a key focus of DEWNR's Erosion Protection Field Survey (EPFS) Program (formerly called the Land Condition Monitoring Program), undertaken since 1999. The EPFS Program (Appendix D) has sought to standardise the terminology used regarding erosion in order to help clarify issues and discussion of risk factors (G Forward DEWNR 2010, pers. comm.):

- **'Erosion potential'** – describes a soil's susceptibility to erosion in relation to inherent soil erodibility and topography and is independent of management.
- **'Erosion risk'** – describes the predisposition of land to erosion if a wind or rainfall event occurs. Erosion risk is based on soil surface condition resulting from the combination of inherent susceptibility ('potential') and management.

Factors affecting erosion potential

Wind erosion potential is assessed in relation to inherent soil erodibility (primarily taking account of clay content and coherence), depth of erodible soil, land form and average annual rainfall. Water erosion potential is assessed in relation to inherent soil erodibility (primarily taking account of clay content, degree of aggregation, permeability and depth to water-impeding layer) and slope (gradient and length). These assessments are based on standard criteria contained within Maschmedt 2002.

Comprehensive spatial information on wind and water erosion potential is contained within the State Land & Soil Information Framework (see Soil & Land Program 2007a,b). Maps of wind and water erosion potential (Figures 6 & 7) only show overviews of available information (refer to Section 2.5).

Wind erosion mainly occurs in lower rainfall areas of the cropping zone (250 to 400 mm per year) especially on sand and sandy loam soils. Soils with a very sandy texture with little organic matter lack coherence and are easily moved by wind when there is inadequate surface cover. Well structured loam to clay soils, which form into masses of aggregates or clumps, are less vulnerable to wind erosion, but can also suffer from wind damage when soils are bare, dry and in a very loose or disturbed condition (DWLBC 2009b). Water erosion is more prevalent in higher rainfall areas (more than 400 mm per year), especially on slopes, poorly structured soils and soils in a loose (e.g. cultivated) condition.

Wind and water erosion potential classes and their respective areas across southern South Australia are summarised in Appendix B. Assessments of inherent soil erodibility (and resultant erosion potential classes) take no account of vegetative soil cover, which can vary significantly between seasons or be lost following a bushfire. Soil erodibility has been assessed under the uniform assumption that land is in a bare clean, cultivated state to provide consistency of assessment. This reflects a uniform worst case scenario in the context of traditional tillage-based cropping systems (but otherwise management is not factored into erosion potential assessments). Increasing classes of erosion potential have increasing limitations, with associated management implications and impacts on the viability of cropping.

However, it should be noted that adoption of modern, 'best practice' farming methods (e.g. no-till, zero-till, stubble retention, clay spreading, improved soil structure) can (in some cases) assist land managers to overcome inherent erosion potential issues through better management which means that overall erosion risk is kept at acceptable levels. In other words, new cropping techniques may allow cropping to occur where previously it was not viable. The modelling undertaken in this study adopts the conventional understanding that land of Class 5 and greater erosion potential is not suited for cropping, and therefore has been excluded from the analysis (see Section 3.9).

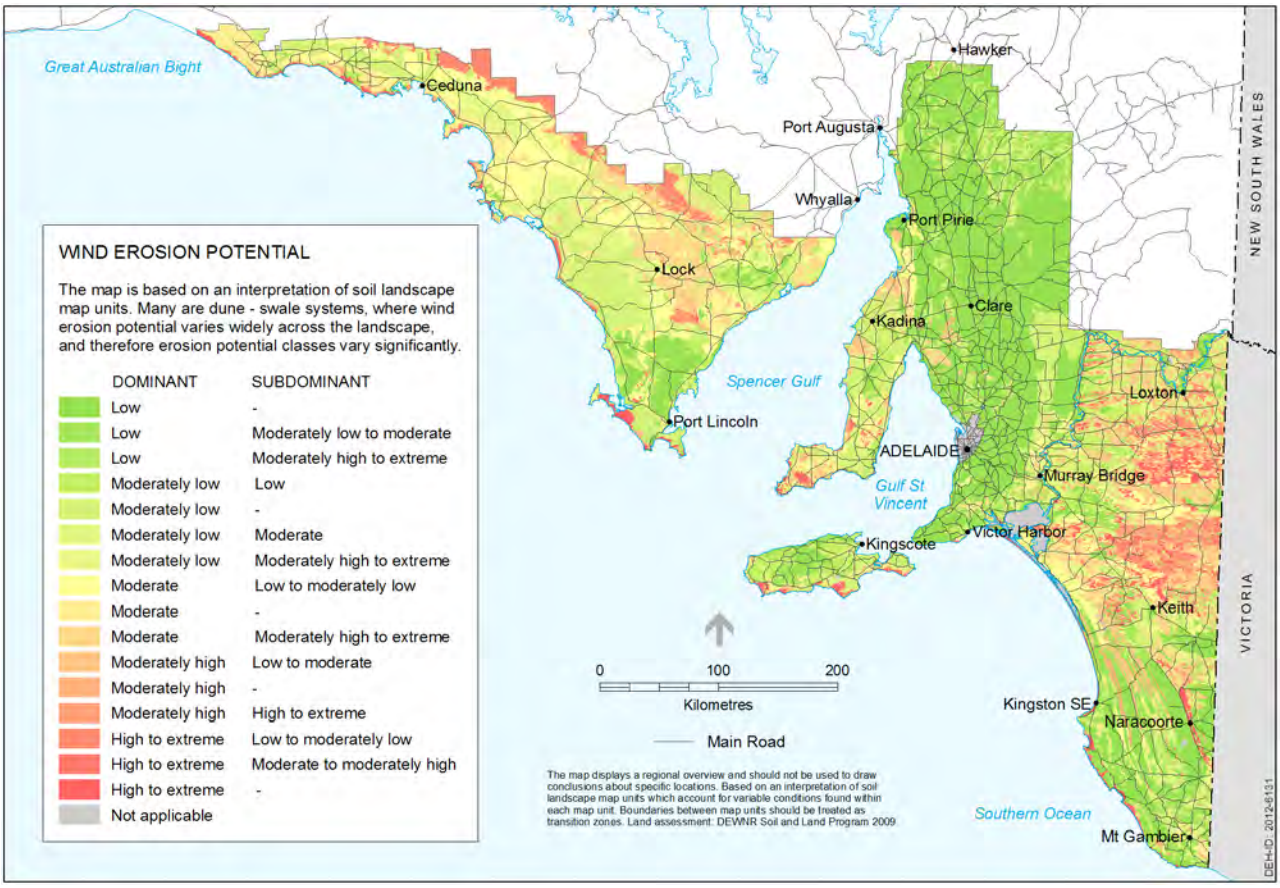


Figure 6. Wind erosion potential (or inherent susceptibility to wind erosion)

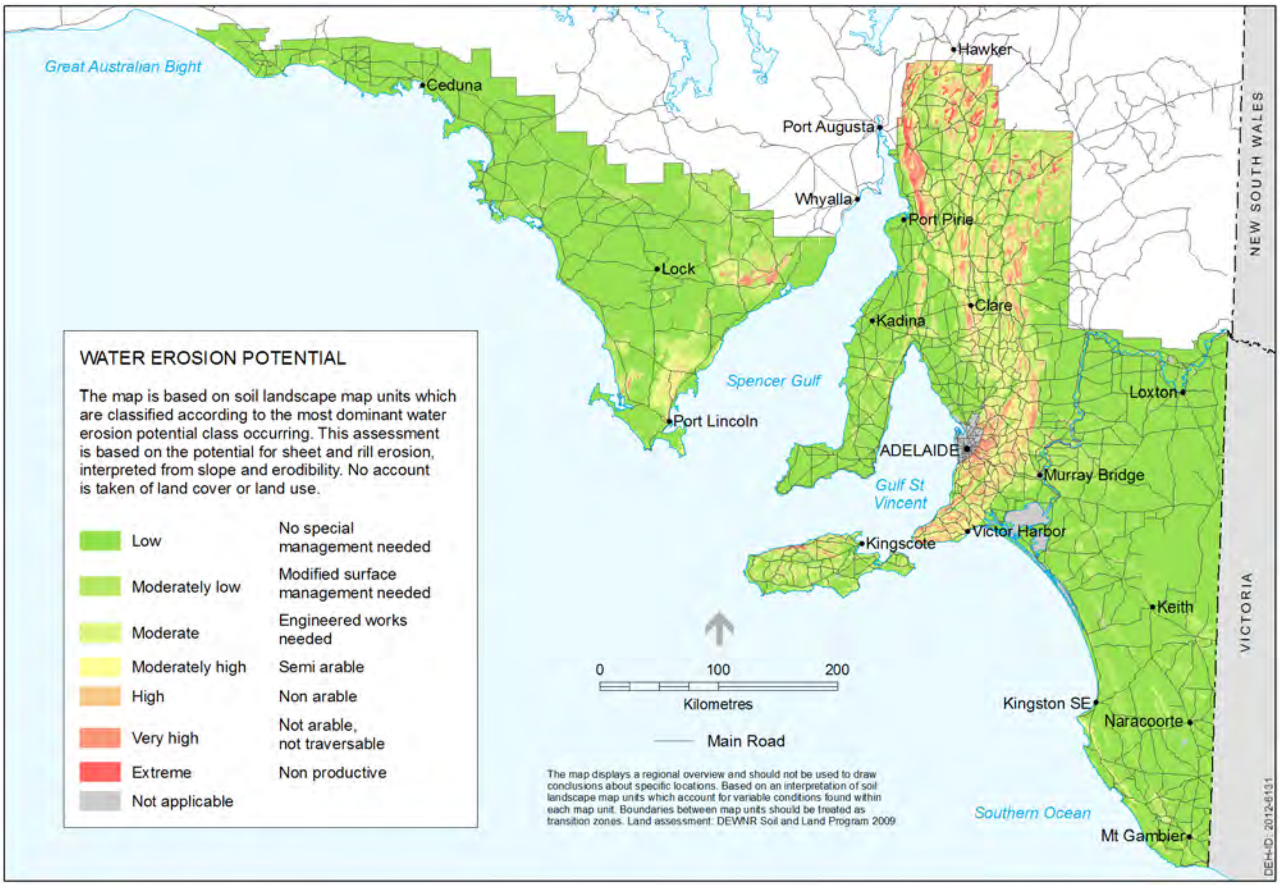


Figure 7. Water erosion potential (or inherent susceptibility to water erosion)

DWLBC 2009a provided an expert assessment of likely changes to wind erosion potential classes under different climate change scenarios for the NRM Regions of South Australia. This was performed on the basis that average annual rainfall criteria are used in the assessment of wind erosion potential classes (Maschmedt 2002). The work documented in this report takes an alternative and more developed approach to this, by simulating soil cover levels to gain a better understanding of erosion risk due to climate change impacts on biomass levels.

Factors affecting erosion risk

Primary factors contributing to erosion risk are summarised in Table 2. These fall into the categories of (i) inherent susceptibility or potential of the soil and landscape to erode, (ii) management which leads to soil disturbance (e.g. stock traffic, tillage, etc.), (iii) surface cover (% coverage, bulk and structure of the cover) and (iv) the number of days that the soil is in a bare or loose condition.

Table 2. Primary factors contributing to erosion risk

Primary factors	Wind erosion	Water erosion
(i) Inherent site susceptibility (potential):		
• Soil and land type	✓	✓
• Slope (and slope length)		✓
• Annual rainfall zone	✓	
(ii) Management:		
• Soil disturbance or looseness (e.g. due to cultivation)	✓	✓
(iii) Soil cover:		
• Cover height	✓	
• % surface cover		✓
• Bulk/ volume	✓	✓
• Anchorage (how easily detached are plants by wind or water)	✓	✓
(iv) Exposure:		
• Number of days that soil is in a bare or loose condition	✓	✓

Notes:

1. Primary factors will determine the level of erosion risk.
2. Contextual or seasonal factors provide the context for why land is in a particular condition at a particular time. These include: management rotation, grazing, cultivation methods, burning off, improvement practices (e.g. clay spreading, contour banking), seasonal rainfall, etc.
3. The intensity of storm events (wind or rainfall), in combination with the primary factors listed above, will determine the severity of actual erosion.
4. The height of surface cover is more important for wind erosion risk (to reduce wind speed at the surface), whereas the % surface cover is more important for water erosion risk (to protect soil from raindrop impact).

Some factors vary in importance between wind and water erosion. Wind erosion is influenced by the structure of plant residues (ie. height and anchorage), more than by the total weight of residue or % surface cover. Tall, standing, well anchored stubble lifts air movement away from the surface reducing the impact of winds. As a guide, suggested minimum cover levels range from 15% of total surface area on loams to 50% on sands. In general, more cover is needed on sandy soils, exposed hills and soil disturbed by livestock or cultivation. (DWLBC 2009b).

The proportion of soil covered is a more important factor for water erosion than the total weight of residue. This is because some crop residues (e.g. grain legume stubbles) can blow and clump together, leaving significant areas of soil exposed. Greater coverage of the soil area reduces the erosive impact of raindrops and optimises rainfall infiltration. Recommended minimum cover levels range from 60% of total surface area on gently sloping land to 75% on moderate slopes. Steeper slopes, poorly structured soils or soils disturbed by grazing or cultivation require more cover. (DWLBC 2009b)

Some erosion risk may be inevitable (Forward 2009) – due to climatic extremes and/or the need for soil disturbance in particular situations (e.g. breaking up hard-setting soils or controlling pests, weeds and diseases) – however minimising erosion is seen as an important and common goal for both public and private benefit.

Erosion risk can be reduced by (DWLBC 2009a,b, M-A Young Rural Solutions SA 2010, pers. comm.):

- retaining a sufficient amount of vegetation or plant residues on the soil surface to reduce the impacts of raindrops, slow and deflect wind, and help trap and bind soil particles from being blown or washed away
- keeping soil particles aggregated and not in a loose or disturbed state where particles can easily move by wind or water action, by minimising disturbance with farm machinery or livestock
- Minimising the time that soil is bare of cover or in a disturbed or detached condition

Surface cover levels (in t/ha) are often discussed in the context of assessing the grazing potential of stubbles while considering the management need to retain so-called 'critical cover' levels for erosion protection (M-A Young Rural Solutions SA 2010, pers. comm.; DWLBC 2009b). In this context it is normal for indicative estimates of critical surface cover requirements on wind and water erosion prone sites, with different soil types, to be discussed with landholders. While the concept of critical cover levels for erosion protection is relatively easy for landholders and NRM managers to relate to, typically cover levels in t/ha are discussed as a guide only. It should be recognised that cover levels in t/ha are not a good stand-alone indicator of erosion risk (or protection). As discussed above, typically it is the quality of the surface cover (% coverage, height, anchorage) that is more important than the quantity of cover. Indeed, field observations have shown examples of over 4 t/ha of surface cover but a high erosion risk (with an EPFS Program surface cover rating of 5 or greater, see Appendix D or Forward 2011) (M-A Young Rural Solutions SA 2010, pers. comm.). Also there is the technical consideration that the amount of cover needed (of a certain quality) will vary according to erosion potential class, not just soil type. Crop species (e.g. legume vs cereal) is also a factor in terms of the longevity of protection (ie. how quickly crop residues degrade in quality).

What are appropriate erosion risk indicators in this study?

Crop simulation models such as APSIM can only provide outputs in the form of dry matter (grain or biomass) in tonnes per hectare (t/ha). Estimates of post-harvest stubble dry matter, in t/ha, can be obtained by subtracting grain yield from total biomass at maturity. As the quality of stubble is a key factor in assessing erosion risk, our analysis will assume the optimal stubble management option where stubbles remain standing and undisturbed so that predicted cover levels in t/ha can be interpreted to offer the best potential protection from erosion. This allows the focus to be placed back on the potential climate-induced changes in wheat crop biomass levels and hence potential changes in the capacity of land managers to protect soils from erosion. Accepting these limitations, **post-harvest stubble dry matter (t/ha),** also called 'post-harvest biomass', is seen as a key indicator in this study.

> Stubble cover in t/ha is not a good stand-alone indicator of erosion risk.
>
> On the ground, factors such as % cover, height, anchorage, soil disturbance and the number of days that soils are in a bare or loose condition are the most important in determining erosion risk.
>
> However this study uses crop simulation modelling that limits us to considering biomass predictions in t/ha.

For the purpose of this project, estimates of critical (or minimum) cover levels to protect land from wind and water erosion have been established in consultation with DEWNR EPFS Program managers and regional land management consultants. These are based on erosion potential classes (which take account of soil type as well as other factors) and are outlined in Table 7. It is important to note that they assume a high level of stubble quality, are considered as a guide only, and shouldn't be taken out of context as precise benchmarks of erosion risk or protection.

APSIM outputs thus provide the opportunity to estimate, under different soil and climate scenarios:

- Average post-harvest biomass (t/ha)
- The % chance (frequency) that post-harvest biomass levels will be below 'critical cover' levels needed to protect land of various wind and water erosion potential classes

Consideration was also given to more sophisticated indicators of erosion risk, such as the numbers of days per year that soil is in a bare condition (ie. interpreted as having below critical cover levels). This type of scenario is illustrated in Figure 8, where in the absence of grazing, stubbles will break-down via natural decay processes[9]. In situations of low biomass production and significant natural decay there may be periods of time prior to

[9] Stubbles in contact with the soil can decay via the action of soil microbial activity. Rainfall, wind, sunlight, insects and other animals also play a part in stubble break down.

emergence of new crops when below critical stubble cover levels are present. APSIM is able to model the natural breakdown of stubble residues, as a function of the quantity of stubble present, temperatures and, importantly, rainfall patterns. However the process and interpretation to present this as an indicator is not straightforward. It would require a further level of analysis to interpret APSIM stubble decay simulations across the study area to disentangle the influence of (i) the level of starting stubble (resulting from the prior growing season), from (ii) the subsequent non-growing-season rainfall patterns which drive its decay. This was not pursued as an indicator in this study as it was thought to be unlikely to produce clear and useful messages owing to the counteracting influences of growing season and non-growing season rainfall.

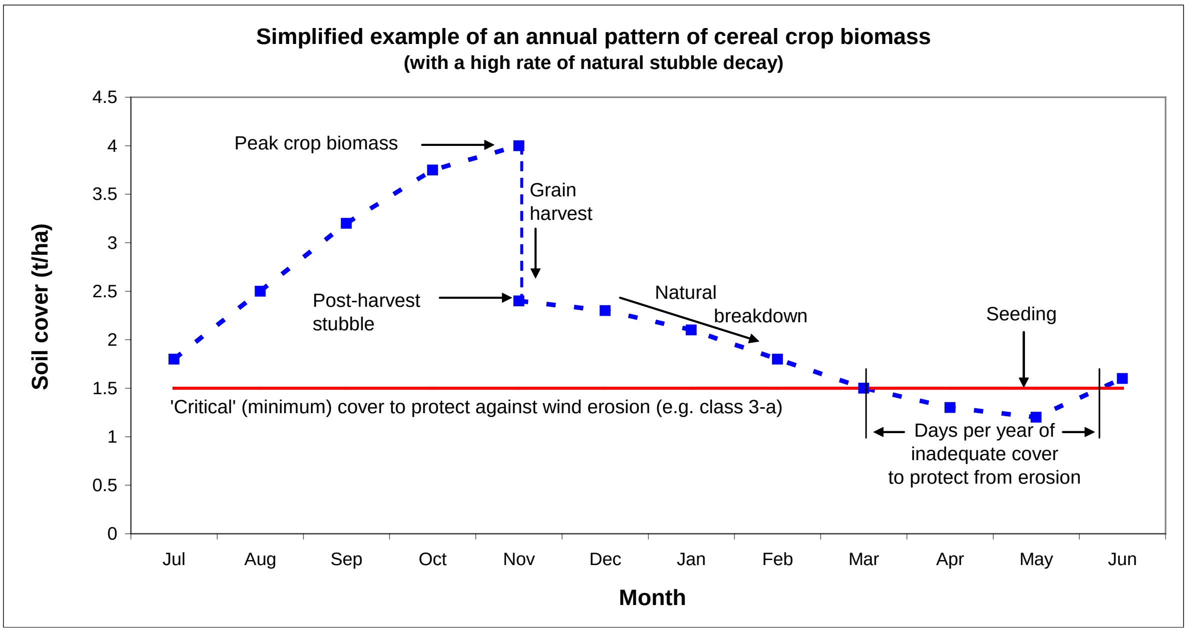


Figure 8. **Representative example annual pattern of soil cover under cropping, assuming natural stubble breakdown in the absence of grazing.**

Actual seasonal monitoring of ground cover decline on agricultural land is undertaken throughout the cropping regions by the DEWNR EPFS Program. For example, over the period 1999/00 – 2009/10, the average surface cover rating across the Northern and Yorke (N&Y) agricultural region declined from 1.8 in October to 5.4 in June the following year (Figure 9). It should be noted this decline represents the average result from over 2000 surveyed sites, including varying grazing management practices and natural breakdown conditions. As a guide, these values might correspond to a height reduction (e.g. flattening of stubble) from around 40cm (rating 1-2) to around 2cm (rating 5-6). Definitions of surface cover ratings from the EPFS Program are described in Appendix D and vary from "1" (40cm or higher residues with 75-100% cover) to "8" (bare ground or 0% cover). Surface cover rating values are not directly comparable with stubble cover estimates in t/ha. A surface cover rating of 5 provides only light cover and is considered adequate for erosion protection. Surface cover ratings greater than 5 are considered at risk of erosion.

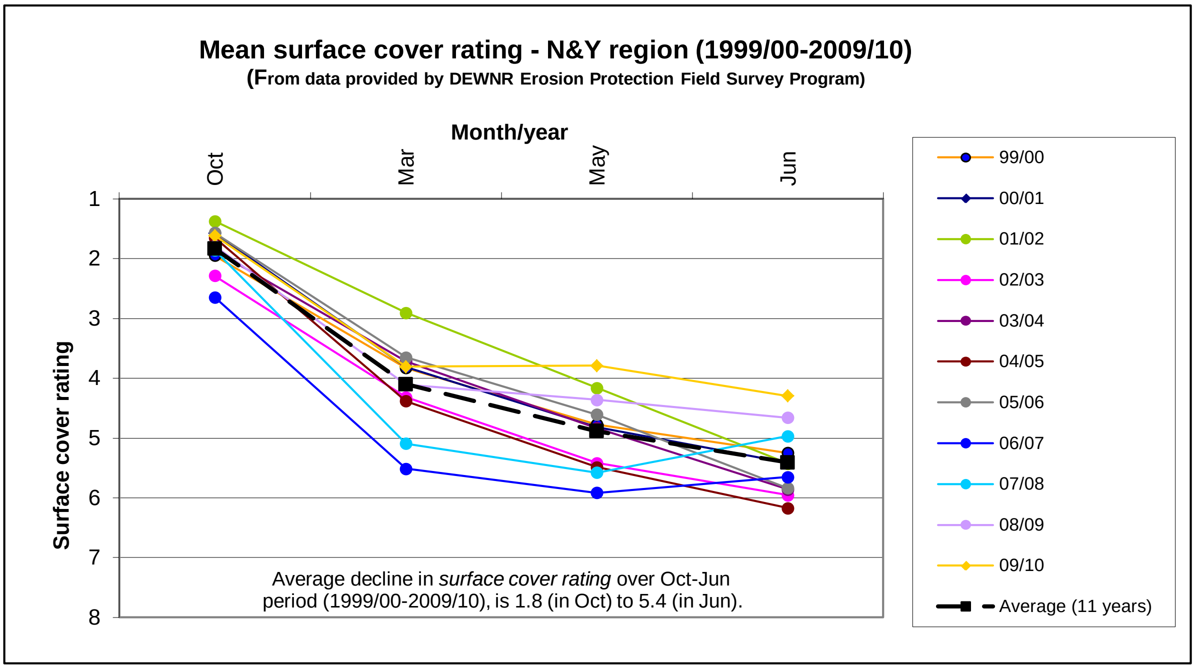


Figure 9. **The greatest change in mean "surface cover rating" typically occurs between the October and June surveys, as shown in this example data from the N&Y region (1999/00-2009/10) (Source: DEWNR EPFS Program, G Forward DEWNR 2010, pers. comm.)**

3. Method

3.1 Overview

The modelling approach used in this study has arisen through an iterative, developmental process. The simulation model provides predictions of wheat yield, crop biomass and erosion risk for all arable areas of South Australia (suited to dryland cereal cropping) assuming independent wheat crops every year over the period 1900-2009. Simulations are based on historic climate data and simulated climate change scenarios. The key production and erosion risk indicators identified for this modelling investigation are as follows (on a dry matter basis):

- *Wheat grain yield (t/ha)
- *Post-harvest biomass (t/ha) – defined as peak above-ground biomass minus grain yield
- Frequency (% chance) of post-harvest biomass below defined critical cover levels

*In particular, the simulated <u>average</u> wheat grain yield and post-harvest biomass provide representative statistical values relevant to each scenario, based on long-term climate datasets. Determination of the frequency of post-harvest biomass below critical cover levels also requires analysis of long-term (1900-2009) simulation runs.

This minimum set of indicators is designed to provide critical information on the potential impacts of climate change and were determined using the crop simulation tool APSIM. Being a point-based model, APSIM needs to be run separately for each combination of soil and climate data. To provide information at a regional scale requires an 'upscaling' method that considers spatial variation in soil properties and climatic conditions.

Previous broadscale crop simulation studies of this type in South Australia (e.g. Luo et al. 2005b; Bryan et al. 2007, 2010) have linked APSIM to a spatial coverage of 'most common' soil types. However this approach does not take maximum advantage of the existing soil and landscape spatial data available for South Australia's agricultural zone (Hall et al. 2009, Soil & Land Program 2007a). Most common (or dominant) soils often account for less than 50% of a soil landscape mapping unit. To gain a more representative spatial analysis of regional impacts it is necessary to include sub-dominant soils. To date, the challenges of considering multiple soil components for every mapping polygon and establishing detailed APSIM soil characterisations for every soil type have been too great to tackle.

A key innovation adopted in this project has been the use of 'modelling soil profiles', which are derived from analyses of key soil attribute spatial data contained within the State Land & Soil Information Framework (SL&SIF, refer to Section 2.5). All soil types and soil areas are accounted for via grouping into 'modelling soil profiles' defined in terms of (i) surface clay content and (ii) total plant-available waterholding capacity (PAWC or 'bucket size') – which are seen as critical parameters influencing soil-plant-water relationships[10]. This allowed development of a manageable set of representative soil characterisation files for use in ASPIM crop simulation runs.

In establishing the soil and climate classes the project team had to find a balance between a desire for higher resolution outputs (ie. more classes) and the need to constrain the time required for modelling (ie. less classes). Meaningful and physically representative groupings were also considered (e.g. soil texture classes) in deciding on the various modelling classes used. Multiple APSIM runs were then required to model the various combinations of soils, regional climate zones, and also different climate change scenarios.

3.2 Upscaling methodology

The 'upscaling' process that was undertaken is summarised below (also see Figure 10):

(1) ***Modelling soil profiles*** – were defined to take account of variation in soil properties of importance for crop performance (Section 3.3).

(2) ***Regional climate zones*** – were initially defined for APSIM modelling using selected intervals of average growing season rainfall (Ave GSR) and average growing season temperature (Ave GS Temp), linked to spatial grids of these parameters (Section 3.4). Each climate zone requires a corresponding long-term, daily climate file to run APSIM. These climate zones were not delineated further in presenting the results, as a further step [see (7) below] was taken to interpolate results at finer Ave GSR intervals for greater mapping resolution.

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[10] It should be noted that 'surface clay content' is a mapped soil attribute, while PAWC is a derived soil attribute, based on a combination of other (often 'best estimate') soil attributes (see Table 3, note 3)

(3) ***Climate files*** – representative, long-term (100+ year), good quality daily climate files were identified or synthesised, which link to each individual regional climate zone (Section 3.5). Collectively these files represent the 'historic' climate scenario. APSIM climate files require daily data for the following parameters: rainfall (mm), minimum and maximum temperatures (°C), and solar radiation (MJ/m²).

(4) ***Climate scenarios*** – to model alternative climate change scenarios, the complete set of historic climate files were then adjusted in accordance with selected climate change scenarios (Section 3.6).

(5) ***APSIM runs*** – were undertaken for selected combinations of 'modelling soil profile', regional climate zone (at nominal 50 mm Ave GSR intervals), climate scenario and specific site-based daily climate files (summarised in Section 3.7).

This involves a large number of APSIM runs which can be conceptualised by an 'APSIM input matrix' where each cell represents a different APSIM run with its own inputs and outputs. For example, an APSIM input matrix with 16 'modelling soil profiles' (4 % clay classes x 4 PAWC classes), 21 regional climate zones (3 Ave GS Temp x 7 Ave GSR classes) each represented by a distinct daily climate file, and 4 climate (1 historic and 3 alternative climate change) scenarios – represents 1344 distinct APSIM runs (with 100+ years of seasonal outcomes from each run). This number of APSIM runs becomes even larger when alternative daily climate files are required to simulate zones of similar Ave GSR and Ave GS Temp conditions but with different seasonal rainfall distribution and reliability (see Section 3.5).

APSIM parameters were reset in January each year so that each season could be modelled independently, without the influence of carry-over or long-term cumulative effects on crop residues or soil conditions (e.g. organic matter, nutrient and moisture levels).

(6) ***Summary statistical results*** – were evaluated from the 100+ seasonal outcomes, arising from each APSIM run (e.g. average biomass, percent chance of not exceeding various critical cover values). The summary statistics then represent the simulated output for that particular modelled scenario.

(7) ***Interpolation to increase resolution*** – while Ave GSR intervals of 50 mm were used to help constrain the APSIM modelling task, this was considered a relatively coarse scale in terms of expected crop performance. To achieve greater resolution for mapping, APSIM summary results were subsequently interpolated down to 10 mm Ave GSR intervals within an Excel spreadsheet.

(8) ***GIS analysis and mapping*** – was undertaken throughout the project, associated with the following key stages:

a. During development and visualisation of the modelling approach.

b. Ultimately each individual soil component within each soil landscape map unit (across the State's cropping zone) has been linked to a 'modelling soil profile' (Section 3.3), climate zone (Section 3.4) and corresponding daily climate file (Section 3.5). This enables mapping of the interpolated, summary APSIM results.

c. Further GIS analysis was undertaken to identify soil landscape components: a) with below critical cover needed for erosion protection (Section 3.8), and b) not suitable for cropping which have been excluded from the analysis (Section 3.9).

d. Mapping values and spatial data statistics have been evaluated within the GIS environment after any necessary analyses had been performed at the spatially undefined soil component level (also refer to Section 2.5).

e. As the modelling is based on wheat cropping across all identified arable land, the ***map outputs*** display yield, biomass or erosion risk predictions wherever wheat cropping is possible. However, because all arable land is not cropped each year, for the purpose of determining ***spatial data statistics*** (which report annual average production of grain, post-harvest biomass or land areas of below critical cover), an assumption has been made that wheat cropping occupies a percentage of arable land consistent with the total field crop areas (varying by regions) averaged from 10 years of PIRSA crop reports. This has been done to better reflect the actual proportion of dryland cropping and expected annual tonnages for the major grains (as discussed further in Section 4.4).

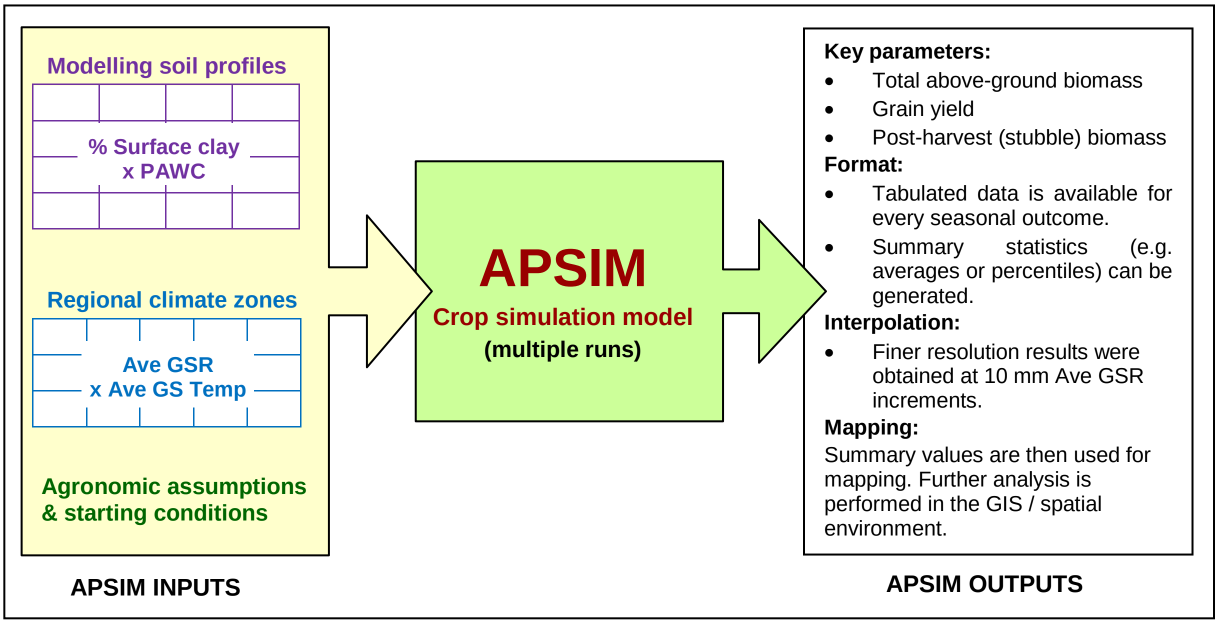


Figure 10. Upscaling methodology

Notes: (1) Each cell in the 'modelling soil profiles' matrix is represented by a conceptual soil profile with a distinct APSIM soil characterisation file. This is taken to represent a subset of mapped soils defined by a limited range of surface clay content and PAWC. Collectively, all 'modelling soil profiles' take account of all soil areas used for cropping.

(2) Each cell in the 'Regional climate zones' matrix represents a long-term daily climate file (based on historic climate data, or *alternative climate change scenarios). Each regional climate zone corresponds to a spatially defined area.

(3) *Alternative climate change scenarios are expressed as modifications to the daily climate records used to model the various regional climate zones. Each climate change scenario generates a whole new set of outputs.

(4) Agronomic assumptions and seasonal starting conditions are held constant across the study area and across climate change scenarios.

3.3 Modelling soil profiles

Recent updates to the SL&SIF (see Section 2.5) to align with national standards used by the Australian Soil Resource Information System (ASRIS; www.asris.csiro.au) (McKenzie et al. 2005), have provided quantitative and semi-quantitative estimates of a range of critical functional soil attributes. Attributes associated with soil moisture storage, evaporation and plant water uptake (discussed below) are of particular benefit for crop simulation modelling. Additional SA-format and National-format attribute datasets are used in the analysis of wind and water erosion risk (Section 3.8) and whether or not a land area is considered suitable for cropping (Section 3.9).

To cover such a large study area (and the broad continuum of soil types that might be cropped within it) project team members Peter Hayman and David Maschmedt developed a novel approach that drastically reduces the number of soil types that needed to be modelled through APSIM. 'Modelling soil profiles' were established which enable the categorisation of any soil by its (i) surface % clay content and (ii) plant-available waterholding capacity (PAWC) or 'bucket size' (in layman's terms). PAWC is derived from a number of attribute datasets, as per note 3 in the table below.

> Two critical soil attributes were used for simulating crop growth:
>
> - Surface clay content (%) determines how much moisture is held near the surface, with greater susceptibility to evaporative loss; as well as 'wilting point' moisture content.
> - PAWC ('bucket size') determines how much plant-available water can be stored when rainfall occurs.

The classification of mapped soils into 'modelling soil profiles' using the attributes surface clay content and PAWC is summarised in the table below, and their distribution is shown in Appendix E. The 16 'modelling soil profiles' span a range of soil profile types from shallow sands to shallow clay, and deep sands (or sandy surface texture-contrast soils) to deep clay (or clay loam) soils. This modelling accounts for sub-surface properties only through PAWC. This means, for example, that deep sands, sand over loams and sand over clay soils will be treated the same if they have the same surface clay content and same total PAWC.

Table 3. Classification of South Australia's National-format attribute data into16 'modelling soil profiles' (with corresponding potentially arable areas identified in this study*)

Total PAWC ("bucket size")	Surface % Clay Content: 0-5 % *[3.75]* (Surface: Sands)	>5-10 % *[7.5]* (Surface: Loamy sands)	>10-20 % *[15]* (Surface: Sandy loams)	>20 % *[30]* (Surface: Clay loams – clays)
30-50 mm *[40]*	**#1** 518,100 ha (7.1%)	**#5** 298,700 ha (4.1%)	**#9** 432,000 ha (5.9%)	**#13** 215,400 ha (3.0%)
>50-70 mm *[60]*	**#2** 464,100 ha (6.4%)	**#6** 216,000 ha (3.0%)	**#10** 769,800 ha (10.5%)	**#14** 292,000 ha (4.0%)
>70-90 mm *[80]*	**#3** 410,600 ha (5.6%)	**#7** 153,600 ha (2.1%)	**#11** 1,475,800 ha (20.2%)	**#15** 414,100 ha (5.7%)
>90 mm *[120]*	**#4** 194,500 ha (2.7%)	**#8** 165,200 ha (2.3%)	**#12** 897,000 ha (12.3%)	**#16** 385,800 ha (5.3%)

Shallow sands (#1); Shallow clay loams, clays (#13); Deep sands, or Sandy surface texture-contrast soils (#4); Deep clay loams, clays, etc. (#16)

Notes: 1. * Approximately 7 million ha of arable land with potential suitability for dryland cereal cropping was included in the analysis. Approximately 8.5 million ha of the State's agricultural zone was excluded from analysis (as defined in Section 3.9). Soils with PAWC < 30 mm were considered too marginal for cropping and were among the areas excluded.

2. These 16 classes assign all soil components from the entire soil landscape mapping framework to a 'modelling soil profile', excepting soils with PAWC < 30 mm.

3. National (ASRIS) format data across a number of attributes was used to calculate the layer by layer contribution to total PAWC. That is, 'layer thickness' x (1-'coarse fragment content') x ('field capacity' water content – 'wilting point' water content), was summed for each layer down the profile until the 'depth to impeding layer for annual crops and pastures' was reached.

4. Values in italics and square brackets were used in the APSIM modelling to represent each grouping of soils assigned to a 'modelling soil profile'.

Each 'modelling soil profile' was represented by a single custom-built APSIM soil file. The detailed 'modelling soil profile' characterisations for use in APSIM were developed by SARDI Climate Applications in discussion with Dr Anthony Whitbread (CSIRO), and although containing a level of generalisation, were consistent with real soils data stored in the 'APSoil' database (Dalgliesh et al. 2012, http://www.apsim.info/wiki/APSoil.ashx). This involved a developmental process to create generic moisture-holding characteristics down the profile which reflected a level of realism for each of the 16 'modelling soil profiles' but did not attempt to capture the detailed characteristics of specific local areas or soil types. This approach to the APSIM soil characterisation represents a generalisation or streamlining in the modelling that is considered appropriate for this regional-scale assessment. However, it overlooks more detailed soil characterisations that could have been made if the objective was to achieve greater accuracy in local-scale simulations. This meant that APSIM soil parameters used to differentiate changes in texture and PAWC down the profile, site drainage and waterlogging influences (among other parameters) were either changed systematically or kept constant. By contrast, if APSIM soil parameters were based on all available localised soil and land attribute data there would be a wide variation in APSIM soil parameters, and hence a potentially wide array of soil variables influencing the model outcomes.

In this study, the term 'modelling soil profile' encapsulates both the:

1) classes or groups of mapped soils (Table 3), and
2) APSIM soil files representing each group.

Representative APSIM soil files capture the critical soil parameters relevant to a regional-scale analysis. These are related back to soil landscape mapping to assess the spatial extent of results.

The rationale for adopting a more streamlined approach was: (i) to maintain clarity in interpreting results (too many variables adds confusion and can obscure the key messages), (ii) keeping the modelling task to a manageable size, consistent with our regional-scale analysis (ie. less variation in soil parameters means fewer 'modelling soils' to incorporate), and (iii) earlier modelling by SARDI indicated that the 'size of PAWC' had a larger influence on crop performance than the 'shape of PAWC'. Further points of clarification regarding our treatment of soils and a discussion of the limitations in adopting this regional-scale approach are contained in Appendix A and Section 3.11.

An example actual site soil moisture profile obtained from the APSoil database is shown in Figure 11. APSoil site data is obtained from field measurements (Burk & Dalgliesh 2008) but was not used in this study due to insufficient coverage across the State. The respective APSIM soil characterisations used for the 'modelling soil profiles' are summarised in Table 4 and Appendix F. Mapped soils in the SL&SIF were assigned to a 'modelling soil profile' on the basis of surface texture and estimates of profile moisture holding characteristics previously derived by expert interpretation.

Table 4. APSIM soil parameters for the 'modelling soil profiles'

Surface % clay content	Total PAWC ('bucket size') increments modelled (mm)	Lower limit/ wilting point, at surface (mm/m)	Upper limit/ field capacity, at surface (mm/m)	*U	*Cona	*Diffuse constant	*Diffuse slope
3.75	***40, 60, 80, 120***	67	175	4	2	250	22
7.5	***40, 60, 80, 120***	87	204	4	2	88	35
15	***40, 60, 80, 120***	127	261	4	2.5	88	35
30	***40, 60, 80, 120***	208	377	6	4	40	16

* Soil hydraulic parameters required for APSIM modelling: 'U' = stage 1 evaporation coefficient, 'Cona' = stage 2 evaporation coefficient, 'Diffuse constant' = constant term in diffusivity calculation, 'Diffuse slope' = slope term in diffusivity calculation. [To convert upper and lower limit values in mm/m to % volumetric moisture content, as shown in the APSoil example of figure 11, divide by 10; e.g. 300 mm/m = 30% volumetric moisture content.]

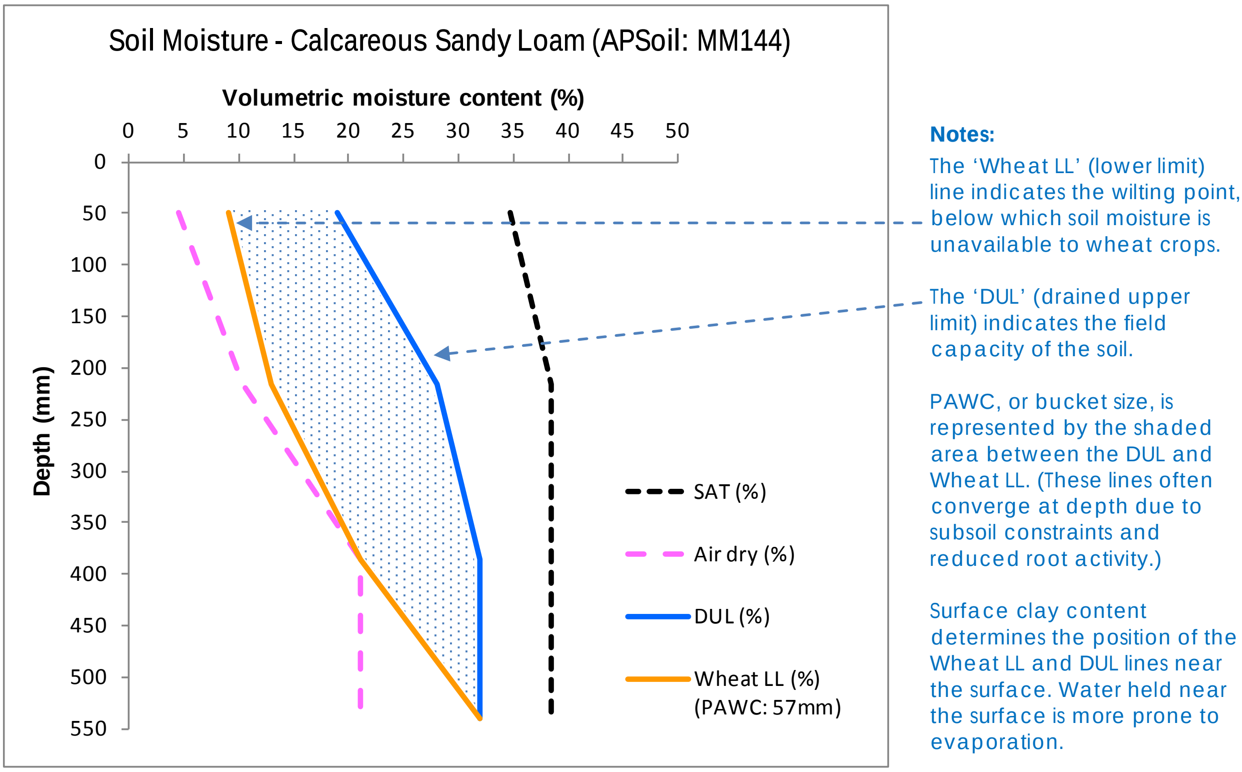


Figure 11. Example of an actual measured site soil moisture profile that can be used for APSIM crop simulation modelling (source: http://www.apsim.info/Wiki/APSoil.ashx). Similar generic moisture holding profiles were synthesised to represent our 16 'modelling soil profiles' (Appendix F).

3.4 Regional climate zones

Spatially interpolated 5km x 5km gridded average climate (monthly rainfall and temperature) data from the period 1957-2009 was used to delineate regional climate zones (and corresponding Ave GSR and Ave GS Temp values) across the State. Zones were based on the growing season (assumed to span the months of April to October). This data was obtained from the Bureau of Meteorology (BoM) through the SILO database (http://www.bom.gov.au/silo/). This period of data was consistent with the earlier NYNRM Region pilot project work (Liddicoat et al. 2011), which preceded this State-wide project. It should be noted that while our preference was to use long-term (100+ year) climate station records in the APSIM modelling (to capture climate variability), a shorter time period of approximately the last 50 years was chosen to provide a more reliable timeframe for spatial interpolation of regional average climate zones across the State (reflecting improvements in the distribution and quality of climate monitoring over time).

Twenty-one regional climate zones were initially identified for APSIM modelling on the basis of incremental classes of Ave GSR and Ave GS Temp, as shown in Table 5 and Figure 12. This involves the input of specific time series climate files (with certain Ave GSR and Ave GS Temp) for modelling in APSIM, which are taken to represent a sub-set or range of climate zones in geographical space (the GIS environment). Climate files with nominal 50 mm Ave GSR increments helped constrain the total number of APSIM runs, however 50 mm GSR increments are considered too coarse for predicting crop yields. As such, summary results (e.g. Ave yield and Ave post-harvest biomass) from the APSIM modelling were subsequently derived at 10 mm Ave GSR increments prior to mapping. This was achieved (in an Excel spreadsheet) through linear interpolation between results for the 50 mm Ave GSR increments. The increased spatial resolution of 10 mm Ave GSR increments (= 29 Ave GSR zones) is shown in Figure 13. The 10 mm increment Ave GSR classes (Figure 13) and Ave GS Temp classes (Table 5, Figure 12) were assigned to the soil landscape mapping polygons to provide a basis for further evaluation and mapping of results.

A lower limit Ave GSR class of 170-180 mm was chosen to reflect the marginal end of cropping across the State (comparable with Ave GSR at Waikerie). An upper limit Ave GSR class of 450-460 mm was chosen because beyond this conditions are generally too wet and cold for wheat production in South Australia.

A subsequent analysis of the availability and suitability of daily climate files required for the APSIM modelling identified that two key climate site records (with appropriate modifications) could be used as a basis for providing representative daily climate files for different regional climate zones across the State (see Section 3.5 for further explanation). Hence the specific values used in APSIM modelling (Table 5 below) are based on incremental changes (wetter/ drier and warmer/ cooler) from the original Snowtown and Maitland site climate records. A summary of all scenarios modelled is shown in Section 3.7.

Table 5. Regional climate zone representative values used in APSIM State-wide modelling

Daily climate files based on:	**Average Growing Season Rainfall [Ave GSR] (mm)**	**Average Growing Season Temperature [Ave GS Temp] (°C)**
Snowtown	*177, 207, 257, 307, 357, 407, 457* (x 7 GSR values)	*11.5, 13, 14.5* (x 3 GS Temp values)
Maitland	*286, 336, 386* *(x 3 GSR values)*	*13.4, 14.9* (x 2 GS Temp values)

Notes: A series of synthesised daily climate files at nominal Ave GSR intervals of 50 mm were used for the APSIM modelling. Daily climate files were based on original Snowtown and Maitland daily climate records (see Section 3.5), for which the original Ave GSR and Ave GS Temp values are underlined in the table above. Summary APSIM results were subsequently interpolated at 10 mm Ave GSR increments to provide higher resolution for mapping.

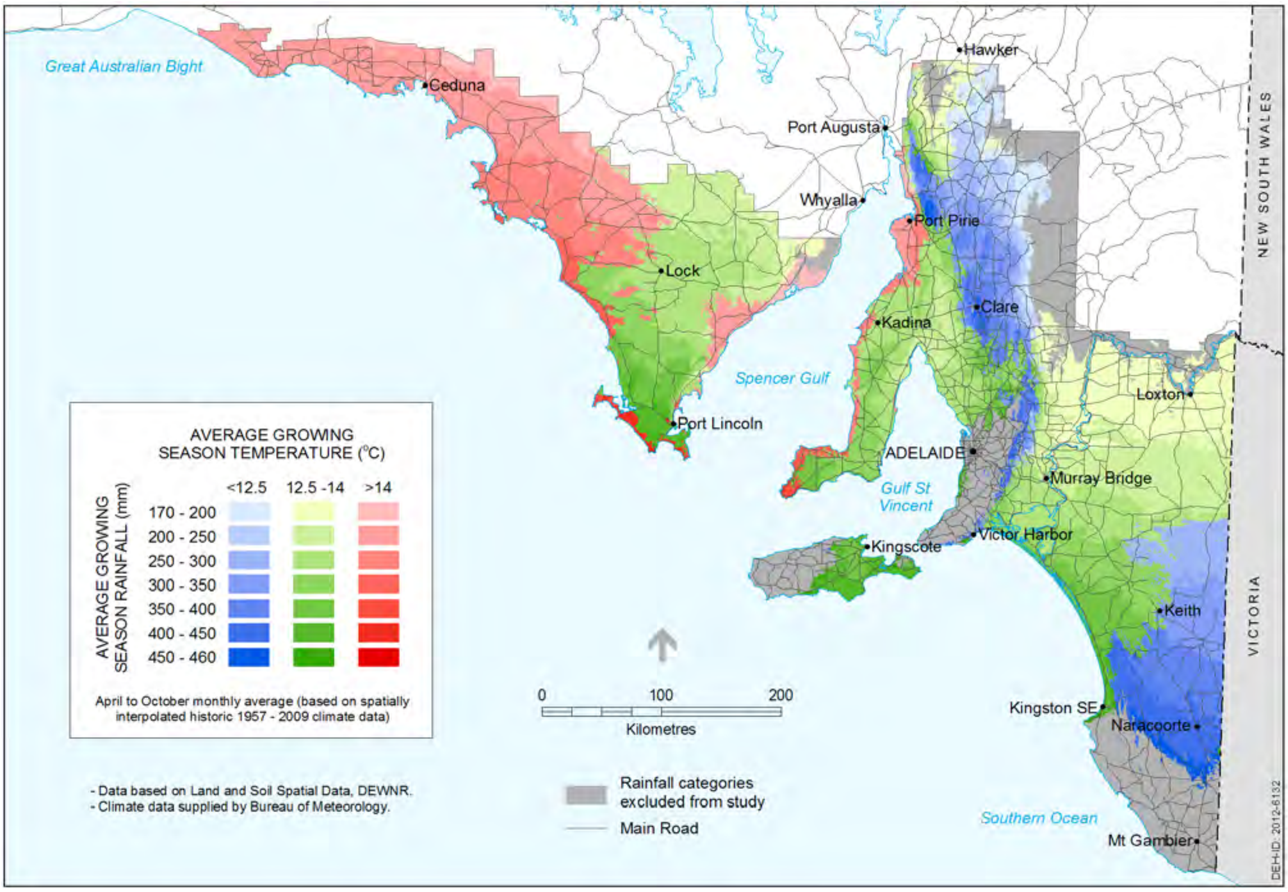


Figure 12. Indicative regional climate zones used in the APSIM modelling

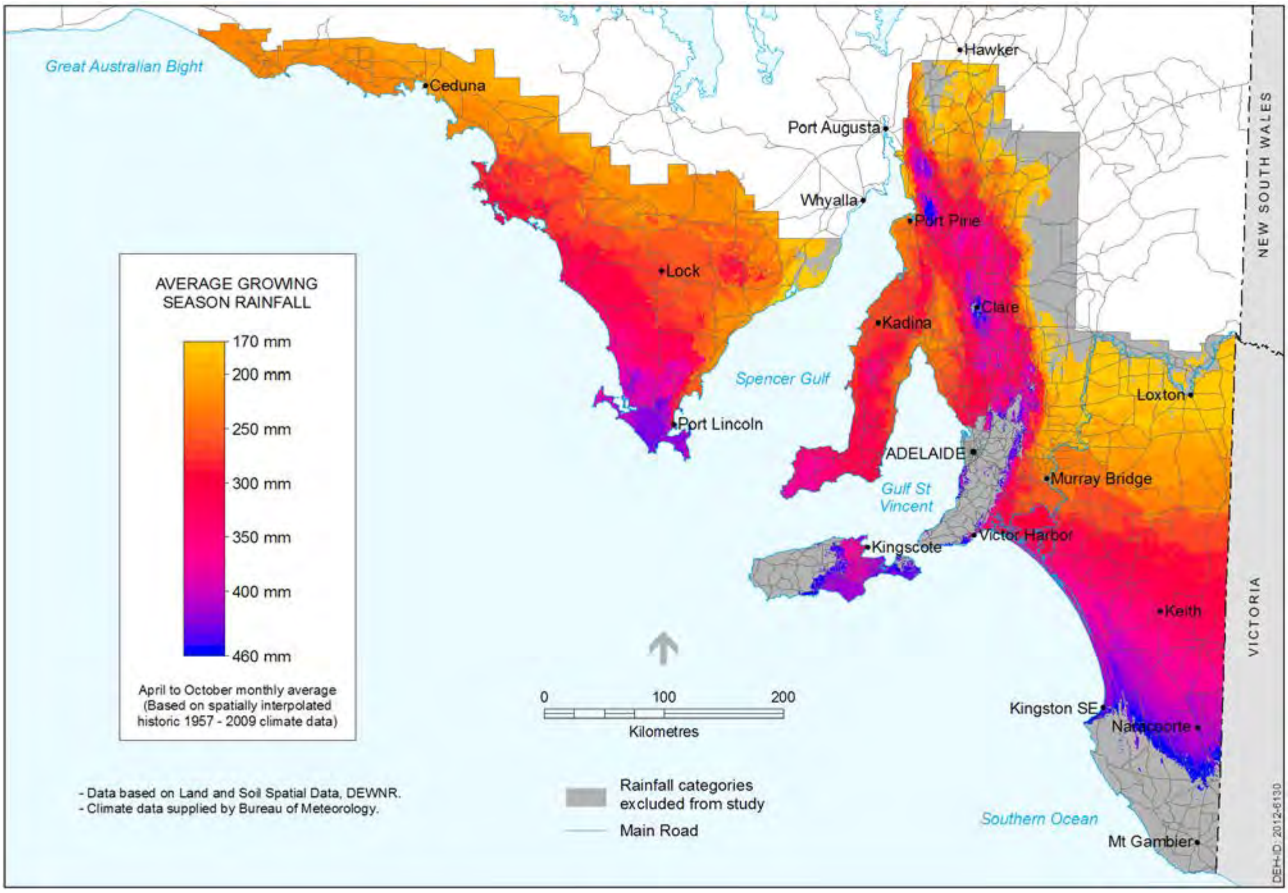


Figure 13. Average growing season rainfall (10 mm increments) across SA's cropping zone

3.5 Daily climate files

To generate the APSIM runs, individual, representative daily climate files are required for each distinct regional climate zone (ie. with the corresponding Ave GSR and Ave GS Temp) as described in Section 3.4. Requirements considered in the selection of respective daily climate files were as follows:

- availability – of daily data
- representativeness – of the particular area or region
- quality – accuracy, reliability, minimal missing data
- long-term – ideally 100 year record or longer to capture seasonal variability
- spatial coverage – need to cover all cropping regions of the State

Our original intent was to consider the SA grains belt as having nine climate regions (and representative climate stations) in a matrix format, with three 'columns' going west to east (Eyre Peninsula, Mid and Upper North, South East and Murray Mallee) and three north-south 'rows' for low, medium and high rainfall. When it came time to inspecting prospective quality climate stations from right across the State, the records were found to be of variable quality and duration and sometimes did not contain all the necessary parameters for APSIM modelling.

With a desire to standardise the modelling approach (ie. obtaining a good coverage across the State, without data gaps and ideally using the same length of records), it was decided to investigate whether 'synthetic' climate data could be utilised – to provide consistent climate data and fill data gaps – by uniformly scaling up or down the daily records from a quality site (or sites) to imitate other neighbouring regional climate zones with different Ave GSR and Ave GS Temp conditions.

The approach of scaling selected climate station datasets in this manner, to represent neighbouring climate zones (which lacked suitable long-term daily climate files), warranted further investigation based on:

- outcomes from previous APSIM simulation work examining the use of spatial analogues to better understand potential climate change impacts. (Hayman et al. 2010b, see copy in Appendix G, describe the use of APSIM with a modified site rainfall record to produce a similar yield probability distribution to another drier site, with an equivalent level of rainfall reduction.)
- findings from earlier work that average growing season rainfall is typically a very good predictor of average simulated wheat yields (Alexander et al. 2008), regardless of the actual location.
- in individual seasons it is expected that the timing of climatic conditions (such as rainfall and temperature) will influence crop growth, however over a long-term climate record their impact on average productivity would be minor compared to key parameters such as the total growing season rainfall.

To test this approach, SARDI performed a number of preliminary APSIM runs comparing APSIM outputs (for a given 'modelling soil profile') using actual site climate records versus remote site records that were modified to match the Ave GSR and Ave GS Temp (achieved by uniform scaling up or down of daily rainfall and temperature values). Example data and further information regarding this test work is provided in Appendix H.

The initial SARDI test work was surprisingly successful, indicating that a minimal number of carefully selected quality sites could be systematically adjusted to adequately replicate other neighbouring climate zones (Ave GSR and Ave GS Temp) together with their long-term yield probability distributions (as shown in percentile-percentile plots and other summary statistics). This provided confidence in the approach that was ultimately adopted for this study. Moreover, similar results came from expanded testing of the same key climate records (refer to * below) when adjusted to imitate other climate zones (and corresponding yield probability distributions from actual site climate data) from across the cropping zone. Some review feedback on this approach and further points of clarification are contained in Appendix A.

Following this work, SARDI discovered that sufficient simulation accuracy for our modelling purposes could be achieved by systematically synthesising a suite of commonly formatted daily climate datasets, providing coverage across the entire cropping zone, including areas where actual daily climate data was not available. The full set of original and adjusted daily climate files collectively represent the 'historic' climate (or 'no climate change') scenario, and these are summarised in Section 3.7. Climate change scenario datasets, discussed in the next section, which incorporated warming, drying and increasing CO_2 levels, could also be synthesised in a similar fashion.

*The following quality daily climate station records were the sites selected for subsequent scaling to create the coverage of climate zones (and climate files) for use in the State-wide APSIM modelling (also refer to Table 5, Section 3.4):

- Snowtown – across all cropping areas, except on higher rainfall areas of Yorke Peninsula
- Maitland – across higher, more reliable rainfall areas on Yorke Peninsula.

All long-term daily climate files are based on BoM SILO records for these locations over the period 1900-2009.

3.6 Alternate climate (climate change) scenarios

Rainfall is expected to be the first order issue driving yield and biomass across much of South Australia, where production is largely moisture limited. Rainfall projections under climate change are also more uncertain than projections for rising temperature and CO_2. Given the importance of rainfall to South Australian cropping enterprises and the uncertainty surrounding future trends, the alternate climate change scenarios modelled have varied rainfall decline while fixing the level of warming and CO_2 increase. Whilst temperature will influence biomass and water balance, wheat variety selection to adapt to faster crop development (with hotter temperatures) is relatively easily undertaken by farmers. As crop variety selection is likely to reduce (or potentially nullify) any temperature impacts modelled through APSIM this provides additional justification for focussing investigations on variable rainfall scenarios.

The simulated warming, CO_2 increase and range of rainfall decline outlined below are consistent with the projected envelope of likely change by 2030 (CSIRO & BoM 2007). Climate scenarios are summarised as follows:

(1) **No climate change**, based on historic data, atmospheric CO_2 concentration 390 parts per million (ppm)

(2) **Relative rainfall change –5%**, temperature change (max & min) +1.5°C, atmospheric CO_2 concentration 480ppm

(3) **Relative rainfall change –10%**, temperature change (max & min) +1.5°C, atmospheric CO_2 concentration 480ppm

(4) **Relative rainfall change –20%**, temperature change (max & min) +1.5°C, atmospheric CO_2 concentration 480ppm

Climate records for the alternative future climate change scenarios were generated by modifying the entire set of 'historic' daily climate files (see Section 3.4) via uniform scalar multiplication of respective daily rainfall values and a fixed step increase in both daily temperatures and CO_2 concentration.

3.7 Summary of all modelling scenarios

The entire set of scenarios modelled in this study is summarised below.

Table 6. Summary of all scenarios modelled

		Ave GS Temp classes		
		<12.5 °C	**12.5-14.5 °C**	**>14.5 °C**
Ave GSR classes	170-180 mm	**S**	**S**	**S**
	180-190 mm	S	S	S
	190-200 mm	S	S	S
	200-210 mm	**S**	**S**	**S**
	210-220 mm	S	S	S
	220-230 mm	S	S	S
	230-240 mm	S	S	S
	240-250 mm	S	S	S
	250-260 mm	**S**	**S**	**S**
	260-270 mm	S	S	S
	270-280 mm	S	S	S
	280-290 mm	S	S, **M**	S, **M**
	290-300 mm	S	S, M	S, M
	300-310 mm	**S**	***S,** M	**S,** M
	310-320 mm	S	S, M	S, M
	320-330 mm	S	S, M	S, M
	330-340 mm	S	S, **M**	S, **M**
	340-350 mm	S	S, M	S, M
	350-360 mm	**S**	**S,** M	**S,** M
	360-370 mm	S	S, M	S, M
	370-380 mm	S	S, M	S, M
	380-390 mm	S	S, ***M**	S, **M**
	390-400 mm	S	S	S
	400-410 mm	**S**	**S**	**S**
	410-420 mm	S	S	S
	420-430 mm	S	S	S
	430-440 mm	S	S	S
	440-450 mm	S	S	S
	450-460 mm	**S**	**S**	**S**
X 16 Modelling Soil Profiles				
X 1 Historic, plus X 3 additional Climate Change scenarios				

Bold, blue text indicates where APSIM runs were undertaken

Normal text indicates where summary results were interpolated

A smaller climatic range (ie. shaded area) was repeated using Maitland-based climate files. This applied to higher rainfall areas of Yorke Peninsula only.

Notes: 'S' indicates modified Snowtown climate files (*S = original GS climate). 'M' indicates modified Maitland climate files used only on Yorke Peninsula (*M = original GS climate).

In total this represents:

- 1,728 APSIM runs, each of which produces 100+ years of seasonal outcomes. This is based on:
  - 21 Snowtown-based + 6 Maitland-based Ave GS climate files
  - x 16 'modelling soil profiles'
  - x 4 climate scenarios
- or, following interpolation of APSIM summary results to 10 mm Ave GSR intervals – 6,976 distinct combinations of Ave GS climate class x soil x climate scenario, for which APSIM summary results were recorded in table format. This resulted from:
  - 29 x 3 Snowtown-based + 11 x 2 Maitland-based Ave GS classes (as per table above)
  - x 16 'modelling soil profiles'
  - x 4 climate scenarios

3.8 Erosion risk analysis

Erosion risk is modelled by comparing simulated seasonal post-harvest biomass outcomes (above-ground biomass at maturity minus grain yield) against best-estimates of critical cover requirements needed to protect against wind or water erosion, applicable for land with differing erosion potential (see further discussion below). If post-harvest biomass (in any season) is less than critical cover levels this indicates that land is 'at risk', or has increased erosion risk, but this is not a definitive prediction that erosion will occur. The comparison is performed at the soil landscape map unit component level (refer to Section 2.5), and tracked as both the % area of the mapping polygon that the component occupies, and importantly the frequency at which it fails to reach critical cover levels. Separate analyses can be conducted to determine the frequency and severity (land area) of erosion risk due to (i) wind, (ii) water, and (iii) wind or water. (The latter, combined analysis uses whichever has the greater critical cover requirement at a location.)

From looking at 100+ years of model results, the frequency that post-harvest biomass will be below defined critical cover levels (also defined at harvest time) provides information on the relative likelihood of land degradation for particular combinations of soil, landscape, regional climate zone, and climate change scenario.

Maps are presented as the "proportion of landscape below critical cover" at a number of selected frequencies (ie. "in at least 4 years in 10", "... 2 years in 10", "... 1 year in 10", and "... 1 year in 100"). This approach was taken in order to highlight the changes in frequency and severity of erosion risk for erosion prone land. By contrast, if mapping polygons were used to display a spatially and temporally averaged 'frequency of below critical cover', we would be unable to highlight potential areas requiring attention to address erosion issues under climate change. This is because such a map would dilute (or obscure) results for soils with the greatest frequency of below critical cover, due to averaging of results across all spatially undefined components within a mapping polygon. (For further information refer to Section 2.5 regarding the nature of the soil and land spatial datasets.)

The analysis assumes no influence from management (e.g. no grazing of stubbles), however, it does allow for natural stubble breakdown. This breakdown occurs leading up to the critical erosion risk period when cover levels are at their lowest around seeding time. By assuming stubble is undisturbed by management, the modelling approximates the potential of wheat cropping systems to protect land from erosion. No cumulative effects are considered as seasons are treated independently of each other.

'Critical' cover levels to protect against wind and water erosion

The State Land & Soil Information Framework contains wind and water erosion potential attribute data for every component area within every soil landscape map unit across the agricultural areas of the State. Factors considered in the assessment of wind and water erosion potential are based on standard criteria contained within Maschmedt 2002 (as outlined in Section 2.7).

Six classes of wind erosion potential, and seven classes of water erosion potential are defined (not including the 'not applicable' category). For both wind and water erosion potential – classes 1 to 3 define low, moderately low and moderate erosion potential, class 4 has moderately high potential (rendering the land only semi-arable), and classes 5 and higher are considered non arable (not suitable for cropping) due to the severity of the potential for erosion. Areas of land within each class are shown in Appendix B. Maps of wind and water erosion potential (which display an overview of the available information) are shown in Figures 6 and 7.

The greater the erosion potential, the more protective cover (vegetative biomass) needs to be retained to protect the soil from erosion. In continuous cropping situations, the soil is most vulnerable to erosion during the period between harvest and establishment of the subsequent crop. Estimates of critical cover levels for soil protection have been determined on the basis of wind and water erosion potential classes (Table 7), from a meeting with DEWNR staff involved with the Erosion Protection Field Survey Program and soil and land management consultants from Rural Solutions SA. It should be recognised that estimation of critical cover levels is an area requiring greater research (taking account of modern no-till systems) as the values determined for this study are based on 20-25 year old wind tunnel and runoff simulation work (e.g. Leys & Heinjus 1991) when traditional tillage systems (with greater levels of soil disturbance and less standing stubble) were the norm. As such, the estimates provided in Table 7 (although based on the best available knowledge) are relatively cautious in light of current farming systems and crop establishment methods. It is also acknowledged that more accurate erosion risk indicators consistent with the EPFS Program (e.g. stubble height, density of surface coverage, anchorage, etc.) are better for assessing erosion risk however such indicators are unable to be considered by crop simulation models such as APSIM.

Critical cover levels are required at any time of the year, but especially when stubble levels are at their lowest around seeding time in the following season. Natural microbial decay rates between harvest and seeding can be as high as 50% of post-harvest stubble following poor finishing seasons (associated with low grain fill and high nutrient content remaining in stubbles) (M-A Young Rural Solutions SA 2010, pers. comm.). However for the purpose of this modelling exercise a uniform natural decay rate of 30% is assumed to be more representative of average conditions (M Wurst Rural Solutions SA 2010, pers. comm.). This 30% natural decay factor has been built into a set of adjusted critical cover requirements (see column titled 'At harvest' in Table 7) which enables the immediate assessment of post-harvest biomass levels. For example, on class 4a wind erosion prone land, if post-harvest biomass levels (at the end of a particular season) are just over 3.6 t/ha this will be sufficient to meet critical cover requirements, allowing for 30% decay between harvest and seeding time in the following year (3.6 t/ha x 0.7 = 2.5 t/ha).

While useful for this modelling study, these critical cover figures (in t/ha) should not be applied universally for field assessments of erosion risk.

Table 7. **Critical cover requirements (t/ha) based on classes of erosion potential. (These 'best estimate' values are adapted from DWLBC 2009b, following discussions between staff and consultants involved with DEWNR's Erosion Protection Field Survey Program.)**

Wind erosion prone land			**Water erosion prone land**		
Class:	***At harvest***	*At seeding*	*Class:*	***At harvest***	*At seeding*
1a	**0**	0	1e	**0**	0
2a	**0.9**	0.6	2e	**1.4**	1
3a	**2.1**	1.5	3e	**2.9**	2
4a	**3.6**	2.5	4e	**4.3**	3
5a, 7a	N/A	N/A	5e, 6e, 7e	N/A	N/A

Notes: Class 1 land (for both wind and water erosion) is not inherently at risk, therefore no critical level of cover is specified. Class 5 land and over is generally not cropped. There is no class 6a for wind erosion. Critical cover requirements normally apply around seeding time after a period of natural decay and ground cover is usually at its lowest level. A uniform natural decay factor of 30% has been built into the 'at harvest' critical cover levels which allow immediate assessment of seasonal post-harvest levels. [These are calculated such that 'critical cover at harvest' x 0.7 = 'critical cover at seeding'.] **These values are applicable in the context of this modelling exercise and should not be generally applied in field assessments of erosion risk.**

3.9 Land excluded from analysis

Non-arable land (in terms of potential for dryland cereal cropping) has been excluded from the analysis, mapping and data calculations. Rules to identify these excluded areas reflect the various limitations that make land generally unsuitable for cropping. For the purpose of this study, non-arable land is described in terms of National and SA-format attribute datasets as well as derived parameters as follows:

- Very poorly or poorly drained land (ASRIS drainage class 1 or 2)
- Surface stone > 35%
- Subgroup soil classes = L1* (shallow soil on rock), N1* (peat), N2* (saline soil) or N3* (wet soil), RR (rock), WW (water) and XX (not applicable)
- Slope greater than or equal to 18% - which is considered too steep for cropping machinery.
- High erosion potential (wind or water erosion potential classes of 5 or greater)
- Very low PAWC (< 30 mm) – which is considered marginal for cropping[11].

All land identified as arable was then assessed in relation to 2008 land use mapping data (see Figure 14), with any non-agricultural land excluded. Only areas of cropping, grazing modified pastures and irrigation land use were retained in the analysis. Average growing season rainfall between 170-460 mm was also used to limit the study area (as described in Section 3.4). This band of Ave GSR was thought to span between the driest and wettest limits of dryland (rain-fed) cereal cropping in SA and areas outside of this were also excluded from analysis.

[11] During warm days in Spring, 6-8 mm per day of evaporation can occur. Soils with less than 30 mm PAWC will generally have little to no buffer to prevent crops from reaching terminal drought.

Furthermore, any mapping polygon (soil landscape map unit) with a non-arable area greater than or equal to 70% is considered non-arable and excluded from the analysis. For mapping display purposes only, where the non-arable area is less than 70%, the remaining arable areas are rescaled to represent 100% of the mapping polygon. The combined areas excluded from analysis are shown in grey on the map figures in Section 4.

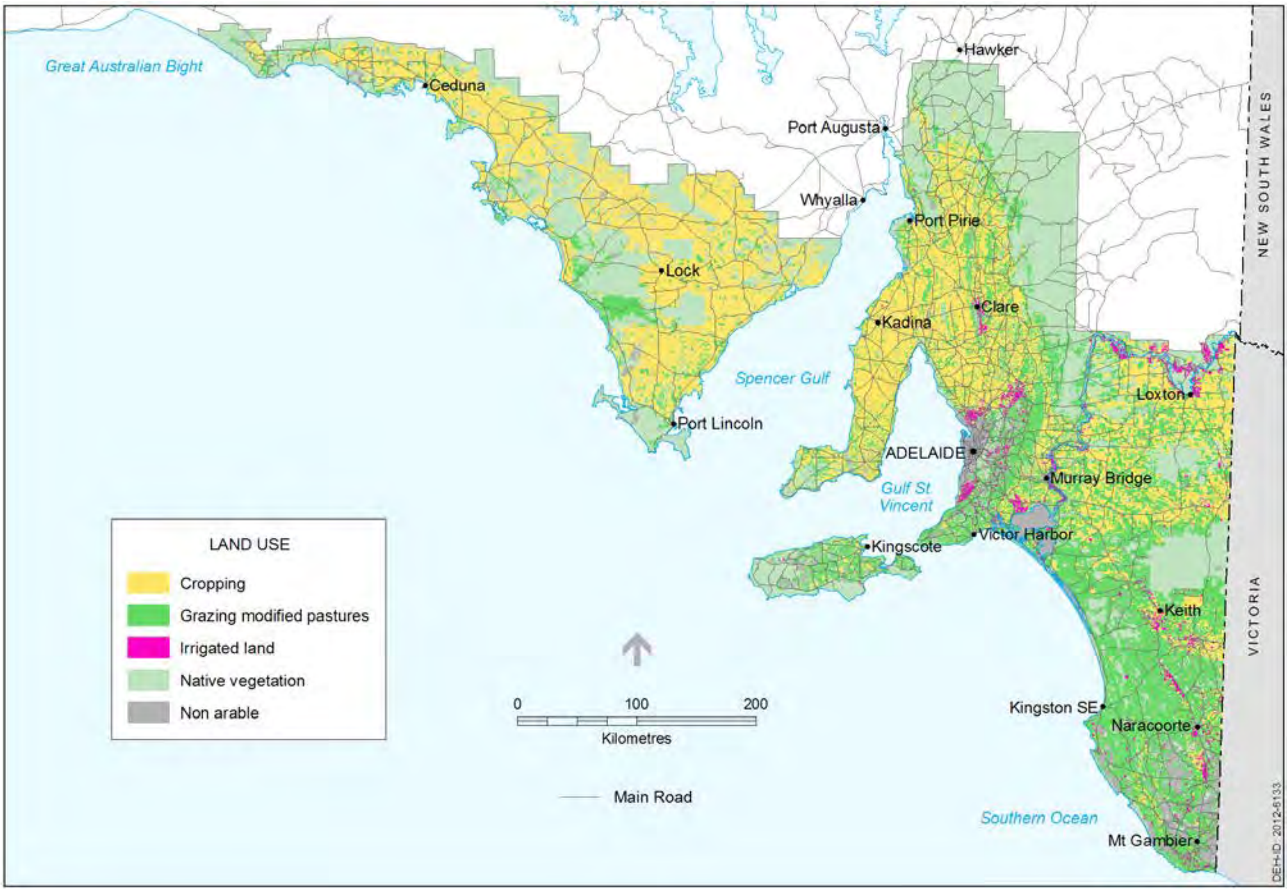


Figure 14. Major land uses of Southern South Australia (SA Land Use Mapping 2008). 'Cropping' land includes land that is cropped on a continuous basis or in a crop/pasture rotation.

3.10 Other APSIM modelling assumptions

A number of assumptions were contained within the APSIM crop simulation modelling:

- ***Wheat cropping*** – a fixed management regime was modelled with no pasture or crop rotations included. To be precise, independent wheat crops were modelled every year (not continuous wheat cropping) as stubble levels and other simulation parameters were reset at the start of each season. The rationale for modelling repeated independent wheat crops with constant management as opposed to a more realistic management rotation is that this study is specifically investigating the influence of climate x soil on crop productivity (and hence soil cover). Taking a simplified approach provides a clearer picture of the underlying relationships and helps eliminate confounding variables such as crop type, carryover of stubbles, nitrogen or soil moisture from previous years.
- ***Technology*** – model settings are consistent with modern practices which minimise soil disturbance, such as stubble retention and no-till.
- ***Sowing density*** – 180 plants/m^2
- ***Sowing depth*** – 40 mm
- ***Row spacing*** – 220 mm
- ***Wheat cultivar*** – a medium maturing wheat cultivar (Janz) was chosen (as used widely within APSIM crop simulation modelling in SA).
- ***Sowing rule*** – crops were not sown by the model on a pre-determined static date for all seasons. Planting date varied for each season, dependent on the occurrence of 10 mm of rainfall over 3 consecutive days between May 1 and July 1, or on July 1 if this did not occur.
- ***Soil water*** - Soil water levels were reset to zero at the start of each year and allowed to accumulate from 1 Jan each year.

- **Nitrogen (N)** – Starting nitrogen rates were set at 70kg/ha NO_3 in the soil (reset every January) and 90kg/ha N as urea added at sowing. N values were reset on January 1 each year to avoid confounding results between years.

  Nitrogen unlimited scenarios (250 kg N/ha as urea at sowing) were modelled in the pilot project work in a Northern & Yorke low rainfall zone, however this appeared to cause problems with simulating excessive biomass (compared to grain). It is thought that high N levels can cause higher levels of structural carbohydrate deposition (vegetative growth), which is not easily mobilised into grain later in the season (Unkovich et al. 2010).

  N levels are not thought to have a major bearing on the focus of this study, in looking at erosion risk where low or below critical stubble cover levels may occur due to low rainfall. In such occasions of very low rainfall, N levels will not be the limiting factor, and high N levels will not be utilised.

  N levels are more important to grain and biomass predictions in high rainfall years, when higher N levels can be utilised. Assuming a constant N level in the modelling may limit simulated grain and biomass levels in high rainfall years, which may be reflected in average grain and biomass predictions, particularly in higher rainfall areas.

3.11 Limitations

A number of limitations relevant to this study are discussed below:

- **Assumptions** – the assumptions made in this modelling will not apply in every situation across the entire cropping zone of SA, however they provide a common reference base to assess modelling results.
- **Real world complexity** – modelling will never be able to mimic all the complexity and interactions associated with real world biophysical and climate systems.
- **Soil types** – this study utilises big picture 'modelling soil profiles' with simplified, standardised and systematically varying parameters designed for regional reporting of yield, biomass and erosion risk. The modelling soil profiles can be related back to soil landscape mapping (to assess the spatial extent of results), but are also used in the context of point-based APSIM crop simulations. Here, APSIM soil files are normally used to describe as many soil and landscape parameters as possible at a particular location. However, due to time and resource constraints, consideration of all available local-scale soil and landscape data has not been possible and instead we have adopted simplifications or generalisations in a number of soil parameters which were perceived to have lower order significance. This means for the crop simulations our results assume an average landscape position which is generally well drained and on reasonably flat land. Waterlogging, water flows across the land surface and lateral flows within the soil are not considered in the crop simulation modelling. [Erosion risk areas and critical cover requirements are assessed using SL&SIF soil and land attribute datasets which include consideration of sloping land, but this level of additional detail in soil and land characteristics is not considered in the APSIM modelling.]

  The generalisation of APSIM soil parameters has been a deliberate strategy, undertaken to reduce confounding in model results and provide a cost-effective coverage of key soil parameters at the appropriate scale. However this also means that the 'modelling soil profiles' developed in this study are <u>not suitable for</u>:

  - paddock level assessments (this is also a limitation of SL&SIF soil and land attribute datasets)
  - reporting differences in crop performance at local scales
  - reporting differences in crop performance between specific soil types, or between specific sites
  - capturing the full complexity of soil properties and plant growth responses with variable climate exhibited by specific soil profiles.

  While the crop simulation modelling in this study does not attempt to model differences between specific soil types (ie. a texture-contrast sand-over-clay soil and a deep sand will be modelled the same if they have the same surface clay content and total PAWC), nor account for localised landscape conditions, the 'modelling soil profiles' do provide a useful indication of crop performance in terms of key soil moisture holding parameters.

  Subsoil constraints (in terms of physical or chemical barriers to root growth) are taken into account via SL&SIF estimates of 'depth to impeding layer', 'coarse fragment content' and resulting calculation of PAWC. Consequently, this determines the assignment of a particular mapped soil ('soil component' of a map unit) to a particular 'modelling soil profile'. A detailed understanding of plant-soil relations is needed when relating actual soils to the 'modelling soil profiles'. For example subsoil constraints (such as natural toxic chemical layers in clayey subsoils) which impede roots need to be recognised in field estimates of soil PAWC.

  Extremes of soil condition (e.g. poor sands or very heavy clays) are not differentiated in the modelling and simulation results for these situations are not expected to match actual crop performance.

- **Critical cover levels** – The level of post-harvest biomass (as a proxy for stubble cover) in t/ha does not give a true depiction of erosion risk. By assuming stubble retention and no disturbance we are investigating potential changes in the optimum cover levels under climate change. Assuming a uniform natural decay rate eliminates further complication due to the interaction of inter-seasonal factors influencing stubble microbial breakdown. These include quantity of stubbles, nutrient content and summer-autumn rainfall patterns, and regional and temporal variation in these factors. This approach suits our primary goal of investigating the influence of growing season x soil profile type on crop growth (and hence soil cover).

- **Variability in climate change scenarios** – Alternative future climate scenarios were generated from historic examples of daily temperature and rainfall records, modified by a fixed temperature rise and % rainfall declines (see Sections 3.4-3.6). Climate files are based on a very limited number of sites, which have been selected to satisfy the particular requirements of this modelling exercise. While this data is able to represent long-term historic variability in climate adequately across the cropping zone (in the specific context of this crop simulation modelling as discussed in Section 3.5 and Appendix A), the limited origins of the climate data should be recognised.

  This also means that modelled future climate scenarios have the same variability as the historic climate datasets used in the study. Although scaling down daily climate records will affect the number of effective rain days as the amount of rainfall is scaled down and approaches values where low rainfall events are prone to evaporative loss before moisture can be used.

  With uncertainty over future climate, it is unclear how representative historic climate datasets will be in terms of future climate variability. For example, global climate model projections for the Australian region indicate that rainfall patterns may change with increased intensity of individual rainfall events and longer dry spells between (McInnes et al. 2003, CSIRO & BoM 2007), although some estimates of the projected increase in rainfall intensity in South Australia are for up to only a 2% increase by 2050 (D Ray BoM 2009, pers. comm., LGA 2011).

  The generation of future climate scenarios with changing climate variability involves another level of complexity, for example by generating artificial baseline climate data from a stochastic weather generator (Luo et al. 2009). Changing the variability of climate would introduce another factor requiring disentanglement in the analysis of results, and reflect further uncertainty in the sphere of climate change projections. For the sake of clarity in this investigation climate variability was based only upon the selected quality daily climate records that were adjusted for use across the different climate zones.

- **Extreme events** – extreme events such as heatwaves, severe hot winds, flash flooding, etc. can greatly impact on crop yields, plant biomass and associated erosion risk. In general terms the ability to simulate extreme events is beyond the scope of current crop simulation models. Anecdotally, extreme temperature events seem to be already causing substantial reductions in productivity. It is suggested that this will adversely affect grain yields more than biomass or surface cover (B Mudge Rural Solutions SA 2010, pers. comm.). It is suspected that APSIM is not capturing the full impact of heat stress, however APSIM does capture the effects of higher temperature on accelerating crop growth and some of the impact on water use (Alexander et al. 2008). Better understanding of temperature impacts is an evolving area with ongoing research, involving heating wheat plants in the field, being undertaken by SARDI and The University of Adelaide (Talukder et al. 2010, Alexander et al. 2010).

- **Carry-over effects** – Some soils with larger PAWC provide a buffering capacity to carry-over moisture and nutrients between seasons. This can help to even out fluctuations in growing season rainfall, or carry forward the influence of decadal wetting or drying cycles. However the complexity of carry-over effects has been disregarded in this study, in order to effectively study the influence of annual rainfall variations. This means that soil water and nutrients are reset in APSIM at the start of each growing season.

  An example of potential complexity in carry-over effects is the observation that some high PAWC texture-contrast soils have historically yielded better than deep sandy soils in dry years, with crops gaining access to stored subsoil moisture. However in recent times after an extended run of dry seasons, during which subsoil moisture levels have declined, sandier soils have been yielding better (due to lower wilting points) than heavier texture-contrast soils in dry seasons (M-A Young Rural Solutions SA 2010, pers. comm.).

  Surface cover provided by carry-over of the previous season's stubble residue is also not taken into account by the model. In many cropped paddocks, a portion of the surface cover is provided by stubble residue from the previous season. This has been an important factor in some of the recent drought years. While some paddocks did not have sufficient rain to grow enough biomass to provide protection, they were protected by stubble from the previous year's crop (M-A Young Rural Solutions SA 2010, pers. comm.).

- **Crop variety selection** – a single medium maturing wheat variety has been used in the crop simulation modelling in order to reduce confounding in model results. If different varieties were used this would be expected to have more impact on yield results rather than biomass.

- **Pests, weeds and diseases** – these will typically reduce potential grain yields and biomass but are not considered by our modelling. As discussed, this is because we are interested in potential climate change impacts to optimum grain yields and stubble cover levels. Also, changes in these influences arising from climate change are not considered.

- **Economic modelling** – it is considered beyond the scope of this study to investigate the impacts of climate change on the profitability of cropping enterprises. As a minimum this would require consideration of input costs and farm commodity prices, which tend to fluctuate year by year.

4. Results and Discussion

4.1 Preliminary APSIM water balance analyses

APSIM water balance of key soil types

During the method development phase for this project (which began with the NYNRM Region pilot study, Liddicoat et al. 2011), preliminary APSIM runs were undertaken to better understand how APSIM was simulating the water balance of key soil types (Hayman and Alexander 2010). This work was performed to see if APSIM was matching expectations for the partitioning of water between transpiration (indicating plant growth), evaporation, surface runoff and drainage past the root zone. Four example soil types were tested: shallow sand, shallow clay, deep sand and deep clay. A summary of this preliminary work is presented in Appendix I along with a brief discussion of findings and feedback from regional farming systems consultants. While some modelling limitations were recognised, this early work provided confidence in the approach being undertaken – with APSIM results found to be generally consistent with field observations and other water balance studies.

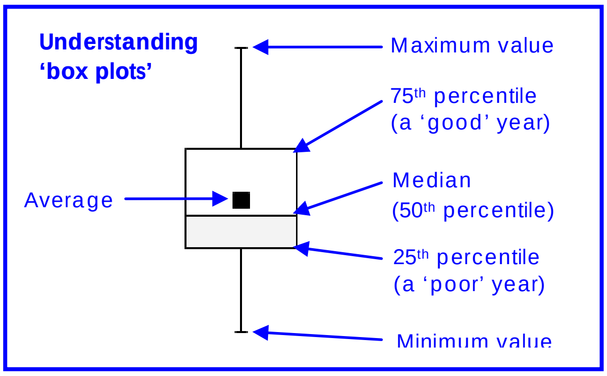
4.2 Findings from the APSIM runs

As indicated in Section 3.7, this State-wide crop growth modelling exercise has generated a large amount of raw data, available for subsequent interpretation, mapping and spatial analysis. Importantly, future users of this modelling will want to know what degree of faith can be placed in the results. A key question is perhaps: how has the model performed in simulating historic conditions? If the simulated historic results, across modelling soil profiles and across regional areas, look within a realistic range (in the context of the modelling assumptions) this provides greater confidence in the simulation results, should climate change with declining rainfall become a reality.

With this in mind, initial results presented here concentrate on the modelling results generated for the historic (no climate change) scenario. As it is impractical to present all the data generated, a selection of data illustrating the major relationships between model parameters is shown. Feedback on maps of simulated historic grain yields has also been sought, and comparisons with available State-wide wheat yield records have been made, as outlined in Section 4.5. Model results for the climate change scenarios are then presented in the form of maps and spatial data statistics.

4.2.1 Simulated 'historic' results – climate zone x soil profile type x seasonal variation

Figures 15-17 illustrate examples of the variability in simulated historic crop performance, in terms of grain yield, post-harvest biomass and harvest index[12] arising due to variation in Ave GSR zone, soil type and seasonal rainfall. These are in the form of box plots, as explained below. The examples are from the 13.3°C average GS Temp zone only, low Ave GSR (207 mm) and moderately high Ave GSR (407 mm).



The box plots in the following figures display the following features:

(1) Minimum and maximum simulated results at the end of the high/low lines

(2) 1st quartile (25th percentile) and 3rd quartile (75th percentile) results at the lower and upper edges of the boxes. For grain yield this is indicative of typical poor and typical good years respectively.

(3) The median result, shown by the horizontal line through the middle of the box. This marks the mid-point of the distribution, with half of all results above and half below the median.

(4) The average result (arithmetic mean) shown as the point in the middle of the box.

[12] Harvest index (HI) = grain yield/shoot biomass (dry matter basis), where shoot biomass = total above-ground biomass. In the terminology of this project, HI = grain yield / (grain yield + post-harvest biomass)

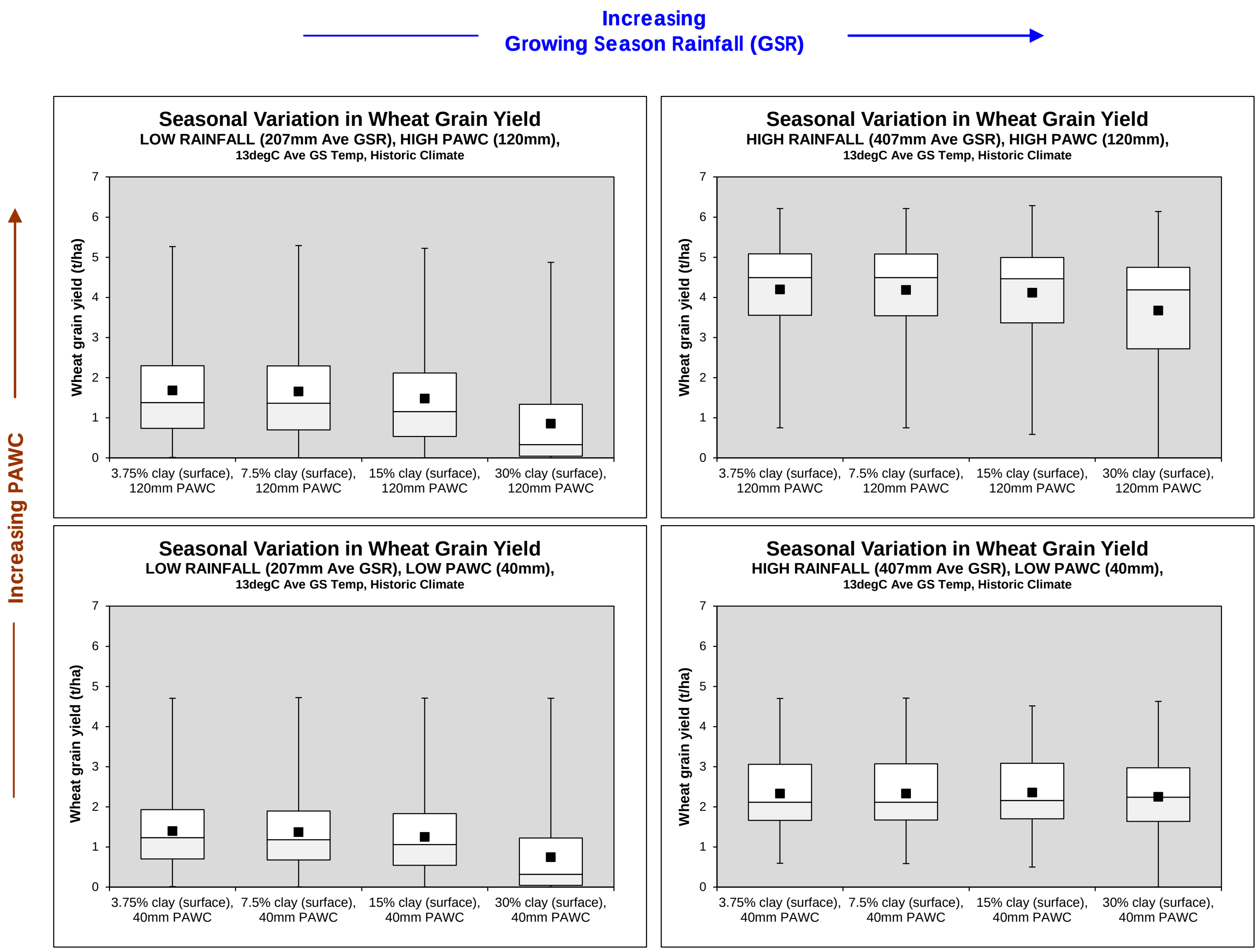


Figure 15. Variability in APSIM simulated wheat grain yields with varying GSR ('low' versus 'high') and PAWC ('low' versus 'high') for all surface soil textures. Results are based on *adjusted historic (1900-2009) Snowtown climate records (*adjusted to represent different Ave GSR zones) and constant 13.3°C average GS Temp. Box plots are described on page 33.

The following observations from these plots are consistent with field observations:

- Increasing Ave GSR or PAWC generally increase potential production outcomes
- For a given climate setting and PAWC, average productivity generally declines with increasing surface clay content. This is strongly exacerbated in dry climate zones.
- High PAWC soils have the greatest capacity to respond with high yields in higher rainfall situations.

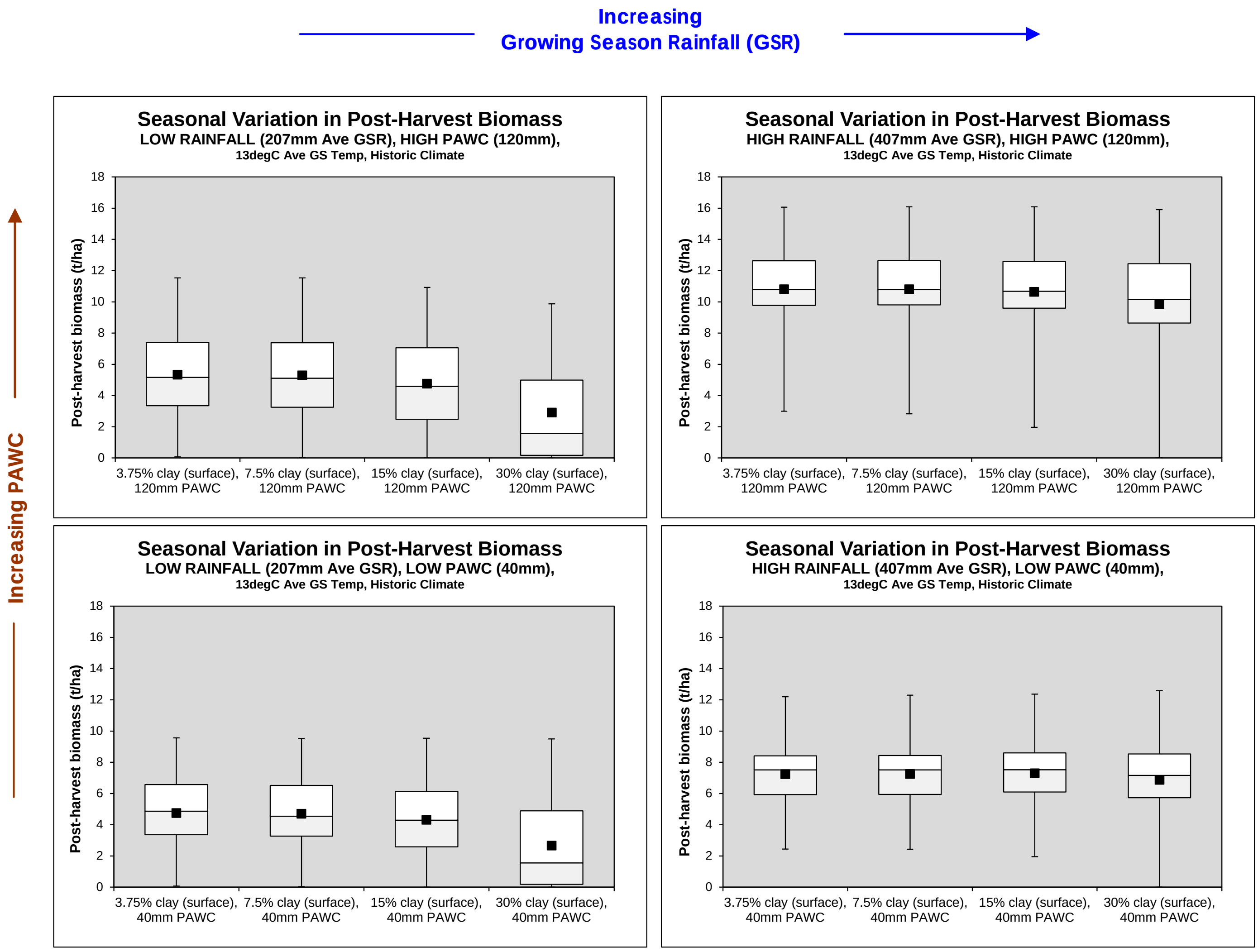


Figure 16. **Variability in APSIM simulated post-harvest biomass with varying GSR ('low' versus 'high') and PAWC ('low' versus 'high') for all surface soil textures. Results are based on *adjusted historic (1900-2009) Snowtown climate records (*adjusted to represent different Ave GSR zones) and constant 13.3°C average GS Temp. Box plots are described on page 33.**

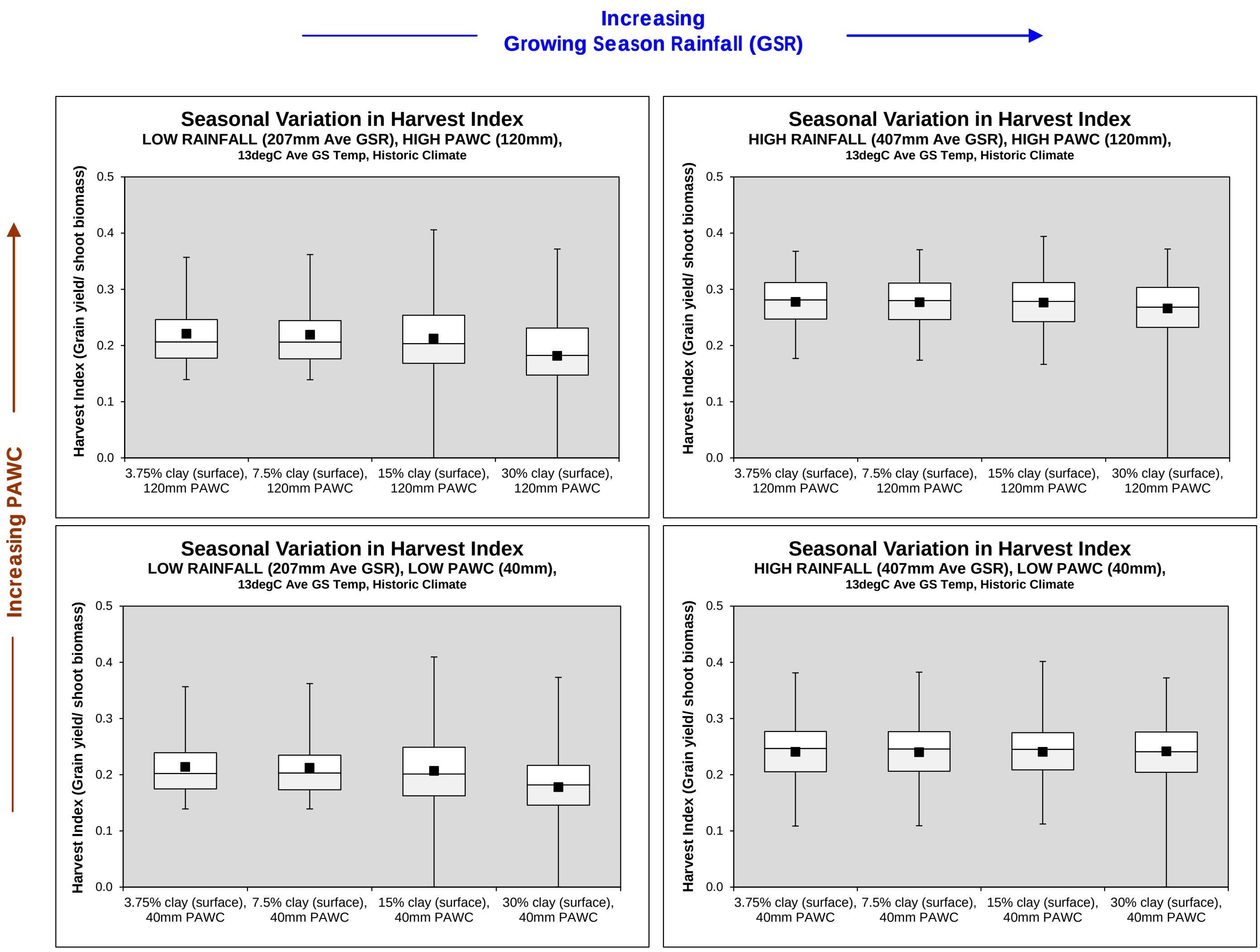


Figure 17. Variability in APSIM simulated harvest index (ie. grain yield / total shoot biomass) with varying GSR ('low' versus 'high') and PAWC ('low' versus 'high') for all surface soil textures. Results are based on *adjusted historic (1900-2009) Snowtown climate records (*adjusted to represent different Ave GSR zones) and constant 13.3°C average GS Temp. Box plots are described on page 33.

In Figure 17, variability in 'harvest index' (HI) results are presented which is the ratio of grain yield/ total above-ground biomass. From sampling a large number of dryland crops across Australia, Unkovich et al. 2010 report an average harvest index value for wheat of 0.37, which translates to a stubble: grain ratio of around 1.7 [13]. From investigations in South Australia, Masters et al. 2011 report an expected normal stubble: grain ratio of 1 to 1.5 t/ha stubble per tonne of grain (indicating HI ~ 0.5 to 0.4); with stubble: grain ratios higher than this typically found in seasons with good winter rains followed by a dry spring. Example simulated average HI values (shown above) in the range 0.2 to 0.3 correspond to stubble: grain ratios of 4 and 2.3 respectively. On the basis of these results, our modelling appears to provide an over-estimate of post-harvest biomass, which has been reflected in feedback from regional consultants.

This study uses the parameter 'post-harvest biomass' (defined as total above-ground biomass at maturity minus grain yield) as a proxy for 'stubble biomass', however it should be recognised that discrepancies will arise between the two, because the real world process of cutting stubble at a certain height and spreading of residual straw and chaff from the rear of the header is not considered by the model. As an indication of the potential difference between modelled post-harvest biomass and what might be measured in the field, Allen 1988 reported from wheat straw recovery field trials that up to 10% of dry matter could not be accounted for and was assumed to comprise unrecoverable chaff losses associated with the threshing process. If such a factor was applied to downscale our post-harvest biomass estimates, the example corresponding simulated average 'stubble': grain ratios would be brought down closer to expected values (ie. values of 3.6 and 2.1

[13] Using mean values of shoot dry matter and grain yield provided by Unkovich et al. 2010.

respectively; although this is still higher than the average stubble: grain ratio of 1.7 indicated by Unkovich et al. 2010).

While it is recognised that our model tends to over-estimate post-harvest biomass results (compared to stubble: grain ratios typically observed in the field) arguably this is balanced out by the use of relatively cautious estimates for post-harvest critical cover requirements in the erosion risk analysis (refer to Section 3.8).

4.2.2 Simulated 'historic' results – long-term average results

Figures 18 and 19 illustrate the variability in simulated historic average crop performance (grain yield and post-harvest biomass) arising due to variation in Ave GS climate zone (ie. Ave GSR and Ave GS Temp) and soil profile type (ie. PAWC and surface % clay content).

These figures provide a visual representation of selected simulated historic average data presented in tables in Appendices J and K.

The following observations are made – which are generally consistent with the view that rainfall is a key limiting factor for dryland cereal cropping in South Australia:

- As expected, Ave GSR is the main driver of changes in average productivity.
- PAWC (ie. the capacity of a soil to store rainfall that is available to plants) appears to be the second most important driver of changes in average productivity.
- Differences in surface % clay content and Ave GS Temp have a lesser impact on average production levels compared to Ave GSR and PAWC.
- Incremental rates of productivity change vary with Ave GSR:
    - If Ave GSR increases, from a low Ave GSR starting point, relatively high average productivity gains could be achieved per mm of additional Ave GSR (compared to lesser productivity gains if starting from a high GSR starting point).
    - Conversely, under a drying climate, dry areas may experience the greatest rate of productivity loss, per mm decline in Ave GSR. (This does not account for changes in CO_2 levels or Ave GS Temp.)
    - There is a flattening of production response with increasing Ave GSR. Possible reasons for this include: moisture storage limitations (due to PAWC); nitrogen limitation and nitrogen leaching at high rainfall levels; and the inability of crops to utilise available moisture during cold conditions. (Rainfall is also not fully utilised in field situations where waterlogging or surface runoff occurs, although these are not well accounted for in the APSIM modelling.)
- There is lower peak production, and flattening out at lower Ave GSR values, for shallower soils (ie. soils with a smaller 'bucket size' are less able to take advantage of higher rainfall.)
- Larger PAWC soils are less limiting and better able to respond with increasing productivity as Ave GSR increases.
- Higher surface % clay contents have a greater negative impact on average production levels at low Ave GSR.

It is also worth noting that the use of a single 'medium maturity' wheat variety in the APSIM modelling across different climate zones has produced results (Figs 18 & 19) indicating a minor trade-off between grain yield and post-harvest biomass. This is because, for a given wheat variety and soil type, warmer temperatures will cause earlier flowering and maturation, effectively giving the plant less time to grow overall biomass. As such, the influence of warming Ave GS Temp indicated in the following figures would typically be addressed to a degree in the real world by farmers making different crop variety selections.

It should be noted that warmer temperatures also appear to influence the climate change scenario results (see maps shown in Section 4.3) and different variety selections will be made to help adapt and optimise desirable crop growth properties. However these climate change simulations suggest, for areas that experience greater rainfall limitation, there is potential for a trade-off between production and sustainable land management outcomes (ie. optimising grain yield at the expense of declining post-harvest biomass to protect soils).

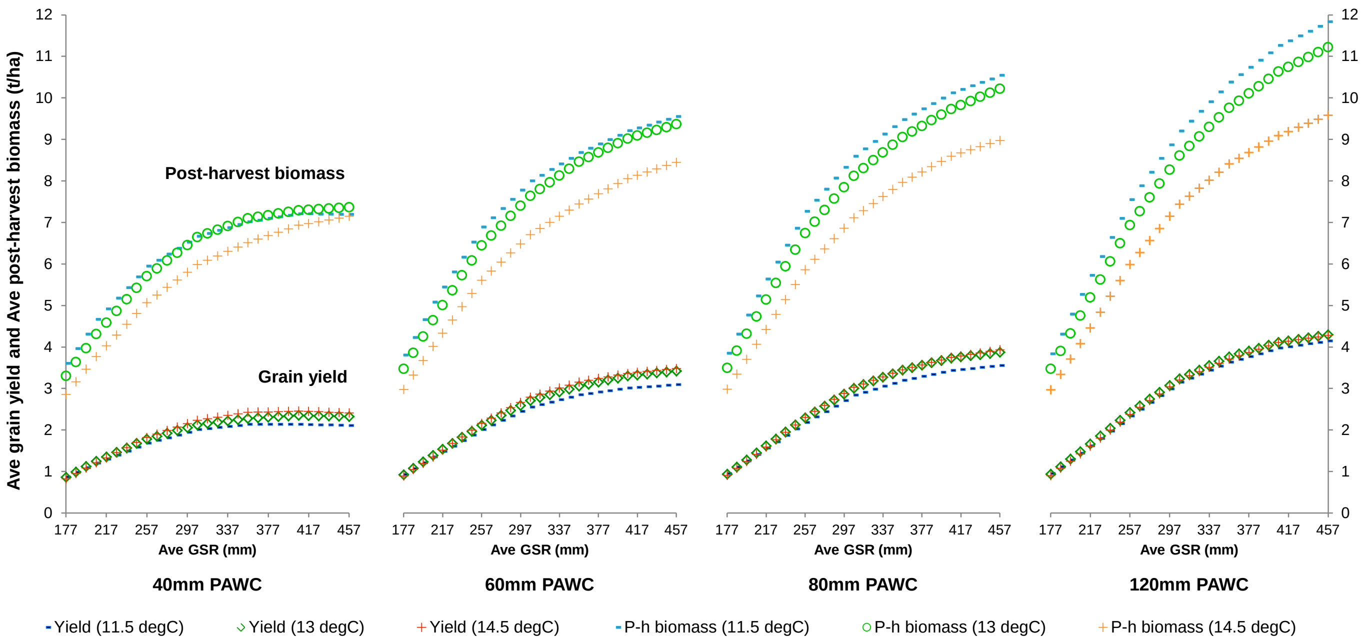


Figure 18. **Simulated historic average grain yield and post-harvest biomass (in t/ha) under varying Ave GSR (177-457 mm), PAWC (40, 60, 80, 120 mm) and Ave GS Temp (11.5, 13, 14.5 °C). All plots have constant 15% surface clay content. This chart presents a limited selection of the detailed historic simulation outputs contained in Appendices J and K. Results from Snowtown-based climate files only are shown.**

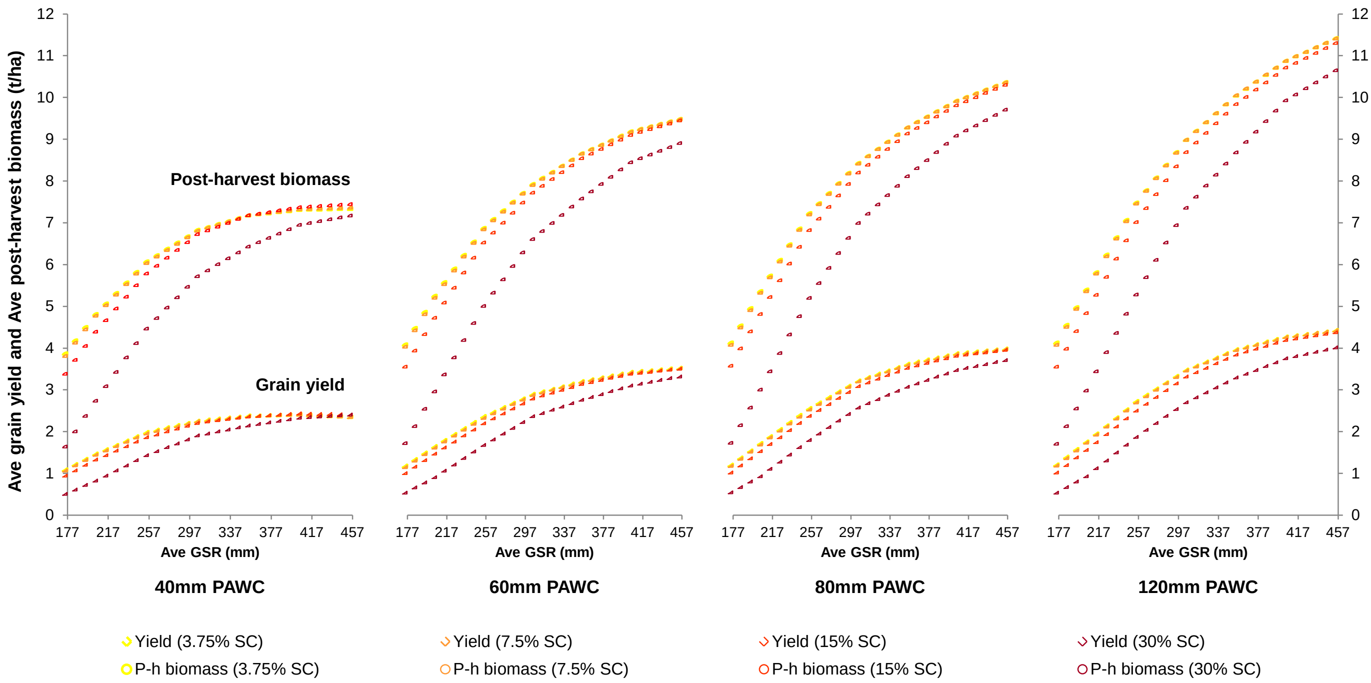


Figure 19. **Simulated historic average grain yield and post-harvest biomass (in t/ha) under varying Ave GSR (177-457 mm), PAWC (40, 60, 80, 120 mm) and surface clay (SC) content (3.75, 7.5, 15, 30 %). All plots have constant 13 °C Ave GS Temp. This chart presents a limited selection of the detailed historic simulation outputs contained in Appendices J and K. Results from Snowtown-based climate files only are shown.**

4.3 Mapping outputs

State-wide maps for historic and changed climate scenarios are presented for the following key indicators:

- ***Average wheat grain yield*** (t/ha) – Figure 20, with percentage and absolute change from simulated historic levels – Figures 22, 24
- ***Average post-harvest stubble*** (t/ha) – Figure 21, with percentage and absolute change from simulated historic levels – Figures 23, 25
- For erosion risk – ***Proportion of landscape below critical cover levels (at different frequencies of occurrence)*** – Figures 26-29.

Land at risk of wind or water erosion

The method of presenting erosion risk as the 'proportion of landscape below critical cover levels (at different frequencies of occurrence') is designed to highlight areas of potential erosion risk that would otherwise be hidden (or diluted) by presenting a spatially and temporally averaged value for each mapping polygon.

Additional maps

A range of additional maps listed in Appendix L have been generated for various scenarios and regions. This includes highlighting potential impacts to particular NRM Regions, and highlighting wind and water erosion risk separately. These maps are available from the DEWNR Soil and Land Program, email: Craig.Liddicoat@sa.gov.au

Separate map series are possible for 'land at risk of wind erosion', 'land at risk of water erosion', or 'land at risk of wind or water erosion'. The latter example maps are shown here (Figures 26-29) in which seasonal post-harvest biomass outcomes have been compared to whichever is the greater critical cover requirement, for wind or water erosion protection. To underpin these complex maps – the frequency at which various critical cover levels (from Table 7) fail to be reached have been tabulated for each modelled scenario.

A frequency (likelihood of occurrence) of 'at least 1 year in 10' is seen as a useful benchmark of erosion risk. Spatial data statistics for simulated climate change impacts on the total land area with below critical cover at the 1 year in 10 frequency of occurrence are presented in the next section. Erosion risk maps showing wind and water erosion risk separately, with a likelihood of at least 1 year in 10 are shown in Appendices M and N.

General observations – yield and biomass maps

Mapping of t/ha grain yields and post-harvest biomass under the climate change scenarios suggests:

- The fringe of drier, marginal cropping areas will be most impacted under declining rainfall, and marginal areas may expand further south
- Currently wetter regions may experience little impact, or a slight boost in production due to varying potential contributions from: warmer temperatures, the CO_2 fertilisation effect and reduced nitrogen leaching. However, these potential benefits are negated (to varying degrees in different regions) under progressive rainfall decline scenarios, as crop growth becomes increasingly moisture limited.
- At 5% rainfall decline, post-harvest biomass production is adversely impacted to a greater extent than grain yield (which may increase slightly in many situations) [A possible explanation for this is discussed in Section 4.2.2.]

General observations – erosion risk maps

The maps show a general progression from (i) a small total area affected by frequent erosion risk to (ii) a large total area with infrequent erosion risk (e.g. for 'worst on record' seasons). The maps also show that the erosion issue is a gradational problem, increasing in extent with poorer seasons and with a drying climate. This provides a guide to areas that might show up first with increased erosion risk due to low biomass growth in poorer seasons. These are the areas that land managers will need to monitor if projections of a drying climate become a reality.

Under higher rainfall reduction levels the spatial extent of areas modelled with frequent erosion risk (e.g. 'at least 4 years in 10') increases significantly. If these areas of high frequency of erosion risk are realised there will be a need to seek alternative sustainable land management or land use options.

It should be re-iterated that the modelling results are based on post-harvest biomass levels, and do not account for management actions such as over-grazing, burning or cultivation. They also do not account for any potential changes in the frequency or severity of severe weather events that may occur under climate change.

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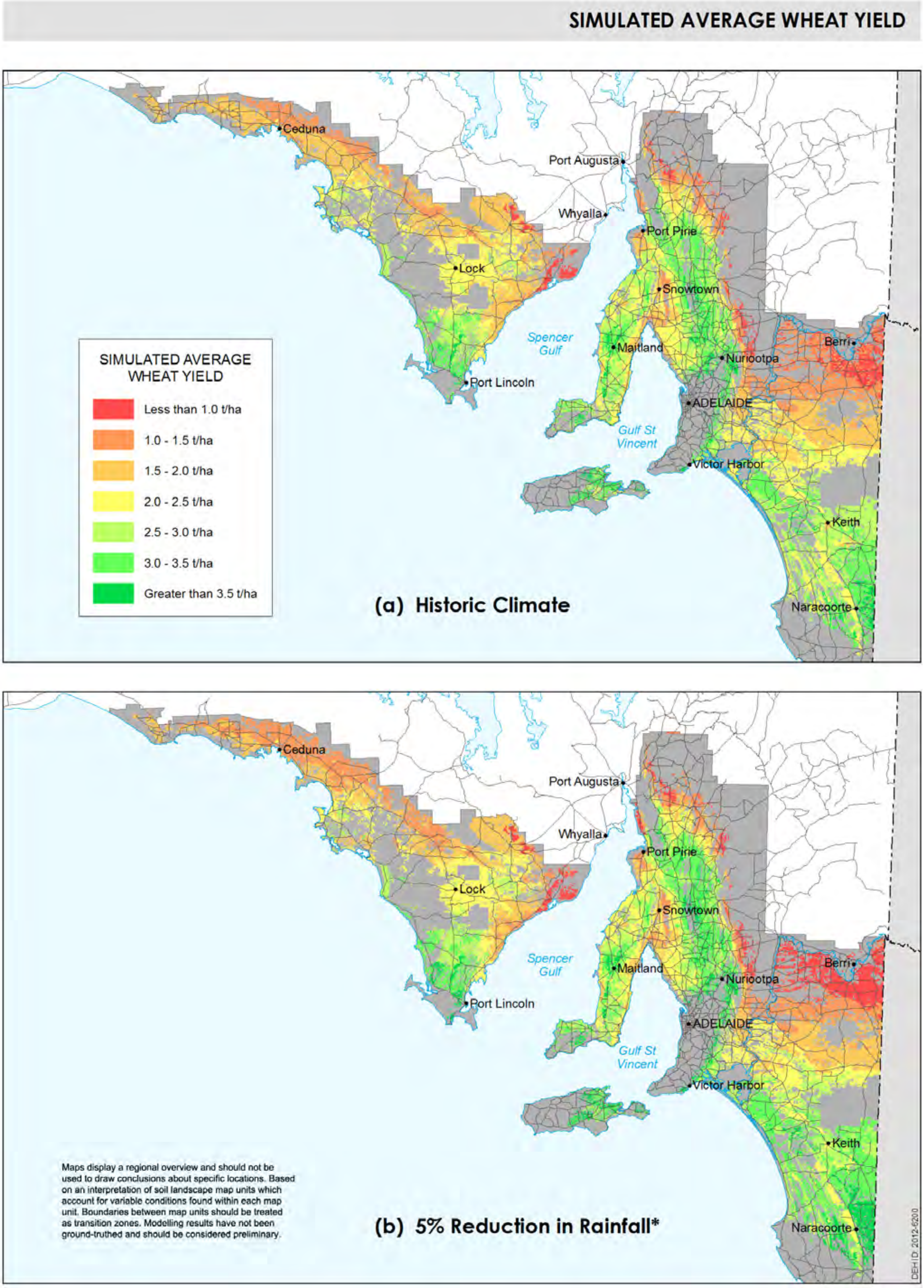
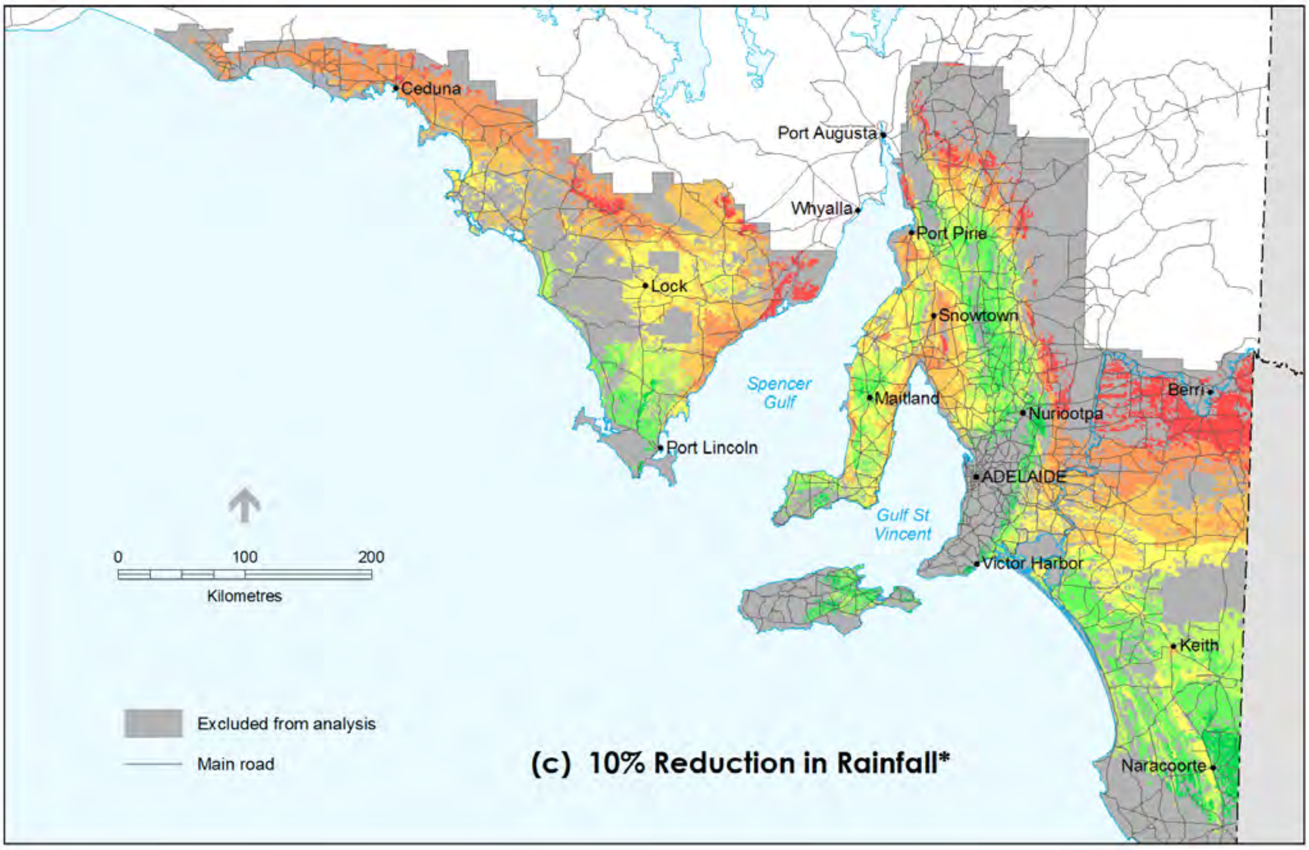
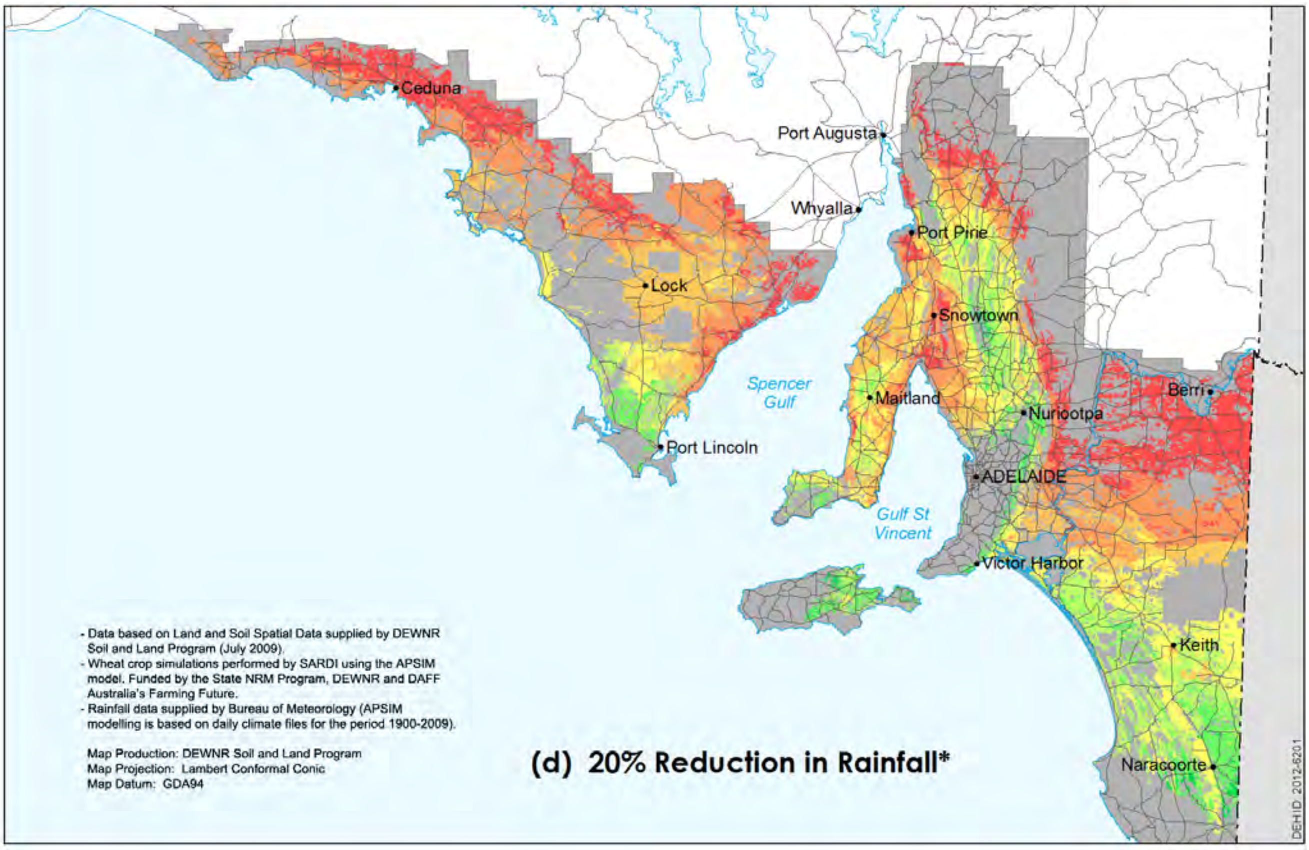


Figure 20. **Simulated long-term average wheat grain yields under historic climate (a), and climate change scenarios (b), (c) and (d). *Climate change scenarios also include elevated temperature and CO_2 levels.**

FOR ALTERNATIVE CLIMATE SCENARIOS



(c) 10% Reduction in Rainfall*



(d) 20% Reduction in Rainfall*

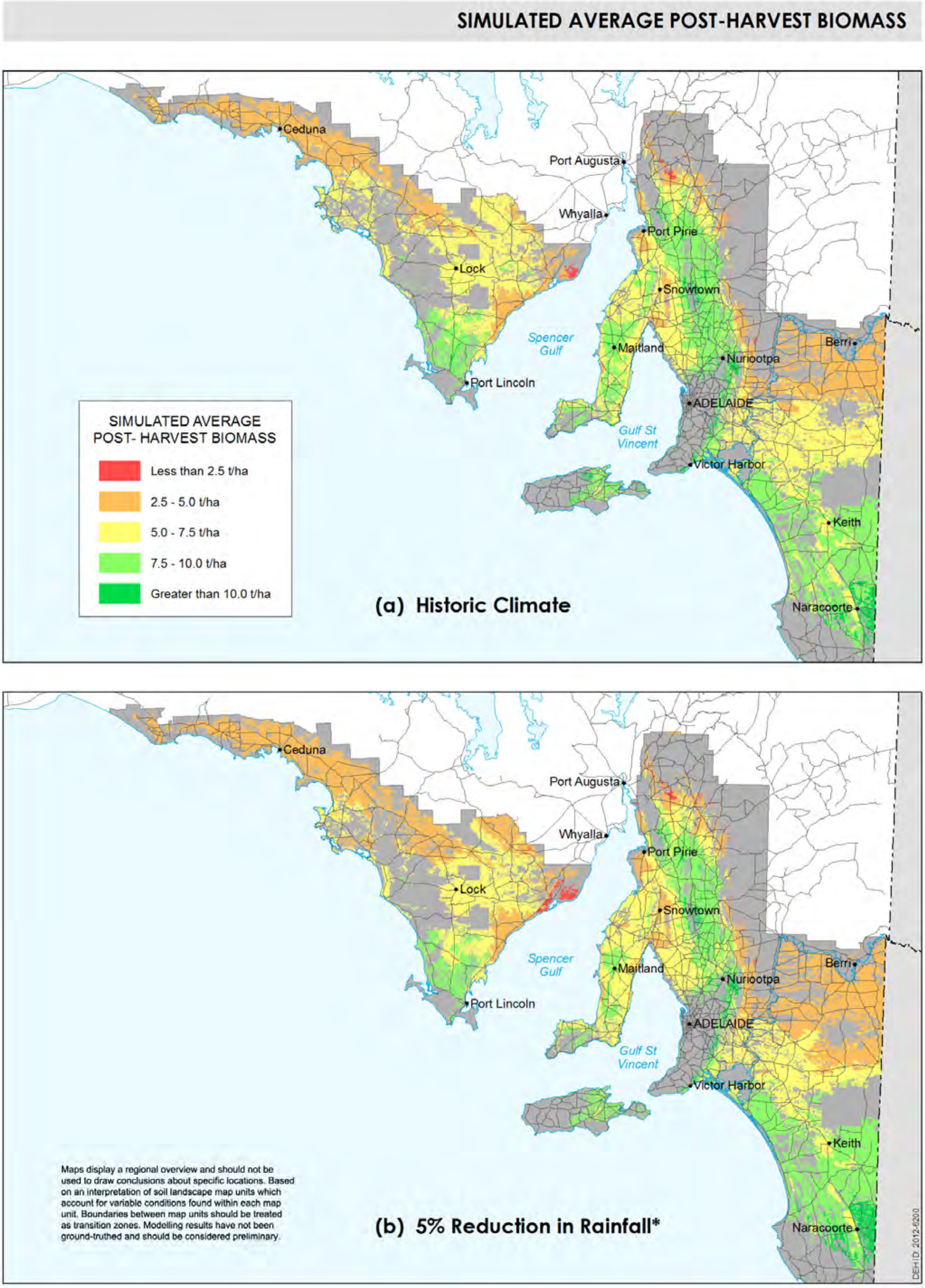
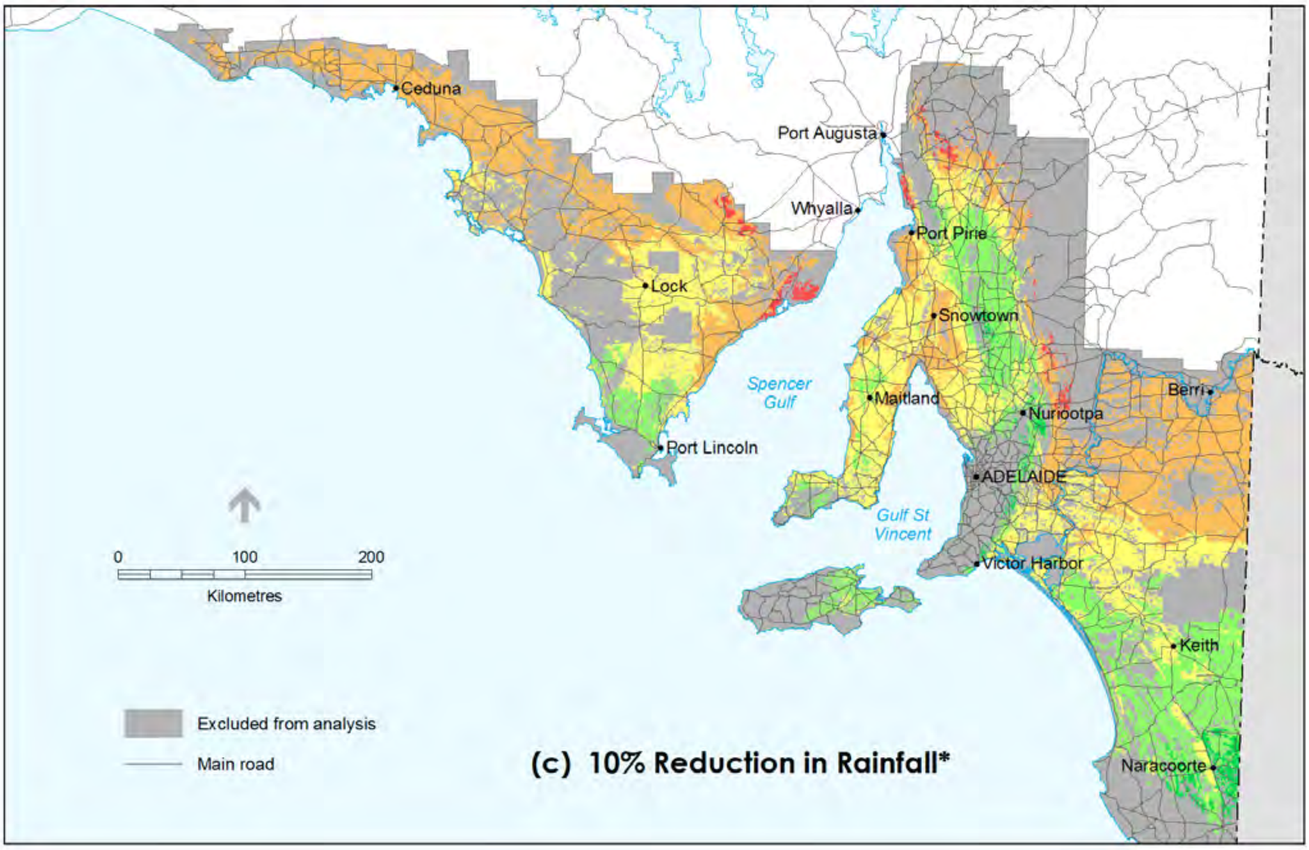
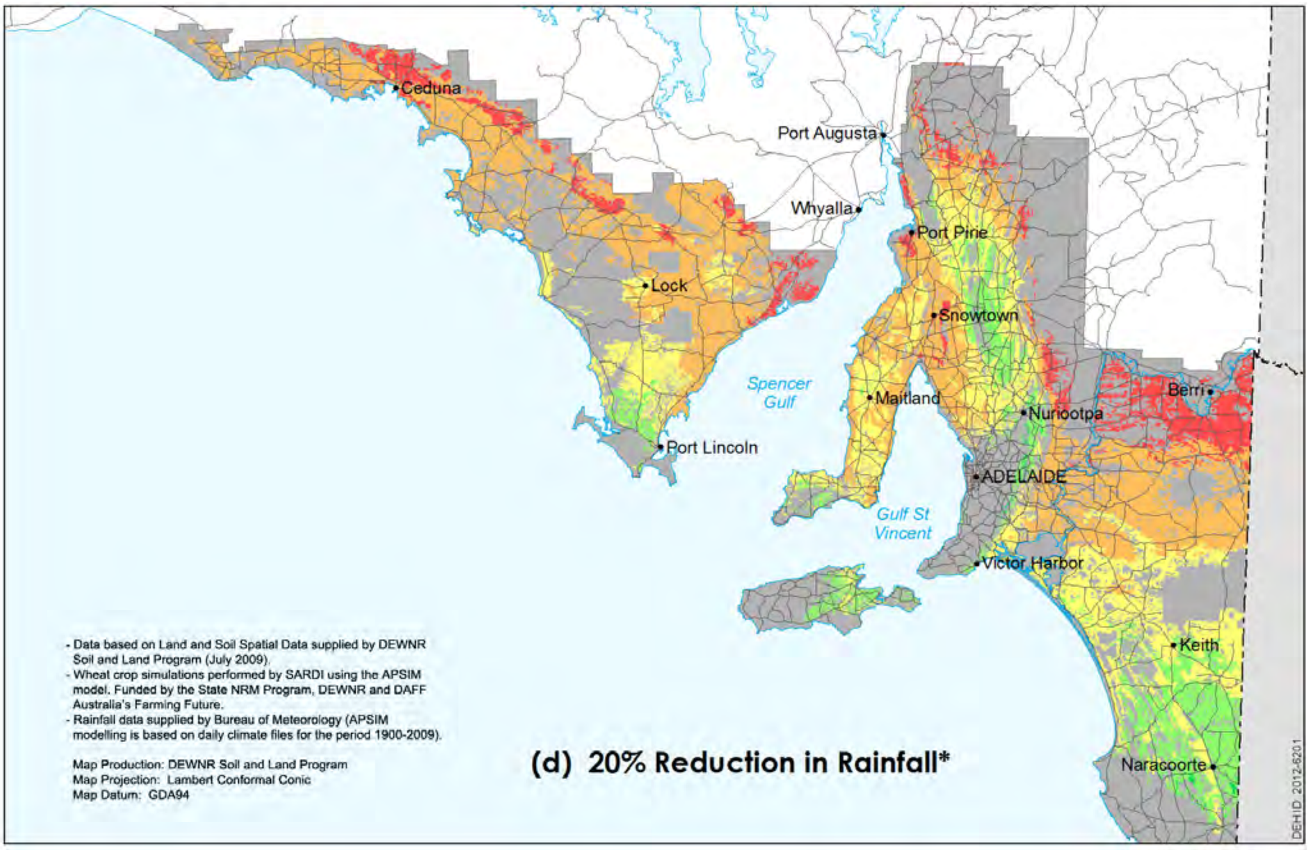


Figure 21. **Simulated long-term average wheat grain yields under historic climate (a), and climate change scenarios (b), (c) and (d). *Climate change scenarios also include elevated temperature and CO_2 levels.**

FOR ALTERNATIVE CLIMATE SCENARIOS





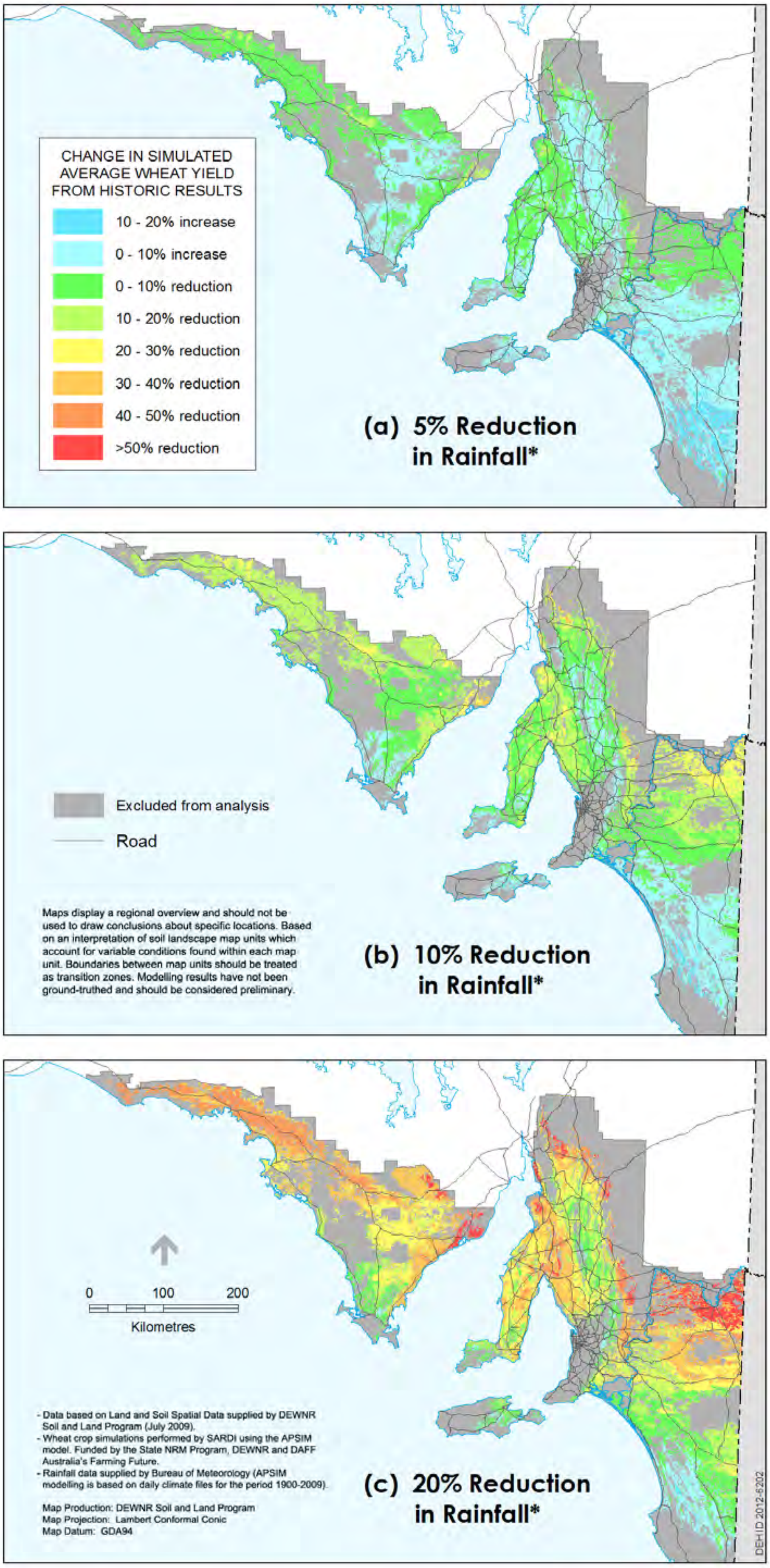


Figure 22. **Percentage change in simulated average wheat yields (t/ha) compared to historic scenario. *Climate change scenarios also include elevated temperature and CO_2 levels.**

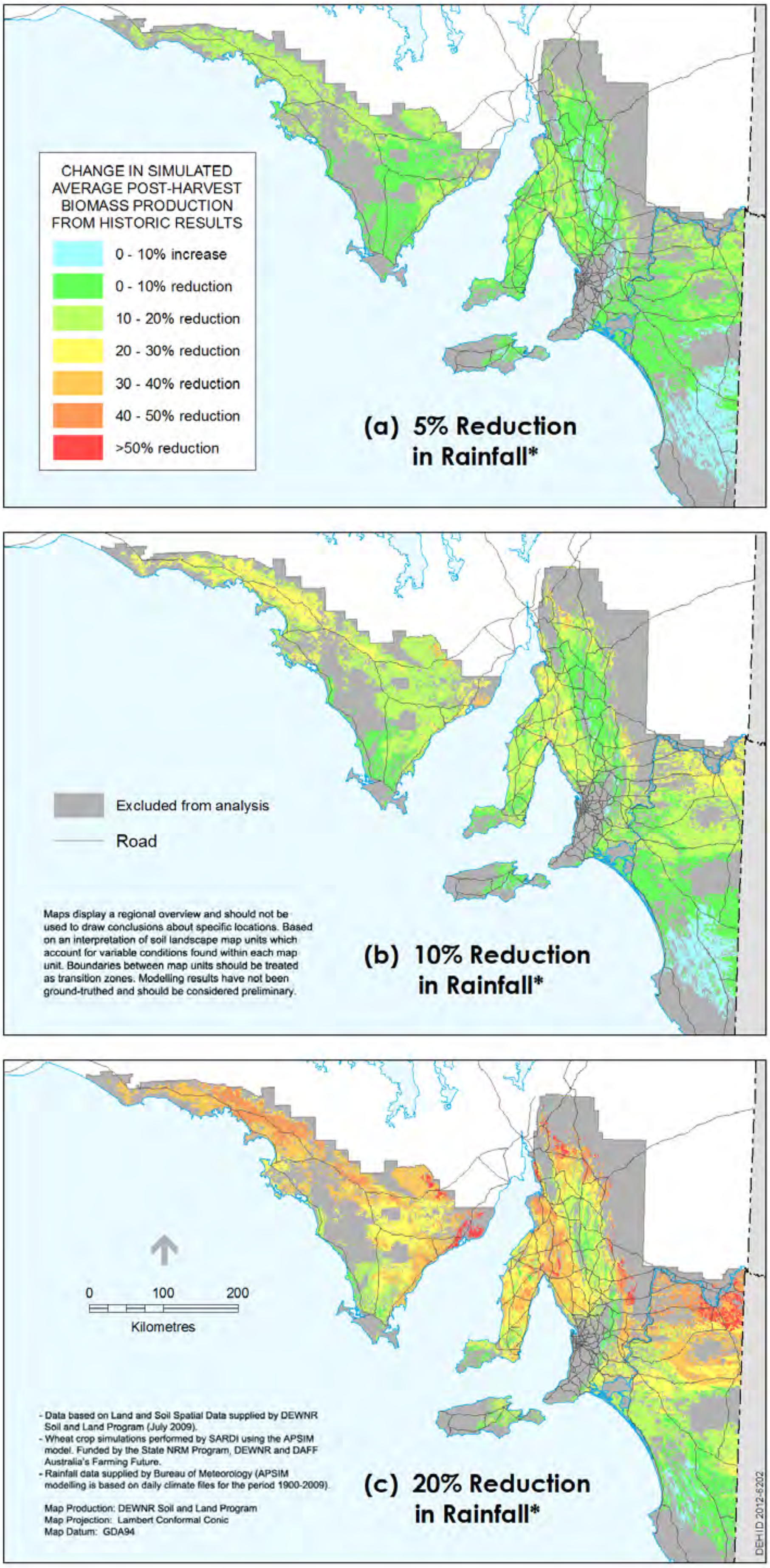


Figure 23. Percentage change in simulated average post-harvest biomass (t/ha) compared to historic scenario. *Climate change scenarios also include elevated temperature and CO_2 levels.

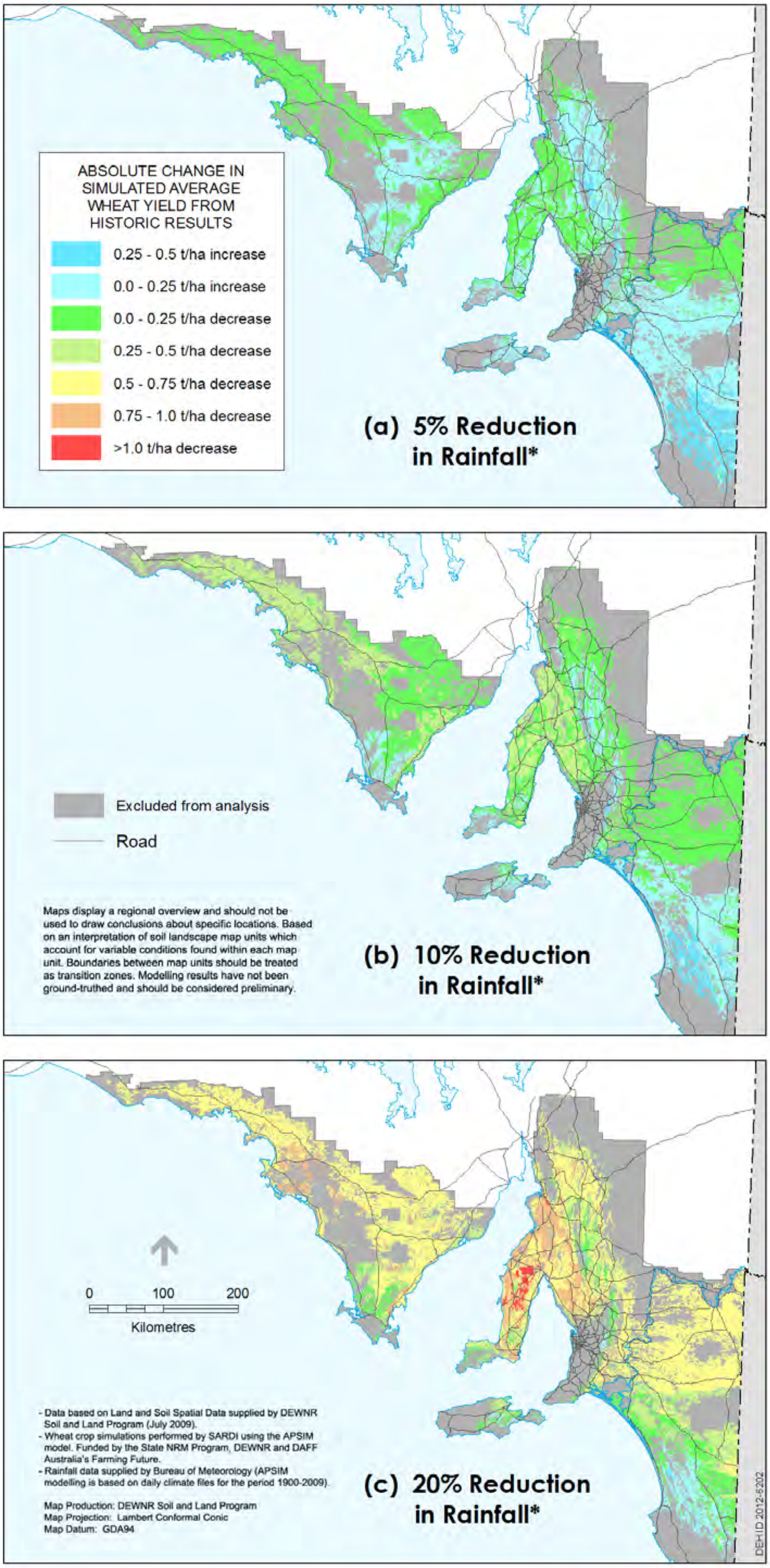


Figure 24. **Absolute change in simulated average wheat yields (t/ha) compared to historic scenario. *Climate change scenarios also include elevated temperature and CO_2 levels.**

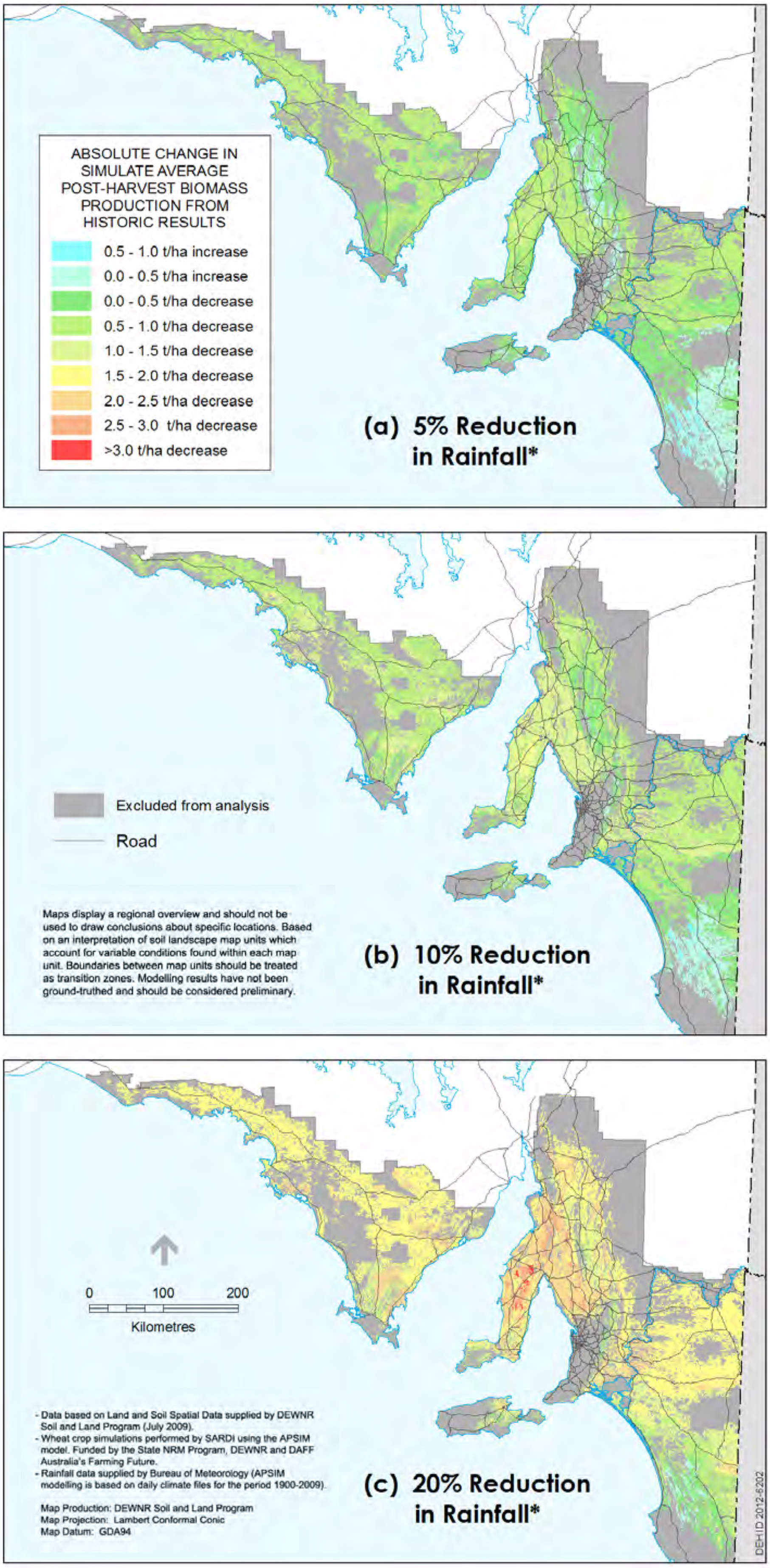


Figure 25. **Absolute change in simulated average post-harvest biomass (t/ha) compared to historic scenario. *Climate change scenarios also include elevated temperature and CO_2 levels.**

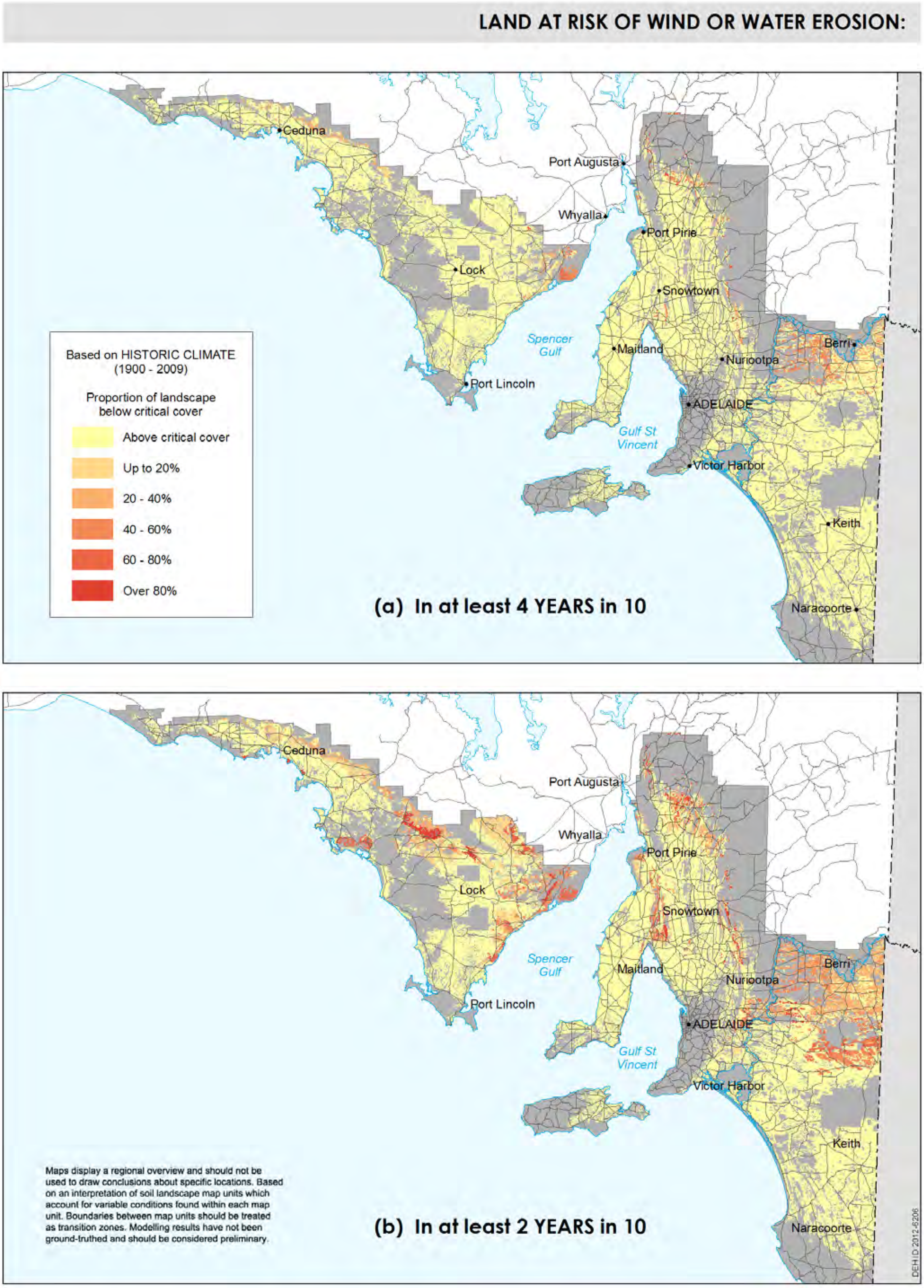
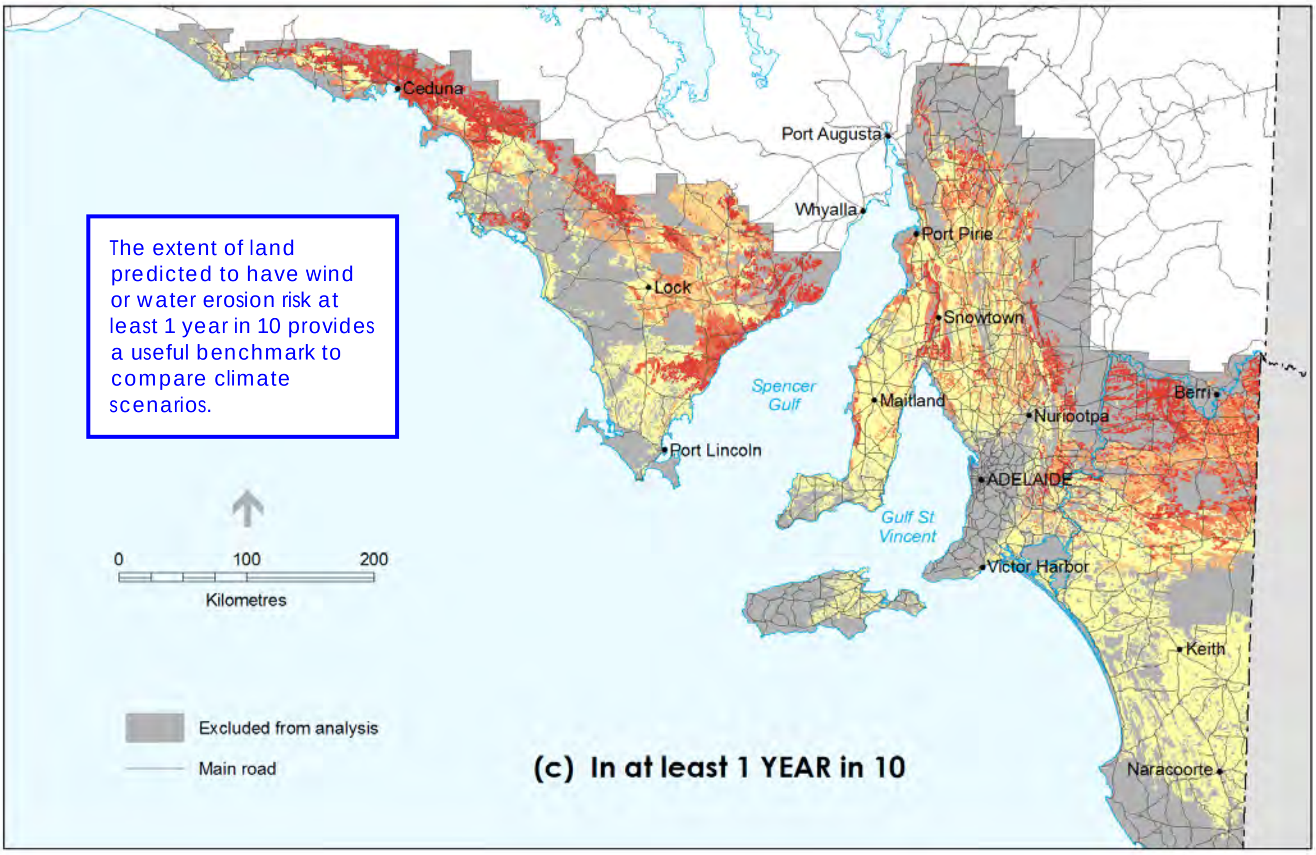
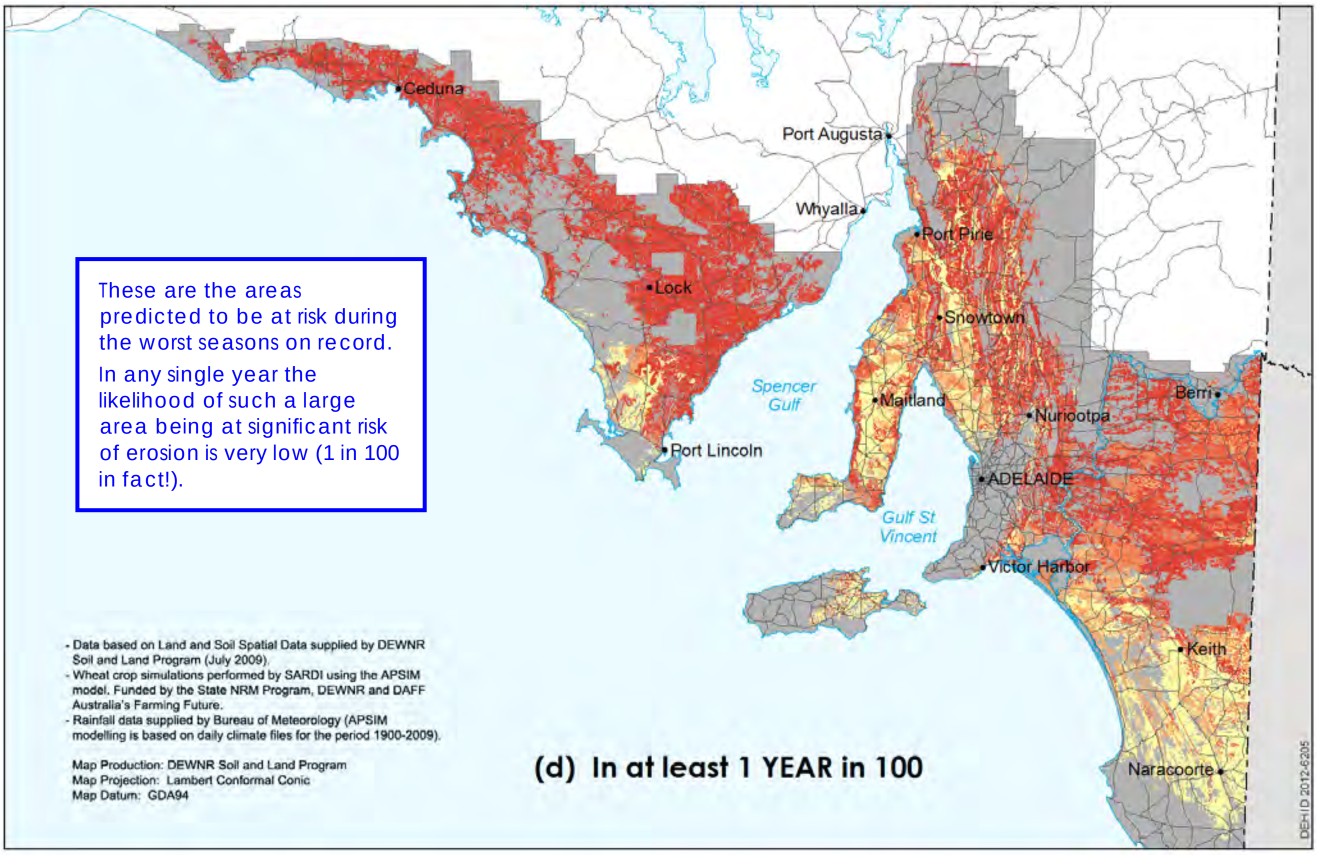


Figure 26. **Simulated extent of land with below critical cover indicating increased risk of wind or water erosion under historic climate (1900-2009), at different frequencies (likelihood) of occurrence, assuming wheat cropping.**

HISTORIC CLIMATE





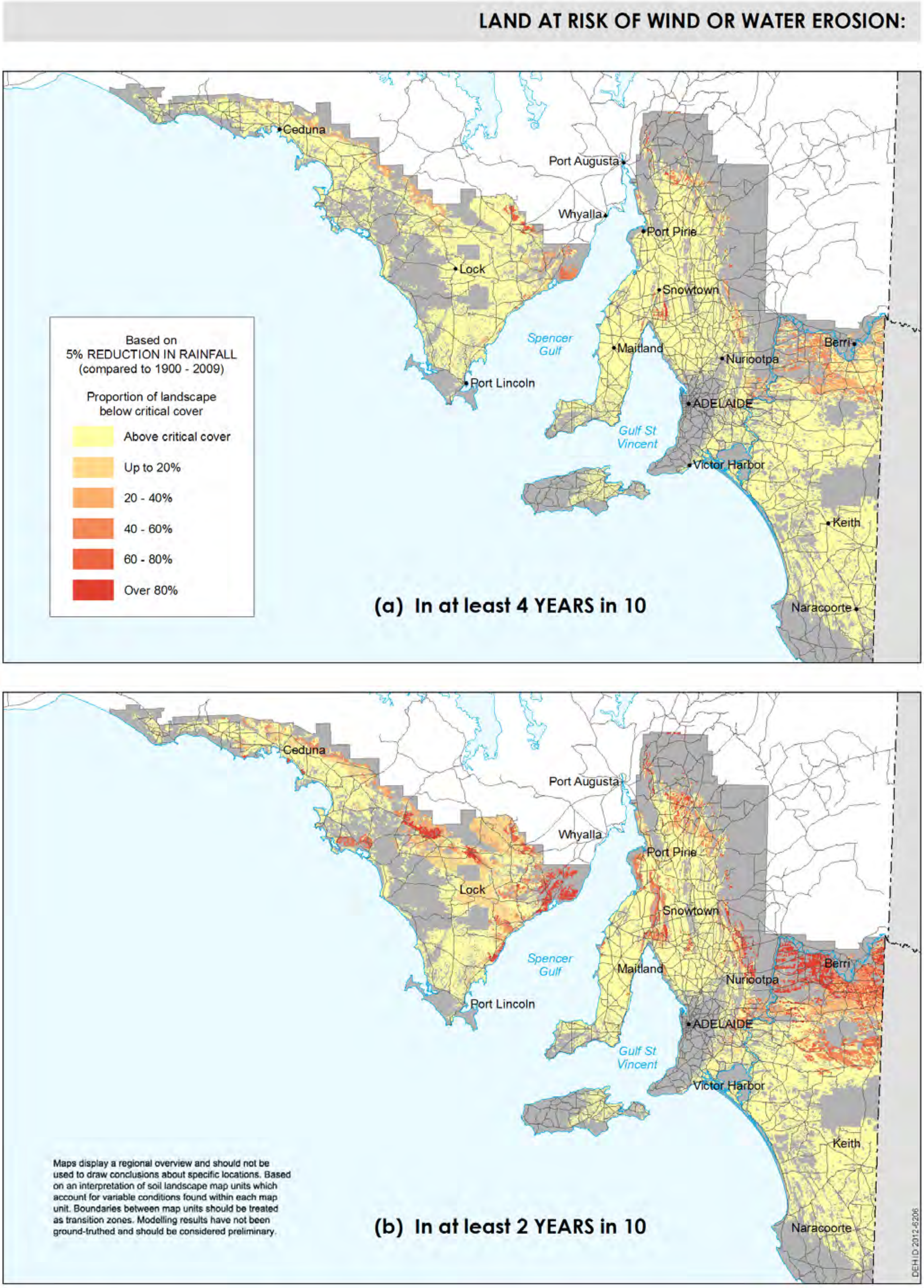
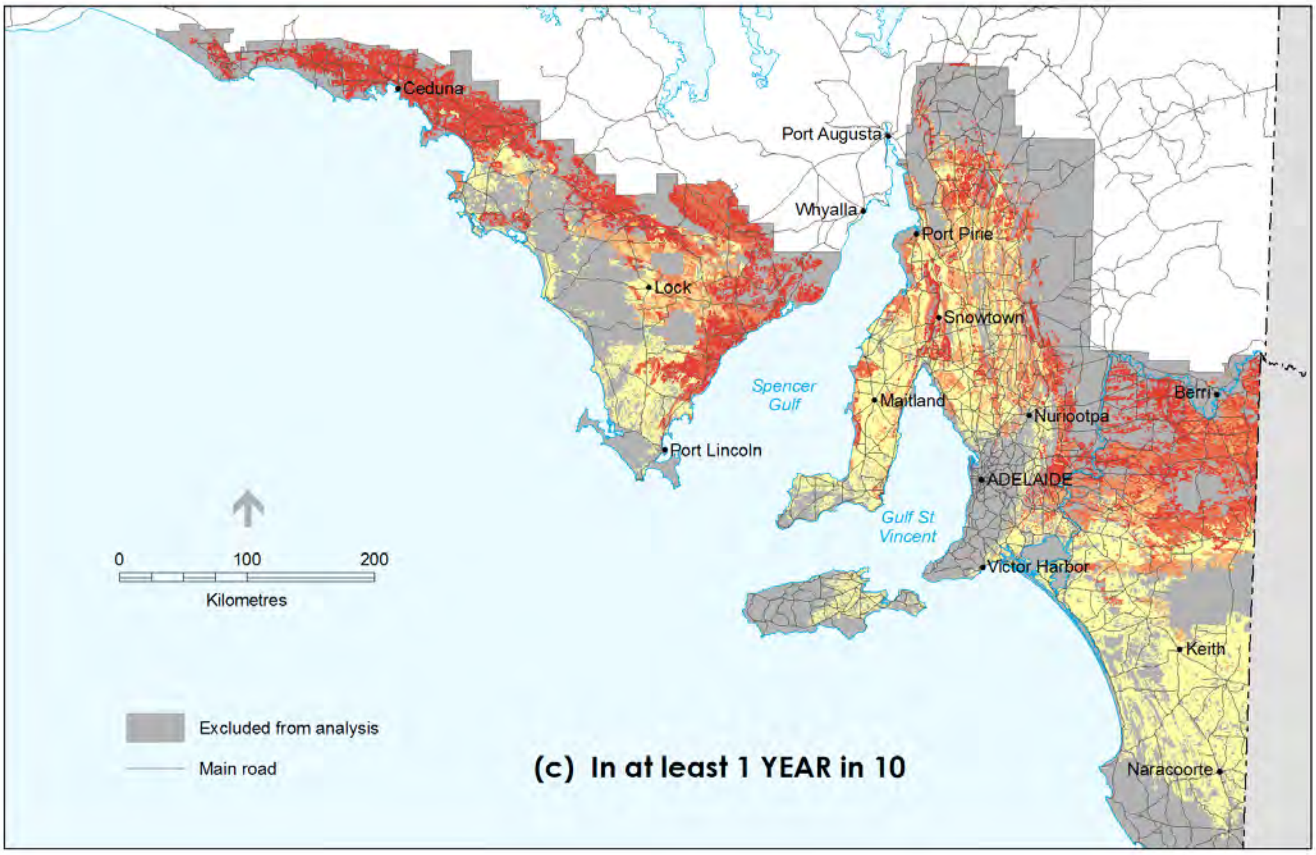
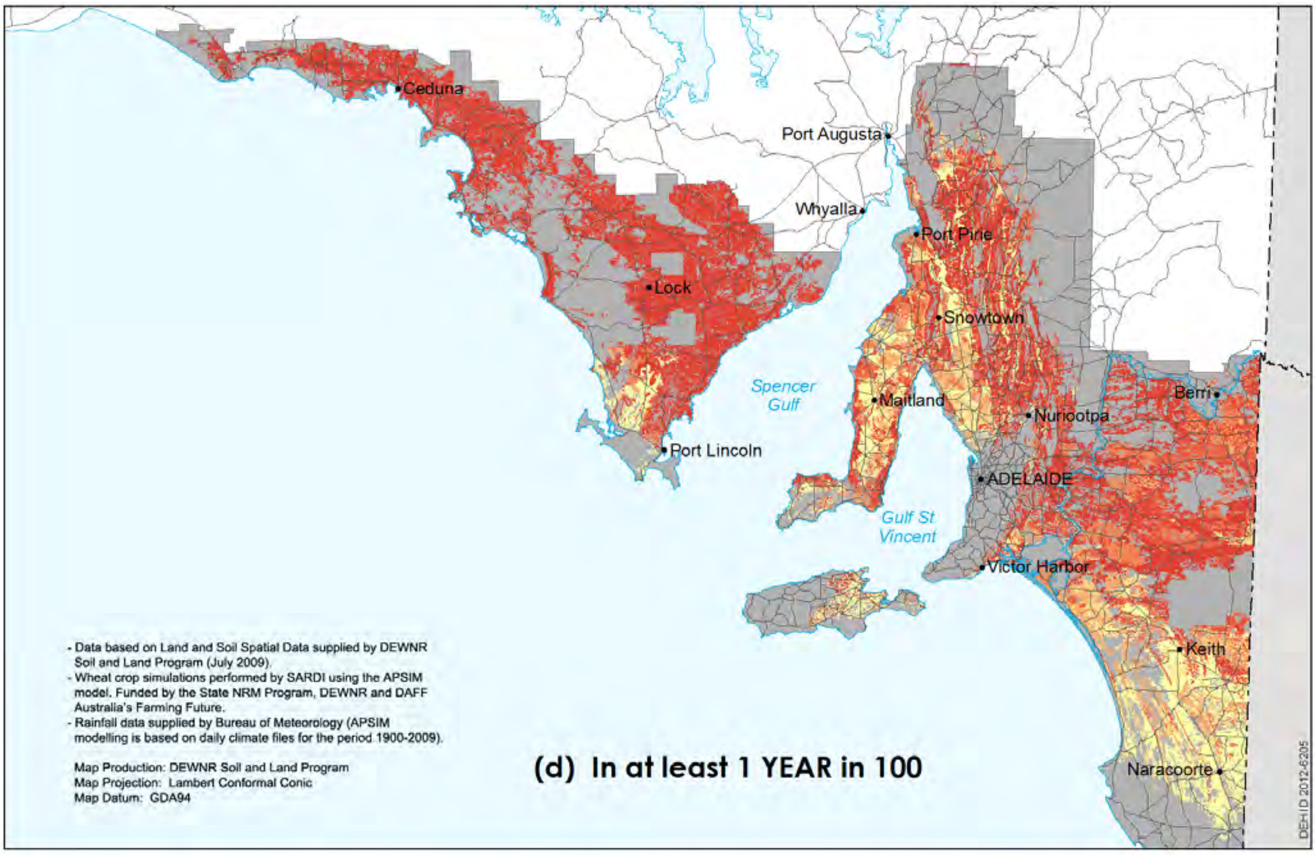


Figure 27. **Simulated extent of land with below critical cover indicating increased risk of wind or water erosion under climate change with 5% rainfall reduction (compared to 1900-2009), at different frequencies (likelihood) of occurrence, assuming wheat cropping.**

5% REDUCTION IN RAINFALL





LAND AT RISK OF WIND OR WATER EROSION:

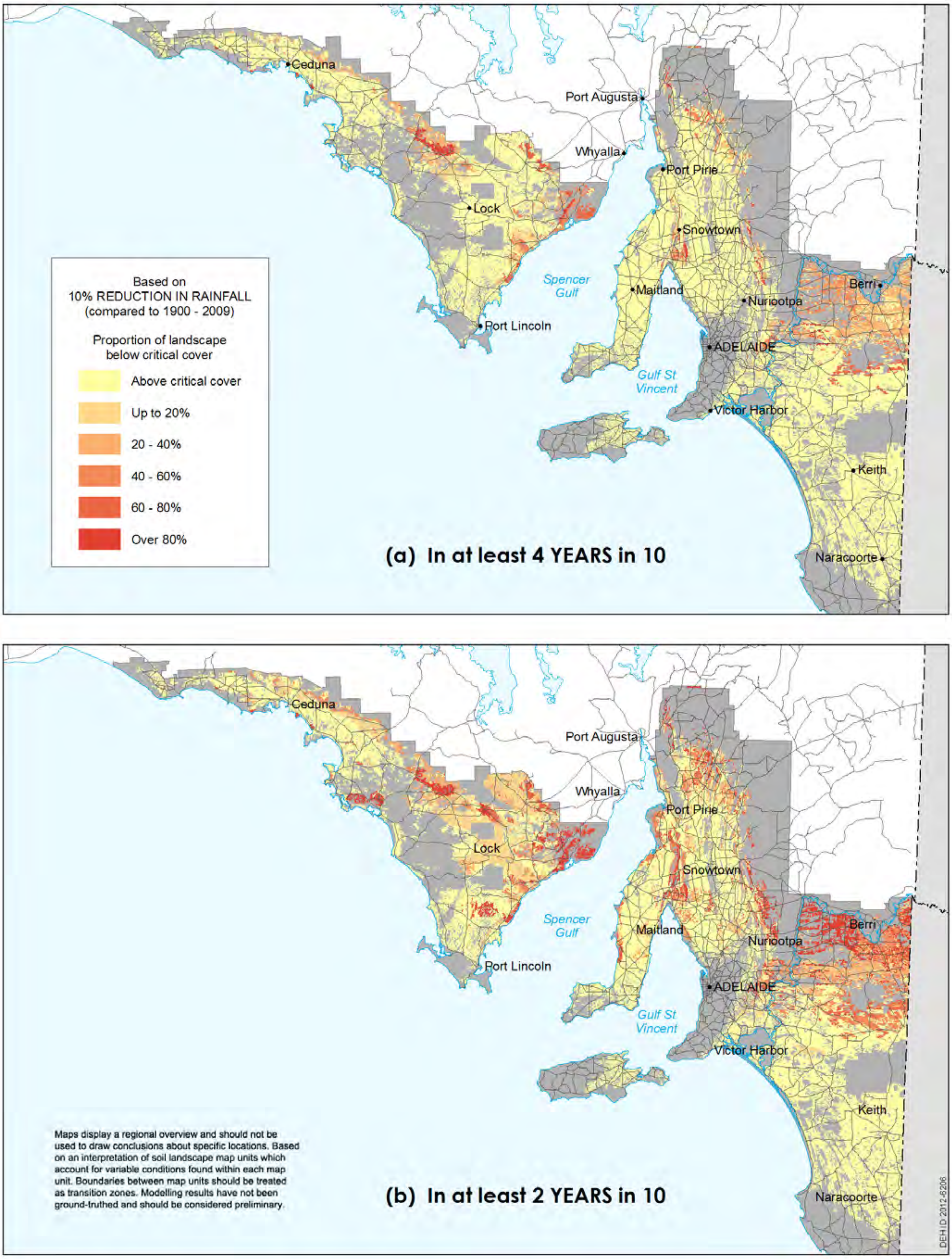
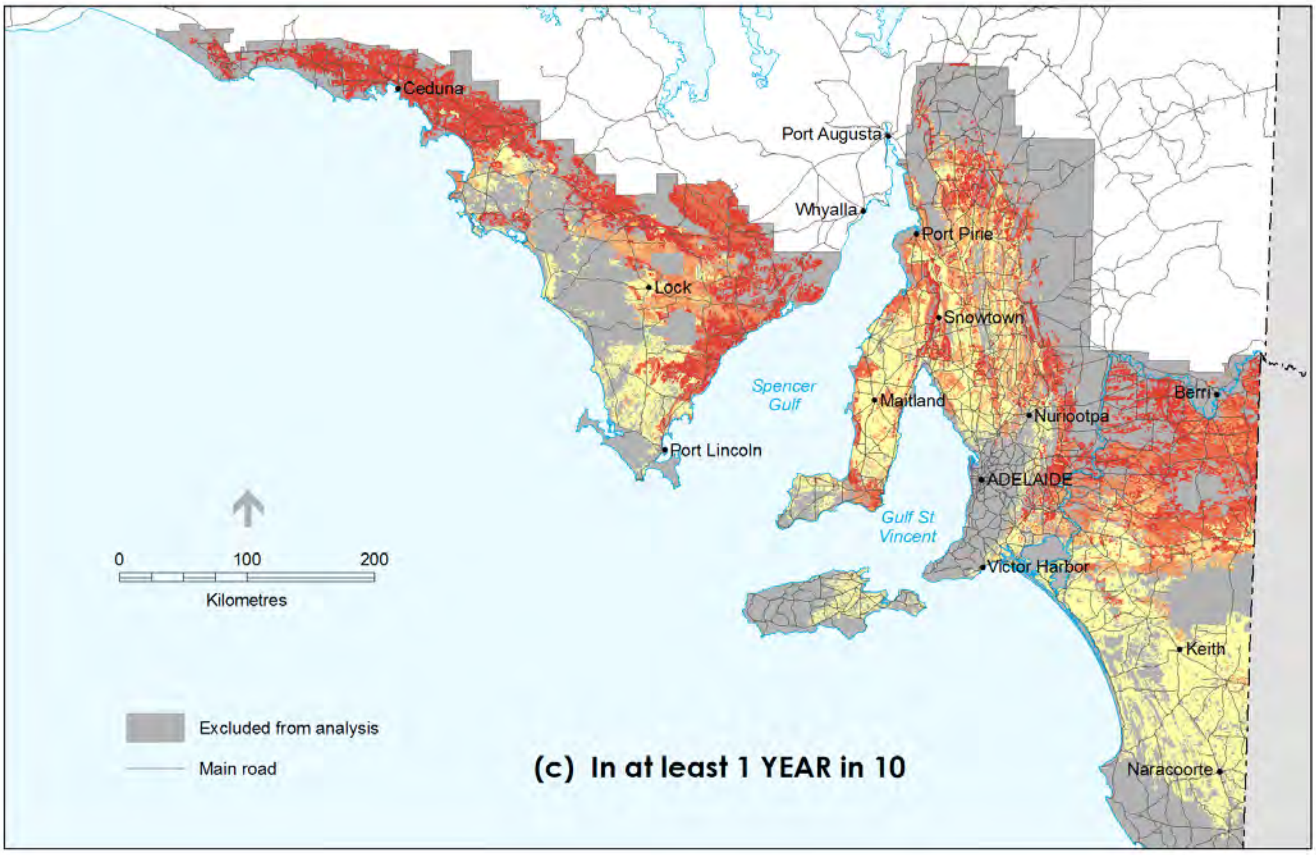
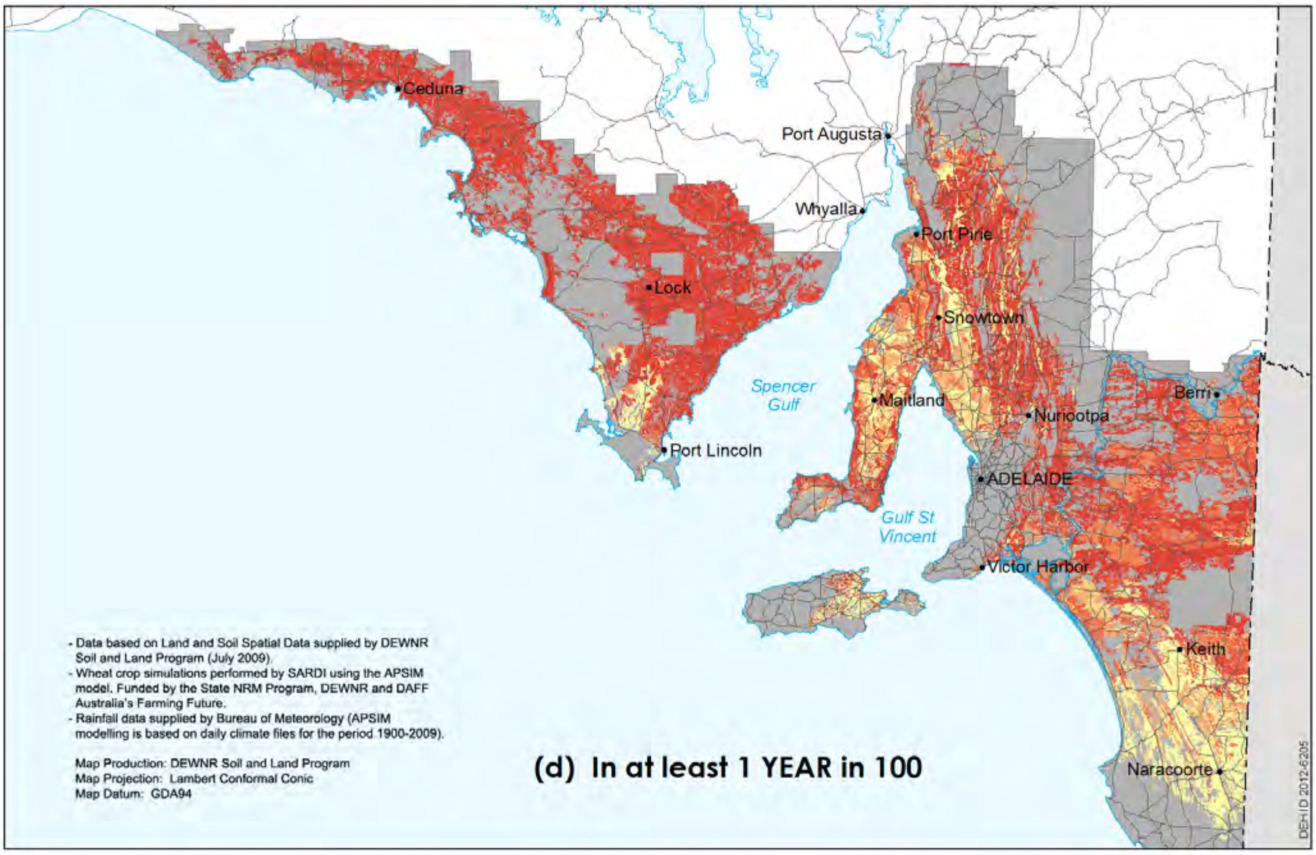


Figure 28. **Simulated extent of land with below critical cover indicating increased risk of wind or water erosion under climate change with 10% rainfall reduction (compared to 1900-2009), at different frequencies (likelihood) of occurrence, assuming wheat cropping.**

10% REDUCTION IN RAINFALL



(c) In at least 1 YEAR in 10



(d) In at least 1 YEAR in 100

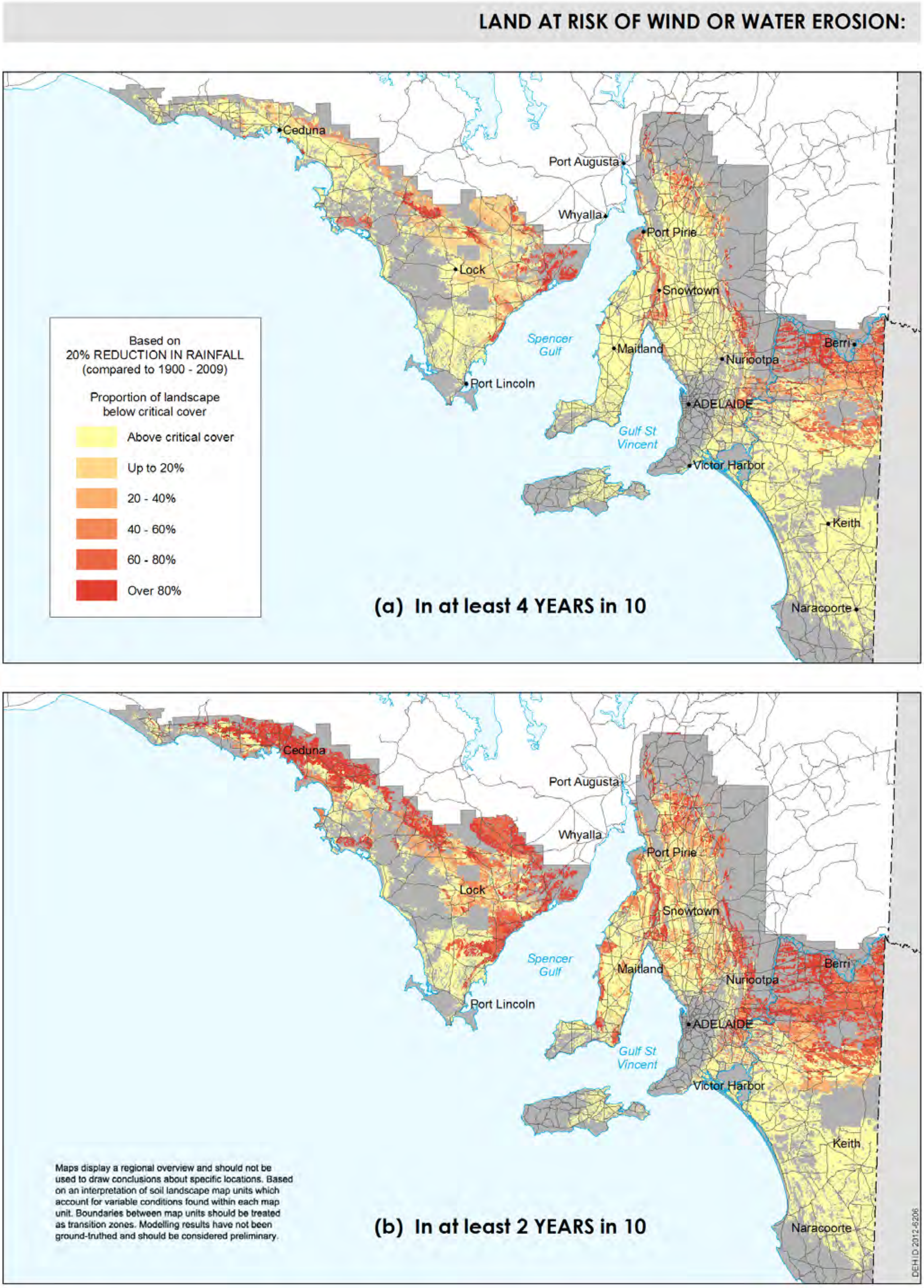
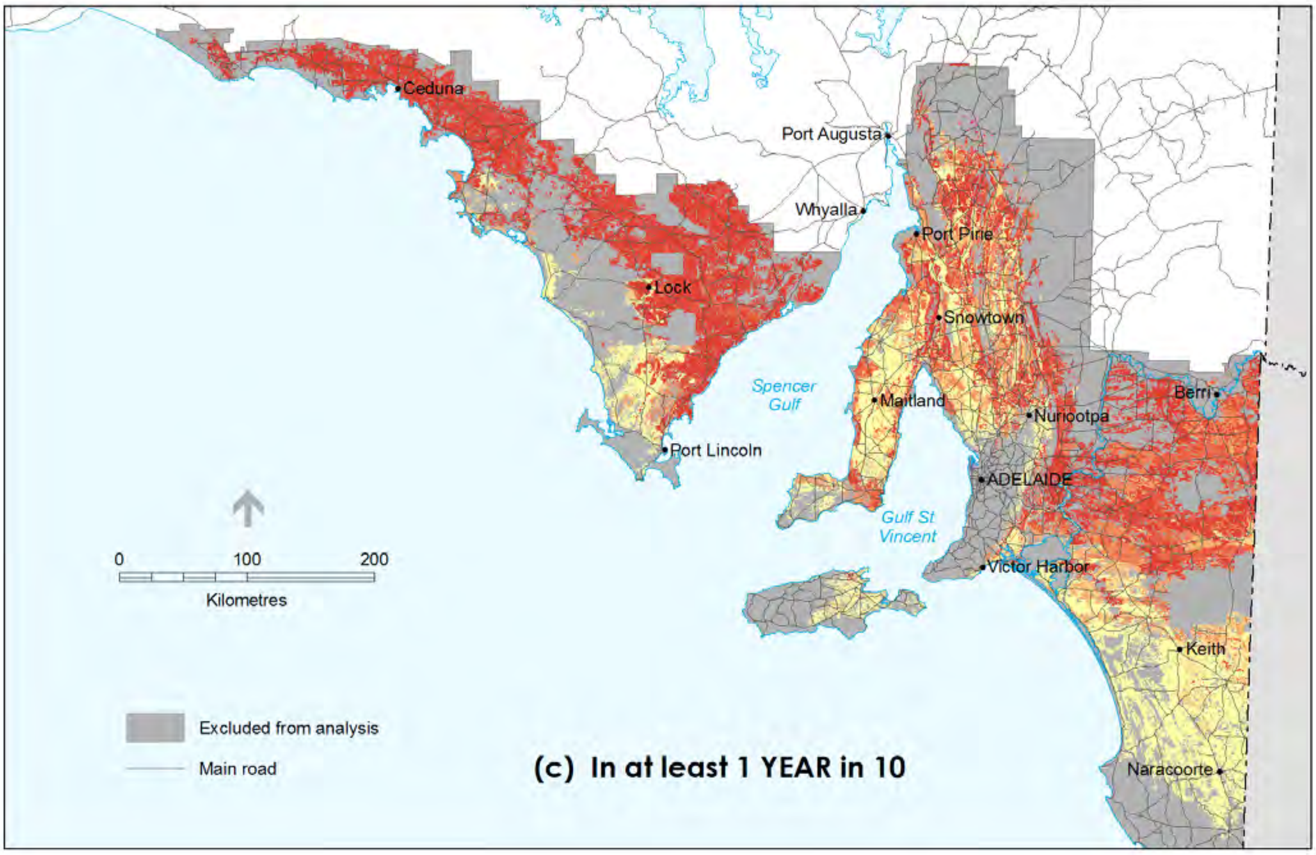
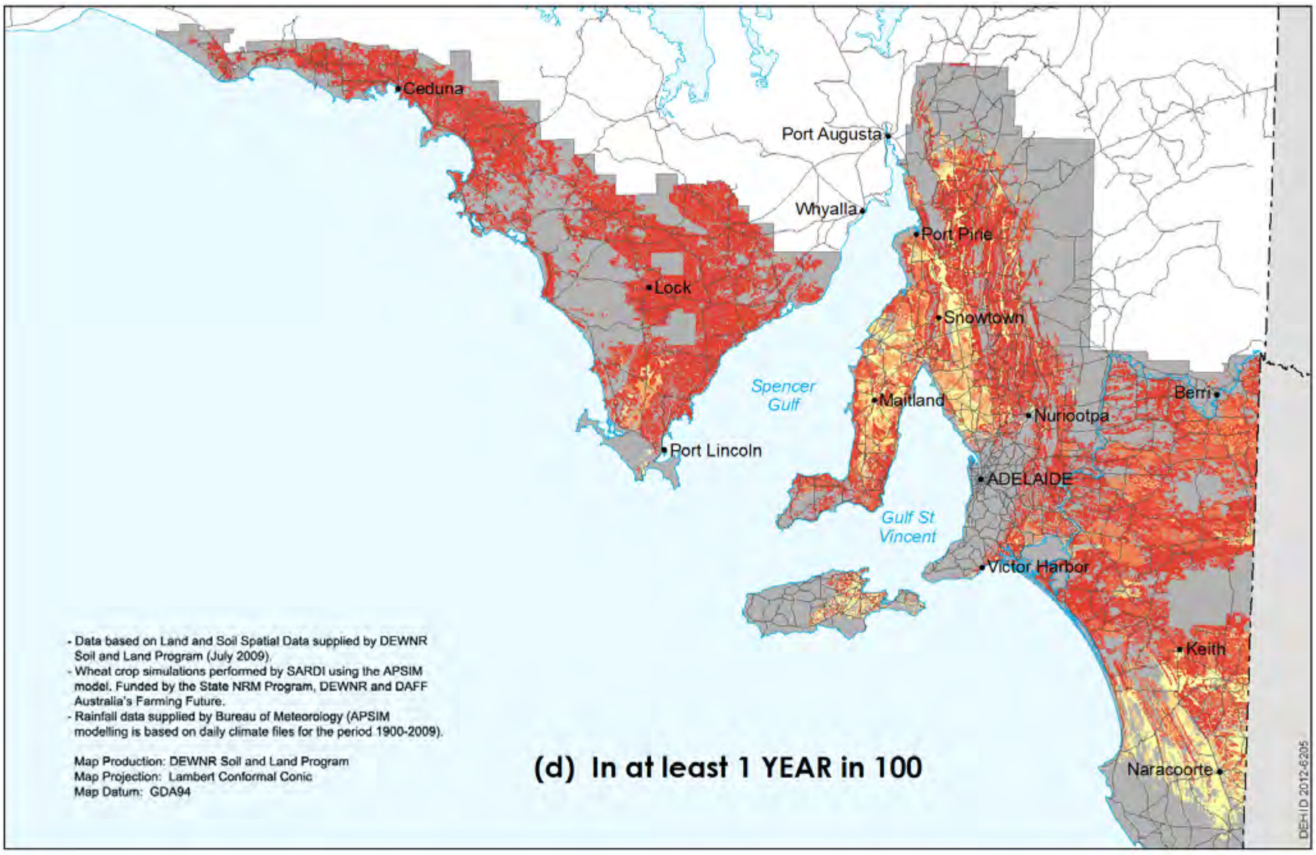


Figure 29. Simulated extent of land with below critical cover indicating increased risk of wind or water erosion under climate change with 20% rainfall reduction (compared to 1900-2009), at different frequencies (likelihood) of occurrence, assuming wheat cropping.

20% REDUCTION IN RAINFALL



(c) In at least 1 YEAR in 10



(d) In at least 1 YEAR in 100

4.4 Summary spatial data

Summary spatial data statistics are provided for (i) grain production, (ii) post-harvest biomass production, and (iii) the area of land with below critical cover for wind or water erosion protection at a frequency of 1 year in 10. Data for NRM Regions and Australian Bureau of Statistics (ABS) Statistical Local Areas (SLA) have been evaluated to reflect different scales of policy and management considerations, as well as availability of validation data (see Section 4.5). Data for PIRSA crop reporting districts are also discussed below and examined further in Section 4.5. Maps showing ABS SLAs, PIRSA crop reporting districts and NRM Regions are contained in Appendix O. The modelling (including the summary spatial data statistics) takes account of all component areas of all soil landscape map units (refer to Section 2.5).

Summary spatial data statistics are based on the analysis of all arable land with potential suitability for dryland (rain-fed) cropping (as described in Section 3.9) in the following manner:

1) Grain and biomass yield estimates in t/ha are evaluated from the simulated total production (in tonnes) across the total arable land area (ha), in each particular area of interest.
2) However, when reporting data statistics for total average annual production in tonnes, or total land area (ha) of below critical cover, predictions based on simulated wheat cropping over the total arable area will be a considerable over-estimate compared to what might be expected in reality (across a mixed farming landscape). This is because not all arable land in any given year in any given district is used for the production of wheat. To better utilise the simulated production values generated in this study – as a guide to potential impacts on dryland cropping in general – total tonnage estimates (and total land areas with below critical cover) have been downscaled in a way that reflects regional variation in the typical areas under field crops. This has been achieved by evaluating the 10 year average 'total field crop area', for each crop reporting district, from PIRSA's archived Crop and Pasture Reports (2002/03 – 2011/12) (PIRSA 2003-2012). The average 'total field crop areas' (for each PIRSA crop reporting district) were then expressed as a percentage of the total potentially arable land area identified for this study, and assumed to apply to each constituent SLA or combined as an area-weighted average % in the case of NRM Regions. These figures are reported in the tables below under the column heading 'assumed % of arable land cropped'. Summary 10 year average data extracted from the abovementioned PIRSA crop reports is contained in Appendix P.

4.4.1 Summary spatial data – by NRM Regions

Yield and biomass (NRM Regions)

Table 8 presents simulated potential impacts from a range of future climates to total average wheat grain and post-harvest biomass production (t) and yields (t/ha), by NRM Regions. Simulated impacts on cumulative State-wide production / tonnage estimates for grain and post-harvest biomass are also shown in Figures 30 and 31 (expressed in megatonnes, Mt, or millions of tonnes). Percentage changes in simulated grain and post-harvest biomass tonnages across the different NRM Regions are shown in Table 9.

Table 8. Simulated total annual average wheat grain and post-harvest biomass production by NRM Regions (assuming regional wheat crop areas based on 10 year average 'total field crop areas' derived from PIRSA Crop Reports). Historic and climate change scenarios are shown.

	NRM Region	Arable Land (ha)	**Assumed % of Arable Land Cropped	**Total Average Wheat Grain Production (t)	**Total Average Post-harvest Biomass Production (t)	Average Grain Yield (t/ha)	Average Post-harvest Biomass (t/ha)
HISTORIC CLIMATE	Adelaide & Mt Lofty Ranges	199,200	50	291,100	811,200	2.92	8.15
	Eyre Peninsula	2,226,300	63	2,773,400	7,894,700	1.98	5.63
	Kangaroo Island	86,900	23	65,900	180,900	3.30	9.05
	Northern & Yorke	1,704,300	78	3,332,500	9,580,300	2.51	7.21
	South Australian Murray-Darling Basin	1,615,500	55	1,551,200	4,891,200	1.75	5.50
	South East	1,123,800	23	733,900	2,185,600	2.84	8.46
	STATEWIDE	6,956,100	57	8,941,100	26,222,600	2.24	6.56
5% RAINFALL REDUCTION*	Adelaide & Mt Lofty Ranges	199,200	50	294,300	759,800	2.96	7.63
	Eyre Peninsula	2,226,300	63	2,728,700	7,112,500	1.95	5.07
	Kangaroo Island	86,900	23	68,700	175,500	3.44	8.78
	Northern & Yorke	1,704,300	78	3,356,400	8,912,200	2.52	6.70
	South Australian Murray-Darling Basin	1,615,500	55	1,566,500	4,475,200	1.76	5.04
	South East	1,123,800	23	794,700	2,207,800	3.07	8.54
	STATEWIDE	6,956,100	57	9,096,600	24,564,800	2.27	6.14
10% RAINFALL REDUCTION*	Adelaide & Mt Lofty Ranges	199,200	50	275,800	717,200	2.77	7.20
	Eyre Peninsula	2,226,300	63	2,462,500	6,580,200	1.76	4.69
	Kangaroo Island	86,900	23	67,200	170,800	3.36	8.54
	Northern & Yorke	1,704,300	78	3,085,700	8,311,400	2.32	6.25
	South Australian Murray-Darling Basin	1,615,500	55	1,399,800	4,110,100	1.58	4.63
	South East	1,123,800	23	768,300	2,139,600	2.97	8.28
	STATEWIDE	6,956,100	57	8,389,000	23,023,500	2.10	5.76
20% RAINFALL REDUCTION*	Adelaide & Mt Lofty Ranges	199,200	50	230,200	616,200	2.31	6.19
	Eyre Peninsula	2,226,300	63	1,902,500	5,383,800	1.36	3.84
	Kangaroo Island	86,900	23	62,600	158,100	3.13	7.91
	Northern & Yorke	1,704,300	78	2,477,300	6,936,900	1.86	5.22
	South Australian Murray-Darling Basin	1,615,500	55	1,065,200	3,298,900	1.20	3.71
	South East	1,123,800	23	692,100	1,954,200	2.68	7.56
	STATEWIDE	6,956,100	57	6,825,700	19,460,000	1.71	4.87

Notes: *Climate change scenarios also include elevated temperature and CO2 levels.
**Simulated potential total production values are based on regional crop areas equivalent to 10yr average (2002/03 - 2011/12) 'total field crop areas' derived from PIRSA Crop Reports. This is shown in the table above via the column 'assumed % of arable land cropped'.

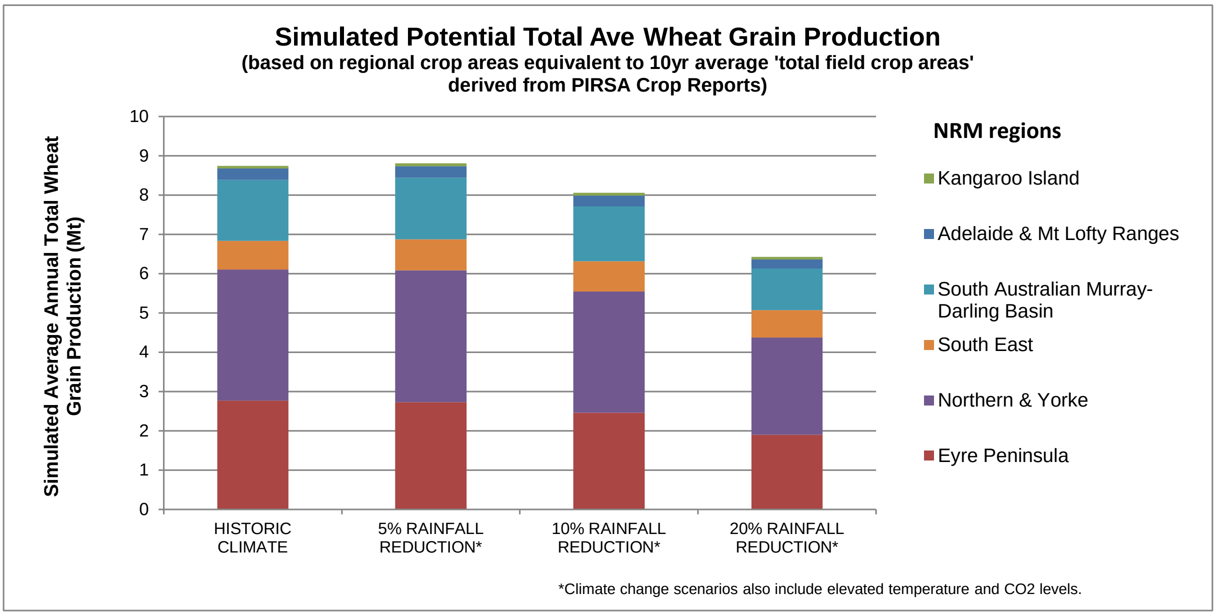


Figure 30. Simulated potential impacts on total annual average wheat grain production (Mt) across SA.

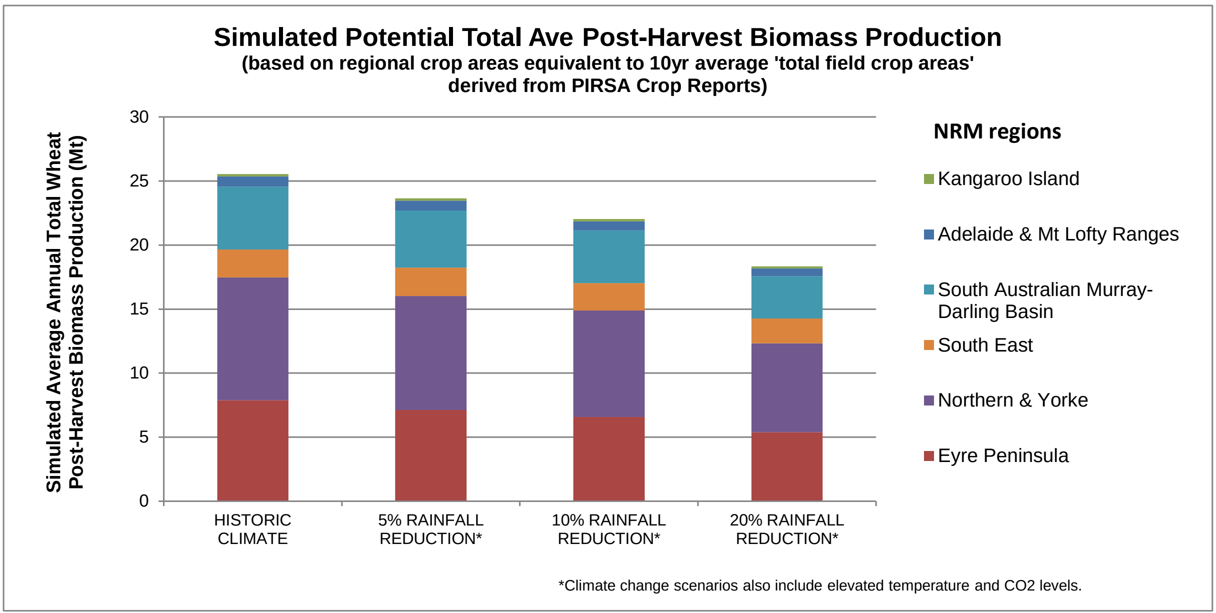


Figure 31. Simulated potential impacts on total annual average post-harvest biomass production (Mt) across SA.

Figures 30-31 indicate that on a State-wide basis:

- Average annual grain production may be boosted slightly under 5% rainfall decline combined with increased CO_2 levels and warming by 1.5°C.
- 10-20% rainfall declines will result in declining average annual grain production for the State.
- Crop biomass levels remaining after harvest (available to protect soils from erosion) will progressively decline with reducing rainfall.

It should be noted that the spatial extent of this modelling has been limited to areas historically suited to dryland cereal cropping. It was not the focus of this study to investigate potential new opportunities for cereal cropping (in historically unsuitable areas) that may emerge under a warming, drying climate.

Table 9. Percentage changes in simulated total annual average wheat grain and post-harvest biomass production by NRM Regions (compared to the 'historic' scenario). Increasing yellow shading indicates greater % loss in production. Red % change values with negative sign indicate losses. Black % change values indicate improvements.

Scenario	NRM Region	Arable Land (ha)	% Change in Total Average Wheat Grain Production	% Change in Total Average Post-harvest Biomass Production
5% RAINFALL REDUCTION*	Adelaide & Mt Lofty Ranges	199,200	1.1	-6.3
	Eyre Peninsula	2,226,300	-1.6	-9.9
	Kangaroo Island	86,900	4.2	-3.0
	Northern & Yorke	1,704,300	0.7	-7.0
	South Australian Murray-Darling Basin	1,615,500	1.0	-8.5
	South East	1,123,800	8.3	1.0
	STATEWIDE	6,956,100	1.7	-6.3
10% RAINFALL REDUCTION*	Adelaide & Mt Lofty Ranges	199,200	-5.2	-11.6
	Eyre Peninsula	2,226,300	-11.2	-16.7
	Kangaroo Island	86,900	1.9	-5.6
	Northern & Yorke	1,704,300	-7.4	-13.2
	South Australian Murray-Darling Basin	1,615,500	-9.8	-16.0
	South East	1,123,800	4.7	-2.1
	STATEWIDE	6,956,100	-6.2	-12.2
20% RAINFALL REDUCTION*	Adelaide & Mt Lofty Ranges	199,200	-20.9	-24.0
	Eyre Peninsula	2,226,300	-31.4	-31.8
	Kangaroo Island	86,900	-5.0	-12.6
	Northern & Yorke	1,704,300	-25.7	-27.6
	South Australian Murray-Darling Basin	1,615,500	-31.3	-32.6
	South East	1,123,800	-5.7	-10.6
	STATEWIDE	6,956,100	-23.7	-25.8

Notes: *Climate change scenarios also include elevated temperature and CO_2 levels.

Erosion risk (NRM Regions)

Table 10 presents simulated potential impacts from climate change on land area with below critical cover with a frequency of 1 year in 10, indicating increased erosion risk by (i) wind, (ii) water, and (iii) wind or water. This analysis assumes the percentage of arable land under wheat cropping varies by regions based on 10 year average 'total field crop areas' derived from PIRSA Crop Reports (refer to Section 4.4). Figure 32 presents this information on a cumulative State-wide basis, with contributions from each NRM Region. Changes in the percentage of cropped land with below critical cover (indicating progressive changes in erosion risk under climate change) are shown in Table 11. Note that despite declining rainfall, overall water erosion risk is predicted to rise. This is because rainfall will still occur but reduced biomass production means less protection for soils.

Areas of below critical cover indicating elevated risk of water erosion on Eyre Peninsula (EP) in Figure 32 appear to be overemphasised when compared to regional differences in the severity of water erosion potential shown in Figure 7. In particular, when compared against the NYNRM Region. Modelling results indicate significant areas of below critical cover for water erosion protection may emerge on EP under climate change; however knowledge of erosion potential classes and associated management implications are important to put this in context.

Areas of below critical cover predicted for EP presented in this section of the report will have a significant contribution from land with only 'moderately low' water erosion potential (Class 2e). Control of erosion risk when cropping on land of this class can typically be achieved through careful surface management measures (e.g. no-till, stubble retention, working along contours if cultivating). This contrasts with the Northern and Yorke region where significant areas of below critical cover indicating increased water erosion risk, will have a greater contribution from land with 'moderate' and 'moderately high' water erosion potential (Classes 3e and 4e). These classes typically require greater levels of management to prevent erosion, including contour banks if cultivating on Class 3e land, while Class 4e land is only semi-arable.

Table 10. Simulated potential impacts of climate change on land area with below critical cover at least 1 year in 10, indicating increased risk of (i) wind, (ii) water, and (iii) wind or water erosion (assuming regional wheat crop areas based on 10 year average 'total field crop areas' derived from PIRSA Crop Reports). Land areas comprise class 2 to 4 erosion potential land, with varying critical cover and management requirements (refer to Table 7 and Appendix B).

Scenario	NRM Region	Arable Land (ha)	**Assumed % of Arable Land Cropped	**Land Area (ha) with Below Critical Cover At Least 1 year in 10, Indicating Increased Risk of WIND Erosion	**Land Area (ha) with Below Critical Cover At Least 1 year in 10, Indicating Increased Risk of WATER Erosion	**Land Area (ha) with Below Critical Cover At Least 1 year in 10, Indicating Increased Risk of WIND or WATER Erosion
HISTORIC CLIMATE	Adelaide & Mt Lofty Ranges	199,200	50	1,700	8,800	10,500
	Eyre Peninsula	2,226,300	63	502,700	107,900	589,900
	Kangaroo Island	86,900	23	0	100	100
	Northern & Yorke	1,704,300	78	49,100	209,500	255,300
	South Australian Murray-Darling Basin	1,615,500	55	302,800	79,200	362,000
	South East	1,123,800	23	100	600	700
	STATEWIDE	6,956,100	57	856,400	406,200	1,218,600
5% RAINFALL REDUCTION*	Adelaide & Mt Lofty Ranges	199,200	50	1,800	12,300	14,100
	Eyre Peninsula	2,226,300	63	690,200	239,600	862,300
	Kangaroo Island	86,900	23	0	300	300
	Northern & Yorke	1,704,300	78	80,600	274,000	345,300
	South Australian Murray-Darling Basin	1,615,500	55	417,600	108,700	490,800
	South East	1,123,800	23	1,100	3,000	4,200
	STATEWIDE	6,956,100	57	1,191,400	637,800	1,716,900
10% RAINFALL REDUCTION*	Adelaide & Mt Lofty Ranges	199,200	50	2,100	13,800	16,000
	Eyre Peninsula	2,226,300	63	731,900	247,800	909,900
	Kangaroo Island	86,900	23	0	300	300
	Northern & Yorke	1,704,300	78	120,600	301,000	406,900
	South Australian Murray-Darling Basin	1,615,500	55	439,300	121,400	520,500
	South East	1,123,800	23	1,200	4,400	5,600
	STATEWIDE	6,956,100	57	1,295,100	688,700	1,859,200
20% RAINFALL REDUCTION*	Adelaide & Mt Lofty Ranges	199,200	50	4,300	25,500	29,700
	Eyre Peninsula	2,226,300	63	1,096,000	295,600	1,194,000
	Kangaroo Island	86,900	23	0	800	900
	Northern & Yorke	1,704,300	78	172,500	403,200	550,700
	South Australian Murray-Darling Basin	1,615,500	55	569,400	154,400	647,000
	South East	1,123,800	23	11,300	8,700	20,000
	STATEWIDE	6,956,100	57	1,853,600	888,300	2,442,200

Notes: *Climate change scenarios also include elevated temperature and CO2 levels.
**Based on regional crop areas equivalent to 10yr average (2002/03 - 2011/12) 'total field crop areas' derived from PIRSA Crop Reports.

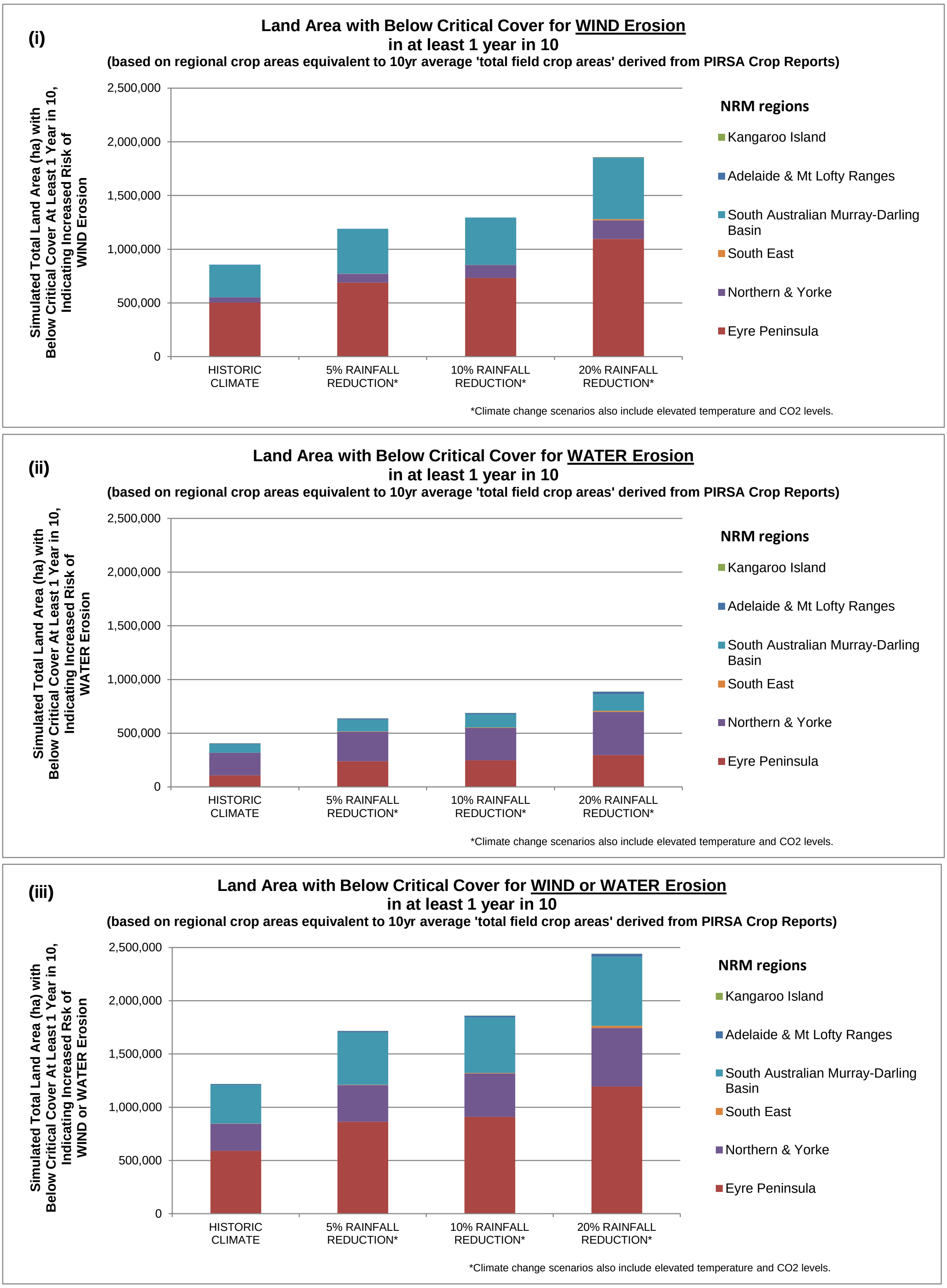


Figure 32. **Simulated climate change impacts on land area (ha) with below critical cover at least 1 year in 10, indicating increased risk of: (i) wind erosion, (ii) water erosion, and (iii) wind or water erosion. Estimates are based on regional wheat crop areas equivalent to 10 year average 'total field crop areas' derived from PIRSA Crop Reports. Total land areas are comprised of class 2 to 4 erosion potential land, with varying critical cover and management requirements (refer to Table 7 and Appendix B).**

Table 11. Simulated climate change impacts on percentage of cropped land with below critical cover at least 1 year in 10, indicating increased risk of: (i) wind, (ii) water, and (iii) wind or water erosion. Values are colour coded from green (lowest erosion risk) to orange (highest erosion risk). Land areas comprise class 2 to 4 erosion potential land, with varying critical cover and management requirements (refer to Table 7 and Appendix B).

Scenario	NRM Region	Arable Land (ha)	**Assumed % of Arable Land Cropped	% of Cropped Land with Below Critical Cover At Least 1 Year in 10, Indicating Increased Risk of WIND Erosion	% of Cropped Land with Below Critical Cover At Least 1 Year in 10, Indicating Increased Risk of WATER Erosion	% of Cropped Land with Below Critical Cover At Least 1 Year in 10, Indicating Increased Risk of WIND or WATER Erosion
HISTORIC	Adelaide & Mt Lofty Ranges	199,200	50	2	9	11
	Eyre Peninsula	2,226,300	63	36	8	42
	Kangaroo Island	86,900	23	0	1	1
	Northern & Yorke	1,704,300	78	4	16	19
	South Australian Murray-Darling Basin	1,615,500	55	34	9	41
	South East	1,123,800	23	0	0	0
	STATEWIDE	6,956,100	57	21	10	30
5% RAINFALL REDUCTION*	Adelaide & Mt Lofty Ranges	199,200	50	2	12	14
	Eyre Peninsula	2,226,300	63	49	17	61
	Kangaroo Island	86,900	23	0	1	1
	Northern & Yorke	1,704,300	78	6	21	26
	South Australian Murray-Darling Basin	1,615,500	55	47	12	55
	South East	1,123,800	23	0	1	2
	STATEWIDE	6,956,100	57	30	16	43
10% RAINFALL REDUCTION*	Adelaide & Mt Lofty Ranges	199,200	50	2	14	16
	Eyre Peninsula	2,226,300	63	52	18	65
	Kangaroo Island	86,900	23	0	2	2
	Northern & Yorke	1,704,300	78	9	23	31
	South Australian Murray-Darling Basin	1,615,500	55	49	14	59
	South East	1,123,800	23	0	2	2
	STATEWIDE	6,956,100	57	32	17	46
20% RAINFALL REDUCTION*	Adelaide & Mt Lofty Ranges	199,200	50	4	26	30
	Eyre Peninsula	2,226,300	63	78	21	85
	Kangaroo Island	86,900	23	0	4	4
	Northern & Yorke	1,704,300	78	13	30	41
	South Australian Murray-Darling Basin	1,615,500	55	64	17	73
	South East	1,123,800	23	4	3	8
	STATEWIDE	6,956,100	57	46	22	61

Notes: *Climate change scenarios also include elevated temperature and CO2 levels.
**Based on regional crop areas equivalent to 10yr average (2002/03 - 2011/12) 'total field crop areas' derived from PIRSA Crop Reports.

4.4.2 Summary spatial data – by Statistical Local Areas (SLAs)

Yield and biomass (SLAs)

Table 12 presents simulated potential impacts from climate change to average wheat grain yield and post-harvest biomass (in t/ha), by Statistical Local Areas. Percentage changes in these values (compared to simulated historic results) are shown in Table 13. Only significant cropping areas (based on ABS statistical data) are reported.

Erosion risk (SLAs)

Table 14 presents simulated potential impacts from climate change on land area with below critical cover with a frequency of 1 year in 10, indicating increased erosion risk by (i) wind, (ii) water, and (iii) wind or water. This analysis assumes the percentage of arable land under wheat cropping varies by regions based on 10 year average 'total field crop areas' derived from PIRSA Crop Reports (refer to Section 4.4). Changes in the percentage of cropped land with below critical cover (indicating progressive changes in erosion risk under climate change) are shown in Table 15.

Table 12. Simulated climate change impacts on average wheat grain yield (t/ha) and post-harvest biomass (t/ha), by Statistical Local Areas. [*Climate change scenarios also include elevated temperature and CO_2 levels.]

Note: there is no need to assume a % of arable land under cropping for these results. The ratio of production (tonnes)/ area (ha) is primarily based on the total arable area. Where other summary spatial data statistics are shown based on the 10 year average 'total field crop area' (derived from PIRSA crop reports), both production (t) and area (ha) are scaled down accordingly, but their ratio remains the same.

			Average Grain Yield (t/ha)				Average Post-Harvest Biomass (t/ha)			
	Statistical Local Area	Arable Land (ha)	Historic Climate	5% Rainfall Reduction*	10% Rainfall Reduction*	20% Rainfall Reduction*	Historic Climate	5% Rainfall Reduction*	10% Rainfall Reduction*	20% Rainfall Reduction*
'Eyre' Statistical Division	Ceduna (DC)	305,000	1.54	1.42	1.25	0.86	4.34	3.75	3.42	2.58
	Cleve (DC)	296,100	2.06	2.09	1.87	1.46	6.08	5.54	5.11	4.24
	Elliston (DC)	162,800	2.37	2.40	2.19	1.76	6.67	6.12	5.70	4.84
	Franklin Harbour (DC)	129,700	1.43	1.40	1.22	0.87	4.54	4.02	3.62	2.78
	Kimba (DC)	266,500	1.76	1.77	1.55	1.14	5.47	4.93	4.50	3.55
	Le Hunte (DC)	261,800	1.73	1.65	1.46	1.07	4.87	4.28	3.91	3.11
	Lower Eyre Peninsula (DC)	183,800	3.02	3.13	3.01	2.67	8.35	7.93	7.62	6.82
	Streaky Bay (DC)	318,800	1.97	1.85	1.65	1.23	5.19	4.53	4.17	3.35
	Tumby Bay (DC)	189,400	2.41	2.44	2.25	1.84	6.83	6.31	5.92	5.03
	Unincorp. West Coast	112,100	1.68	1.56	1.38	0.97	4.62	4.01	3.67	2.84
	Eyre SD AVERAGE		2.00	1.97	1.78	1.39	5.70	5.14	4.77	3.91
'Murray Lands' Statistical Division	Karoonda East Murray (DC)	253,900	1.67	1.67	1.46	1.06	5.30	4.78	4.37	3.42
	Loxton Waikerie (DC) - East	299,500	1.13	1.07	0.91	0.58	3.99	3.46	3.06	2.16
	Loxton Waikerie (DC) - West	80,800	1.04	0.97	0.81	0.51	3.79	3.25	2.84	1.97
	Mid Murray (DC)	166,800	1.65	1.64	1.46	1.08	5.27	4.80	4.40	3.45
	Murray Bridge (RC)	74,000	2.08	2.12	1.89	1.46	6.24	5.70	5.23	4.31
	Renmark Paringa (DC) - Paringa	32,100	1.02	0.94	0.79	0.48	3.72	3.18	2.78	1.90
	Southern Mallee (DC)	299,500	1.93	1.99	1.77	1.37	5.98	5.53	5.10	4.20
	The Coorong (DC)	474,500	2.60	2.75	2.62	2.27	7.47	7.13	6.82	6.08
	Murray Lands SD AVERAGE		1.64	1.64	1.46	1.10	5.22	4.73	4.33	3.44
'Northern' Statistical Division	Flinders Ranges (DC)	20,000	1.27	1.21	1.03	0.69	4.18	3.63	3.21	2.33
	Mount Remarkable (DC)	154,900	1.94	1.97	1.77	1.36	6.03	5.61	5.14	4.15
	Northern Areas (DC)	219,200	2.89	3.01	2.83	2.35	8.55	8.36	7.93	6.79
	Orroroo/Carrieton (DC)	76,600	1.59	1.62	1.41	1.03	5.47	5.11	4.58	3.51
	Peterborough (DC)	40,300	1.47	1.50	1.30	0.94	5.21	4.86	4.35	3.29
	Port Pirie C Dists (M) Bal	121,100	2.41	2.31	2.08	1.61	6.49	5.73	5.26	4.26
	Northern SD AVERAGE		1.93	1.94	1.74	1.33	5.99	5.55	5.08	4.05
'Outer Adelaide' Statistical Division	Alexandrina (DC) - Coastal	14,200	3.11	3.26	3.13	2.74	8.68	8.36	8.04	7.19
	Alexandrina (DC) - Strathalbyn	49,600	2.76	2.83	2.63	2.17	7.74	7.23	6.80	5.86
	Barossa (DC) - Angaston	9,100	3.37	3.64	3.53	3.19	9.90	10.06	9.74	8.90
	Barossa (DC) - Barossa	16,400	3.29	3.47	3.35	3.01	9.41	9.32	8.99	8.15
	Kangaroo Island (DC)	86,900	3.30	3.44	3.36	3.13	9.05	8.78	8.54	7.91
	Light (RegC)	95,900	3.04	3.07	2.89	2.40	8.37	7.83	7.42	6.35
	Mallala (DC)	64,800	2.45	2.41	2.17	1.69	6.92	6.23	5.71	4.67
	Outer Adelaide SD AVERAGE		3.04	3.16	3.01	2.62	8.58	8.26	7.89	7.00
'South East' Statistical Division	Kingston (DC)	138,000	2.66	2.95	2.90	2.74	8.19	8.53	8.36	7.89
	Naracoorte and Lucindale (DC)	233,100	3.06	3.36	3.27	3.04	9.22	9.55	9.30	8.67
	Tatiara (DC)	434,300	2.83	3.06	2.93	2.58	8.51	8.63	8.34	7.49
	Wattle Range (DC) - East	29,400	3.01	3.28	3.21	2.99	9.14	9.47	9.24	8.61
	South East SD AVERAGE		2.89	3.16	3.08	2.84	8.77	9.04	8.81	8.16
'Yorke and Lower North' Statistical Division	Barunga West (DC)	123,900	2.50	2.44	2.19	1.70	6.80	6.07	5.58	4.59
	Clare and Gilbert Valleys (DC)	132,300	3.20	3.34	3.20	2.76	9.21	9.05	8.68	7.64
	Copper Coast (DC)	44,900	2.40	2.33	2.09	1.58	6.67	5.94	5.43	4.37
	Goyder (DC)	230,400	2.27	2.35	2.17	1.75	7.06	6.82	6.38	5.30
	Wakefield (DC)	286,700	2.32	2.30	2.07	1.60	6.69	6.05	5.55	4.50
	Yorke Peninsula (DC) - North	291,700	2.71	2.69	2.47	1.96	7.41	6.67	6.23	5.19
	Yorke Peninsula (DC) - South	102,700	2.72	2.79	2.64	2.27	7.48	6.98	6.63	5.82
	Yorke and Lower North SD AVERAGE		2.59	2.61	2.40	1.94	7.33	6.80	6.35	5.34

Table 13. Percent change in simulated wheat grain yield and post-harvest biomass under climate change (compared to simulated historic values), by Statistical Local Areas. Increasing yellow shading indicates greater % loss in production. Red % change values with negative sign indicate losses. Black % change values indicate improvements. Note: simulated yield and biomass values in t/ha do not change when arable land areas are discounted. [*Climate change scenarios also include elevated temperature and CO_2 levels.]

			Average Grain Yield				Average Post-Harvest Biomass			
	Statistical Local Area	Arable Land (ha)	Historic Climate (t/ha)	5% Rainfall Reduction* (% change)	10% Rainfall Reduction* (% change)	20% Rainfall Reduction* (% change)	Historic Climate (t/ha)	5% Rainfall Reduction* (% change)	10% Rainfall Reduction* (% change)	20% Rainfall Reduction* (% change)
'Eyre' Statistical Division	Ceduna (DC)	305,000	1.54	-7.8	-18.8	-44.4	4.3	-13.5	-21.2	-40.5
	Cleve (DC)	296,100	2.06	1.1	-9.3	-29.4	6.1	-8.8	-15.8	-30.2
	Elliston (DC)	162,800	2.37	1.2	-7.6	-25.7	6.7	-8.3	-14.6	-27.5
	Franklin Harbour (DC)	129,700	1.43	-2.0	-14.7	-39.0	4.5	-11.5	-20.2	-38.8
	Kimba (DC)	266,500	1.76	0.6	-11.8	-34.9	5.5	-9.8	-17.8	-35.0
	Le Hunte (DC)	261,800	1.73	-4.5	-15.8	-38.3	4.9	-12.0	-19.6	-36.2
	Lower Eyre Peninsula (DC)	183,800	3.02	3.7	-0.2	-11.6	8.4	-5.0	-8.7	-18.3
	Streaky Bay (DC)	318,800	1.97	-5.8	-16.0	-37.3	5.2	-12.6	-19.5	-35.4
	Tumby Bay (DC)	189,400	2.41	1.0	-6.5	-23.5	6.8	-7.6	-13.3	-26.3
	Unincorp. West Coast	112,100	1.68	-6.7	-17.9	-41.9	4.6	-13.1	-20.6	-38.6
	Eyre SD AVERAGE		2.00	-1.3	-10.7	-30.5	5.7	-9.7	-16.3	-31.3
'Murray Lands' Statistical Division	Karoonda East Murray (DC)	253,900	1.67	0.1	-12.3	-36.4	5.3	-9.8	-17.5	-35.5
	Loxton Waikerie (DC) - East	299,500	1.13	-5.3	-19.8	-48.5	4.0	-13.2	-23.2	-45.8
	Loxton Waikerie (DC) - West	80,800	1.04	-6.9	-21.8	-51.4	3.8	-14.2	-24.9	-48.0
	Mid Murray (DC)	166,800	1.65	-0.4	-11.9	-34.9	5.3	-9.0	-16.6	-34.5
	Murray Bridge (RC)	74,000	2.08	1.8	-9.3	-29.9	6.2	-8.7	-16.3	-31.0
	Renmark Paringa (DC) - Paringa	32,100	1.02	-7.2	-22.4	-52.4	3.7	-14.4	-25.3	-49.0
	Southern Mallee (DC)	299,500	1.93	2.7	-8.3	-29.1	6.0	-7.5	-14.7	-29.7
	The Coorong (DC)	474,500	2.60	5.6	0.5	-12.6	7.5	-4.5	-8.7	-18.7
	Murray Lands SD AVERAGE		1.64	0.2	-10.8	-32.8	5.2	-9.4	-17.1	-34.2
'Northern' Statistical Division	Flinders Ranges (DC)	20,000	1.27	-4.2	-18.7	-45.4	4.2	-13.1	-23.0	-44.2
	Mount Remarkable (DC)	154,900	1.94	1.3	-9.1	-29.9	6.0	-6.9	-14.7	-31.3
	Northern Areas (DC)	219,200	2.89	4.1	-2.2	-18.7	8.5	-2.3	-7.2	-20.6
	Orroroo/Carrieton (DC)	76,600	1.59	2.1	-11.2	-35.1	5.5	-6.5	-16.2	-35.8
	Peterborough (DC)	40,300	1.47	2.4	-11.3	-36.3	5.2	-6.8	-16.5	-36.8
	Port Pirie C Dists (M) Bal	121,100	2.41	-4.3	-13.9	-33.5	6.5	-11.7	-19.0	-34.3
	Northern SD AVERAGE		1.93	0.5	-10.0	-31.1	6.0	-7.3	-15.2	-32.3
'Outer Adelaide' Statistical Division	Alexandrina (DC) - Coastal	14,200	3.11	4.9	0.6	-12.0	8.7	-3.7	-7.4	-17.2
	Alexandrina (DC) - Strathalbyn	49,600	2.76	2.3	-4.9	-21.4	7.7	-6.6	-12.1	-24.3
	Barossa (DC) - Angaston	9,100	3.37	8.0	4.6	-5.4	9.9	1.7	-1.6	-10.0
	Barossa (DC) - Barossa	16,400	3.29	5.6	1.7	-8.5	9.4	-0.9	-4.5	-13.3
	Kangaroo Island (DC)	86,900	3.30	4.2	1.9	-5.0	9.0	-3.0	-5.6	-12.6
	Light (RegC)	95,900	3.04	0.9	-5.0	-21.0	8.4	-6.5	-11.4	-24.2
	Mallala (DC)	64,800	2.45	-1.5	-11.2	-30.8	6.9	-10.0	-17.4	-32.5
	Outer Adelaide SD AVERAGE		3.04	3.8	-1.2	-14.0	8.6	-3.8	-8.0	-18.4
'South East' Statistical Division	Kingston (DC)	138,000	2.66	10.7	8.9	3.0	8.2	4.1	2.1	-3.7
	Naracoorte and Lucindale (DC)	233,100	3.06	9.8	7.1	-0.7	9.2	3.5	0.8	-6.0
	Tatiara (DC)	434,300	2.83	8.2	3.7	-8.8	8.5	1.4	-2.1	-12.1
	Wattle Range (DC) - East	29,400	3.01	8.8	6.7	-0.5	9.1	3.6	1.1	-5.8
	South East SD AVERAGE		2.89	9.4	6.6	-1.8	8.8	3.2	0.5	-6.9
'Yorke and Lower North' Statistical Division	Barunga West (DC)	123,900	2.50	-2.4	-12.3	-32.2	6.8	-10.8	-17.9	-32.5
	Clare and Gilbert Valleys (DC)	132,300	3.20	4.5	-0.1	-13.8	9.2	-1.7	-5.7	-17.0
	Copper Coast (DC)	44,900	2.40	-2.8	-13.1	-34.2	6.7	-11.0	-18.7	-34.6
	Goyder (DC)	230,400	2.27	3.6	-4.5	-23.1	7.1	-3.4	-9.7	-25.0
	Wakefield (DC)	286,700	2.32	-1.2	-11.1	-31.1	6.7	-9.5	-17.1	-32.8
	Yorke Peninsula (DC) - North	291,700	2.71	-1.0	-8.9	-27.8	7.4	-10.0	-15.9	-29.9
	Yorke Peninsula (DC) - South	102,700	2.72	2.3	-3.0	-16.6	7.5	-6.7	-11.3	-22.1
	Yorke and Lower North SD AVERAGE		2.59	0.6	-7.2	-24.9	7.3	-7.3	-13.3	-27.1

Table 14. Simulated climate change impacts on land area with below critical cover at least 1 year in 10, indicating increased risk of: (i) wind, (ii) water, and (iii) wind or water erosion, by SLA (assuming regional wheat crop areas based on 10 year average 'total field crop areas' derived from PIRSA Crop Reports). Land areas comprise class 2 to 4 erosion potential land, with varying critical cover and management requirements (refer to Table 7 and Appendix B).

				**Land Area (ha) with Below Critical Cover, At Least 1 Year in 10, Indicating Increased Risk of WIND Erosion				**Land Area (ha) with Below Critical Cover At Least 1 Year in 10, Indicating Increased Risk of WATER Erosion				**Land Area (ha) with Below Critical Cover At Least 1 Year in 10, Indicating Increased Risk of WIND or WATER Erosion			
	Statistical Local Area	Arable Land (ha)	**Assumed % of Arable Land Cropped	Historic Climate	5% Rainfall Reduction*	10% Rainfall Reduction*	20% Rainfall Reduction*	Historic Climate	5% Rainfall Reduction*	10% Rainfall Reduction*	20% Rainfall Reduction*	Historic Climate	5% Rainfall Reduction*	10% Rainfall Reduction*	20% Rainfall Reduction*
'Eyre' Statistical Division	Ceduna (DC)	305,000	47	119,300	141,700	141,700	143,300	0	0	0	0	119,300	141,700	141,700	143,300
	Cleve (DC)	296,100	75	60,800	76,000	92,100	188,900	16,500	58,900	61,400	76,600	74,700	110,900	129,000	211,100
	Elliston (DC)	162,800	47	7,500	10,700	16,900	43,500	100	1,000	1,500	5,500	7,500	11,700	18,300	48,400
	Franklin Harbour (DC)	129,700	75	49,800	63,200	68,600	84,600	36,700	49,500	50,400	56,400	73,800	89,300	93,500	96,100
	Kimba (DC)	266,500	75	48,000	67,800	80,000	199,200	12,000	84,200	88,000	94,400	57,100	141,500	157,300	199,200
	Le Hunte (DC)	261,800	47	59,400	83,600	85,700	122,100	300	2,300	2,400	3,000	59,700	85,600	87,700	122,700
	Lower Eyre Peninsula (DC)	183,800	86	0	100	300	3,300	5,800	8,900	10,400	17,100	5,800	9,000	10,600	19,600
	Streaky Bay (DC)	318,800	47	58,000	81,800	83,200	125,600	10,900	10,900	10,900	11,200	65,300	89,000	90,500	133,100
	Tumby Bay (DC)	189,400	86	21,800	29,200	29,600	59,300	42,200	67,300	68,000	85,900	63,300	79,500	80,500	114,100
	Unincorp. West Coast	112,100	47	19,600	51,400	51,400	52,700	2,000	2,000	2,000	2,000	21,600	52,700	52,700	52,700
	Eyre SD TOTAL	2,226,200	62	444,100	605,500	649,400	1,022,500	126,600	285,200	294,900	352,200	548,200	810,900	861,900	1,140,400
'Murray Lands' Statistical Division	Karoonda East Murray (DC)	253,900	49	43,600	73,700	76,100	98,500	7,100	10,000	10,800	11,700	49,000	77,600	80,500	101,200
	Loxton Waikerie (DC) - East	299,500	62	117,200	143,100	143,900	144,200	17,100	17,500	17,600	17,700	120,500	146,700	146,900	147,000
	Loxton Waikerie (DC) - West	80,800	62	45,000	49,800	50,100	50,100	0	0	0	0	45,000	49,800	50,100	50,100
	Mid Murray (DC)	166,800	57	31,200	57,700	57,800	71,400	17,200	21,800	22,200	25,500	45,400	69,400	69,900	80,800
	Murray Bridge (RC)	74,000	57	4,900	13,000	17,500	29,200	4,200	7,200	7,600	8,900	8,800	19,100	23,000	33,700
	Renmark Paringa (DC) - Paringa	32,100	62	14,600	16,400	17,100	17,100	2,000	2,000	2,000	2,000	15,500	17,000	17,100	17,100
	Southern Mallee (DC)	299,500	49	42,400	54,100	59,900	98,900	800	8,000	11,000	23,900	43,100	61,400	70,000	102,900
	The Coorong (DC)	474,500	22	1,200	3,000	4,200	22,100	600	4,100	6,100	9,900	1,800	7,000	10,200	31,000
	Murray Lands SD TOTAL	1,681,000	46	300,100	410,900	426,600	531,400	49,200	70,700	77,300	99,800	329,100	448,100	467,700	563,700
'Northern' Statistical Division	Flinders Ranges (DC)	20,000	70	1,700	3,000	3,200	4,900	8,700	9,800	10,100	10,100	9,100	10,500	10,900	11,000
	Mount Remarkable (DC)	154,900	70	3,800	8,400	9,700	13,100	29,800	38,900	40,400	51,500	33,200	46,200	48,200	61,100
	Northern Areas (DC)	219,200	70	0	0	200	300	25,700	38,700	45,300	77,900	25,700	38,700	45,400	78,200
	Orroroo/Carrieton (DC)	76,600	70	1,300	2,600	5,800	7,400	25,400	32,400	33,700	35,300	26,500	34,100	37,000	39,200
	Peterborough (DC)	40,300	70	2,000	3,900	6,700	7,900	9,800	12,700	13,700	14,900	10,900	14,900	17,100	18,800
	Port Pirie C Dists (M) Bal	121,100	70	6,800	7,500	11,900	17,000	15,400	18,700	19,700	24,900	22,200	26,200	31,600	41,900
	Northern SD TOTAL	632,200	70	15,600	25,400	37,500	50,700	114,900	151,200	162,700	214,600	127,600	170,600	190,300	250,100
'Outer Adelaide' Statistical Division	Alexandrina (DC) - Coastal	14,200	29	0	100	100	500	0	100	200	900	0	200	300	1,400
	Alexandrina (DC) - Strathalbyn	49,600	29	300	400	1,000	2,600	600	1,100	1,900	3,100	900	1,500	2,800	5,400
	Barossa (DC) - Angaston	9,100	59	0	0	0	0	100	200	300	400	100	200	300	400
	Barossa (DC) - Barossa	16,400	59	0	0	0	0	1,100	1,800	1,900	2,400	1,100	1,800	1,900	2,400
	Kangaroo Island (DC)	86,900	23	0	0	0	0	100	300	300	800	100	300	300	900
	Light (RegC)	95,900	59	0	0	0	200	9,300	12,400	13,900	25,500	9,300	12,400	13,900	25,700
	Mallala (DC)	64,800	59	2,000	2,100	2,500	4,800	500	600	700	1,200	2,500	2,700	3,200	5,900
	Outer Adelaide SD TOTAL	337,000	44	2,300	2,600	3,700	8,100	11,800	16,600	19,100	34,300	14,100	19,100	22,700	42,000
'South East' Statistical Division	Kingston (DC)	138,000	22	0	0	0	0	0	0	0	0	0	0	0	0
	Naracoorte and Lucindale (DC)	233,100	27	0	0	0	0	0	0	100	200	0	0	100	200
	Tatiara (DC)	434,300	22	0	0	0	4,000	0	200	800	2,400	0	200	800	6,400
	Wattle Range (DC) - East	29,400	27	0	0	0	0	0	0	0	0	0	0	0	0
	South East SD TOTAL	834,800	24	0	0	0	4,000	0	200	1,000	2,600	0	200	1,000	6,600
'Yorke and Lower North' Statistical Division	Barunga West (DC)	123,900	91	9,400	18,900	24,300	35,500	6,000	6,600	8,500	11,300	15,400	25,400	32,600	44,800
	Clare and Gilbert Valleys (DC)	132,300	74	0	0	0	0	15,500	21,400	23,900	41,700	15,500	21,400	23,900	41,800
	Copper Coast (DC)	44,900	91	900	1,200	1,800	4,600	300	300	300	400	1,200	1,500	2,100	4,900
	Goyder (DC)	230,400	74	13,300	17,200	20,700	23,800	51,700	62,300	68,300	85,200	63,300	75,800	82,600	100,500
	Wakefield (DC)	286,700	74	11,500	13,900	14,900	26,000	37,400	47,000	50,800	60,100	48,800	58,500	63,300	81,800
	Yorke Peninsula (DC) - North	291,700	91	11,700	18,900	21,900	34,000	9,300	13,200	16,600	21,000	21,000	32,000	37,500	52,800
	Yorke Peninsula (DC) - South	102,700	91	100	3,900	24,700	28,300	0	200	200	200	100	4,100	24,900	28,500
	Yorke and Lower North SD TOTAL	1,212,500	82	46,900	74,100	108,300	152,200	120,200	151,000	168,700	219,900	165,300	218,700	266,900	355,100

Notes: *Climate change scenarios also include elevated temperature and CO2 levels.
**Based on regional crop areas equivalent to 10yr average (2002/03 - 2011/12) 'total field crop areas' derived from PIRSA Crop Reports.

Table 15. Simulated climate change impacts on percentage of cropped land with below critical cover at least 1 year in 10, indicating increased risk of: (i) wind, (ii) water, and (iii) wind or water erosion, by SLA. Values are colour coded from green (lowest erosion risk) to orange (highest erosion risk). Land areas comprise class 2 to 4 erosion potential land, with varying critical cover and management requirements (refer to Table 7 and Appendix B).

				% of Cropped Land with Below Critical Cover, At Least 1 Year in 10, Indicating Increased Risk of WIND Erosion				% of Cropped Land with Below Critical Cover, At Least 1 Year in 10, Indicating Increased Risk of WATER Erosion				% of Cropped Land with Below Critical Cover, At Least 1 Year in 10, Indicating Increased Risk of WIND or WATER Erosion			
	Statistical Local Area	Arable Land (ha)	**Assumed % of Arable Land Cropped	Historic Climate	5% Rainfall Reduction*	10% Rainfall Reduction*	20% Rainfall Reduction*	Historic Climate	5% Rainfall Reduction*	10% Rainfall Reduction*	20% Rainfall Reduction*	Historic Climate	5% Rainfall Reduction*	10% Rainfall Reduction*	20% Rainfall Reduction*
'Eyre' Statistical Division	Ceduna (DC)	305,000	47	83	99	99	100	0	0	0	0	83	99	99	100
	Cleve (DC)	296,100	75	27	34	41	85	7	27	28	34	34	50	58	95
	Elliston (DC)	162,800	47	10	14	22	57	0	1	2	7	10	15	24	63
	Franklin Harbour (DC)	129,700	75	51	65	71	87	38	51	52	58	76	92	96	99
	Kimba (DC)	266,500	75	24	34	40	100	6	42	44	47	29	71	79	100
	Le Hunte (DC)	261,800	47	48	68	70	99	0	2	2	2	49	70	71	100
	Lower Eyre Peninsula (DC)	183,800	86	0	0	0	2	4	6	7	11	4	6	7	12
	Streaky Bay (DC)	318,800	47	39	55	56	84	7	7	7	7	44	59	60	89
	Tumby Bay (DC)	189,400	86	13	18	18	36	26	41	42	53	39	49	49	70
	Unincorp. West Coast	112,100	47	37	98	98	100	4	4	4	4	41	100	100	100
	Eyre SD TOTAL	2,226,200	62	32	44	47	74	9	21	21	25	40	59	62	82
'Murray Lands' Statistical Division	Karoonda East Murray (DC)	253,900	49	35	59	61	79	6	8	9	9	39	62	65	81
	Loxton Waikerie (DC) - East	299,500	62	63	77	77	78	9	9	9	10	65	79	79	79
	Loxton Waikerie (DC) - West	80,800	62	90	99	100	100	0	0	0	0	90	99	100	100
	Mid Murray (DC)	166,800	57	33	61	61	75	18	23	23	27	48	73	74	85
	Murray Bridge (RC)	74,000	57	12	31	41	69	10	17	18	21	21	45	55	80
	Renmark Paringa (DC) - Paringa	32,100	62	73	82	86	86	10	10	10	10	78	85	86	86
	Southern Mallee (DC)	299,500	49	29	37	41	67	1	5	7	16	29	42	48	70
	The Coorong (DC)	474,500	22	1	3	4	21	1	4	6	9	2	7	10	30
	Murray Lands SD TOTAL	1,681,000	46	39	53	56	69	6	9	10	13	43	58	61	73
'Northern' Statistical Division	Flinders Ranges (DC)	20,000	70	12	21	23	35	62	70	72	72	65	75	78	79
	Mount Remarkable (DC)	154,900	70	4	8	9	12	27	36	37	47	31	43	44	56
	Northern Areas (DC)	219,200	70	0	0	0	0	17	25	30	51	17	25	30	51
	Orroroo/Carrieton (DC)	76,600	70	2	5	11	14	47	60	63	66	49	64	69	73
	Peterborough (DC)	40,300	70	7	14	24	28	35	45	49	53	39	53	61	67
	Port Pirie C Dists (M) Bal	121,100	70	8	9	14	20	18	22	23	29	26	31	37	49
	Northern SD TOTAL	632,200	70	4	6	8	11	26	34	37	49	29	39	43	57
'Outer Adelaide' Statistical Division	Alexandrina (DC) - Coastal	14,200	29	0	2	2	12	0	2	5	22	0	5	7	34
	Alexandrina (DC) - Strathalbyn	49,600	29	2	3	7	18	4	8	13	22	6	10	19	38
	Barossa (DC) - Angaston	9,100	59	0	0	0	0	2	4	6	7	2	4	6	7
	Barossa (DC) - Barossa	16,400	59	0	0	0	0	11	19	20	25	11	19	20	25
	Kangaroo Island (DC)	86,900	23	0	0	0	0	1	2	2	4	1	2	2	5
	Light (RegC)	95,900	59	0	0	0	0	16	22	25	45	16	22	25	45
	Mallala (DC)	64,800	59	5	5	7	13	1	2	2	3	7	7	8	15
	Outer Adelaide SD TOTAL	337,000	44	2	2	2	5	8	11	13	23	10	13	15	28
'South East' Statistical Division	Kingston (DC)	138,000	22	0	0	0	0	0	0	0	0	0	0	0	0
	Naracoorte and Lucindale (DC)	233,100	27	0	0	0	0	0	0	0	0	0	0	0	0
	Tatiara (DC)	434,300	22	0	0	0	4	0	0	1	3	0	0	1	7
	Wattle Range (DC) - East	29,400	27	0	0	0	0	0	0	0	0	0	0	0	0
	South East SD TOTAL	834,800	24	0	0	0	2	0	0	1	1	0	0	1	3
'Yorke and Lower North' Statistical Division	Barunga West (DC)	123,900	91	8	17	22	31	5	6	8	10	14	23	29	40
	Clare and Gilbert Valleys (DC)	132,300	74	0	0	0	0	16	22	24	43	16	22	24	43
	Copper Coast (DC)	44,900	91	2	3	4	11	1	1	1	1	3	4	5	12
	Goyder (DC)	230,400	74	8	10	12	14	30	37	40	50	37	44	48	59
	Wakefield (DC)	286,700	74	5	7	7	12	18	22	24	28	23	28	30	39
	Yorke Peninsula (DC) - North	291,700	91	4	7	8	13	4	5	6	8	8	12	14	20
	Yorke Peninsula (DC) - South	102,700	91	0	4	26	30	0	0	0	0	0	4	27	30
	Yorke and Lower North SD TOTAL	1,212,500	82	5	7	11	15	12	15	17	22	17	22	27	36

Notes: *Climate change scenarios also include elevated temperature and CO2 levels.
**Based on regional crop areas equivalent to 10yr average (2002/03 - 2011/12) 'total field crop areas' derived from PIRSA Crop Reports.

4.5 Model verification and feedback (simulated historic results)

The simulation model APSIM has been used and tested under South Australian conditions in the medium rainfall zone (Yanusa et al. 2004) and in low rainfall environments (Sadras et al. 2003, Whitbread & Hancock 2008, Whitbread et al. 2008). It has also been widely used and evaluated by consultants and farmers across the region using 'Yield Prophet', the online version of APSIM (Hochman et al. 2009). The challenge for this project is to test the reliability of the simulated yields on a regional basis. This is more difficult than evaluating simulations for an actual field site as there is no "golden standard" to be judged against. Some form of verification is important because if the model predictions of crop growth for the historic (no climate change) situation are close to expected values, there will be more confidence in the results of the climate change scenarios.

Given the large spatial coverage of this study and the modelling assumptions (and corresponding limitations) recognised earlier (refer to Sections 2.3, 3.10, 3.11), there are inherent challenges with trying to verify the simulation results. In particular there are difficulties in comparing the simulated results with actual historic records because:

- Practices have improved over time. This means that older historic data is expected to under-estimate crop growth potential, while more recent historic production records are of greater relevance to our simulated results.
- Short periods of data may not adequately represent long-term climate (including decadal wetting and drying cycles, and year to year fluctuations in the movement of rain-bearing weather systems across the State).
- Data from specific paddocks will involve agronomic factors that can't be assumed to apply across a much larger study area; or are possibly associated with particular soil types (and localised variations in soil type) that are not well understood.

> Many stakeholders are likely to place greater confidence in the modelling if ***absolute predictions*** are close to regional expectations or actual historic records.
>
> Arguably, however, the simulations provide valuable information in their own right, in particular noting the ***relative differences in results*** between soils, regions and climate change scenarios.
>
> Model assumptions and limitations need to be kept in mind when assessing the results.

Nevertheless, it is important to take a critical look at the model results to see how the simulated historic results compare against available long-term records across the State, and with regional expert expectations for average grain yields. The following approaches have been used to assess the simulated historic results:

(1) Comparison with Australian Bureau of Statistics (ABS) data

(2) Comparison with PIRSA Crop and Pasture Reports

(3) Feedback from regional farming systems and land management consultants

(4) Comparison with previously collated district and soil type grain yield estimates gathered by expert consensus

4.5.1 Comparison with ABS data

The ABS collects data via the 'Agricultural Census' and 'Agricultural Survey' (http://abs.gov.au). Agricultural Census data, which provides information at the smaller Statistical Local Area (SLA) level, is available up to and including the 2000-01 season, and then approximately every fifth year (including 2005-06). Over the past decade, in between the Agricultural Census years, the Agricultural Survey has been conducted annually and provides data at the larger Statistical Division (SD) and State levels. Mapping boundaries for SLAs and SDs are shown in Appendix O.

Farming systems improve over time. Therefore more recent surveys are of greater relevance when comparing ABS data with the simulated historic results (which assume modern practices). To help assess the model outputs, simulated historic average yield results are compared to the following datasets:

- 10 year (1991/92 – 2000/01) ABS average yields by Statistical Local Areas
- 20 year (1990/91 – 2009/10) ABS average yields by Statistical Divisions

Comparison of simulation results with these ABS datasets (see Figure 33a,b) indicates that, although simulation values are generally higher than ABS average yield values, both sets of data show a relatively close relationship across the State. This notion is supported by the calculation of root mean square error (RMSE) values of 0.55 t/ha when compared against SLA-based and SD-based datasets. Supporting data for the comparison between ABS average values and simulated historic results is contained in Appendix Q. This includes 20 year time series plots of ABS average yield values by SD.

4.5.2 Comparison with PIRSA Crop and Pasture Reports

Estimates of field crop production (tonnes) and areas sown (hectares) by crop type, and by crop reporting districts, are prepared on an annual basis by Rural Solutions SA regional farming systems consultants. This data is adapted from ABS Agricultural Census data (available every 5 years) and is adjusted on a yearly basis according to region-specific feedback provided by farmers, advisors and cropping industry organisations including the bulk grain handler Viterra (M Wurst, Rural Solutions SA, 2011, pers. comm.). Released annually by PIRSA (South Australian Government) this dataset arguably provides the best available recent, yearly, State-wide coverage of data with which to compare the simulated historic wheat grain yield results. Figure 33c shows simulated historic average yield values (calculated within PIRSA crop reporting boundaries) plotted against 10 year (2002/03 – 2011/12) average reported wheat grain yields. A RMSE value of 0.52 t/ha was obtained indicating a relatively close association between the simulated historic and recent PIRSA crop report average yield values. Supporting data is contained in Appendices P and R.

As a further comparison, simulated historic average yield values were re-calculated with a simplified modelling approach that considered only most common (or dominant) soil components within each soil landscape map unit (refer to background discussion in Section 3.1). A larger discrepancy arose, when comparing simulation results to observed records (RMSE = 0.63 t/ha) using this approach. This supports the argument that greater predictive accuracy can be achieved by utilising all of the available soil and land information, rather than a simplified approach only using 'most common' soils.

4.5.3 Regional expert feedback

Feedback on the simulated historic wheat grain yield maps was sought from regional soil and land management and farming systems consultants from Rural Solutions SA (David Davenport, Brian Hughes, Richard Saunders and Michael Wurst). In general the feedback suggested that the map of simulated historic wheat grain yields provided a reasonable overview of the distribution of relative average yields across the State. A number of specific examples, across different regions, were highlighted where local experience indicated that the model predictions were either too low or too high (B Hughes & M Wurst, Rural Solutions SA, 2011 pers. comm.). In the lower rainfall Murray Mallee region, grain yield predictions were considered to be 'about right'(R Saunders, Rural Solutions SA, 2011 pers. comm.). Modelled post-harvest biomass was generally thought to be high compared to grain yields. The issue of APSIM not taking into account the impact of pests, weeds and disease can commonly result in over-prediction of crop yield and biomass (N Dalgliesh CSIRO Ecosystem Sciences 2012, pers. comm.) and this may contribute to some of the discrepancies between simulated results and field experience.

Feedback also identified possible situation-specific explanations for discrepancies between the modelling and local experience, with suggestions that the modelling might be:

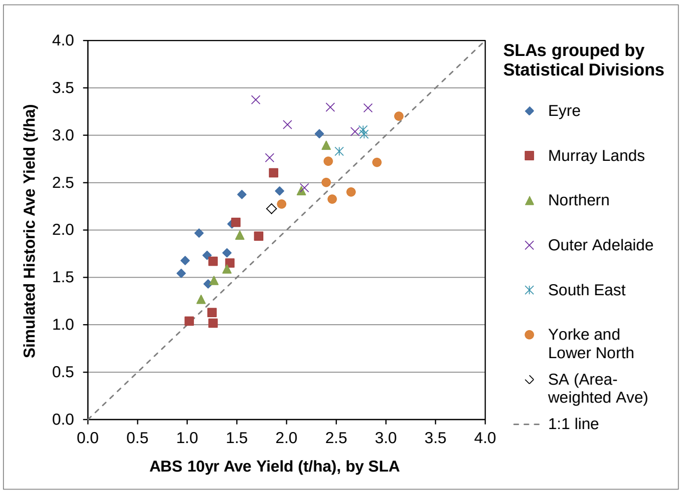
- Under-estimating wheat yields in some moderate to high rainfall areas, and in high rainfall years, possibly due to incorporation of a fixed nitrogen rate in the model; whereas, in practice, farmers are increasingly tailoring nitrogen applications to seasonal conditions. With favourable seasons, farmers are providing in-crop nitrogen sometimes several times (D Davenport, Rural Solutions SA, 2011, pers. comm.). By capitalising on good seasons this can lift the long-term average yield value.
- Under-estimating wheat yields in situations where stored soil moisture (e.g. from pre-season rainfall) is critical. This can be the case in low rainfall areas with sandy (and sandy surface texture-contrast) soils. In low rainfall areas, often soil moisture from pre-season rainfall may be lost to evaporation from heavier texture soils, whereas a mulching effect from sandy surface soils can allow significant moisture to be retained for use during the growing season. Along similar lines, cropping land in lower landscape positions (which receive run-off from neighbouring areas) may retain critical moisture over and above direct rainfall.
- Under-estimating wheat yields where cooler coastal-influenced micro-climates and local rainfall patterns are not captured in the climate files or not simulated in the modelling. (Although some coastal influences will be detected in the 5km x 5km gridded average climate data used to establish the Ave GSR zones; refer to Section 3.4 and Appendix A.)
- Over-estimating yields in some areas that are traditionally subject to waterlogging conditions or surface water runoff in higher rainfall years. This means that in the real world, crops cannot make use of all the available rainfall and actual water use efficiency is below the levels predicted by the modelling.
- Over-estimating yields in some areas where soil conditions traditionally impede nutrient-availability and crop growth, but this is not reflected in the soil parameterisation for the modelling.

On the wider topic of adaptation to a warming, drying climate, comment was also made that radical changes in farming practices in the low rainfall Mallee region made in the period up to 2000, in regard to cropping intensity, type and size of machinery, timing and use of nitrogen fertiliser, and crop types (among other improvements) have proven themselves over 6 years of very low rainfall and drought, through the period 2002 – 2009 (R Saunders, Rural Solutions SA, 2011, pers. comm.).

4.5.4 Comparison with expert anecdotal estimates of median grain yields

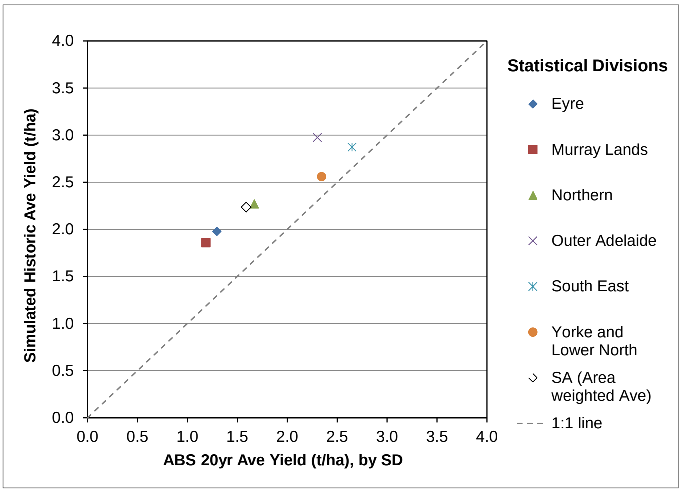
During the early phase of the NYNRM Region pilot study in 2009 (Liddicoat et al. 2011), anecdotal median wheat grain yield estimates from different soil and rainfall settings, in particular districts or localities, were recorded from a meeting with regional soil and land management and farming systems consultants. These anecdotal estimates (provided in Appendix S) were obtained through consensus and based on consultants' experience. Values were gathered to provide a reality check to the APSIM crop simulation modelling. During the meeting, soils (and corresponding yield estimates) were discussed in the context of 'subgroup soil' classes as defined by the State Land & Soil Mapping Program (which are discussed in detail in the reference book Hall et al. 2009). It should be noted that the subsequent modelling of yields (as described in this report) was undertaken using a range of mapped soil and land attributes describing 'surface soil clay content' and 'PAWC' (refer to Section 3.3). These attribute are defined for soil components of each soil landscape map unit, which are based on subgroup soil classes.

When comparing the simulated historic yield values to the expert anecdotal values, a 10km radius buffer was drawn in the vicinity of the locality mentioned. All applicable soil components of soil landscape map units were identified and an area-weighted spatial average yield value was calculated. Respective buffer zones, area-weighted simulated historic average values, and corresponding anecdotal yield estimates are presented in Appendix T. Figure 33d shows a scatter plot of the simulated historic average grain yields against anecdotal median yield estimates. Although the 'median' and 'average' are different statistical measurements, it is of interest to compare these two data sets. A relatively even spread of under-predictions and over-predictions (if the modelling is used to predict the anecdotal estimates), and a RMSE of 0.48 t/ha indicates a relatively close association between these two datasets.



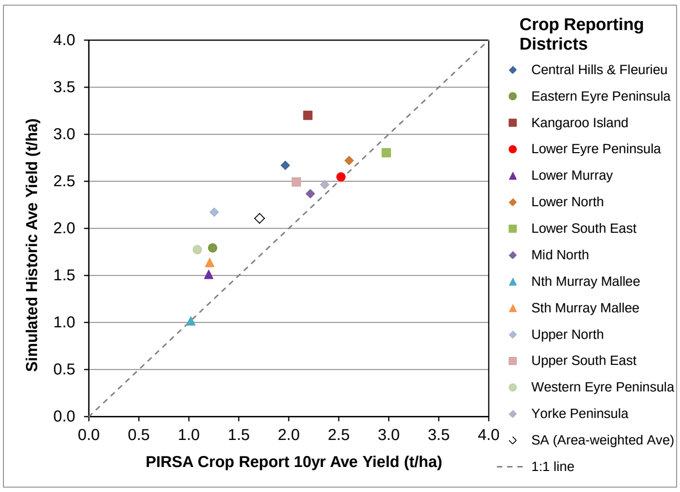
(a) Simulated historic average wheat grain yield versus ***ABS 10 year (1991/92 – 2000/01) average data by Statistical Local Areas***.

RMSE = 0.55 t/ha



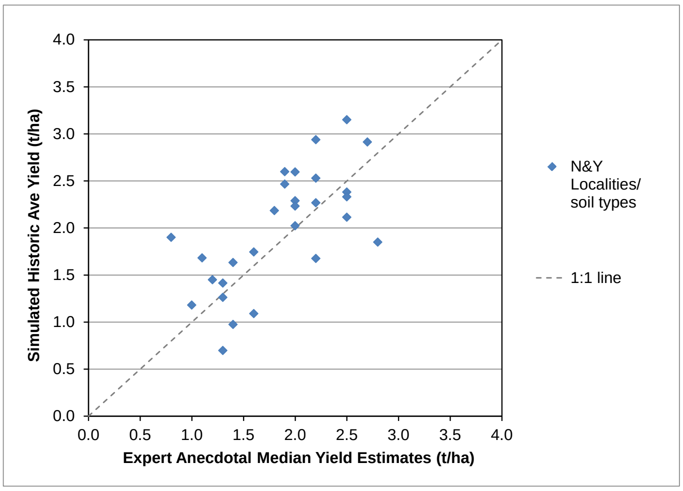
(b) Simulated historic average wheat grain yield versus ***ABS 20 year (1990/91 – 2009/10) average data by Statistical Divisions.***

RMSE = 0.55 t/ha



(c) Simulated historic average wheat grain yield versus ***PIRSA Crop Report 10 year (2002/03 – 2011/12) average data***.

RMSE = 0.52 t/ha



(d) Simulated historic average wheat grain yield (based on 10km buffer zones) versus ***expert anecdotal median yield estimates for nominated localities and soil types in the N&Y region***.

RMSE = 0.48 t/ha

Figure 33. Scatter plots comparing simulated historic average wheat grain yields against: (a) ABS 10 year average data by Statistical Local Areas; (b) ABS 20 year average data by Statistical Divisions; (c) PIRSA Crop Report 10 year average data; and (d) expert anecdotal median yield estimates for nominated localities and soil types in the N&Y region. [Simulated grain yield (t/ha) values are based on analysis of all potentially arable land identified in this study.] Section 4.5.3 outlines a range of possible reasons for discrepancies between these simulated and observational datasets.

5. Conclusions and Recommendations

5.1 Conclusions

Modelling approach

1,728 APSIM runs (each generating 100+ years of seasonal outcomes) were used to examine the influence of soil profile type x regional climate zone x climate change scenarios on wheat crop production and erosion risk indicators across the agricultural zone of South Australia. Despite a considerable modelling effort, this was considered an efficient and cost-effective approach for covering the large diversity of soils and climate settings examined in this study.

The novel approach, involving the establishment of 'modelling soil profiles' to make best use of available detailed soil and land attribute spatial datasets – was considered a valid and valuable alternative to modelling approaches based on site specific, field-measured soil characterisation data, which have insufficient data coverage across the State. Similarly, the extension of previously developed methods by Hayman et al. 2010b to generate daily climate files spanning different regional climate zones across the State, provided an efficient means to systematically deal with climate datasets while also avoiding critical data gaps that would have otherwise limited this State-wide modelling activity.

Consistent with GIS procedures developed within the State Land & Soil Information Framework, analyses of soil and land attributes (required for the production and erosion risk modelling) were undertaken at the spatially undefined soil component level of soil landscape map unit areas (ie. calculations were performed within data tables corresponding to each base level mapping polygon) before model results could be presented in a map, or reported in the form of spatial data statistics.

In general terms, model results appear to provide a slight over-estimate for recent historic average ABS and PIRSA Crop Report grain yields (refer to Figure 33). Differences between simulated values and historic estimates (ABS and PIRSA data) for grain yields vary by districts and regions, but overall root mean square error values indicate the modelling has done a relatively good job of simulating historic average yields across the State. It is also recognised that the modelling will be under-estimating and over-estimating yields in some situations as indicated by feedback from regional experts. Feedback also indicates that the model is over-estimating post-harvest biomass levels (based on expected stubble: grain ratios). The fact that APSIM does not account for weed or disease impacts could partially explain this. This is not seen as a significant issue because relatively cautious 'best estimate' values for critical cover requirements are used within the subsequent erosion risk assessment.

Investigation of both (i) production and (ii) sustainable land management (ie. erosion risk) indicators through this modelling has generated valuable information that will assist future whole-of-landscape decision making, should climate change occur in line with the model scenarios.

Soil and climate interactions

This work has highlighted the importance of soil and land types, interacting with climate, to influence crop production and the frequency of erosion risk due to low stubble biomass (ie. below critical cover levels). Soil plays an important role in providing moisture to plants, and 'good' soils could be viewed as those with the capacity to take in rainfall (minimising surface runoff or drainage beyond the rootzone) and store sufficient water to optimise plant or crop growth – minimising moisture stress or deficit that may occur during the growing season. The analysis of crop performance associated with key moisture holding properties of soils (surface clay content and PAWC), has enabled greater insight into the behaviour of different soil types, and their interactions with climate, across the State.

The modelling has reinforced field observations of the varying performance of different soils under varying seasonal conditions. The key drivers of productivity identified in this study (Ave GSR and soil PAWC) have highlighted the largely rainfall limited nature of dryland cereal cropping in South Australia, and the important limiting effect of soil PAWC in many situations. For soils of the same PAWC, with the same climate and management conditions, higher surface clay contents on average deliver reduced yields and biomass production compared to sandier surfaced soils. The reduced average production for clay surfaced soils is exacerbated in drier climates. This is because high surface clay content corresponds to (i) greater soil moisture storage in the near surface which is prone to evaporative loss and (ii) higher 'wilting point' moisture levels. Higher clay content can also be associated with reduced permeability, higher runoff rates and lower rainfall capture efficiencies (although these effects were not accounted for in the modelling). When soils dry out due to evaporation and transpiration this can often lead to plant water stress sooner on clayey surface soils, than on sandy surface soils. Furthermore, higher wilting point is particularly an issue in low rainfall areas as 'filling' the soil to the level where plants can extract moisture may not regularly occur in a dry year on clayey soils.

Subsoil textures, while not an explicit factor in the modelling, were incorporated through the bulk soil property of PAWC (or 'bucket size'). High PAWC soils have the greatest potential to deliver larger grain and biomass production, taking advantage of higher rainfall climates and seasons. Generally, high PAWC soils are considered the most resilient in drier climates, with greater capacity to capitalise on good rainfall years. Although this will not always be the case, since the high wilting point of some clayey soils makes them less successful in drier climates, even though they have a high PAWC. While not modelled in this study, high PAWC soils also have potential to carry-over water and nutrients between years. While heavy textures (increased clay content) in the surface can impede productive potential in dry climates due to adverse moisture holding properties (ie. high wilting point moisture content and greater surface water storage subject to evaporative loss), increased clay content in the subsoil can be of benefit due to increased PAWC or moisture storage potential. Hence, sandy surfaced soils with a large PAWC are seen as the most resilient to a warming, drying climate (e.g. deep sands and sandy surface texture-contrast soils).

Potential climate change impacts

This study has identified areas with potential for declining productivity and increasing erosion risk under a warming, drying climate. The modelling suggests that drier, more marginal areas will be most vulnerable – as increasing moisture limitation will negate potential benefits from increased CO_2 levels. Importantly, these are the areas where successful land managers are most accustomed to climate risk management, and it is these skill sets that will need to be expanded in response to future climate risk.

In some areas of the State, impacts from low to moderate level climate change (see 5-10% rainfall reduction scenarios) on grain yields appear to be subdued, or in some cases grain yield is boosted slightly. This contrasts with a more pronounced impact on post-harvest biomass and erosion risk for these climate change scenarios. This appears to be linked to the modelling assumption of a single medium maturing wheat variety and the influence of warming which will bring flowering and grain production earlier (leaving less time for the crops to grow vegetative biomass). While, in reality, farmers will make different variety selections to optimise crop performance (including the need to avoid frost damage), the modelling does suggest (for some areas) there will be a general trade-off between optimising grain yield at the expense of residual crop biomass (and soil protection) under declining rainfall.

Meanwhile, cropping systems in the wetter parts of the State are likely to benefit from a warming, drying climate. In these situations, where moisture is not a limiting factor, the increased CO_2 and temperature (in historically cool regions) and perhaps reduced nitrogen leaching have the opportunity to boost plant and crop production levels. New opportunities may also arise in areas that have been historically too wet and cold for cereal cropping, although this was not investigated in this study. Reduced waterlogging will benefit crop production although this was also not considered in the modelling.

Any areas experiencing a decline in average rainfall are also likely to experience a shift in the reliability of rainfall (e.g. fewer above average and average rainfall years and more below average years), relative to the historic records. Accordingly, land managers may need to consider a greater focus on risk management strategies seeking to optimise both production and sustainable land management outcomes in the face of greater seasonal and long-term uncertainty.

The erosion risk assessment compares post-harvest biomass levels against pre-determined critical cover requirements based on wind and water erosion potential classes. Because there is a great deal of spatial variation in wind and water erosion potential, and erosion risk varies in both time and space – the erosion risk maps suggest there will not be 'black and white' answers for areas at risk, excepting perhaps the drier, marginal areas where erosion risk will be a key concern under a drying climate. In general terms, erosion risk appears to be a gradational problem, increasing in extent with poorer seasons and increasing in frequency with a drying climate.

Critical stubble cover levels to offer protection from wind erosion are highly situation specific – but are generally higher for sandy soils which are typically less cohesive than clayey soils, and so are more prone to wind erosion. So despite the potential for higher reliability for crop production on sandy surfaced soils in drier environments, they will continue to be a focus for wind erosion protection. While more prone to poor crop growth, clayey surfaced soils are generally inherently less susceptible to wind erosion. The situation for water erosion varies greatly depending on soil type, in particular the nature of texture and structure with depth. In either case, continued sound management and monitoring to minimise levels of soil disturbance will be critical for sustainable land management.

The erosion risk maps highlight a patchwork of areas which land managers will need to monitor to identify any emerging and recurrent erosion risk issues. At the property scale, levels of cover and erosion risk will vary with individual seasons and soil differences across paddocks. Anecdotal reports suggest that small areas of active erosion can make a big difference to dust generation in a district, so this type of property scale monitoring by farmers will remain an important part of erosion management into the future.

Under higher rainfall reduction levels (-20%) the spatial extent of areas modelled with frequent below critical cover, indicating increased erosion risk (e.g. 'at least 4 years in 10' or 'at least 2 years in 10'), increases significantly. If these areas of high frequency of erosion risk are realised there will be a need to seek alternative sustainable land management or land use options. Farmers will need to continue, and potentially increase, monitoring of erosion risk on their properties, to identify any emerging issues.

The need to adapt to climate change will bring a focus on better risk management by farmers. Under a warming, drying climate there are likely to be increased imperatives for farmers to adopt appropriate current (or development new alternative) 'best practice' management options, and undertake forward planning to ensure that strategies exist to avoid land degradation and retain the productive potential of their land. Potential longer term changes may see a need for new, regionally relevant land use options and farm enterprises to be developed. Within shorter timeframes, there may be a need to adopt new land management or land use options on underperforming parts of the property.

DEWNR will continue to work in partnership with other agencies, industry and NRM stakeholder groups to examine the potential regional implications and support adaptation responses to climate change. DEWNR's work in this area also reflects higher level responsibilities of the South Australian Government (including NRM Regions) to develop regional planning, policy, monitoring and education programs which support sustainable land management and effective climate change adaptation.

5.2 Recommendations

Many of the strategies that may be used to address the early stages of projected climate change are consistent with current industry leading practice in the field of climate risk management, erosion protection, and in the development and adoption of modern conservation farming techniques (ie. stubble retention and reduced tillage systems such as 'no-till'). Recent focus groups with farmers as part of the DAFF funded project "Climate change resilient cropping systems for Australia" identified a series of adaptations to the recent drought which related to storing more water prior to sowing (via conservation farming) and using it more efficiently (sound agronomy). Also new alternative farming systems (e.g. incorporating native species and perennials) that are well adapted to drier conditions are also being investigated and developed in partnership with industry research organisations such as the Future Farm Industries Cooperative Research Centre.

Related to the work documented in this report, recommendations are discussed below to assist with climate change adaptation in the cereal cropping zone of South Australia. These cover aspects of: farm level practice change, research and development, State and regional planning and policy development, industry adaptation and education, and future scenario modelling.

Farm management practices

- Continue to improve water use efficiency to optimise grain and biomass production
- Adopt a range of climate risk management strategies (e.g. flexible and responsive farming techniques; using seasonal indicators to base management decisions)
- Consider soil and land types in management decisions (e.g. farming to land capability, including inherent production potential and risk[14]; assessing required stubble cover and quality; grazing management)

[14] Inherent production potential and risk (associated with soil and climate settings) are considered key parameters in a 'production risk matrix' tool being developed to guide land use and land management decisions. This forms part of a 'Resilient practical farm management' guideline document (Wurst & Mudge 2011) under development by DEWNR and Rural Solutions SA.

- Recognise potential trade-offs between production and NRM outcomes (particularly with impacts to cover levels), to find the right balance for long-term sustainability (e.g. grazing management; baling straw for sale)
- Retain cereal stubbles for soil protection, helping to minimise erosion risk after harvest and into the following season
- Use crop species that leave greater amounts of protective biomass after harvest (particularly in the case of grain legumes)
- Continue uptake of reduced tillage and 'no-till' farming techniques, which include upgrading or modifying seeding equipment to better manage stubbles (such practice change is supported by the availability of tax offsets for conservation farming equipment purchase)
- Investigate alternative land use or management on areas of land prone to higher frequencies of poor crop growth, low economic returns and elevated erosion risk
- Use spatial analogues to consider adaptation options (learn from what farmers are doing in warmer and drier locations).

Research and development

- Develop crop species that leave better quality residues for soil protection after harvest (particularly in the case of grain legumes)
- Continue to develop pasture species that integrate into, and improve, low rainfall farming systems
- Continue research into existing and emerging challenges to improve the resilience of low rainfall farming systems (e.g. erosion and other soil management issues; pest and disease issues)
- Continue research such as TREND (Transect for Environmental Decision Making, funded by the Premier's Science and Research Fund), which is studying the use of spatial analogues for decision making.

State and regional planning and policy development

- That the results of this study are communicated to and understood by regional stakeholders (via NRM Regions and Boards) for discussion of key findings and potential implications of this work
- That the results and implications of this study are incorporated into regional and State climate change planning processes, taking a whole-of-landscape (or integrated) approach
- That results of this study be used in the development of regional planning and policy including in climate change adaptation and land manager educational programs
- That regional engagement, policy and planning development occur in partnership with relevant data custodians and science knowledge holders
- That adaptive management principles be fostered (e.g. acknowledging uncertainty in future climate, the need for ongoing adjustment, and review of responses as knowledge improves with time).

Industry adaptation and education

That industry adaptation to climate change is supported through partnerships and participatory programs (working with existing organisations, networks, alliances, industry groups and research bodies, such as NRM Regions, SANTFA, GRDC, Future Farm Industries CRC, SARDI, CSIRO, universities, Ag Excellence Alliance and regional farm industry groups), to:

- Promote the multiple benefits of erosion protection and sustainable production via conservation farming methods
- Promote a 'climate risk management' approach (e.g. training for farmers and other land managers; raising awareness of appropriate tools that can support climate-based decisions)
- Investigate, identify and develop locally relevant alternative sustainable land use and land management options where required, with direct involvement of land managers (e.g. through peer-to-peer group learning opportunities; exchange of ideas between land managers, industry, research and NRM bodies; investigating new farming systems based on productive native and perennial plants that will be better adapted to a warming, drying climate)
- Provide education and workshop opportunities for land managers to identify low return, marginal, or risky cropping land and consider alternative land management or land use options – with a view to whole-farm and whole-of-catchment or landscape planning for climate change
- Investigate alternative business strategies (e.g. collaborative farming arrangements) and networks (e.g. feed trading) that may support greater resilience within regional farming systems, where financial pressures are exacerbated by climate change
- Monitor developments and improvements in the predictive skill of seasonal outlook models (e.g. through the Bureau of Meteorology).

- Strengthen support for regional and industry programs aimed at improving erosion control
- Encourage and support continued on-farm monitoring of erosion and erosion risk
- Monitor crop biomass production, relating to climate, as a means to further verify the modelling presented in this report
- Revise and update estimates of critical cover requirements in the context of modern farming methods.

For future scenario modelling

- That future modelling investigations (e.g. alternative crop suitability, and social and economic analyses) consider the framework adopted here, which provides a transparent and adaptable approach to better utilise South Australia's comprehensive and consistent coverage of soil and land information
- Examine potential refinements in APSIM simulation of crop biomass levels to improve predictions in line with field-based observations and expected stubble to grain ratios
- That subsequent landscape modelling investigations (addressing issues or questions flowing from this work) be developed in consultation with NRM Regions.

Appendices

Appendix A – Summary of key issues raised during review of the APSIM modelling (from Hayman & Alexander 2012)

External review comments on a draft version of this report have highlighted areas of the APSIM crop simulation modelling methodology and limitations that required greater clarification. A detailed response to the review comments has been prepared by Hayman & Alexander 2012, and this is summarised in this Appendix.

Key issues raised are presented in the form of four main concerns and corresponding responses. Our responses outline the rationale behind the approach and clarify relevant assumptions and limitations. Review comments indicated that SARDI have generally adopted a sensible approach, appropriate for the level and type of big picture reporting undertaken. This includes having a system based on bucket size and creating systematically prepared consistent soil types (as a means to help overcome problems associated with extrapolating data out from a limited suite of potentially very site-specific field-measured soil characteristics). However, a key concern was that in the simplification for regional reporting (and due to budget and time constraints), some of the benefits and opportunities of using APSIM have been lost. It was suggested (for example) that further opportunities might have come from incorporating more local knowledge of soils and cropping systems, and being able to provide reporting products at different scales for different users. While acknowledging some of these points, in the context of this regional-scale analysis it is the authors' opinion that, while some analyses could be done differently, it would not lead to significant changes in the overall conclusions.

The following four concerns (raised during the review process) highlight important issues in the modelling:

Concern #1 – Over-simplification of soil parameters (whereby we adjusted surface soil properties and the waterholding capacity ['bucket size'] of the lower layers but did not adjust hydraulic or texture properties of lower layers ['bucket shape'], including the saturated water flow parameter 'swcon'.)

Response #1 – The surface soil properties and total PAWC (or bucket size) have been identified as primary factors influencing crop biomass and yield, while the hydraulic properties of the lower layers seem to have only a minor impact. In previous work, Hayman & Alexander 2010 compared percentile-by-percentile results (yield, drainage below rootzone, evaporation, transpiration) for two soils with identical surface conditions and the same total bucket size (PAWC) but different bucket shape and found only small differences.

The parameter 'swcon' determines APSIM's treatment of saturated water flows with suggested settings* for clay = 0.3, loams = 0.5, sands = 0.7. Guided by Dr Anthony Whitbread (CSIRO), who was familiar with APSIM soils and had conducted the most comprehensive testing in the region, we applied a 'swcon' value of 0.5 regardless of soil texture, for both surface and lower layers. This approach was also consistent with our regional-scale analysis (using generalised properties rather than many variations of soil files to account for local variations in soil properties). Subsequent additional analyses which adopted the suggested settings for swcon (as above*) changed average yields only by up to 3% across 207-407 mm Ave GSR.

It is acknowledged that the 'modelling soil profiles' should be viewed as big picture modelling soils, suitable for regional-scale reporting. They are not suitable for:

- reporting differences in crop performance at local scales
- reporting differences in crop performance between specific soil types (e.g. deep sand vs sandy surface texture contrast soil) especially where carry-over effects between seasons can play a role (as this is ignored in the modelling).
- paddock level assessments of yield, biomass or erosion risk.

Concern #2 – Not accounting for variability in regional climate and seasonal rainfall distribution (whereby a suite of synthesised climate files were based on actual site records from only two locations)

Response #2 – This was a surprising result, but we can show that this minimal set of carefully selected climate files (from Snowtown and Maitland) can be used to generate a suite of long-term representative regional climate files. Our original intent was to consider the grains belt as having nine climate regions (and representative climate stations) in a matrix format. When viewed in this format (below) it is apparent that Snowtown is only one cell away from the other representative sites. Also Snowtown's Ave GSR (307 mm) is close to the midpoint of the range of Ave GSR (170-460 mm) spanning the dryland cereal cropping zone identified in this study.

	Eyre Peninsula	Mid and Upper North	Murray Mallee and South East
Low Rainfall	Minnipa	Orroroo	Loxton
Medium Rainfall	Lock	Snowtown	Lameroo
High Rainfall	Cummins	Roseworthy	Keith

In a peer-reviewed conference paper, Hayman et al. 2010b examined whether simulated drying of a climate record would produce similar wheat yield results to a different lower rainfall locality – where the long-term Ave GSR values of the 'simulated drying' site and the actual lower rainfall site are the same. Comparisons between the simulated drying and low rainfall site on a year-by-year basis showed a noisy relationship. However a percentile-by-percentile comparison (based on more than 100 seasonal outcomes) showed a much tighter relationship. In this project, the same approach was tested reasonably extensively across the rest of the grains belt, and, after identifying similar tight fitting relationships (in percentile-percentile plots) we identified two long-term climate records that could be adjusted to represent the various regional climate zones in our APSIM modelling. Although year-to-year variation occurs in reality between regions, it is the percentile results (determined from long time series data) that we view as important for reporting probability estimates of erosion risk. Average yield and biomass values are also determined from long time series climate datasets. In other words, the maps and analysis in this report are indicating long-term risk rather than what might happen in any single season. From a large number of comparative simulations performed across the State's cropping zone (using long time series datasets), we have shown that there are no regions that seem to get rainfall "at the right time" more often than other regions in the same rainfall zone with the possible exception of higher rainfall areas of Yorke Peninsula.

Local-scale climate influences (e.g. due to coastal influences or orographic rainfall) are only considered where they are captured in the 5 km x 5 km gridded long-term average spatial climate data (see Section 3.4). This spatial climate data for long-term Ave GSR and Ave GST was used to derive the representative APSIM climate zone values (and respective scaling factors applied to the daily temperature and rainfall records from Snowtown and Maitland) as outlined in Sections 3.3 and 3.4. Regional differences in temperature extremes (e.g. areas more prone to frosts or heatwaves) are not considered in the modelling.

Concern #3 – Not accounting for different nitrogen input levels (whereby a fixed rate of nitrogen was assumed for all locations and rainfall zones)

Response #3 – It is accepted that this is a limitation, however the assumed fixed rate (70kg/ha NO_3 in the soil reset every January and 90kg/ha N as urea added at sowing) will rarely reduce yields in low rainfall environments and only reduce the yields in good seasons in medium and high rainfall regions. This will result in slightly lower long-term average yield estimates but doesn't impact on the key question for erosion risk related to crop biomass levels. The question of the N rate being too high (leading to 'haying off' in dry years) might have an impact on yield in poor seasons, but is unlikely to have an impact on biomass. From an erosion risk perspective (which was a key focus for this study), the interest will be in lower rainfall / low biomass years, where N levels are adequate.

Concern #4 – Not adjusting crop phenology (whereby a single medium maturing wheat variety was assumed in the modelling across all areas)

Response #4 – It is accepted that this is a limitation of the modelling. In reality, farmers will select different varieties to optimise flowering and grain development (avoiding winter frost during critical growth stages and subsequently attempting to maximise grain fill during the remaining productive part of the season). While it is correct that longer and shorter season varieties would make a difference, it is expected this would have more impact on yield rather than biomass (with the latter being more of a focus in terms of erosion risk).

Appendix B – Wind and water erosion potential – summary spatial data statistics

Note: the following spatial data statistics have been derived from the State Land & Soil Information Framework (refer to Soil & Land Program 2007a)

Erosion potential data statistics for Southern South Australia

Table B-1. Wind erosion potential spatial data statistics for Southern SA (Soil & Land Program 2007a)

Wind erosion potential category	[I] Area (ha)	[1] as a % of Total Area	[II] Area not under vegetation (ha)	[II] as a % of Total Area	Management implications	*Class
Low	6,161,500	39%	4,107,400	26%	Wind erosion should not be a significant problem	1a
Moderately low	5,562,100	35%	3,756,300	24%	Adoption of more conservative tillage practices should minimize erosion	2a
Moderate	2,188,400	14%	1,518,900	10%	Reduced tillage, early sowing, modified rotations etc needed to minimize erosion	3a
Moderately high	915,600	6%	633,400	4%	Specialised crops (eg cereal rye) and well managed pasture phases needed	4a
High	426,700	3%	187,800	1.2%	Land is non arable, careful grazing management essential	5a
Extreme	291,100	2%	62,900	0.4%	Land should not be used for cropping or grazing	7a
Not applicable	220,000	1.4%	173,900	1.1%	Not applicable	Xa
Total	*15,765,500*	*100%*	*10,440,600*	*66%*		

Notes: *The letter 'a' denotes classes are specific to the attribute wind erosion potential. Source: State Land & Soil Information Framework (see Soil & Land Program 2007a)

Table B-2. Water erosion potential spatial data statistics for Southern SA (Soil & Land Program 2007a)

Water erosion potential category	[I] Area (ha)	[1] as a % of Total Area	[II] Area not under vegetation (ha)	[II] as a % of Total Area	Management implications	*Class
Low	10,458,600	66%	7,003,900	44%	No specific management needed	1e
Moderately low	2,372,200	15%	1,658,200	11%	Modified surface management needed	2e
Moderate	1,303,300	8%	948,600	6%	Engineering works (e.g. contour banks) needed if cultivated	3e
Moderately high	499,400	3%	297,800	2%	Semi-arable	4e
High	524,800	3%	256,200	2%	Non-arable	5e
Very high	291,800	2%	93,500	0.6%	Steep - non arable, non-traversable	6e
Extreme	98,700	0.6%	10,100	0.1%	Very steep - non arable, non-traversable	7e
Not applicable	216,600	1.4%	172,500	1.1%	Not applicable	Xe
Total	*15,765,500*	*100%*	*10,440,600*	*66%*		

Notes: *The letter 'e' denotes classes are specific to the attribute water erosion potential. Source: State Land & Soil Information Framework (see Soil & Land Program 2007a)

Data statistics continued next page...

Erosion potential data statistics on cleared, arable land by NRM Regions

Table B-3. Wind erosion potential spatial data statistics for cleared, arable land by NRM Regions

NRM Region	Area (ha) of Wind erosion potential category "Low" (Class 1a)	Area (ha) of Wind erosion potential category "Moderately low" (Class 2a)	Area (ha) of Wind erosion potential category "Moderate" (Class 3a)	Area (ha) of Wind erosion potential category "Moderately high" (Class 4a)
Adelaide & Mt Lofty Ranges	165,000	25,800	7,500	900
Eyre Peninsula	216,000	1,522,200	314,400	173,800
Kangaroo Island	54,600	29,000	3,100	300
Northern & Yorke	1,273,800	302,500	62,000	66,000
South Australian Murray-Darling Basin	421,600	667,000	269,800	257,100
South East	337,500	462,400	231,700	92,100
Total (Southern South Australia) = 6,956,100 ha	*2,468,500*	*3,008,900*	*888,500*	*590,200*

Notes: Wind erosion potential categories of "High" and greater are assesses as non-arable. Rules used in this analysis to exclude non-arable land are outlined in Section 3.9. For additional description of wind erosion potential categories refer to the appropriate table on the previous page.

Table B-4. Water erosion potential spatial data statistics for cleared, arable land by NRM Regions

NRM Region	Area (ha) of Water erosion potential category "Low" (Class 1e)	Area (ha) of Water erosion potential category "Moderately low" (Class 2e)	Area (ha) of Water erosion potential category "Moderate" (Class 3e)	Area (ha) of Water erosion potential category "Moderately high" (Class 4e)
Adelaide & Mt Lofty Ranges	102,600	29,600	51,600	15,400
Eyre Peninsula	1,591,500	429,100	194,300	11,500
Kangaroo Island	46,500	17,100	19,700	3,600
Northern & Yorke	965,700	306,000	359,700	72,900
South Australian Murray-Darling Basin	1,255,500	199,500	135,300	25,200
South East	806,400	234,700	82,600	100
Total (Southern South Australia) = 6,956,100 ha	*4,768,300*	*1,216,100*	*843,100*	*128,600*

Notes: Water erosion potential categories of "High" and greater are assesses as non-arable. Rules used in this analysis to exclude non-arable land are outlined in Section 3.9. For additional description of water erosion potential categories refer to the appropriate table on the previous page.

Appendix C – DEWNR soil landscape mapping general disclaimer

The following notes generally apply to all mapping based on the State Land & Soil Information Framework.

NOTES ON USE OF THE MAP:

1. Information is derived from limited field inspection, and is subject to change without notice.
2. Boundaries between mapping units should be treated as transition zones.
3. The map is intended to provide a regional overview and should not be used to draw conclusions about conditions at specific locations.
4. Under no circumstances must the scale of the map be enlarged beyond its scale of mapping.
5. Advice from DEWNR Soil and Land Program should be sought prior to using this information for commercial decision making.
6. Under no circumstances may the data or information associated with this map or any accompanying report be altered in any way without the express permission of DEWNR Soil and Land Program.

Additional Information

a) More detailed spatial information relating to the overviews presented in this report are available from the DEWNR Soil and Land Program, email: Craig.Liddicoat@sa.gov.au

b) The scale and coverage of soil and land mapping are shown below.

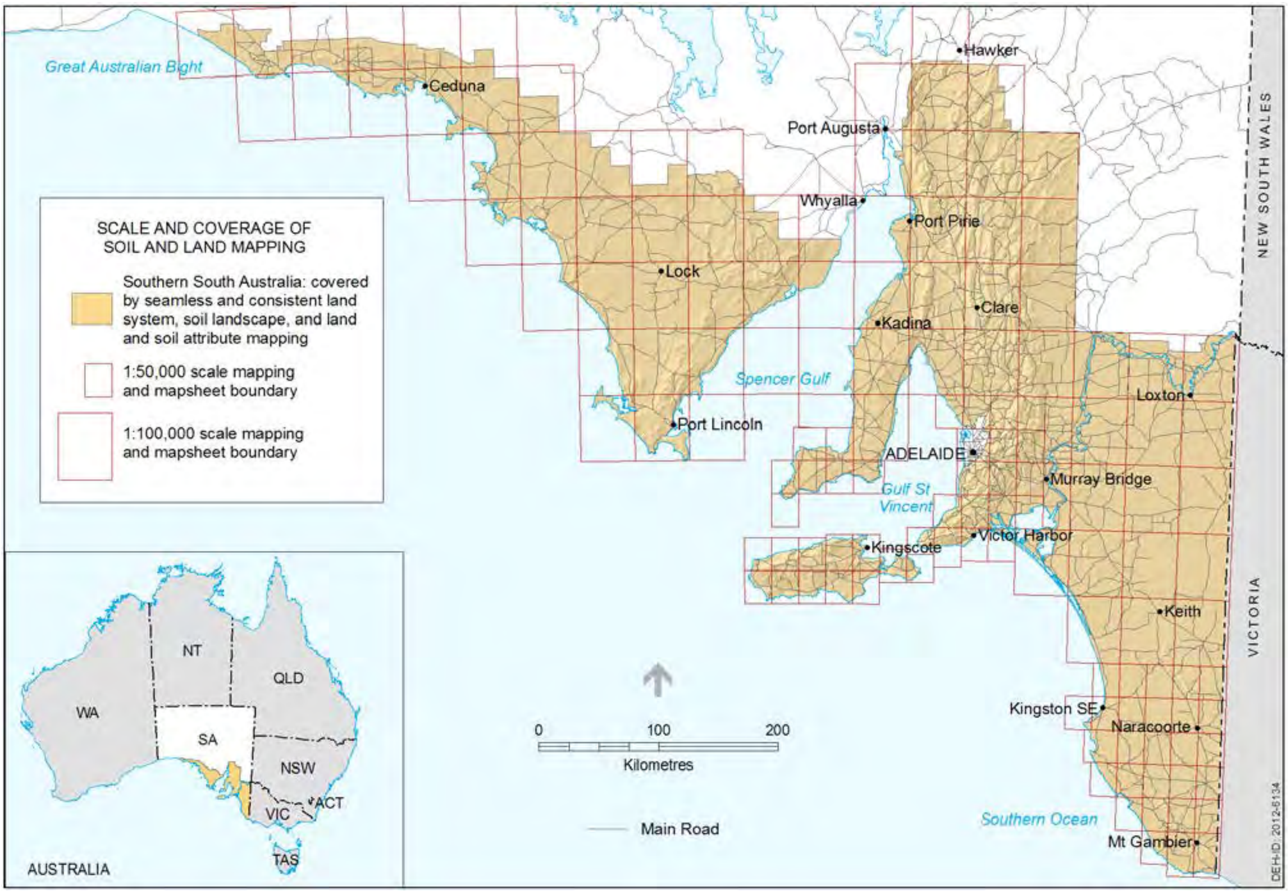


Figure C-1. Scale and coverage of South Australia's soil and land mapping.

Appendix D – Erosion Protection Field Survey (EPFS) Program

About the DEWNR EPFS Program

Wind and water erosion risk and protection indicators reported by the EPFS program are based on field assessments of representative transects across the State's major agricultural cropping regions, repeated four times per year. These surveys are undertaken in the form of a rapid roadside ('windscreen') survey, where over 3,500 sites are assessed representing a large area, to provide a snapshot of conditions at a regional scale (Forward 2011; M-A Young 2010, pers. comm.).

Survey sites have been georeferenced and characterised for inherent erosion susceptibility factors (relating to land type, soils, slope and rainfall zone). Variable erosion risk factors are then recorded during the survey, including (Forward 2011):

- Disturbance rating – degree of disturbance due to cultivation and/or stock traffic.
- Cover rating – based on height, cover %, bulk/ volume, anchorage. Cover height is used as a primary factor when assessing wind erosion susceptible sites, and cover % is used as a primary factor when assessing water erosion susceptible sites. Bulk and anchorage are considered in both wind and water erosion assessments.

Survey results feed into primary indicators called the "erosion protection indices" (wind erosion risk index [wind ERI] and water ERI respectively). These are estimates of the cumulative annual period for which cropped land is adequately protected from the risk of soil erosion, either on all crop land, or specifically on land inherently prone to wind or water erosion (G Forward 2010, pers. comm.).

This methodology has proven useful for State-wide erosion protection monitoring and the data is seen as the primary measure for the Target 70 "Sustainable Land Management" in South Australia's Strategic Plan 2011.

Cover ratings

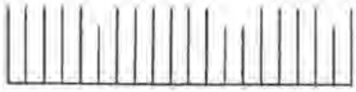
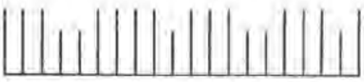
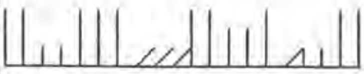
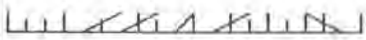
Surface 'cover rating' applies to combined dry and green material on the soil surface.

Definitions for cover rating table

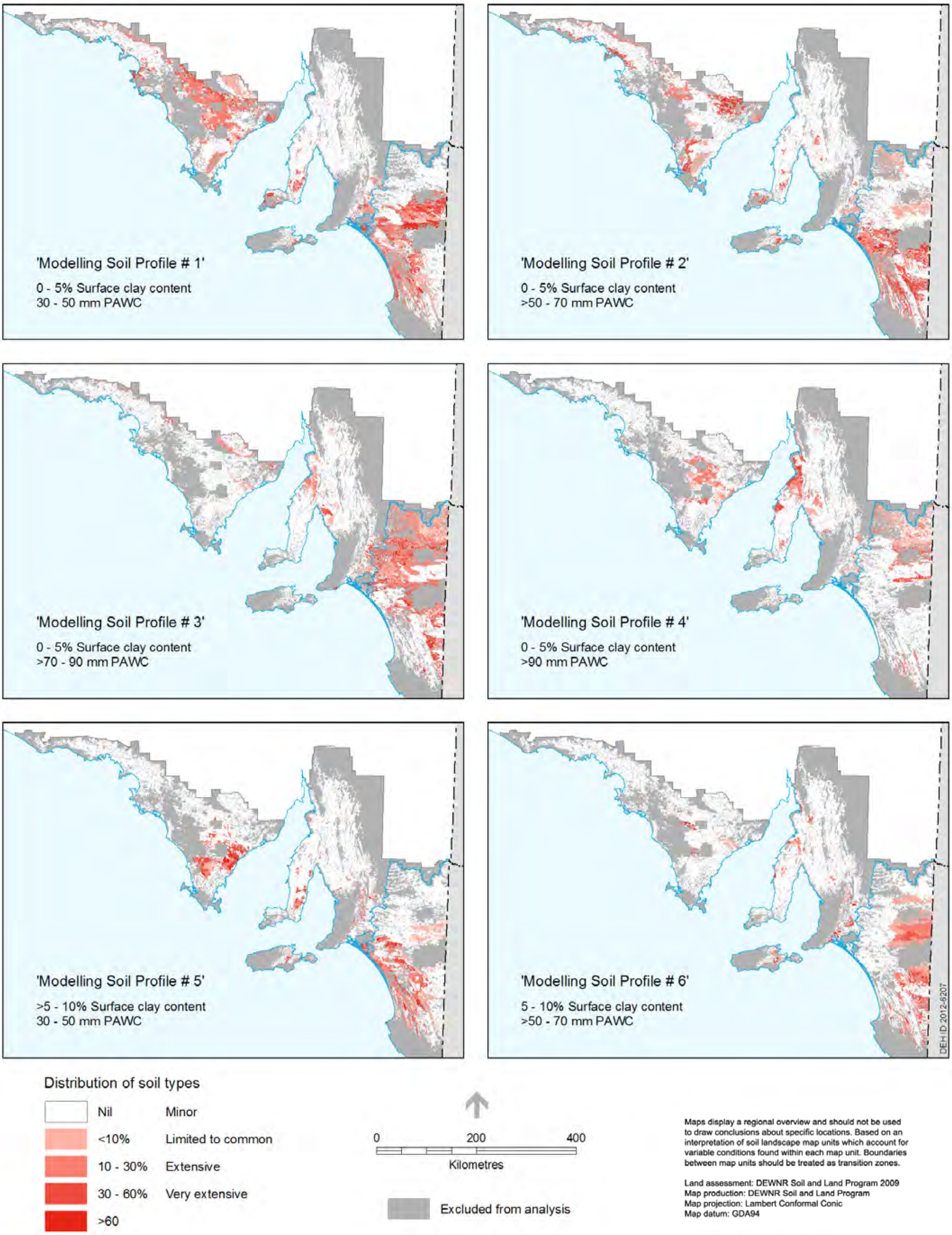
Height	Height of the surface cover. This is the primary factor to use to assess sites with inherent susceptibility to wind erosion (TRwind >=2).
Cover %	Percentage of the soil surface covered with plant material or stones etc. as viewed from the roadside (oblique view). This is the primary factor to use to assess areas with inherent susceptibility to water erosion (TRwater >=2). At sites where TRwater >=2 and TRwind >=2, assess these as inherently prone to wind erosion.
Bulk	This is the overall amount (volume) of the surface cover material. For example, canola stubble vs. cereal stubble, both with similar height of cover will have different bulks. This is a secondary factor to assess cover rating at all sites.
Anchorage	The degree to which the **surface cover** is attached to the soil (e.g. undisturbed plant crowns) or detached (unanchored) by cultivation, grazing etc. This is a secondary factor to assess cover rating at all sites.

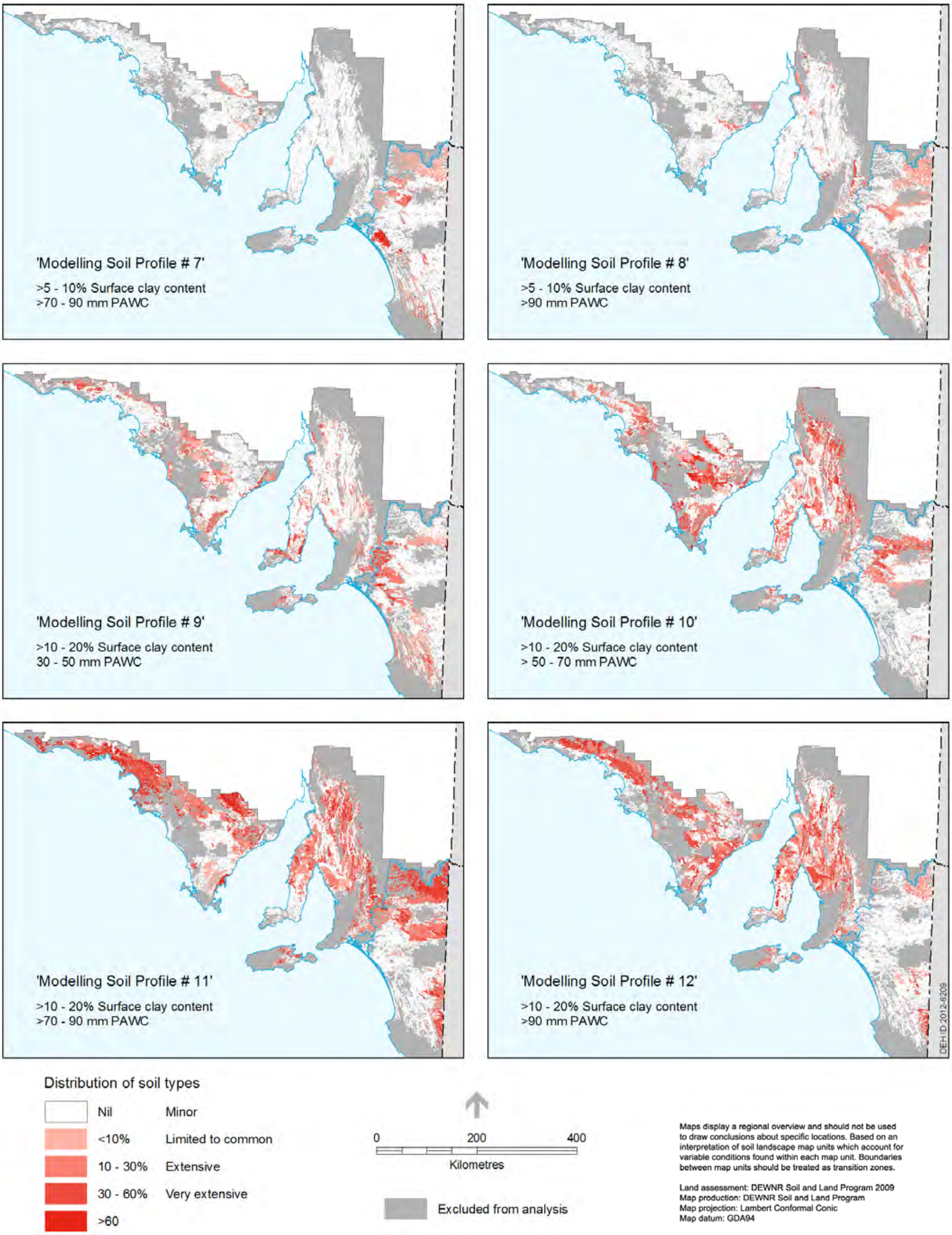
(Notes: TRwind = Topographic rating for wind erosion, TRwater = Topographic rating for water erosion.)
(Source: Forward 2011)

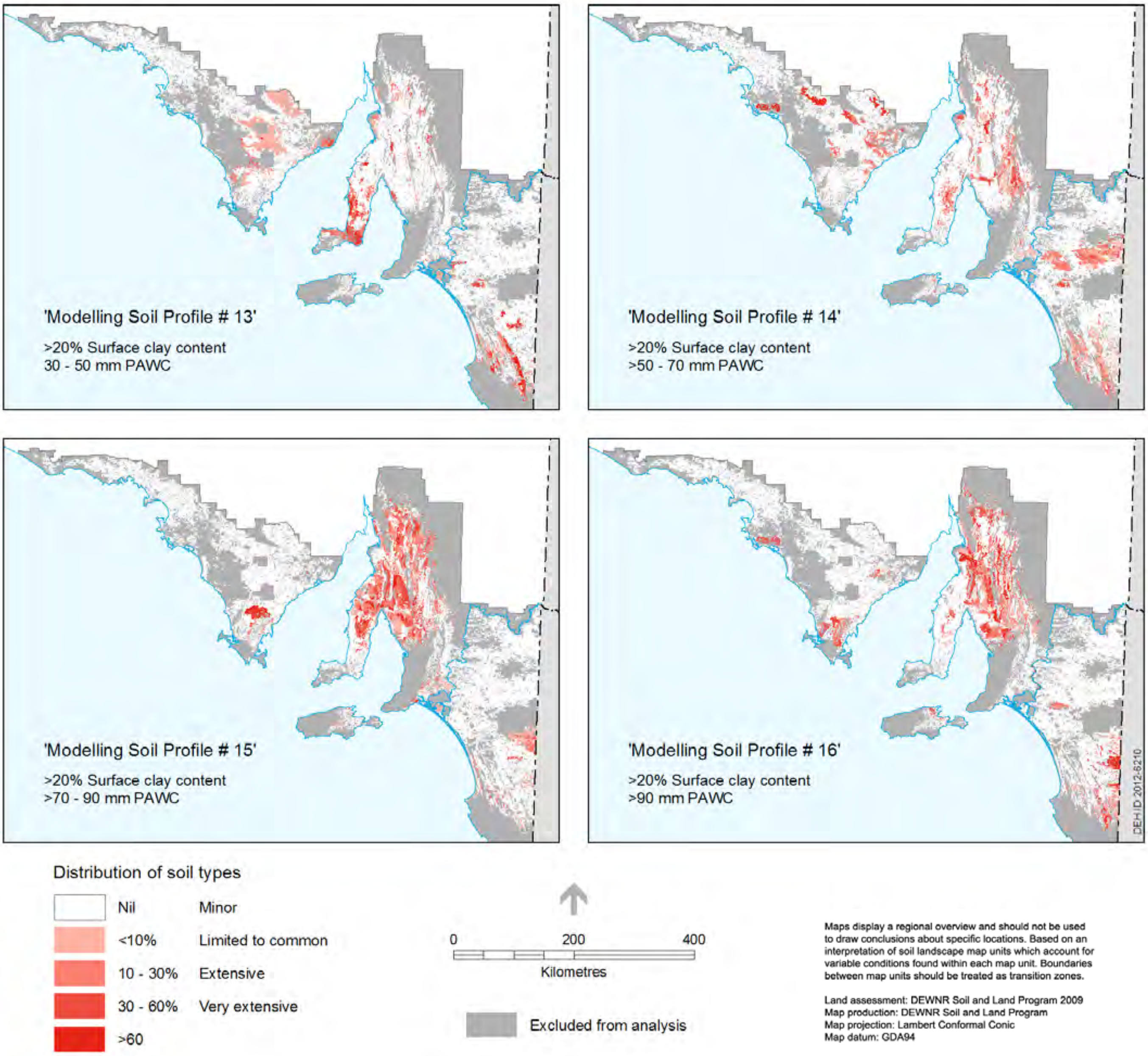
Cover Rating Table (Forward 2011)

Rating	Height (wind erosion)	Cover % (water erosion)	
1	Residues **40cm or higher**.	**75 to 100%**	
	Bulk: Very high level of plant matter Anchorage: Majority of cover is anchored and stable, not (easily washed or blown away).		
2	Residues **between 10cm and 40cm.**	Even coverage of approx. **75 to 100%**	
	Bulk: high amount of plant matter, most of which is standing Anchorage: Majority of cover is anchored.		
3	Residue height variable from **less than 10cm to 40cm**.	More variable cover of approx. **75 to 100%**	
	Bulk: moderate to high but more variable across the paddock Anchorage: Cover often slightly flattened and damaged		
4	Residues **2cm-10cm,** but of moderate bulk. Residues a mixture of upright and flattened.	**50 to 75%** cover, residue colour dominates	
	Bulk: Moderate Anchorage: Majority of residues are anchored, although often flattened or damaged.		
5	**2cms of relatively even but thin residue** cover remain; or, **cover variable from sparse 40cm to less than 2cm** cover	**50 to 75%** cover, **Residue colour still dominates**	
	Bulk: Low, damaged through moderately heavy grazing or traffic by animals and/or machinery. Anchorage: majority of residues are anchored, most residues are damaged.		
6	**Height is variable** and **less than 10cm high to bare.**	**Soil colour dominates, 25 to 50%** cover	
	Bulk: Low amounts of plant material. Anchorage: some residues are anchored; most are damaged through grazing or cultivation.		
7	Mostly bare although **some residues can be seen**. Grazed or cultivated virtually **bare.**	**Soil colour dominates, 1 to 25%** Scattered residues (and/or rocks) remain.	
	Bulk: minimal amount of plant material. Anchorage: Any residues probably unanchored		
8	Nil cover **(bare)**	**0%** cover	
	Bulk: Nil Anchorage: Nil		

Appendix E – Distribution of the 16 'modelling soil profiles'

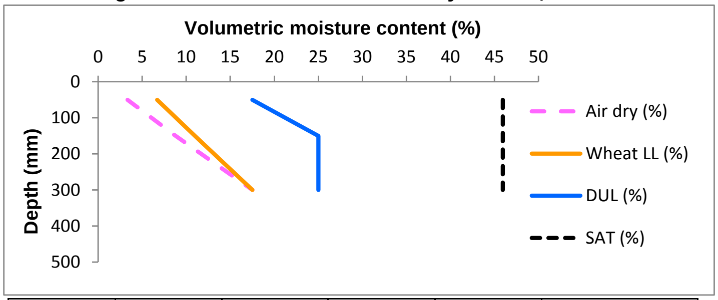



'Modelling Soil Profile # 7'
>5 - 10% Surface clay content
>70 - 90 mm PAWC
'Modelling Soil Profile # 8'
>5 - 10% Surface clay content
>90 mm PAWC
'Modelling Soil Profile # 9'
>10 - 20% Surface clay content
30 - 50 mm PAWC
'Modelling Soil Profile # 10'
>10 - 20% Surface clay content
> 50 - 70 mm PAWC
'Modelling Soil Profile # 11'
>10 - 20% Surface clay content
>70 - 90 mm PAWC
'Modelling Soil Profile # 12'
>10 - 20% Surface clay content
>90 mm PAWC
DEH ID 2012-6209
Distribution of soil types
Nil Minor
<10% Limited to common
10 - 30% Extensive
30 - 60% Very extensive
>60
0 200 400
Kilometres
Excluded from analysis
Maps display a regional overview and should not be used to draw conclusions about specific locations. Based on an interpretation of soil landscape map units which account for variable conditions found within each map unit. Boundaries between map units should be treated as transition zones.
Land assessment: DEWNR Soil and Land Program 2009
Map production: DEWNR Soil and Land Program
Map projection: Lambert Conformal Conic
Map datum: GDA94


'Modelling Soil Profile # 13'
>20% Surface clay content
30 - 50 mm PAWC
'Modelling Soil Profile # 14'
>20% Surface clay content
>50 - 70 mm PAWC
'Modelling Soil Profile # 15'
>20% Surface clay content
>70 - 90 mm PAWC
'Modelling Soil Profile # 16'
>20% Surface clay content
>90 mm PAWC
DEH ID 2012-6210
Distribution of soil types
Nil Minor
<10% Limited to common
10 - 30% Extensive
30 - 60% Very extensive
>60
0 200 400
Kilometres
Excluded from analysis
Maps display a regional overview and should not be used to draw conclusions about specific locations. Based on an interpretation of soil landscape map units which account for variable conditions found within each map unit. Boundaries between map units should be treated as transition zones.
Land assessment: DEWNR Soil and Land Program 2009
Map production: DEWNR Soil and Land Program
Map projection: Lambert Conformal Conic
Map datum: GDA94

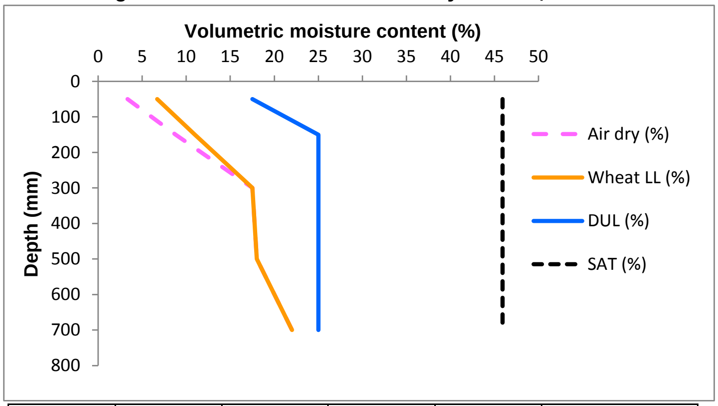
Appendix F – 'Modelling soil profile' moisture characteristics used in APSIM

'Modelling Soil Profile #1': 3.75% Surface clay content, 40 mm PAWC



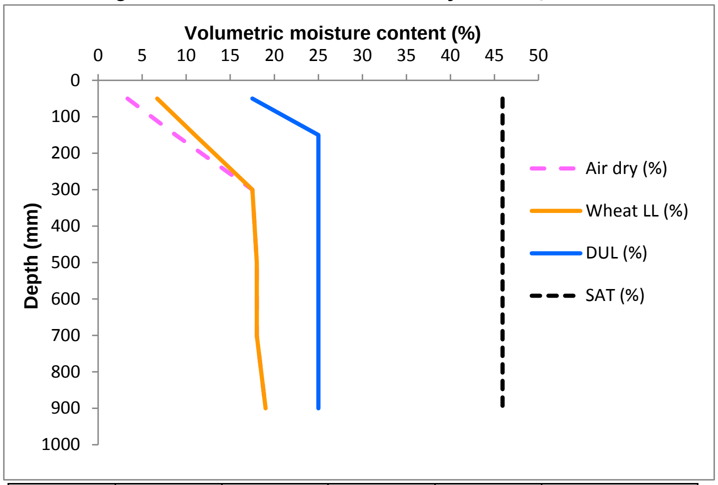
Depth (cm)	Air Dry (%)	Wheat LL (%)	DUL (%)	SAT (%)	Wheat PAWC (mm)
0-10	3.4	6.7	17.5	45.9	10.8
10-20	8.8	11.0	25.0	45.9	14
20-40	17.5	17.5	25.0	45.9	15
				Total PAWC (mm)	39.8

'Modelling Soil Profile #2': 3.75% Surface clay content, 60 mm PAWC



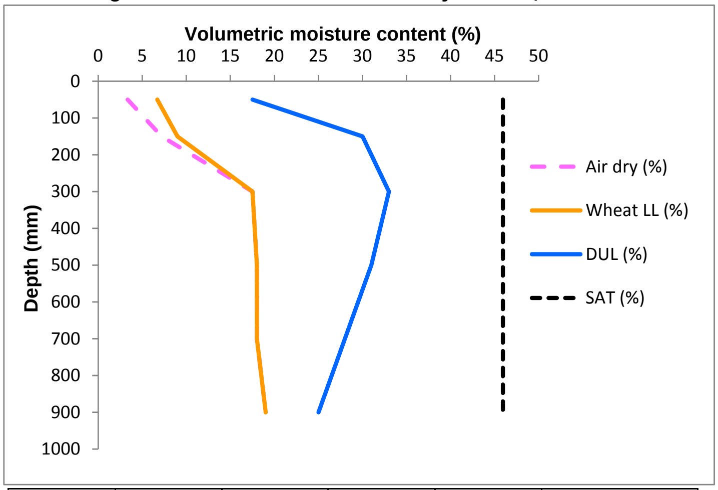
Depth (cm)	Air Dry (%)	Wheat LL (%)	DUL (%)	SAT (%)	Wheat PAWC (mm)
0-10	3.4	6.7	17.5	45.9	10.8
10-20	8.8	11.0	25.0	45.9	14
20-40	17.5	17.5	25.0	45.9	15
40-60	18.0	18.0	25.0	45.9	14
60-80	22.0	22.0	25.0	45.9	6
				Total PAWC (mm)	59.8

'Modelling Soil Profile #3': 3.75% Surface clay content, 80 mm PAWC



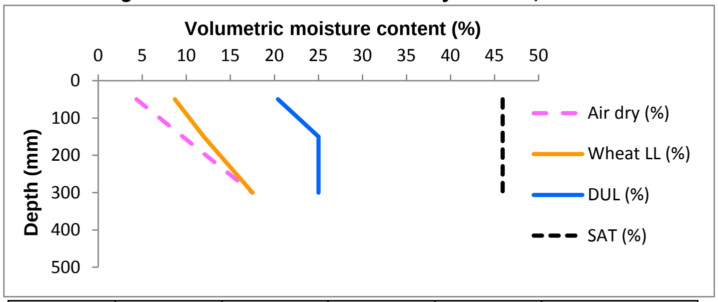
Depth (cm)	Air Dry (%)	Wheat LL (%)	DUL (%)	SAT (%)	Wheat PAWC (mm)
0-10	3.4	6.7	17.5	45.9	10.8
10-20	8.8	11.0	25.0	45.9	14
20-40	17.5	17.5	25.0	45.9	15
40-60	18.0	18.0	25.0	45.9	14
60-80	18.0	18.0	25.0	45.9	14
80-100	19.0	19.0	25.0	45.9	12
				Total PAWC (mm)	79.8

'Modelling Soil Profile #4': 3.75% Surface clay content, 120 mm PAWC



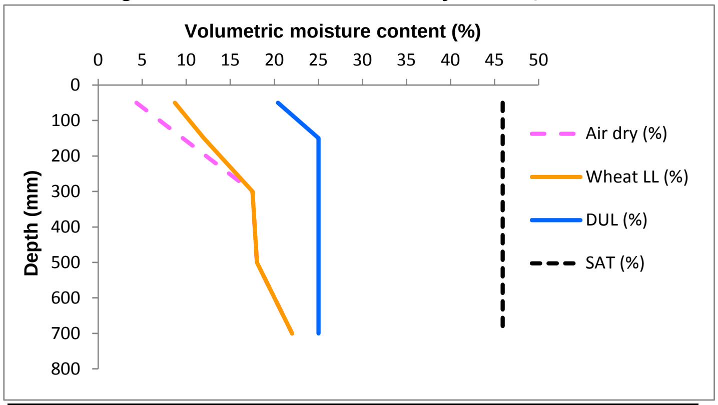
Depth (cm)	Air Dry (%)	Wheat LL (%)	DUL (%)	SAT (%)	Wheat PAWC (mm)
0-10	3.4	6.7	17.5	45.9	10.8
10-20	7.2	9.0	30.0	45.9	21
20-40	17.5	17.5	33.0	45.9	31
40-60	18.0	18.0	31.0	45.9	26
60-80	18.0	18.0	28.0	45.9	20
80-100	19.0	19.0	25.0	45.9	12
				Total PAWC (mm)	120.8

'Modelling Soil Profile #5': 7.5% Surface clay content, 40 mm PAWC



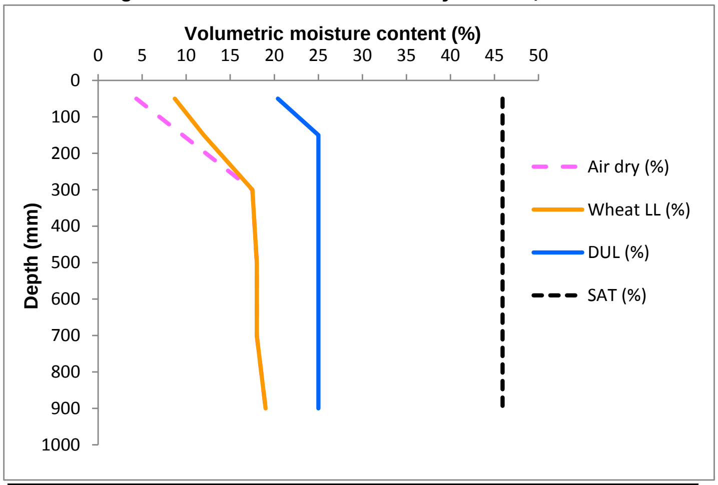
Depth (cm)	Air Dry (%)	Wheat LL (%)	DUL (%)	SAT (%)	Wheat PAWC (mm)
0-10	4.4	8.7	20.4	45.9	11.7
10-20	9.6	12.0	25.0	45.9	13
20-40	17.5	17.5	25.0	45.9	15
				Total PAWC (mm)	39.7

'Modelling Soil Profile #6': 7.5% Surface clay content, 60 mm PAWC



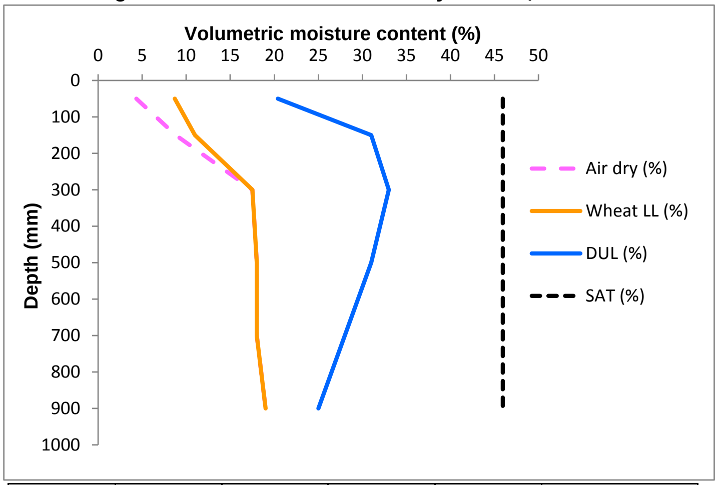
Depth (cm)	Air Dry (%)	Wheat LL (%)	DUL (%)	SAT (%)	Wheat PAWC (mm)
0-10	4.4	8.7	20.4	45.9	11.7
10-20	9.6	12.0	25.0	45.9	13
20-40	17.5	17.5	25.0	45.9	15
40-60	18.0	18.0	25.0	45.9	14
60-80	22.0	22.0	25.0	45.9	6
				Total PAWC (mm)	59.7

'Modelling Soil Profile #7': 7.5% Surface clay content, 80 mm PAWC



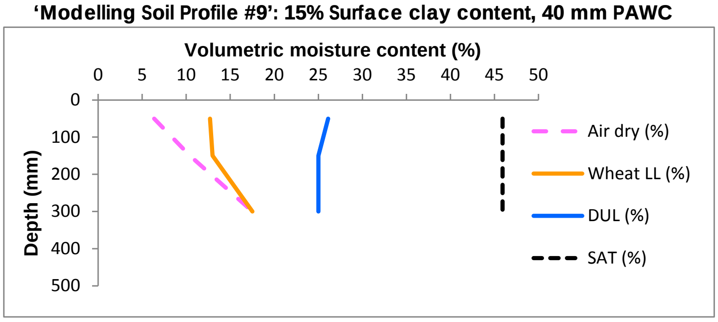
Depth (cm)	Air Dry (%)	Wheat LL (%)	DUL (%)	SAT (%)	Wheat PAWC (mm)
0-10	4.4	8.7	20.4	45.9	11.7
10-20	9.6	12.0	25.0	45.9	13
20-40	17.5	17.5	25.0	45.9	15
40-60	18.0	18.0	25.0	45.9	14
60-80	18.0	18.0	25.0	45.9	14
80-100	19.0	19.0	25.0	45.9	12
				Total PAWC (mm)	79.7

'Modelling Soil Profile #8': 7.5% Surface clay content, 120 mm PAWC



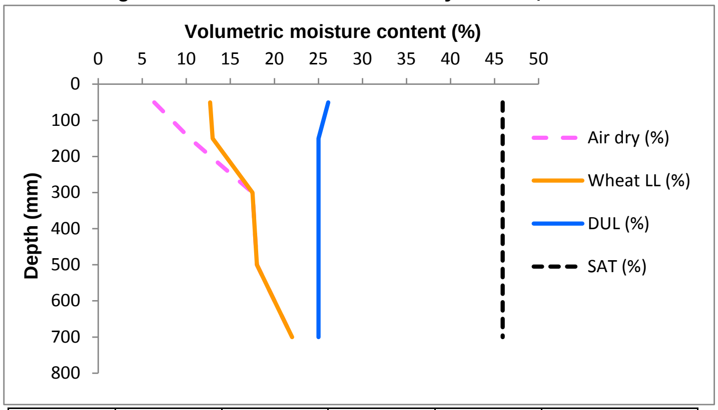
Depth (cm)	Air Dry (%)	Wheat LL (%)	DUL (%)	SAT (%)	Wheat PAWC (mm)
0-10	4.4	8.7	20.4	45.9	11.7
10-20	8.8	11.0	31.0	45.9	20
20-40	17.5	17.5	33.0	45.9	31
40-60	18.0	18.0	31.0	45.9	26
60-80	18.0	18.0	28.0	45.9	20
80-100	19.0	19.0	25.0	45.9	12
				Total PAWC (mm)	120.7

'Modelling Soil Profile #9': 15% Surface clay content, 40 mm PAWC



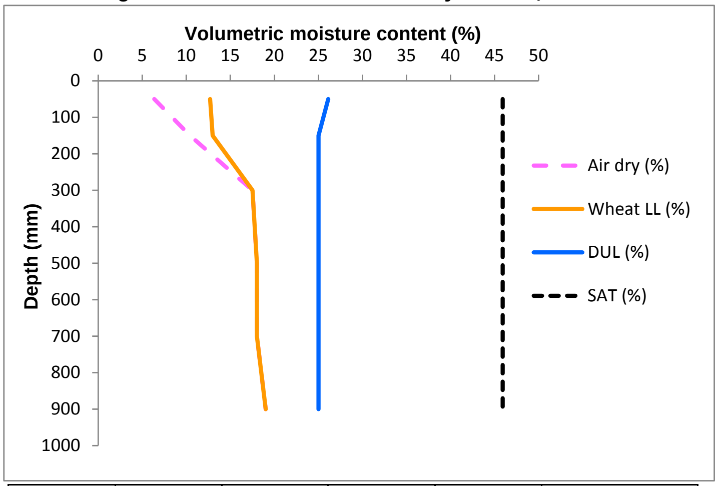
Depth (cm)	Air Dry (%)	Wheat LL (%)	DUL (%)	SAT (%)	Wheat PAWC (mm)
0-10	6.4	12.7	26.1	45.9	13.4
10-20	10.4	13.0	25.0	45.9	12
20-40	17.5	17.5	25.0	45.9	15
				Total PAWC (mm)	40.4

'Modelling Soil Profile #10': 15% Surface clay content, 60 mm PAWC



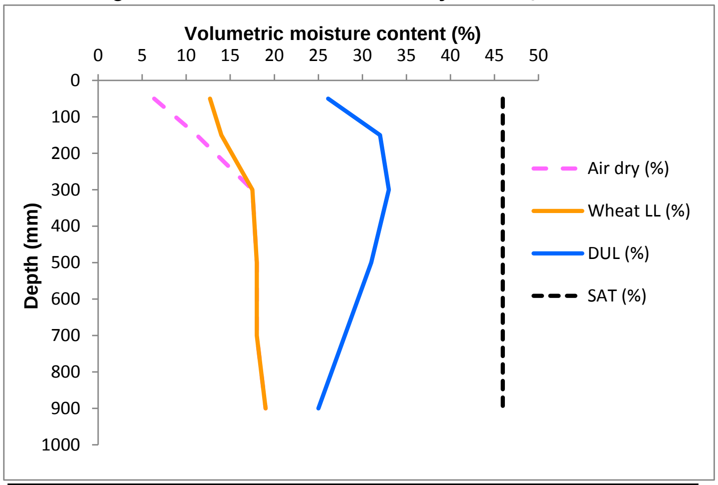
Depth (cm)	Air Dry (%)	Wheat LL (%)	DUL (%)	SAT (%)	Wheat PAWC (mm)
0-10	6.4	12.7	26.1	45.9	13.4
10-20	10.4	13.0	25.0	45.9	12
20-40	17.5	17.5	25.0	45.9	15
40-60	18.0	18.0	25.0	45.9	14
60-80	22.0	22.0	25.0	45.9	6
				Total PAWC (mm)	60.4

'Modelling Soil Profile #11': 15% Surface clay content, 80 mm PAWC



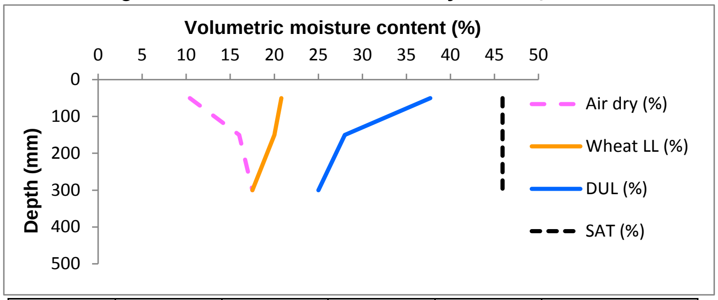
Depth (cm)	Air Dry (%)	Wheat LL (%)	DUL (%)	SAT (%)	Wheat PAWC (mm)
0-10	6.4	12.7	26.1	45.9	13.4
10-20	10.4	13.0	25.0	45.9	12
20-40	17.5	17.5	25.0	45.9	15
40-60	18.0	18.0	25.0	45.9	14
60-80	18.0	18.0	25.0	45.9	14
80-100	19.0	19.0	25.0	45.9	12
				Total PAWC (mm)	80.4

'Modelling Soil Profile #12': 15% Surface clay content, 120 mm PAWC



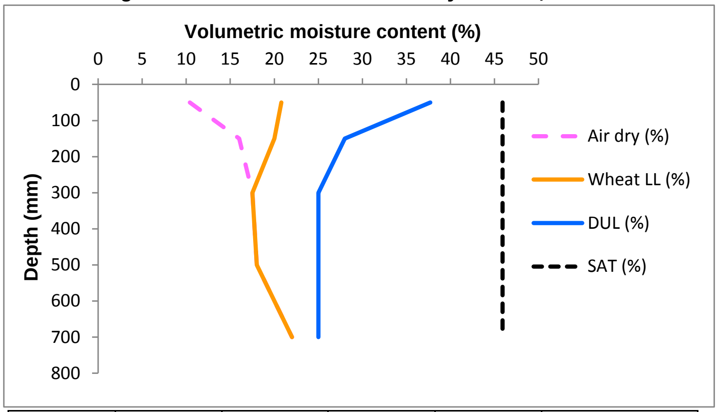
Depth (cm)	Air Dry (%)	Wheat LL (%)	DUL (%)	SAT (%)	Wheat PAWC (mm)
0-10	6.4	12.7	26.1	45.9	13.4
10-20	11.2	14.0	32.0	45.9	18
20-40	17.5	17.5	33.0	45.9	31
40-60	18.0	18.0	31.0	45.9	26
60-80	18.0	18.0	28.0	45.9	20
80-100	19.0	19.0	25.0	45.9	12
				Total PAWC (mm)	120.4

'Modelling Soil Profile #13': 30% Surface clay content, 40 mm PAWC



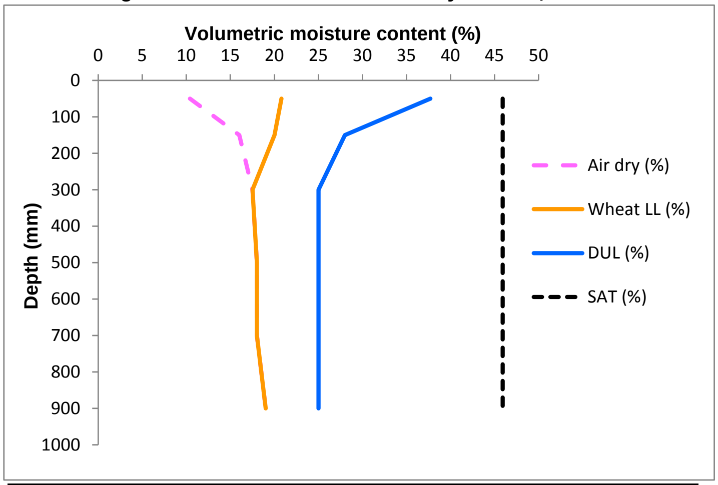
Depth (cm)	Air Dry (%)	Wheat LL (%)	DUL (%)	SAT (%)	Wheat PAWC (mm)
0-10	10.4	20.8	37.7	45.9	16.9
10-20	16.0	20.0	28.0	45.9	8
20-40	17.5	17.5	25.0	45.9	15
				Total PAWC (mm)	39.9

'Modelling Soil Profile #14': 30% Surface clay content, 60 mm PAWC



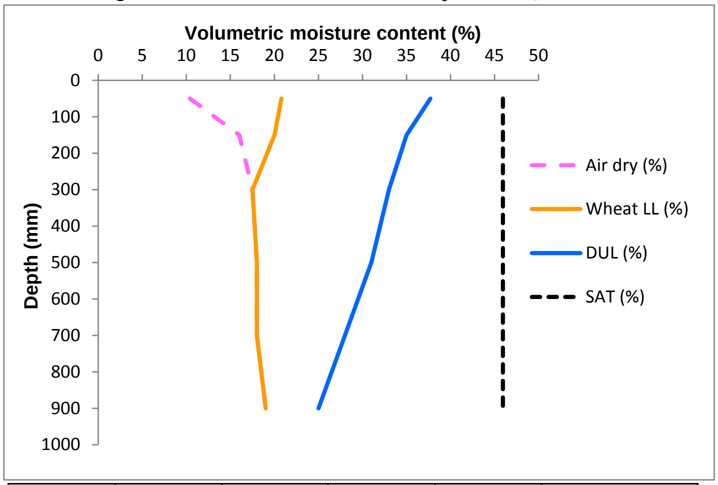
Depth (cm)	Air Dry (%)	Wheat LL (%)	DUL (%)	SAT (%)	Wheat PAWC (mm)
0-10	10.4	20.8	37.7	45.9	16.9
10-20	16.0	20.0	28.0	45.9	8
20-40	17.5	17.5	25.0	45.9	15
40-60	18.0	18.0	25.0	45.9	14
60-80	22.0	22.0	25.0	45.9	6
				Total PAWC (mm)	59.9

'Modelling Soil Profile #15': 30% Surface clay content, 80 mm PAWC



Depth (cm)	Air Dry (%)	Wheat LL (%)	DUL (%)	SAT (%)	Wheat PAWC (mm)
0-10	10.4	20.8	37.7	45.9	16.9
10-20	16.0	20.0	28.0	45.9	8
20-40	17.5	17.5	25.0	45.9	15
40-60	18.0	18.0	25.0	45.9	14
60-80	18.0	18.0	25.0	45.9	14
80-100	19.0	19.0	25.0	45.9	12
				Total PAWC (mm)	79.9

'Modelling Soil Profile #16': 30% Surface clay content, 120 mm PAWC



Depth (cm)	Air Dry (%)	Wheat LL (%)	DUL (%)	SAT (%)	Wheat PAWC (mm)
0-10	10.4	20.8	37.7	45.9	16.9
10-20	16.0	20.0	35.0	45.9	15
20-40	17.5	17.5	33.0	45.9	31
40-60	18.0	18.0	31.0	45.9	26
60-80	18.0	18.0	28.0	45.9	20
80-100	19.0	19.0	25.0	45.9	12
				Total PAWC (mm)	120.9

Appendix G – Hayman et al. 2010b conference paper examining spatial analogues as a means to better understand potential climate change impacts

Using temporal and spatial analogues to consider impacts and adaptation to climate change in the South Australian grain belt

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Abstract
Climate change projections are difficult to use in farm management decision making. Temporal and spatial analogues can complement top down climate change projections. In this paper we investigate the extent that APSIM simulations support the simple notion of finding a run of seasons that was 10% drier or a region that has a 10% drier climate as a proxy for a 10% future drying. We found that within APSIM decreased rainfall could be offset by increased carbon dioxide not only for the mean yield but for the whole distribution from poor seasons to good seasons. Orroroo at the fringe of the grains belt is 17% drier than Booleroo. We found that running APSIM using Booleroo with 17% less rainfall leads to a very similar risk profile of simulated yields as Orroroo in the current climate. We then discuss the broad characteristics of farms in different zones in the SA grains belt. We discuss the strengths and weaknesses of temporal and spatial analogues in the SA grains crop. The end point is not prediction but rather risk management frameworks to consider adaptation options and vulnerabilities.

Key words
Simulation, wheat, risk management

Introduction
One of the goals of Australia's Farming Future program run by DAFF is to work with primary producers to understand the likely impacts of climate change for their enterprise and region. Southern Australia is one of the global regions that show a high degree of inter-model consistency on drying. Climate change projections indicate a relatively narrow range of warming for the SA grains belt in 2030 (0.8 to 1.5°C). Although there is a strong tendency for drying in the models during the winter growing season, there is a wide range of rainfall outcomes with a mid range of about 5% drying but a 1 in 10 chance that the drying will be greater than 10% and some models showing a spring drying of up to 20% (www.climatechangeinAustralia.gov.au).

Three commonly raised problems in applying climate change projections are the uncertainty that stems from different emission scenarios and differing model outcomes; the coarse spatial scale of the global climate models (usually 200km grid) and the coarse temporal scale and distant time periods of 2030 and 2070. These are active areas of research; however the Intergovernmental Panel on Climate Change highlights irreducible uncertainty on both spatial and temporal scales. Even when grain farmers accept the uncertainty there remain difficulties in interpreting how different a 10% decline in rainfall might be to a 15% decline in terms of impacts, adaptation options vulnerabilities.

A complementary approach to the 'top down' projections is to use temporal analogues for future changes. A well known example is the 2003 heatwave in Europe which allowed health researchers, policy makers and the general community to consider the impacts, the causes of resilience and vulnerabilities and adaptation options. A run of very dry seasons on the upper Eyre Peninsula in South Australia was used to identify characteristics of farm enterprises that were sources of resilience (Doudle et al 2009). Ecologists have long used spatial analogues for future changes. Agrogeological zones would be expected to move poleward with a warming and drying trend. Dating back to Goyder in the 1860s the South Australian grains belt has been understood as a transect from 'safe' high to medium rainfall land to low rainfall with extensive grazing and the desert to the north. The medium rainfall to low rainfall zone in South Australia covers a spectrum from intensive cropping with a high frequency of relatively high risk and high return crops such as canola and pulses to increasing proportion of cereal with lower inputs and then grazing enterprise with opportunity cropping. Figure 1 shows grain farms and the annual rainfall isohyets. The two main factors for rainfall in the region are distance from the western coast and topography, especially in the central region.

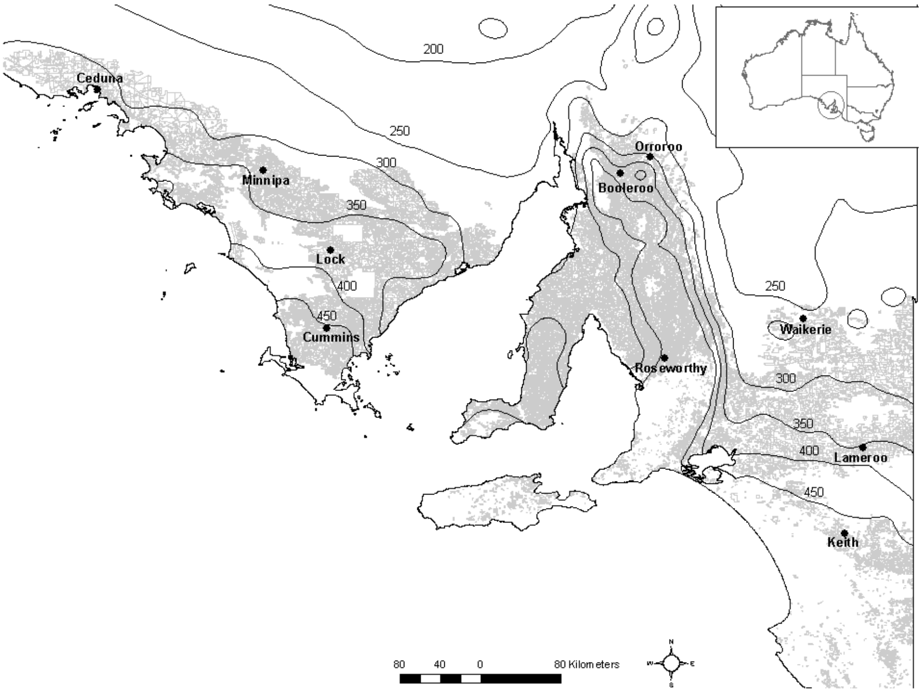

Figure 1. Annual rainfall isohyets for SA grains belt. Grain farms shown with grey shading.

Methods

For both temporal and spatial analogues the challenge is to provide meaningful climate data and analysis. APSIM simulations along transects can be used to combine climate with soils data and management options. In addition to mean wheat yields, APSIM simulations can present a probability distribution which contributes to discussions on risk. Climate data for the simulations came from the SILO database (http://www.nrw.qld.gov.au/silo/) and software within APSIM was used to simulate climate change. Higher carbon dioxide levels are simulated by modifying the transpiration and radiation use efficiency and the historical climate record is perturbed with a rainfall (% change) or temperature factor (degree change). This is consistent with the approach used by Crimp et al 2007. APSIM version 7.1 was used with the same soil in all simulations (available moisture holding capacity of 80mm). A medium maturity wheat cultivar was sown on May 20 each year with soil water reset on May 18. Days to flower were about 140 days and nutrition was non-limiting except in very wet years.

To support discussion between farmers, researchers and policy makers on spatial analogues it is useful to have a framework for summarising some of the key differences. The South Australian grains belt is divided into three broad north-south transects; the Eyre Peninsula, the Northern and Yorke region and the eastern section of the state from the lower South East to the Murray Mallee bound in the north by the Murray river. All these regions run from high rainfall in the south to low rainfall in the north and can be discussed in latitudinal bands of low, medium and high rainfall. The data for this framework came from discussion with farmers and key advisers and should be considered preliminary data. The growing cost data came from the PIRSA gross margin handbook.

Results and Discussion

APSIM simulations

While it is relatively simple to find a spatial or temporal analogue that is 10% drier, there is no analogue in time or space that has higher carbon dioxide levels. Given uncertainty in the level of drying and uncertainty in future levels of carbon dioxide and how these will change transpiration and radiation use efficiency, a convenient simplification would be to consider the trade-off between drying on one hand and carbon dioxide on the other. As shown by Crimp et al 2007, this offset is evident in simulated mean wheat yields. We were not aware of this being shown for the 100 point distribution of yields from poorest to best seasons. Figure 2 shows using Orroroo climate (in upper north of grains belt see Figure 1) that a 10% drying can be off-set by an increase in carbon dioxide across the distribution. The panel on the left shows that this is a reasonably tight relationship on a year by year comparison (in the case of 480ppm, R^2=0.99, root mean square error

(RMSE) 0.19t/ha). To assess future risk profiles a percentile point against percentile point comparison is more instructive than a year by year comparison. As shown in the panel on the right side of Figure 2, the percentile by percentile comparison is a closer fit (RMSE 0.07t/ha).

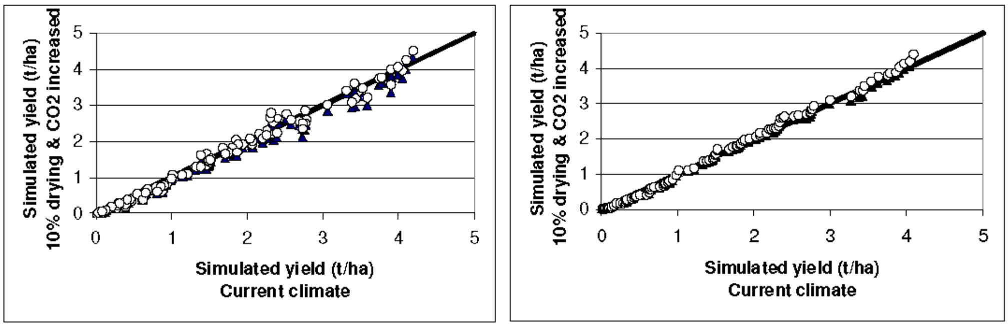

Figure 2: APSIM simulated wheat yields for Orroroo comparing current climate (1900-2009) with a future climate that is 10% drier and CO_2 concentrations of 430 ppm (triangles) and 480 ppm (open circles). The left hand panel is year by year comparisons, the right hand panel shows percentile point comparison.

It is important to note that this analysis had a fixed sowing time, so the emphasis is on water used for crop growth. Under a drier climate there will be less sowing opportunities and there is no carbon dioxide benefit that will off-set the sowing opportunities. Figure 2 shows the relatively small difference between 430 and 480ppm of carbon dioxide. It must also be remembered that this is a simulation analysis and there are many complexities and unknown factors in the response of crops to carbon dioxide fertilisation (Gifford 2004). Nevertheless APSIM is the currently available tool and widely used to investigate questions of carbon dioxide fertilisation (Crimp et al 2008).

Booleroo is about 30km South West from Orroroo. Orroroo gets about 17% less in-crop rainfall than Booleroo. A reasonable question is whether Orroroo is a spatial analogue for Booleroo at 17% less rainfall (or some combination of rainfall reduction and carbon dioxide fertilisation).

Figure 3 shows that on a year by year comparison there is a noisy relationship (R^2=0.76 RMSE 0.45 t/ha) but when this is expressed as a percentile by percentile comparison (shown on the left panel) the relationship is much tighter (R^2=0.99 RMSE 0.12 t/ha). This suggests that using APSIM as an analytical tool for spatial analogues for drying is valid at least within relatively close sites and modest amounts of drying.

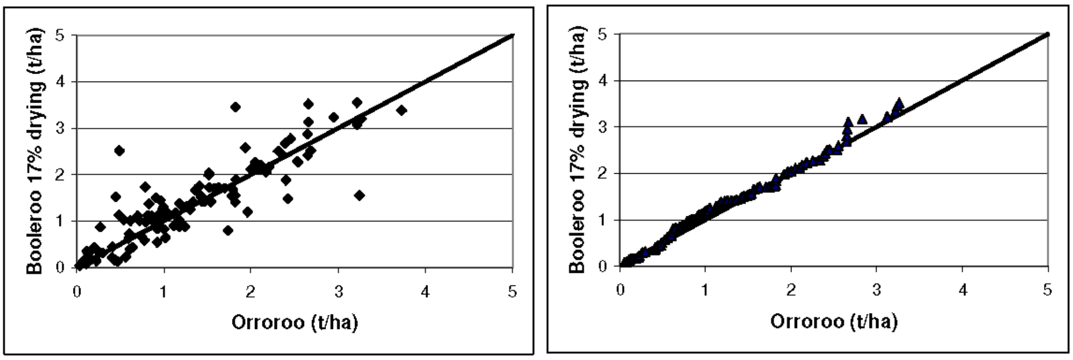

Figure 3: APSIM simulated wheat yields comparing Orroroo climate (1900-2009) to Booleroo climate (1900-2009) with rainfall reduced by 17%. The left hand panel is year by year comparisons, the right hand panel shows percentile point comparison.

Framework comparing regions

Table 1 provides a summary of the characteristics of farming systems in rainfall zones on the Eyre Peninsula. Similar summary tables for the Northern and Yorke region and these allow comparison across rainfall zones. In the Northern and Yorke region land values in the medium and higher rainfall zones are higher due to soil types and proximity to a capital city. In the run of recent poor seasons farmers in the low rainfall regions of the upper north with heavier soils have suffered more than the low rainfall farmers on Eyre Peninsula or Murray Mallee.

Table 1. summary of key characteristics on Eyre Peninsula. Wh = wheat, Bar = barley, FPea = field pea, Cn = Canola, Past = pasture, in most cases volunteer pasture. Farm size and land value are broad estimates with many exceptions.

Rainfall (annual)	Low 300-325	Medium Low 325-375	Medium High 375-450	High 450-600
Typical sequence	Wh-Bar-Past	Wh-Bar-FPea-Past – Wh	Cn-Wh-FPea-Cn-Wh-Bar	Wh-Bar-Lup-Wh Past-Past
Break crops	Very limited	Limited	Canola common	Range of break crops- soil limit rather than climate
Soils	Sandy	Sandy	Heavy soils	Heavy soils, often shallow
Climate limit	Very hot dry springs	Hot dry springs	Sufficient rain to cover high inputs and risky crops	Waterlogging
Dominant constraints & challenges	Low unreliable rainfall and hostile subsoils	Unreliable rainfall, getting crop/stock balance right	Herbicide resistant weeds. High cost structure.	High cost structure, Herbicide resistant weeds and foliar diseases
Farm size (ha)	3,500	2,500	1,500	1,000
Land Value ($/ha)	500	1000	3000	4000
Variable cost ($/ha)	80	120	250	300
Wheat yield (t/ha) Poor Avg Good	03 **1** 1.5	1 **2** 2.5	2 **3** 5	2 **3.5** 5

Discussion with farmers in medium rainfall regions indicate that in recent dry seasons they tend to drop canola and pulse crops from their farming system and rely on cereals and in some cases are running lower input cereal operations like the drier regions. Unless there is a substantial change to the economics of grain farming, a warming drying trend will hasten the trend to fewer, larger farms (Barr 2009). There are some advantages from a drying trend in the wettest parts of the state that currently suffer water-logging.

The use of space as a proxy for time and the use of recent droughts as temporal analogues are useful ways to engage farmers, advisers and policy makers in thinking about climate change. The advantage of temporal analogues is that the soil and farming system is held constant; a limit to this approach is that it is very dependent on the particular run of seasons and how these have interacted with commodity prices. An advantage of spatial analogues is that it allows comparisons of farming systems and this points to some of the system changes that are likely. Spatial analogues must be used carefully as there are many factors other than climate that define a farming system, for example soil types. A feature of many successful low rainfall farming enterprises in recent times has been the use of light textured soils that have much lower amounts of water lost as soil evaporation. The main advantage of spatial and temporal analogues is that farmers and their advisers already use them in their thinking about adaptation. Used thoughtfully, these are simple but powerful tools, and using APSIM as a sophisticated climate analyser we could only find support for this approach.

Acknowledgements

This work is part of DAFF funded Australia's Farming Future and SA PSRF funded TREND program.

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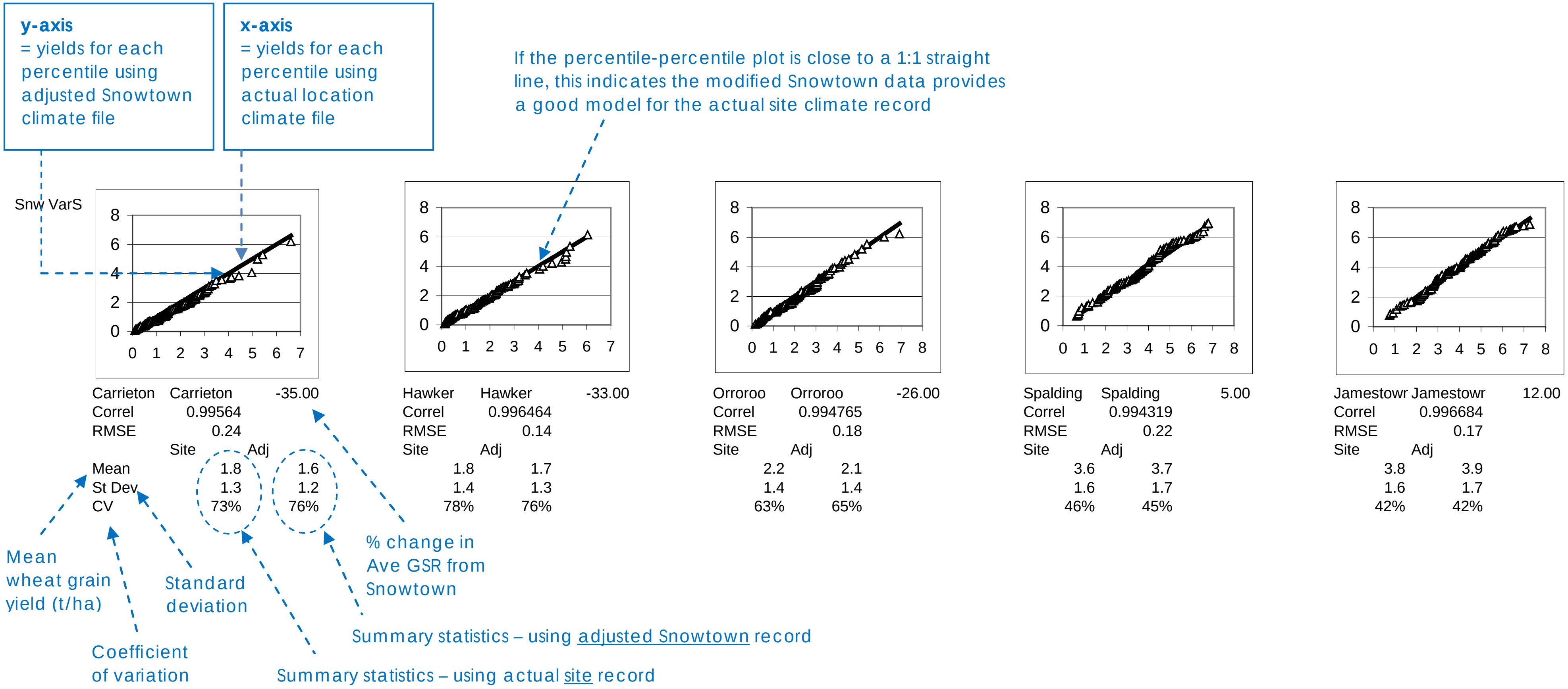
Appendix H – Example SARDI test work results: Using modified climate files to model sites in other regional climate zones

Wheat is mostly grown across a range of average growing season rainfall (Ave GSR) from 200-400 mm. SARDI have found that taking a climate station with a mid range Ave GSR (e.g. Ave GSR of Snowtown = 307 mm) and modifying it (wetter or drier), can provide a good model for predicting crop performance at other sites. From a range of good quality site records that were tested, Snowtown appears to provide a very good base climate file that can be modified (wetter/ drier and cooler/ warmer) to model other locations across the State. The exception to this appears to be more reliable, higher rainfall sites such as around Maitland and Warooka on Yorke Peninsula (YP) which receive better rainfall in low decile rainfall years. In this case, the good quality Maitland climate record provided the base file for modelling reliable, higher rainfall zones on YP.

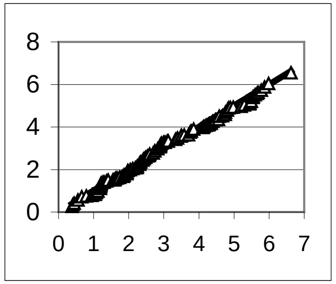
Example test results:

(i) Using Snowtown for Mid-Upper North sites – percentile by percentile comparisons of simulated wheat grain yields.

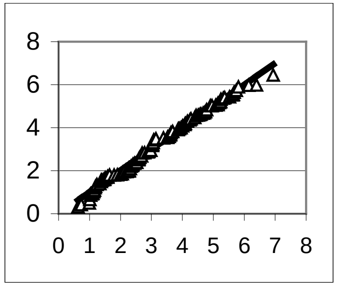


(ii) Using Snowtown for Central sites – percentile by percentile comparisons of simulated wheat grain yields.

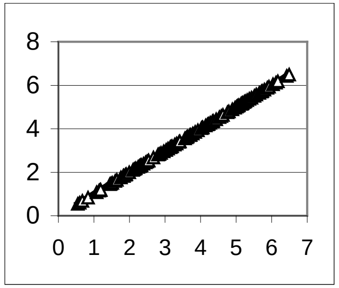
Snw VarS



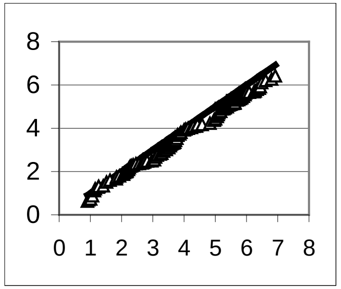
Balaklava	-11	
Correl	0.997	
RMSE	0.14	
Site		Adj
Mean	3.0	2.9
St Dev	1.6	1.6
CV	56%	55%
Skew	0.29	0.2
Kurt	-1.0	-1.0



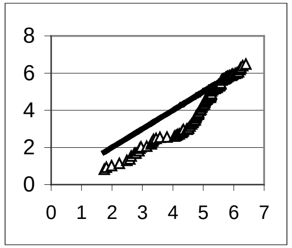
Kadina		-6
Correl		0.995
RMSE		0.16
Site	Adj	
	3.2	3.2
	1.6	1.6
	50%	51%
	0.2	0.1
	-1.0	-1.1



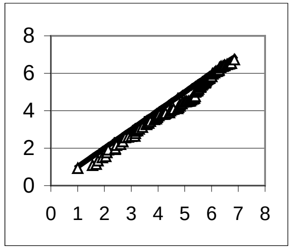
Snowtown		0
Correl		1.000
RMSE		0.00
Site	Adj	
	3.5	3.5
	1.6	1.6
	47%	47%
	0.0	0.0
	-1.1	-1.1



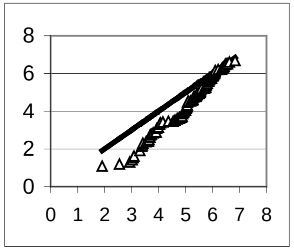
Roseworth		4
Correl		0.997
RMSE		0.34
Site	Adj	
	3.9	3.6
	1.7	1.6
	44%	45%
	-0.2	-0.2
	-1.1	-1.1



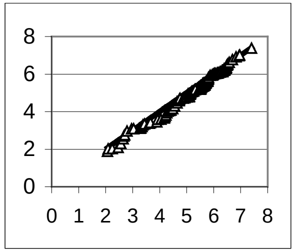
Warooka		15
Correl		0.971
RMSE		0.85
Site	Adj	
	4.7	4.0
	1.2	1.6
	25%	40%
	-1.0	-0.4
	0.2	-0.9



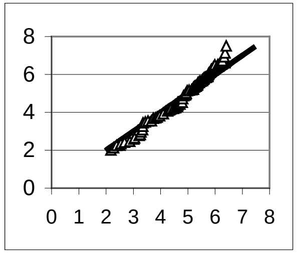
Kapunda		20
Correl		0.994
RMSE		0.37
Site	Adj	
	4.6	4.3
	1.6	1.6
	34%	37%
	-0.7	-0.5
	-0.4	-0.7



Maitland		26
Correl		0.989
RMSE		0.76
Site	Adj	
	5.0	4.4
	1.2	1.5
	23%	35%
	-0.9	-0.6
	0.4	-0.5



Clare		58
Correl		0.995
RMSE		0.21
Site	Adj	
	5.0	4.9
	1.4	1.4
	27%	29%
	-0.8	-0.7
	0.0	-0.3



Parndana		61
Correl		0.993
RMSE		0.29
Site	Adj	
	4.8	4.9
	1.2	1.4
	24%	28%
	-1.0	-0.7
	0.1	-0.3

Appendix I – Preliminary APSIM water balance analyses for four hypothetical soil types – low rainfall pilot study area (from Hayman & Alexander 2010)

During the NYNRM Region pilot project (Liddicoat et al. 2011), preliminary APSIM runs were performed to test and refine the parameters of the 'modelling soil profiles' via close examination of different aspects of crop-soil water balances. This was also undertaken to explore why soils (e.g. light/sandy soils versus heavy/clayey soils) perform differently under varying seasonal conditions. Wheat crop growth in a low rainfall setting (Orroroo) on four hypothetical soil types was simulated: shallow sand, deep sand, shallow clay and deep clay. Aspects of the crop-soil water balance reported included transpiration (which is closely related to shoot biomass and grain yield), soil evaporation, drainage (past the root zone) and runoff (see Figure I-1). Initial yield results were within a realistic range and were consistent with rainfall being the primary driver of yield and biomass.

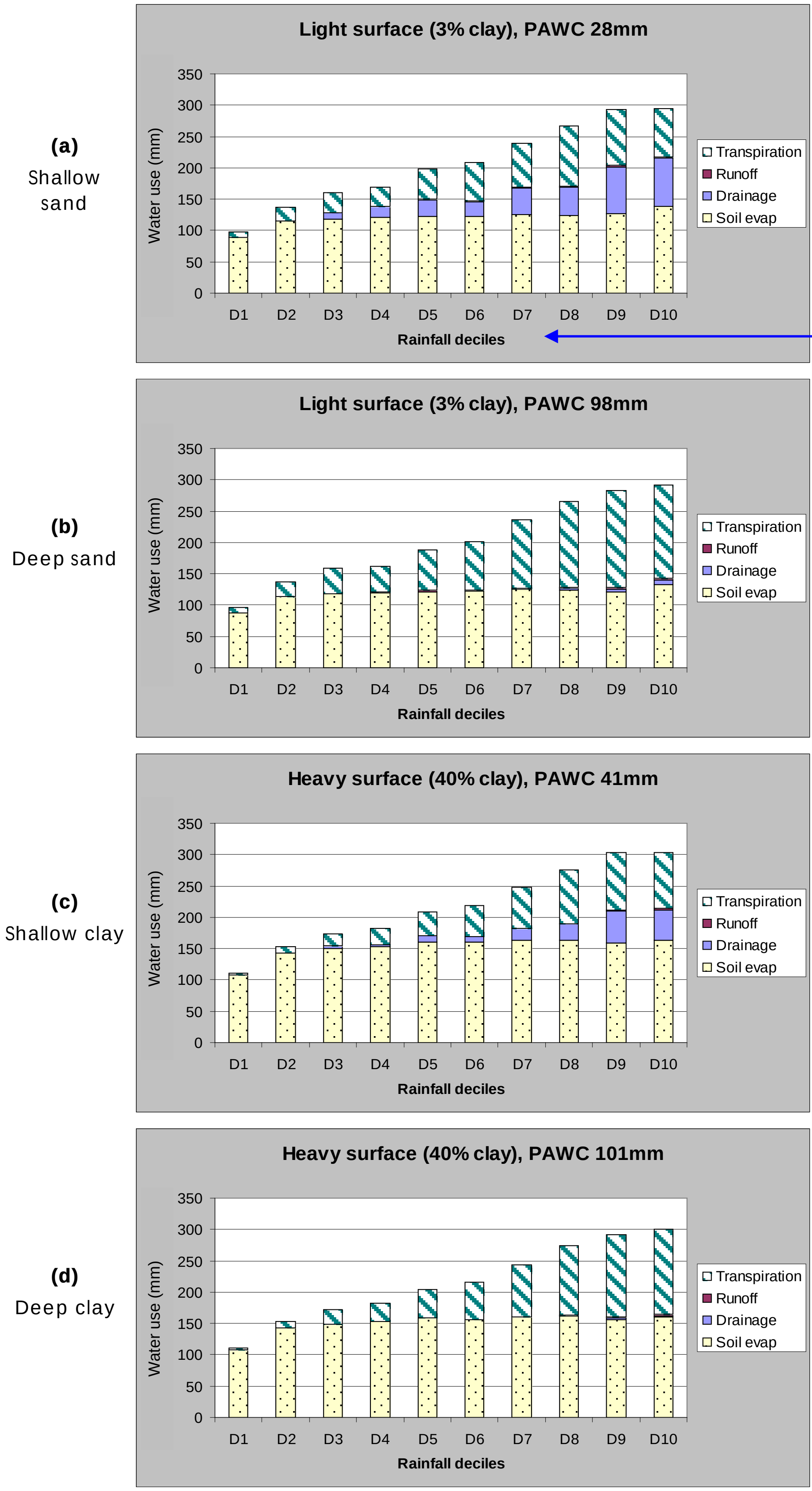
Findings

Preliminary APSIM modelling results from this low rainfall (NYNRM Region pilot project) setting – which were generally consistent with field observations and other water balance studies – suggested that:

- **Soil water evaporation is the main cause of water loss in low rainfall environments** – This is exacerbated in heavier or clayey textured surface soils which store more water in the near surface zone. As evaporation occurs chiefly from the surface layer (largely in the top 10cm as modelled by APSIM) variation in PAWC did not influence the evaporative water loss.

  Clay surface soils lose more water under drying conditions – with moisture loss likely due to a number of factors. Over summer (with warm, dry conditions) evaporation of surface soil water can produce a deficit in soil moisture below the wilting point. Wilting point moisture levels are much greater in clayey soils compared to sandy soils. For germination, more water is required to raise soil moisture levels from evaporative deficit to beyond wilting point (where moisture is available to plants). This relates to the farmer experience that sandy soils will germinate crops sooner, with less rainfall than clayey soils. In dry seasons 10 mm of rainfall will be much more useful on a sandy soil than a clayey one. [Although there can be an artificial impediment to germination in the APSIM model which requires that soil water content in the top layer (assuming 10cm from above) reaches at least wilting point before germination occurs. The field reality may be that field capacity is only reached in the top 5 cm, but that is sufficient to trigger germination resulting in actual crop establishment occurring before the model indicates that it will (N Dalgliesh CSIRO Ecosystem Sciences 2012, pers. comm.)]

  During the season, higher levels of surface soil water evaporation occur in clays because more water is capable of being stored near the surface (~10cm) which is more susceptible to evaporation. [This is likely to be more important prior to canopy closure early in the season. After canopy closure moisture will mostly be lost from the plant structure, with less evaporative loss from the surface soil, so losses will be similar between soil types. (N Dalgliesh CSIRO Ecosystem Sciences 2012, pers. comm.)] In low rainfall environments, less water reaches deeper soil layers in clay than in sandy soils. Higher rates of evaporation and higher wilting point moisture levels in clay surface soils increases the risk of moisture stress and terminal drought, compared to sandy soils (Ludwig & Asseng 2006).
- **Conversely, in dry years low surface clay levels (ie. sandy surface soils) can benefit crop yield and biomass**
- **Drainage occurs in a low percentage of years** – for low rainfall situations and large PAWC soils. Drainage (below the root zone) appears to be a secondary component of water loss, only impacting significantly on shallow soils in higher rainfall years. Soil texture will influence the rate of drainage, but bucket size will be the main factor determining the amount of drainage.
- **Higher rates of drainage occur in shallow soils**
- **Sandy soils can benefit from reduced N leaching with reduced rainfall** – compared to clayey soils which have generally low levels of N leaching. Modelled yields tended to decline for the highest rainfall years in shallow sands, due to the suspected influence of nutrient leaching.
- **In wet years having a bigger bucket size (PAWC) benefits crop yield and biomass** – because more rainfall can be stored in the soil profile.



What are rainfall deciles?

Rainfall totals over any interval (in this case Apr-Oct, or growing season rainfall) are ranked in ascending order, and then split into 10 equally sized groups.

'Decile range 1' (D1) contains the lowest 10% of GSR records. The highest value in this group is termed 'decile 1'. This naming convention continues through decile ranges and decile values 1 to 9. The upper value in 'decile range 10' (D10) is the highest on record.

D1-D3 are representative of 'poor' rainfall years.

D8-D10 are representative of 'good' rainfall years.

D4-D7 can be viewed as 'average' rainfall years.

(Also refer to Fairbanks et al. 2011)

Figure I-1. Distribution of the water balance (transpiration, runoff, drainage, soil evaporation) across growing season (Apr-Oct) rainfall decile ranges for a hypothetical (a) shallow sand, (b) deep sand, (c) shallow clay, (d) deep clay (Hayman and Alexander 2010).

Feedback from regional farming systems consultants

A number of issues were raised in response to the preliminary work, but are difficult to capture within the APSIM modelling:

- **More drainage past the root zone was expected on deep sands**, particularly in wet years (M-A Young, B Hughes, B Mudge Rural Solutions SA 2010, pers. comm.). This may be associated with differences in estimates of PAWC between field situations and the model soils. In other words, for a given field estimate of PAWC the actual soil may have a smaller PAWC (due to root inefficiencies at depth) and lose more water below the root zone than a corresponding 'modelling soil profile'.
- **Duplex soils** (e.g. sand or loam over clay) generally become waterlogged in wet seasons (M Wurst Rural Solutions SA 2010, pers. comm.). This is currently difficult to model due to a lack of available knowledge of the relationship between waterlogging and crop growth (P Hayman SARDI 2010, pers. comm.). Strong texture changes will also tend to impact negatively on root growth and impede soil moisture wicking, which influences evaporative loss (B Hughes Rural Solutions SA 2010, pers. comm.).
- **The out-of-season water balance (ie. stored soil moisture)** is considered of great importance in severely water constrained environments (such as in parts of the low rainfall NYNRM pilot study area). There is reasonable confidence that APSIM can simulate water balance within the growing season, however it is suggested that improvements should be made in modelling the out-of-season water balance. In low rainfall environments, a small change in opening plant-available water can have a major impact on yield. In some soil types (mainly lighter ones in this environment) and particularly under climate change, it is expected that out-of-season moisture will be an important productivity driver and needs to be modelled as accurately as possible (B Mudge Rural Solutions SA 2010, pers. comm.). Research work with Anthony Whitbread (CSIRO) is ongoing to improve understanding of surface and subsoil hydraulic properties, to account for water available from out-of-season rainfall.

Additional comments from Peter Hayman (SARDI)

It is recognised that there is a need to continuously improve crop simulation modelling techniques, and this is an ongoing and evolving process which extends beyond the scope of this project. Other simulation models, such as SWIM (http://www.clw.csiro.au/products/swim/), can be used to study the movement of water in a soil profile, but require a lot more parameters. Some issues raised may limit the consideration of model outputs in some situations. However they generally do not detract from the focus of the study which is to investigate crop growth and soil cover (and potential changes in the frequency of below critical cover) associated with dry years. In interpreting the modelling results, they should not be seen as trying to replicate the behaviour of specific soil types (e.g. a texture contrast soil with a sandy loam surface and clayey subsoil). Rather, results provide a guide to the behaviour of soil groups broadly corresponding to 'modelling soil profiles'.

Appendix J – Tabulated APSIM results: Average Wheat Grain Yield (based on modified Snowtown climate records) [Red = low; green = high]

(i) Simulated long-term average Wheat Grain Yields (kg/ha) – HISTORIC CLIMATE

PAWC (mm)	Ave GSR (mm) \ % Surface Clay	3.75			7.5			15			30		
	Ave GS Temp (°C)	11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5
40	177	1016	1015	982	989	993	952	869	862	828	449	423	364
	187	1124	1141	1115	1097	1118	1085	980	991	956	551	531	479
	197	1233	1268	1247	1206	1244	1219	1091	1121	1084	652	638	594
	207	1341	1394	1380	1314	1369	1353	1202	1250	1212	753	746	709
	217	1431	1497	1496	1405	1472	1469	1299	1357	1334	862	867	836
	227	1521	1600	1613	1495	1574	1586	1395	1463	1456	970	989	963
	237	1611	1704	1729	1586	1677	1702	1492	1570	1578	1079	1111	1090
	247	1701	1807	1845	1677	1780	1819	1588	1677	1699	1187	1232	1217
	257	1790	1910	1961	1767	1883	1935	1685	1783	1821	1296	1354	1344
	267	1845	1964	2030	1822	1940	2005	1750	1852	1905	1385	1449	1444
	277	1899	2018	2098	1876	1997	2076	1816	1921	1988	1474	1543	1544
	287	1953	2071	2167	1930	2054	2146	1881	1990	2071	1564	1638	1644
	297	2007	2125	2235	1985	2111	2216	1947	2059	2154	1653	1733	1743
	307	2061	2179	2304	2039	2168	2287	2012	2128	2238	1742	1828	1843
	317	2078	2203	2330	2058	2192	2315	2037	2158	2275	1785	1875	1909
	327	2095	2227	2356	2077	2217	2343	2062	2189	2313	1827	1923	1975
	337	2112	2251	2383	2096	2241	2371	2087	2220	2351	1870	1970	2041
	347	2129	2275	2409	2114	2266	2399	2111	2251	2389	1912	2018	2106
	357	2145	2300	2435	2133	2290	2427	2136	2281	2427	1955	2066	2172
	367	2141	2306	2434	2130	2298	2428	2136	2296	2433	1973	2102	2206
	377	2136	2312	2434	2126	2306	2430	2136	2311	2439	1991	2139	2240
	387	2131	2318	2433	2123	2314	2431	2137	2326	2445	2009	2176	2274
	397	2127	2324	2432	2119	2322	2433	2137	2340	2451	2027	2212	2308
	407	2122	2331	2431	2116	2330	2434	2137	2355	2457	2045	2249	2343
	417	2114	2319	2415	2109	2319	2418	2132	2349	2448	2055	2264	2359
	427	2106	2307	2399	2103	2308	2403	2127	2343	2440	2065	2279	2375
	437	2098	2296	2383	2096	2297	2387	2122	2336	2432	2075	2294	2391
	447	2090	2284	2367	2090	2286	2372	2117	2330	2423	2084	2309	2407
	457	2082	2272	2351	2083	2275	2356	2112	2324	2415	2094	2324	2423
60	177	1099	1099	1064	1069	1074	1037	934	925	894	480	458	391
	187	1239	1256	1228	1209	1230	1201	1073	1081	1048	598	580	529
	197	1380	1413	1393	1350	1386	1364	1212	1237	1201	716	703	668
	207	1521	1570	1557	1491	1542	1528	1350	1392	1354	834	826	806
	217	1649	1714	1714	1619	1684	1686	1483	1537	1515	974	980	962
	227	1777	1857	1872	1748	1826	1843	1616	1682	1676	1113	1134	1117
	237	1905	2000	2029	1877	1968	2000	1749	1827	1837	1252	1288	1273
	247	2034	2143	2186	2005	2111	2158	1882	1971	1998	1392	1442	1428
	257	2162	2286	2344	2134	2253	2315	2014	2116	2159	1531	1597	1583
	267	2260	2393	2457	2233	2362	2429	2123	2236	2285	1659	1734	1717
	277	2358	2500	2571	2333	2472	2544	2232	2355	2412	1787	1872	1851
	287	2456	2607	2684	2432	2581	2658	2341	2475	2538	1916	2009	1984
	297	2554	2713	2797	2531	2691	2772	2449	2594	2664	2044	2147	2118
	307	2653	2820	2911	2630	2800	2887	2558	2714	2791	2172	2284	2252
	317	2708	2881	2975	2685	2862	2953	2617	2782	2864	2245	2363	2352
	327	2762	2942	3040	2739	2923	3020	2675	2851	2938	2318	2441	2453
	337	2817	3003	3105	2794	2985	3087	2734	2919	3011	2390	2520	2553
	347	2872	3063	3169	2849	3046	3154	2792	2988	3084	2463	2598	2654
	357	2927	3124	3234	2903	3108	3220	2851	3057	3158	2536	2677	2754
	367	2956	3169	3268	2933	3153	3255	2884	3106	3200	2585	2746	2818
	377	2985	3214	3302	2962	3198	3290	2916	3155	3241	2633	2816	2882
	387	3014	3259	3336	2992	3243	3325	2949	3204	3283	2682	2886	2947
	397	3042	3304	3370	3022	3288	3360	2982	3253	3325	2730	2955	3011
	407	3071	3349	3404	3051	3333	3395	3014	3302	3366	2779	3025	3075
	417	3080	3369	3423	3062	3353	3414	3030	3326	3390	2810	3068	3120
	427	3088	3388	3442	3073	3373	3433	3046	3350	3413	2841	3111	3165
	437	3097	3408	3461	3083	3394	3452	3062	3374	3437	2873	3154	3209
	447	3106	3428	3480	3094	3414	3471	3078	3398	3461	2904	3197	3254
	457	3115	3447	3499	3105	3435	3489	3093	3422	3484	2935	3240	3299
80	177	1127	1121	1090	1096	1098	1064	952	940	908	483	461	393
	187	1284	1294	1269	1254	1269	1242	1105	1109	1075	609	591	538
	197	1441	1468	1448	1412	1441	1420	1258	1279	1243	735	722	683
	207	1599	1641	1627	1570	1612	1598	1412	1448	1410	862	853	828
	217	1750	1809	1804	1722	1780	1775	1566	1617	1589	1017	1026	998
	227	1901	1977	1980	1873	1947	1952	1720	1786	1768	1173	1198	1168
	237	2053	2146	2156	2025	2115	2130	1874	1954	1947	1329	1371	1337
	247	2204	2314	2333	2176	2282	2307	2028	2123	2126	1485	1544	1507
	257	2356	2482	2509	2328	2450	2484	2182	2292	2305	1640	1717	1677
	267	2476	2614	2639	2450	2585	2616	2314	2435	2450	1791	1873	1825
	277	2596	2747	2769	2571	2720	2747	2446	2578	2594	1942	2029	1973
	287	2716	2879	2900	2693	2856	2879	2578	2721	2738	2093	2185	2121
	297	2836	3011	3030	2814	2991	3010	2710	2865	2883	2244	2341	2268
	307	2956	3143	3160	2936	3126	3142	2842	3008	3027	2395	2498	2416
	317	3022	3222	3237	3002	3205	3220	2913	3095	3112	2481	2597	2531
	327	3088	3301	3315	3068	3284	3298	2984	3183	3197	2567	2696	2645
	337	3155	3380	3392	3134	3363	3376	3055	3271	3281	2654	2796	2760
	347	3221	3459	3469	3200	3442	3454	3127	3358	3366	2740	2895	2874
	357	3287	3538	3547	3266	3521	3533	3198	3446	3451	2826	2995	2989
	367	3329	3589	3601	3309	3573	3588	3246	3503	3510	2888	3075	3063
	377	3372	3641	3655	3352	3624	3643	3293	3561	3569	2950	3154	3136
	387	3414	3692	3710	3394	3676	3699	3341	3619	3628	3012	3234	3210
	397	3457	3744	3764	3437	3728	3754	3389	3676	3687	3074	3314	3284
	407	3499	3795	3818	3480	3780	3809	3437	3734	3746	3136	3394	3357
	417	3517	3817	3849	3499	3803	3840	3460	3761	3783	3182	3441	3417
	427	3535	3839	3880	3518	3826	3871	3484	3789	3821	3229	3488	3477
	437	3552	3861	3911	3537	3849	3902	3507	3816	3858	3276	3535	3537
	447	3570	3883	3942	3557	3871	3933	3531	3844	3896	3323	3581	3597
	457	3588	3905	3973	3576	3894	3964	3554	3871	3933	3369	3628	3656
120	177	1139	1134	1096	1110	1106	1068	955	938	904	479	456	385
	187	1307	1317	1279	1277	1289	1251	1117	1118	1078	605	588	530
	197	1474	1499	1462	1444	1472	1434	1279	1298	1252	731	720	675
	207	1642	1681	1644	1612	1655	1616	1441	1477	1426	857	851	820
	217	1821	1875	1838	1792	1848	1811	1620	1667	1616	1042	1040	992
	227	2000	2068	2032	1971	2041	2006	1799	1856	1807	1227	1228	1165
	237	2178	2261	2225	2151	2234	2200	1978	2046	1998	1412	1417	1338
	247	2357	2454	2419	2331	2427	2395	2157	2235	2188	1597	1605	1510
	257	2536	2647	2613	2511	2619	2590	2337	2424	2379	1781	1794	1683
	267	2691	2798	2765	2667	2772	2743	2501	2586	2545	1949	1960	1852
	277	2845	2948	2917	2823	2925	2896	2665	2748	2710	2117	2126	2020
	287	3000	3098	3070	2980	3078	3050	2829	2910	2876	2285	2292	2189
	297	3155	3248	3222	3136	3230	3203	2993	3071	3042	2453	2458	2358
	307	3310	3398	3374	3292	3383	3356	3157	3233	3207	2621	2623	2527
	317	3396	3496	3467	3380	3481	3450	3253	3340	3308	2731	2741	2655
	327	3483	3594	3559	3468	3579	3544	3348	3446	3408	2841	2858	2784
	337	3570	3692	3652	3555	3677	3638	3444	3553	3509	2952	2976	2913
	347	3657	3790	3745	3643	3775	3732	3540	3660	3610	3062	3093	3042
	357	3744	3887	3837	3731	3873	3826	3635	3766	3710	3173	3211	3170
	367	3807	3949	3911	3794	3935	3901	3703	3835	3790	3262	3303	3258
	377	3870	4010	3984	3857	3998	3976	3771	3905	3869	3350	3395	3345
	387	3932	4071	4058	3920	4060	4050	3839	3974	3949	3439	3487	3433
	397	3995	4133	4132	3983	4122	4125	3908	4043	4029	3528	3579	3520
	407	4058	4194	4205	4046	4184	4200	3976	4113	4108	3616	3671	3608
	417	4084	4224	4233	4074	4216	4228	4010	4149	4143	3679	3723	3666
	427	4110	4254	4261	4101	4247	4256	4045	4186	4177	3741	3776	3724
	437	4137	4285	4289	4129	4278	4285	4080	4222	4212	3804	3829	3782
	447	4163	4315	4317	4157	4310	4313	4115	4259	4247	3866	3882	3841
	457	4189	4345	4345	4185	4341	4341	4149	4295	4281	3929	3935	3899

(ii) Simulated long-term average Wheat Grain Yields (kg/ha) – CLIMATE CHANGE: 5% REDUCED RAINFALL

% Surface Clay		3.75			7.5			15			30		
PAWC (mm)	Ave GSR (mm) \ Ave GS Temp (°C)	11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5
40	177	1012	975	904	989	946	883	844	804	739	390	323	270
	187	1152	1123	1047	1127	1093	1023	986	947	874	503	444	382
	197	1293	1271	1190	1266	1240	1162	1128	1091	1009	616	564	495
	207	1433	1419	1333	1404	1387	1301	1271	1235	1144	729	685	607
	217	1542	1544	1453	1514	1512	1423	1387	1366	1276	854	815	733
	227	1651	1669	1574	1623	1638	1546	1503	1498	1408	979	945	860
	237	1760	1794	1695	1733	1764	1668	1619	1629	1540	1103	1075	986
	247	1870	1919	1816	1842	1890	1790	1735	1760	1673	1228	1206	1113
	257	1979	2044	1937	1952	2015	1913	1851	1892	1805	1352	1336	1240
	267	2038	2119	2012	2014	2092	1990	1921	1980	1886	1449	1441	1336
	277	2097	2194	2088	2076	2169	2067	1992	2068	1968	1547	1546	1433
	287	2157	2269	2164	2138	2246	2144	2062	2156	2049	1644	1652	1530
	297	2216	2344	2240	2200	2323	2221	2133	2245	2131	1741	1757	1627
	307	2276	2419	2315	2261	2400	2298	2204	2333	2212	1838	1862	1723
	317	2302	2445	2350	2289	2428	2334	2239	2373	2260	1895	1940	1797
	327	2329	2471	2385	2316	2456	2370	2274	2412	2309	1952	2018	1870
	337	2355	2497	2419	2343	2484	2405	2309	2452	2357	2009	2096	1943
	347	2382	2524	2454	2370	2512	2441	2345	2492	2405	2066	2174	2016
	357	2409	2550	2489	2397	2541	2477	2380	2532	2453	2123	2252	2089
	367	2417	2554	2503	2408	2546	2494	2399	2543	2477	2160	2281	2134
	377	2426	2557	2518	2419	2551	2510	2418	2554	2500	2197	2311	2179
	387	2434	2561	2532	2430	2556	2527	2437	2566	2523	2235	2341	2224
	397	2443	2564	2547	2441	2561	2543	2456	2577	2546	2272	2371	2269
	407	2452	2568	2562	2451	2566	2560	2475	2588	2569	2309	2401	2314
	417	2438	2550	2555	2438	2550	2555	2466	2578	2570	2326	2423	2349
	427	2425	2531	2548	2425	2533	2550	2456	2568	2571	2342	2445	2383
	437	2412	2513	2541	2412	2517	2546	2447	2557	2571	2359	2467	2418
	447	2398	2495	2535	2399	2500	2541	2438	2547	2572	2376	2489	2453
	457	2385	2476	2528	2386	2484	2536	2429	2537	2573	2392	2511	2487
60	177	1081	1040	976	1058	1014	953	896	858	789	412	338	283
	187	1252	1222	1145	1226	1194	1120	1062	1027	947	540	477	409
	197	1423	1404	1314	1394	1373	1286	1229	1196	1105	667	617	535
	207	1594	1585	1483	1562	1553	1453	1395	1365	1263	795	756	661
	217	1743	1750	1645	1711	1718	1615	1548	1534	1432	950	915	814
	227	1892	1915	1807	1860	1883	1778	1701	1704	1601	1105	1073	966
	237	2041	2079	1969	2008	2048	1941	1854	1873	1770	1260	1232	1119
	247	2191	2244	2131	2157	2213	2104	2007	2042	1938	1415	1390	1272
	257	2340	2409	2293	2306	2378	2267	2160	2212	2107	1570	1548	1425
	267	2454	2527	2406	2423	2497	2381	2283	2342	2224	1709	1689	1553
	277	2568	2645	2519	2540	2616	2495	2407	2472	2341	1847	1829	1680
	287	2683	2763	2632	2656	2736	2609	2530	2603	2458	1986	1969	1808
	297	2797	2881	2744	2773	2855	2723	2653	2733	2575	2124	2109	1936
	307	2911	2999	2857	2890	2974	2837	2777	2863	2691	2263	2249	2063
	317	2975	3067	2926	2955	3043	2907	2850	2940	2774	2353	2362	2172
	327	3040	3134	2995	3019	3112	2977	2924	3016	2856	2444	2475	2280
	337	3104	3201	3065	3084	3181	3047	2997	3093	2938	2535	2588	2389
	347	3168	3269	3134	3148	3250	3117	3071	3169	3020	2625	2700	2497
	357	3233	3336	3203	3212	3319	3187	3144	3246	3103	2716	2813	2606
	367	3281	3376	3261	3261	3361	3247	3200	3295	3167	2786	2872	2683
	377	3329	3417	3320	3310	3402	3307	3257	3344	3232	2857	2930	2760
	387	3377	3457	3378	3358	3443	3367	3313	3393	3297	2927	2989	2837
	397	3425	3497	3437	3407	3485	3427	3369	3442	3362	2998	3048	2914
	407	3473	3537	3495	3456	3526	3487	3425	3491	3427	3068	3106	2991
	417	3491	3557	3522	3473	3545	3515	3444	3514	3461	3112	3157	3051
	427	3508	3576	3550	3491	3565	3542	3464	3538	3495	3157	3207	3111
	437	3525	3595	3577	3509	3585	3570	3483	3561	3529	3201	3257	3171
	447	3542	3614	3605	3527	3604	3598	3502	3584	3563	3245	3307	3231
	457	3559	3634	3632	3545	3624	3626	3522	3607	3597	3290	3357	3291

% Surface Clay		3.75			7.5			15			30		
PAWC (mm)	Ave GSR (mm) \ Ave GS Temp (°C)	11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5
80	177	1095	1057	984	1072	1028	962	902	861	792	414	338	283
	187	1281	1253	1161	1255	1222	1136	1082	1044	956	546	483	412
	197	1467	1448	1339	1437	1416	1310	1263	1227	1120	679	627	542
	207	1652	1644	1516	1620	1611	1484	1444	1410	1284	811	771	671
	217	1825	1825	1694	1793	1793	1663	1619	1595	1466	982	941	830
	227	1998	2007	1871	1967	1976	1842	1794	1780	1648	1154	1112	988
	237	2171	2188	2049	2140	2158	2021	1969	1965	1830	1325	1282	1147
	247	2344	2370	2226	2314	2341	2200	2145	2150	2011	1496	1453	1305
	257	2517	2551	2403	2487	2523	2379	2320	2335	2193	1667	1623	1464
	267	2656	2684	2535	2628	2657	2512	2466	2480	2330	1825	1775	1610
	277	2795	2817	2666	2769	2792	2645	2612	2625	2467	1982	1927	1756
	287	2934	2950	2797	2911	2926	2777	2758	2770	2604	2139	2079	1902
	297	3073	3083	2928	3052	3060	2910	2904	2915	2740	2297	2232	2048
	307	3212	3216	3060	3193	3194	3043	3050	3060	2877	2454	2384	2194
	317	3290	3297	3142	3271	3277	3127	3138	3149	2973	2562	2511	2316
	327	3368	3378	3225	3348	3360	3210	3226	3238	3069	2669	2639	2438
	337	3446	3460	3307	3426	3442	3294	3315	3327	3164	2777	2766	2560
	347	3524	3541	3390	3503	3525	3378	3403	3416	3260	2885	2893	2682
	357	3602	3622	3472	3581	3607	3461	3492	3505	3356	2993	3021	2804
	367	3661	3680	3545	3641	3666	3535	3559	3569	3434	3075	3087	2894
	377	3720	3738	3618	3701	3724	3608	3626	3632	3511	3158	3153	2984
	387	3779	3796	3691	3761	3782	3682	3693	3696	3589	3241	3220	3074
	397	3837	3854	3764	3821	3841	3755	3760	3759	3667	3323	3286	3164
	407	3896	3912	3837	3881	3899	3828	3827	3823	3744	3406	3352	3254
	417	3919	3944	3870	3904	3932	3861	3853	3863	3783	3456	3417	3319
	427	3941	3977	3902	3927	3965	3894	3879	3903	3823	3507	3481	3384
	437	3963	4009	3935	3949	3999	3927	3905	3942	3862	3557	3545	3449
	447	3986	4041	3968	3972	4032	3960	3931	3982	3901	3608	3609	3514
	457	4008	4073	4000	3995	4065	3993	3957	4022	3940	3658	3674	3579
120	177	1103	1059	983	1076	1027	963	901	855	791	408	333	276
	187	1293	1258	1160	1266	1226	1137	1086	1043	954	539	475	404
	197	1484	1456	1337	1456	1426	1311	1272	1230	1117	670	618	533
	207	1674	1655	1514	1646	1626	1485	1458	1417	1280	801	760	661
	217	1866	1845	1700	1838	1816	1672	1650	1607	1468	989	931	820
	227	2059	2034	1886	2031	2007	1860	1841	1796	1655	1176	1102	980
	237	2251	2223	2072	2223	2197	2048	2033	1986	1843	1364	1273	1139
	247	2444	2413	2258	2415	2388	2235	2225	2175	2030	1551	1444	1299
	257	2636	2602	2445	2608	2579	2423	2417	2365	2218	1739	1615	1458
	267	2793	2758	2592	2768	2735	2572	2581	2531	2369	1896	1779	1616
	277	2951	2913	2739	2928	2891	2721	2745	2698	2520	2053	1943	1773
	287	3108	3069	2886	3087	3048	2870	2909	2864	2670	2210	2107	1931
	297	3266	3224	3033	3247	3204	3019	3074	3031	2821	2367	2271	2089
	307	3423	3379	3180	3407	3361	3169	3238	3197	2972	2524	2436	2246
	317	3520	3476	3274	3504	3459	3263	3344	3302	3079	2653	2577	2373
	327	3616	3572	3368	3601	3557	3358	3450	3407	3185	2782	2719	2499
	337	3713	3669	3462	3697	3656	3452	3557	3512	3292	2912	2861	2625
	347	3809	3766	3556	3794	3754	3546	3663	3617	3398	3041	3003	2752
	357	3906	3862	3650	3891	3852	3641	3769	3722	3505	3170	3145	2878
	367	3971	3939	3736	3958	3930	3728	3844	3803	3597	3259	3230	2989
	377	4037	4016	3822	4024	4007	3815	3919	3885	3690	3348	3314	3101
	387	4102	4093	3908	4091	4084	3903	3994	3966	3782	3438	3398	3213
	397	4168	4170	3994	4158	4161	3990	4068	4047	3874	3527	3483	3325
	407	4233	4247	4080	4224	4238	4077	4143	4129	3967	3616	3567	3436
	417	4266	4280	4116	4258	4273	4113	4180	4171	4011	3676	3632	3510
	427	4299	4313	4151	4292	4307	4149	4217	4213	4056	3736	3698	3584
	437	4333	4346	4187	4326	4341	4184	4255	4255	4100	3795	3763	3658
	447	4366	4380	4222	4359	4376	4220	4292	4297	4144	3855	3829	3732
	457	4399	4413	4258	4393	4410	4255	4329	4338	4189	3915	3894	3806

(iii) Simulated long-term average Wheat Grain Yields (kg/ha) – CLIMATE CHANGE: 10% REDUCED RAINFALL

% Surface Clay		3.75			7.5			15			30		
PAWC (mm)	**Ave GSR (mm)**	**Ave GS Temp (°C) 11.5**	**13.0**	**14.5**	**11.5**	**13.0**	**14.5**	**11.5**	**13.0**	**14.5**	**11.5**	**13.0**	**14.5**
40	177	887	845	770	860	819	754	721	677	619	286	223	181
	187	1020	986	912	993	959	892	854	814	754	391	327	278
	197	1154	1128	1054	1125	1098	1029	986	951	889	497	430	376
	207	1288	1269	1196	1257	1238	1167	1119	1088	1024	603	533	474
	217	1394	1389	1312	1364	1359	1285	1236	1215	1145	713	650	590
	227	1500	1510	1429	1472	1480	1403	1353	1342	1267	824	768	705
	237	1606	1630	1545	1579	1601	1521	1469	1469	1388	934	885	821
	247	1712	1751	1662	1686	1721	1639	1586	1595	1510	1045	1002	937
	257	1818	1871	1779	1794	1842	1757	1702	1722	1632	1155	1120	1052
	267	1892	1964	1865	1868	1936	1844	1781	1822	1723	1258	1237	1157
	277	1966	2057	1952	1943	2030	1931	1859	1921	1813	1361	1355	1261
	287	2040	2150	2038	2017	2124	2019	1937	2020	1904	1464	1473	1366
	297	2114	2243	2125	2091	2218	2106	2015	2120	1995	1567	1591	1470
	307	2188	2336	2211	2166	2313	2193	2093	2219	2086	1670	1709	1575
	317	2224	2374	2258	2204	2352	2239	2140	2271	2146	1751	1800	1657
	327	2261	2412	2304	2242	2392	2286	2188	2323	2207	1832	1891	1740
	337	2297	2449	2350	2281	2432	2333	2235	2375	2267	1913	1982	1822
	347	2334	2487	2397	2319	2472	2379	2283	2427	2327	1993	2073	1905
	357	2370	2525	2443	2357	2512	2426	2331	2479	2387	2074	2164	1987
	367	2385	2536	2464	2374	2524	2449	2354	2500	2417	2107	2201	2039
	377	2400	2547	2485	2390	2536	2472	2378	2521	2447	2140	2238	2091
	387	2415	2557	2506	2406	2548	2496	2402	2542	2478	2173	2276	2144
	397	2430	2568	2528	2423	2560	2519	2425	2563	2508	2206	2313	2196
	407	2445	2579	2549	2439	2572	2542	2449	2584	2538	2239	2350	2248
	417	2439	2568	2550	2435	2563	2546	2450	2580	2547	2267	2376	2282
	427	2434	2558	2552	2431	2554	2550	2451	2576	2557	2294	2401	2315
	437	2428	2547	2554	2427	2545	2554	2452	2572	2566	2321	2427	2349
	447	2423	2536	2556	2423	2536	2558	2453	2568	2576	2348	2452	2383
	457	2417	2525	2557	2419	2527	2562	2454	2564	2585	2376	2478	2416
60	177	934	894	820	909	867	801	753	711	646	299	234	188
	187	1093	1060	983	1065	1032	962	906	867	802	415	351	293
	197	1252	1227	1147	1221	1197	1123	1059	1024	957	531	467	399
	207	1411	1393	1311	1377	1362	1284	1212	1180	1112	647	584	504
	217	1550	1549	1460	1517	1518	1434	1360	1341	1263	780	724	643
	227	1689	1704	1609	1657	1674	1584	1508	1502	1413	912	864	782
	237	1828	1860	1758	1798	1830	1734	1657	1662	1564	1045	1005	921
	247	1968	2016	1906	1938	1986	1884	1805	1823	1714	1177	1145	1060
	257	2107	2172	2055	2078	2142	2034	1953	1984	1864	1310	1285	1199
	267	2235	2307	2186	2207	2277	2164	2080	2123	1996	1454	1436	1330
	277	2362	2441	2316	2335	2412	2294	2206	2262	2127	1598	1586	1460
	287	2490	2576	2447	2463	2546	2424	2333	2401	2259	1743	1736	1591
	297	2618	2711	2577	2592	2681	2554	2460	2541	2390	1887	1887	1721
	307	2746	2845	2708	2720	2816	2685	2586	2680	2522	2031	2037	1852
	317	2823	2926	2787	2798	2899	2765	2677	2770	2614	2149	2166	1973
	327	2901	3007	2866	2877	2981	2845	2767	2860	2707	2266	2294	2093
	337	2978	3088	2946	2955	3064	2925	2857	2950	2799	2384	2423	2214
	347	3056	3168	3025	3033	3147	3005	2947	3040	2891	2501	2551	2335
	357	3133	3249	3104	3111	3229	3086	3038	3130	2984	2619	2680	2456
	367	3182	3294	3159	3161	3275	3142	3094	3185	3046	2679	2742	2534
	377	3231	3338	3214	3211	3321	3198	3150	3239	3109	2740	2804	2612
	387	3280	3382	3269	3261	3367	3255	3206	3294	3172	2800	2867	2689
	397	3329	3427	3324	3311	3413	3311	3262	3349	3235	2861	2929	2767
	407	3378	3471	3379	3361	3459	3367	3318	3403	3297	2921	2991	2845
	417	3407	3494	3419	3390	3483	3408	3349	3433	3344	2978	3044	2908
	427	3435	3518	3459	3418	3507	3449	3381	3462	3391	3035	3097	2972
	437	3463	3541	3499	3447	3530	3490	3412	3491	3438	3092	3150	3035
	447	3492	3564	3539	3476	3554	3531	3444	3520	3484	3149	3203	3098
	457	3520	3587	3579	3505	3578	3572	3475	3550	3531	3207	3256	3162
80	177	940	899	824	914	869	803	755	711	645	299	234	188
	187	1111	1076	994	1082	1046	972	918	876	808	418	352	295
	197	1282	1253	1165	1250	1223	1141	1080	1041	970	536	471	402
	207	1453	1430	1336	1418	1400	1310	1243	1207	1133	655	590	509
	217	1611	1602	1494	1578	1572	1469	1407	1380	1288	800	741	653
	227	1770	1774	1652	1738	1744	1628	1571	1554	1443	946	892	797
	237	1928	1947	1811	1898	1916	1787	1735	1727	1598	1091	1043	940
	247	2087	2119	1969	2057	2088	1946	1900	1901	1752	1237	1194	1084
	257	2245	2292	2127	2217	2260	2105	2064	2075	1907	1382	1346	1228
	267	2398	2439	2279	2371	2409	2258	2215	2229	2063	1547	1506	1370
	277	2550	2586	2432	2524	2558	2410	2366	2384	2219	1712	1667	1512
	287	2703	2734	2584	2677	2707	2563	2517	2538	2375	1877	1828	1654
	297	2855	2881	2737	2830	2856	2715	2668	2693	2531	2042	1989	1796
	307	3008	3029	2889	2984	3005	2868	2819	2847	2687	2206	2149	1937
	317	3104	3125	2982	3081	3102	2963	2930	2953	2794	2340	2293	2077
	327	3200	3221	3075	3178	3199	3057	3040	3058	2900	2473	2436	2216
	337	3297	3317	3168	3276	3297	3152	3151	3164	3007	2606	2579	2355
	347	3393	3413	3261	3373	3394	3247	3261	3269	3114	2740	2722	2494
	357	3489	3509	3354	3470	3491	3342	3372	3374	3221	2873	2865	2634
	367	3549	3566	3423	3531	3548	3411	3439	3438	3296	2947	2936	2723
	377	3610	3622	3491	3591	3605	3480	3506	3502	3371	3020	3008	2813
	387	3670	3679	3559	3652	3662	3549	3573	3566	3447	3094	3079	2902
	397	3730	3735	3628	3712	3719	3618	3640	3630	3522	3168	3150	2992
	407	3790	3791	3696	3773	3776	3686	3707	3694	3597	3242	3221	3082
	417	3826	3835	3746	3809	3821	3737	3747	3743	3652	3307	3286	3155
	427	3862	3878	3797	3846	3866	3787	3788	3791	3707	3372	3350	3229
	437	3898	3921	3847	3882	3911	3838	3828	3840	3762	3438	3414	3302
	447	3934	3964	3897	3919	3956	3888	3869	3889	3817	3503	3478	3375
	457	3970	4007	3947	3955	4001	3938	3909	3938	3872	3568	3542	3449
120	177	941	897	824	914	869	805	749	707	641	288	226	183
	187	1116	1078	997	1089	1051	975	916	874	804	408	347	292
	197	1292	1259	1169	1263	1232	1144	1084	1040	967	527	468	401
	207	1467	1440	1341	1438	1413	1314	1251	1206	1131	647	589	510
	217	1643	1614	1505	1614	1587	1479	1431	1381	1289	801	742	652
	227	1819	1788	1669	1791	1760	1645	1610	1555	1448	956	895	794
	237	1995	1962	1833	1968	1934	1810	1789	1730	1606	1110	1048	936
	247	2171	2136	1997	2145	2108	1975	1969	1904	1765	1264	1201	1078
	257	2347	2310	2161	2322	2281	2141	2148	2079	1923	1419	1354	1220
	267	2516	2482	2325	2491	2456	2306	2313	2256	2091	1586	1517	1376
	277	2684	2655	2489	2661	2631	2472	2477	2434	2258	1753	1680	1532
	287	2853	2827	2654	2831	2805	2638	2641	2611	2425	1920	1842	1688
	297	3022	3000	2818	3000	2980	2803	2806	2789	2593	2087	2005	1844
	307	3190	3172	2982	3170	3155	2969	2970	2966	2760	2254	2168	2001
	317	3304	3283	3087	3284	3268	3075	3100	3087	2877	2409	2334	2143
	327	3418	3395	3192	3399	3380	3180	3229	3208	2995	2564	2501	2285
	337	3532	3506	3298	3514	3493	3286	3358	3329	3112	2718	2668	2427
	347	3645	3618	3403	3628	3605	3392	3488	3449	3230	2873	2835	2570
	357	3759	3729	3508	3743	3718	3497	3617	3570	3347	3028	3001	2712
	367	3833	3800	3592	3818	3789	3582	3697	3648	3436	3114	3080	2807
	377	3906	3870	3676	3892	3860	3667	3778	3725	3525	3201	3158	2902
	387	3979	3941	3761	3967	3931	3752	3858	3803	3614	3288	3237	2997
	397	4053	4012	3845	4042	4003	3837	3938	3881	3702	3375	3316	3093
	407	4126	4082	3929	4116	4074	3922	4018	3958	3791	3462	3394	3188
	417	4168	4135	3981	4157	4128	3975	4065	4018	3855	3530	3468	3283
	427	4209	4189	4033	4199	4181	4028	4112	4078	3919	3598	3541	3378
	437	4250	4242	4085	4240	4235	4081	4158	4138	3982	3666	3615	3474
	447	4291	4295	4137	4281	4289	4133	4205	4198	4046	3734	3688	3569
	457	4332	4348	4189	4322	4342	4186	4251	4258	4109	3802	3762	3664

(iv) Simulated long-term average Wheat Grain Yields (kg/ha) – CLIMATE CHANGE: 20% REDUCED RAINFALL

PAWC (mm)	Ave GSR (mm)	3.75			7.5			15			30			% Surface Clay / Ave GS Temp (°C)
		11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	
40	177	614	572	511	590	550	494	461	411	362	124	98	84	
	187	733	691	627	709	667	610	575	527	474	202	164	135	
	197	853	811	743	827	785	726	689	644	586	280	231	185	
	207	973	931	859	946	902	842	803	761	697	358	297	236	
	217	1088	1054	981	1061	1025	961	922	882	815	454	400	333	
	227	1203	1177	1102	1176	1148	1081	1040	1003	932	550	503	431	
	237	1319	1300	1224	1292	1271	1200	1159	1123	1049	647	606	529	
	247	1434	1424	1346	1407	1394	1319	1277	1244	1166	743	709	626	
	257	1549	1547	1467	1522	1517	1439	1396	1365	1283	839	812	724	
	267	1635	1646	1561	1608	1617	1533	1487	1470	1387	942	917	827	
	277	1721	1746	1655	1694	1716	1628	1578	1576	1491	1044	1021	930	
	287	1807	1845	1749	1780	1816	1723	1669	1681	1596	1147	1126	1033	
	297	1893	1945	1843	1866	1916	1818	1760	1786	1700	1250	1231	1136	
	307	1979	2044	1937	1952	2015	1913	1851	1892	1805	1352	1336	1240	
	317	2032	2113	2004	2007	2086	1983	1913	1971	1876	1437	1428	1323	
	327	2085	2181	2072	2062	2156	2053	1975	2050	1947	1521	1520	1406	
	337	2139	2249	2139	2117	2227	2123	2038	2129	2019	1606	1613	1489	
	347	2192	2318	2207	2172	2297	2193	2100	2209	2090	1690	1705	1572	
	357	2245	2386	2274	2227	2368	2264	2162	2288	2161	1775	1797	1655	
	367	2272	2415	2310	2255	2398	2298	2198	2329	2209	1836	1874	1726	
	377	2299	2444	2346	2283	2429	2333	2234	2370	2257	1897	1950	1797	
	387	2326	2473	2382	2310	2459	2367	2270	2411	2305	1958	2027	1868	
	397	2353	2502	2417	2338	2489	2402	2306	2452	2353	2020	2103	1939	
	407	2380	2531	2453	2366	2520	2437	2342	2493	2401	2081	2180	2010	
	417	2393	2541	2472	2380	2530	2458	2364	2511	2429	2112	2214	2057	
	427	2406	2550	2491	2395	2541	2479	2385	2530	2456	2144	2248	2105	
	437	2419	2560	2510	2410	2551	2500	2406	2548	2483	2176	2282	2153	
	447	2432	2570	2530	2424	2562	2521	2428	2566	2511	2208	2316	2200	
	457	2445	2579	2549	2439	2572	2542	2449	2584	2538	2239	2350	2248	
60	177	631	583	520	609	561	503	472	417	367	127	100	86	
	187	766	720	655	742	696	637	597	547	491	210	171	139	
	197	900	856	790	875	830	772	722	678	616	293	241	193	
	207	1035	993	925	1009	965	906	847	809	740	376	311	246	
	217	1177	1143	1067	1150	1114	1046	988	952	876	487	432	358	
	227	1319	1292	1209	1291	1264	1187	1130	1096	1011	598	552	470	
	237	1461	1442	1351	1432	1414	1327	1271	1239	1147	708	673	582	
	247	1603	1592	1493	1573	1563	1468	1412	1383	1282	819	793	694	
	257	1745	1741	1636	1714	1713	1608	1554	1526	1418	929	914	807	
	267	1864	1875	1767	1832	1846	1740	1675	1663	1556	1058	1041	930	
	277	1983	2008	1898	1951	1979	1872	1796	1800	1694	1186	1168	1054	
	287	2102	2142	2030	2069	2112	2003	1918	1937	1832	1314	1295	1178	
	297	2221	2275	2161	2187	2245	2135	2039	2075	1969	1442	1421	1301	
	307	2340	2409	2293	2306	2378	2267	2160	2212	2107	1570	1548	1425	
	317	2442	2515	2393	2409	2486	2370	2269	2328	2210	1691	1672	1536	
	327	2543	2622	2494	2513	2594	2473	2378	2444	2313	1811	1796	1646	
	337	2645	2728	2594	2617	2702	2575	2487	2560	2416	1931	1919	1756	
	347	2747	2835	2695	2720	2811	2678	2596	2676	2519	2052	2043	1867	
	357	2849	2941	2795	2824	2919	2781	2705	2793	2622	2172	2167	1977	
	367	2910	3007	2861	2885	2985	2846	2776	2865	2699	2263	2274	2079	
	377	2970	3072	2927	2947	3050	2911	2847	2937	2776	2355	2381	2181	
	387	3031	3137	2992	3008	3116	2976	2918	3010	2854	2446	2488	2283	
	397	3092	3202	3058	3070	3182	3041	2989	3082	2931	2538	2595	2385	
	407	3153	3267	3124	3131	3248	3106	3060	3155	3008	2629	2702	2487	
	417	3198	3308	3175	3177	3290	3158	3112	3204	3066	2687	2760	2558	
	427	3243	3349	3226	3223	3333	3210	3163	3254	3124	2746	2818	2630	
	437	3288	3390	3277	3269	3375	3263	3215	3304	3182	2804	2876	2702	
	447	3333	3430	3328	3315	3417	3315	3266	3354	3240	2862	2933	2773	
	457	3378	3471	3379	3361	3459	3367	3318	3403	3297	2921	2991	2845	

PAWC (mm)	Ave GSR (mm)	3.75			7.5			15			30			% Surface Clay / Ave GS Temp (°C)
		11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	
80	177	629	583	518	608	561	502	472	415	365	127	100	86	
	187	768	723	655	745	698	638	599	547	490	210	171	139	
	197	906	864	793	882	835	774	725	679	616	294	241	193	
	207	1044	1004	930	1019	973	911	852	810	741	377	311	246	
	217	1199	1167	1080	1173	1136	1058	1004	966	881	494	438	361	
	227	1353	1330	1229	1326	1299	1206	1156	1121	1022	611	564	476	
	237	1508	1492	1378	1480	1462	1354	1308	1276	1162	728	690	591	
	247	1662	1655	1528	1633	1625	1501	1461	1432	1303	844	817	706	
	257	1817	1818	1677	1787	1788	1649	1613	1587	1443	961	943	821	
	267	1957	1965	1823	1927	1935	1795	1754	1737	1593	1103	1079	950	
	277	2097	2111	1968	2067	2082	1941	1896	1886	1743	1244	1215	1078	
	287	2237	2258	2113	2207	2229	2087	2037	2036	1893	1385	1351	1207	
	297	2377	2405	2258	2347	2376	2233	2179	2185	2043	1526	1487	1335	
	307	2517	2551	2403	2487	2523	2379	2320	2335	2193	1667	1623	1464	
	317	2642	2669	2520	2614	2643	2499	2450	2463	2314	1806	1756	1589	
	327	2768	2787	2637	2740	2763	2618	2579	2591	2434	1945	1889	1714	
	337	2893	2905	2754	2867	2883	2737	2709	2718	2555	2083	2023	1838	
	347	3018	3023	2871	2994	3004	2857	2839	2846	2675	2222	2156	1963	
	357	3144	3141	2988	3120	3124	2976	2969	2974	2795	2360	2289	2088	
	367	3217	3220	3065	3195	3202	3054	3055	3059	2886	2466	2410	2204	
	377	3290	3298	3143	3269	3280	3132	3141	3145	2977	2571	2531	2321	
	387	3364	3376	3221	3343	3358	3209	3227	3230	3068	2677	2651	2437	
	397	3437	3454	3299	3417	3437	3287	3313	3315	3159	2782	2772	2554	
	407	3511	3532	3377	3491	3515	3364	3400	3401	3250	2888	2893	2670	
	417	3567	3584	3441	3548	3567	3429	3461	3459	3319	2958	2958	2752	
	427	3623	3636	3505	3604	3619	3493	3522	3518	3389	3029	3024	2835	
	437	3678	3688	3569	3660	3672	3558	3584	3577	3458	3100	3090	2917	
	447	3734	3740	3632	3716	3724	3622	3645	3635	3528	3171	3156	2999	
	457	3790	3791	3696	3773	3776	3686	3707	3694	3597	3242	3221	3082	
120	177	628	583	521	609	562	504	467	411	361	123	97	83	
	187	768	723	657	746	698	639	593	543	488	205	166	135	
	197	909	863	793	884	835	775	720	674	614	287	235	187	
	207	1049	1003	929	1022	971	911	847	806	740	369	304	239	
	217	1212	1169	1079	1184	1137	1060	1006	964	879	487	430	354	
	227	1374	1334	1229	1346	1303	1208	1166	1122	1018	604	556	469	
	237	1537	1500	1379	1509	1469	1356	1325	1280	1156	721	682	584	
	247	1700	1666	1529	1671	1636	1505	1484	1438	1295	839	807	698	
	257	1863	1831	1679	1834	1802	1653	1644	1596	1434	956	933	813	
	267	2017	1985	1832	1988	1957	1807	1798	1750	1591	1113	1069	942	
	277	2172	2140	1985	2143	2112	1961	1953	1904	1747	1269	1206	1071	
	287	2327	2294	2138	2298	2268	2115	2108	2057	1904	1426	1342	1200	
	297	2481	2448	2291	2453	2423	2269	2263	2211	2061	1583	1478	1329	
	307	2636	2602	2445	2608	2579	2423	2417	2365	2218	1739	1615	1458	
	317	2778	2741	2575	2752	2719	2557	2563	2513	2351	1873	1757	1593	
	327	2920	2879	2706	2896	2859	2691	2709	2661	2485	2007	1900	1728	
	337	3062	3017	2837	3041	2999	2825	2854	2808	2618	2141	2042	1863	
	347	3204	3156	2967	3185	3140	2959	3000	2956	2752	2276	2185	1998	
	357	3347	3294	3098	3329	3280	3093	3146	3104	2885	2410	2327	2133	
	367	3435	3387	3185	3418	3373	3179	3246	3204	2984	2537	2468	2257	
	377	3523	3480	3272	3506	3466	3265	3347	3303	3084	2664	2610	2380	
	387	3612	3572	3359	3595	3560	3351	3447	3403	3183	2791	2751	2504	
	397	3700	3665	3446	3684	3653	3437	3548	3503	3282	2918	2892	2628	
	407	3788	3758	3534	3772	3746	3523	3648	3602	3381	3045	3034	2752	
	417	3856	3822	3613	3841	3812	3603	3722	3674	3463	3128	3106	2839	
	427	3924	3887	3692	3910	3877	3683	3796	3745	3545	3212	3178	2926	
	437	3991	3952	3771	3979	3943	3763	3870	3816	3627	3295	3250	3014	
	447	4059	4017	3850	4047	4008	3843	3944	3887	3709	3378	3322	3101	
	457	4126	4082	3929	4116	4074	3922	4018	3958	3791	3462	3394	3188	

Appendix K – Tabulated APSIM results: Average Post-Harvest Biomass (based on modified Snowtown climate records) [Red = low; green = high]

(i) Simulated long-term average Post-Harvest Biomass (kg/ha) – HISTORIC CLIMATE

PAWC (mm)	Ave GSR (mm)	% Surface Clay 3.75			7.5			15			30		
	Ave GS Temp (°C)	11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5
40	177	4095	3790	3326	4038	3732	3271	3609	3300	2858	1828	1562	1262
	187	4421	4106	3615	4371	4053	3563	3960	3636	3162	2200	1927	1588
	197	4747	4422	3903	4703	4374	3856	4312	3972	3465	2573	2292	1914
	207	5074	4737	4191	5036	4695	4149	4664	4308	3768	2945	2658	2240
	217	5294	4989	4424	5258	4948	4385	4921	4588	4029	3299	3003	2550
	227	5514	5240	4657	5480	5200	4621	5178	4868	4289	3653	3349	2861
	237	5733	5492	4890	5703	5453	4858	5435	5147	4550	4008	3695	3172
	247	5953	5743	5123	5925	5706	5094	5692	5427	4810	4362	4040	3482
	257	6173	5995	5356	6147	5958	5330	5949	5707	5071	4716	4386	3793
	267	6280	6145	5513	6258	6113	5488	6093	5894	5253	4945	4637	4019
	277	6387	6296	5669	6369	6267	5646	6237	6082	5436	5173	4887	4244
	287	6493	6447	5825	6480	6421	5804	6381	6269	5618	5402	5138	4470
	297	6600	6597	5981	6591	6575	5962	6525	6456	5801	5630	5389	4696
	307	6707	6748	6138	6702	6729	6121	6669	6644	5984	5859	5639	4921
	317	6763	6819	6228	6761	6803	6213	6739	6735	6090	5971	5782	5079
	327	6819	6889	6318	6820	6878	6306	6809	6825	6196	6084	5925	5237
	337	6876	6959	6407	6879	6952	6398	6879	6916	6303	6196	6067	5395
	347	6932	7030	6497	6938	7026	6491	6949	7007	6409	6309	6210	5553
	357	6989	7100	6587	6997	7100	6583	7019	7098	6516	6421	6352	5711
	367	7015	7127	6655	7026	7130	6655	7057	7137	6599	6503	6456	5844
	377	7041	7153	6723	7054	7159	6726	7096	7176	6683	6585	6560	5976
	387	7067	7180	6791	7083	7188	6798	7134	7214	6766	6666	6664	6108
	397	7093	7207	6859	7112	7217	6869	7173	7253	6850	6748	6768	6240
	407	7119	7233	6928	7141	7246	6940	7211	7292	6933	6830	6871	6372
	417	7102	7238	6961	7127	7254	6974	7208	7307	6976	6861	6915	6448
	427	7086	7243	6994	7113	7261	7009	7204	7323	7019	6892	6959	6524
	437	7070	7248	7027	7099	7268	7043	7201	7339	7062	6922	7003	6600
	447	7053	7252	7060	7085	7275	7077	7197	7354	7105	6953	7046	6676
	457	7037	7257	7093	7071	7282	7111	7194	7370	7148	6984	7090	6753
60	177	4352	4011	3482	4295	3956	3427	3805	3471	2978	1922	1641	1313
	187	4766	4397	3823	4715	4346	3773	4232	3862	3324	2344	2054	1672
	197	5179	4783	4165	5135	4736	4119	4658	4254	3671	2766	2467	2030
	207	5593	5170	4507	5555	5126	4465	5085	4646	4017	3188	2880	2388
	217	5917	5495	4799	5881	5454	4760	5446	5006	4335	3628	3290	2749
	227	6242	5821	5090	6207	5782	5054	5807	5366	4654	4069	3700	3110
	237	6567	6147	5382	6533	6111	5348	6168	5727	4972	4510	4109	3471
	247	6891	6473	5673	6859	6439	5642	6529	6087	5291	4951	4519	3832
	257	7216	6798	5965	7185	6767	5937	6890	6447	5610	5391	4929	4193
	267	7408	7008	6154	7380	6980	6129	7113	6686	5829	5708	5248	4476
	277	7599	7218	6343	7575	7192	6322	7336	6924	6048	6025	5567	4758
	287	7791	7427	6532	7771	7404	6514	7559	7162	6267	6341	5887	5041
	297	7983	7637	6721	7966	7616	6707	7782	7400	6486	6658	6206	5324
	307	8174	7846	6910	8162	7828	6900	8004	7639	6705	6975	6525	5606
	317	8294	7994	7043	8282	7977	7034	8140	7803	6853	7141	6720	5796
	327	8413	8141	7177	8402	8126	7169	8276	7968	7001	7308	6915	5986
	337	8532	8288	7311	8522	8275	7303	8412	8132	7150	7475	7109	6176
	347	8651	8436	7444	8642	8423	7438	8547	8297	7298	7642	7304	6366
	357	8770	8583	7578	8762	8572	7573	8683	8461	7446	7809	7499	6556
	367	8871	8688	7691	8862	8677	7685	8788	8574	7568	7959	7673	6724
	377	8972	8792	7804	8962	8782	7798	8894	8686	7691	8109	7847	6891
	387	9073	8897	7917	9062	8887	7911	8999	8798	7813	8260	8021	7059
	397	9174	9001	8030	9162	8992	8024	9104	8911	7936	8410	8195	7226
	407	9275	9106	8143	9263	9097	8137	9209	9023	8058	8561	8369	7394
	417	9336	9166	8216	9325	9157	8210	9279	9092	8137	8652	8461	7507
	427	9397	9225	8290	9388	9217	8283	9348	9160	8215	8742	8552	7620
	437	9457	9285	8364	9451	9277	8356	9417	9229	8294	8833	8643	7733
	447	9518	9344	8437	9513	9337	8430	9486	9297	8372	8924	8734	7846
	457	9579	9404	8511	9576	9397	8503	9555	9366	8451	9015	8825	7960

PAWC (mm)	Ave GSR (mm)	% Surface Clay 3.75			7.5			15			30		
	Ave GS Temp (°C)	11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5
80	177	4420	4049	3497	4369	4000	3445	3854	3493	2986	1934	1647	1317
	187	4870	4461	3856	4824	4414	3808	4312	3908	3345	2380	2073	1685
	197	5320	4872	4214	5280	4828	4171	4770	4322	3704	2827	2498	2052
	207	5770	5284	4573	5735	5242	4533	5228	4737	4063	3274	2924	2419
	217	6150	5657	4912	6116	5619	4876	5637	5139	4423	3751	3363	2802
	227	6529	6031	5251	6496	5995	5218	6046	5540	4782	4229	3803	3186
	237	6908	6404	5589	6877	6371	5560	6455	5941	5142	4706	4242	3570
	247	7287	6777	5928	7258	6747	5902	6864	6343	5502	5183	4681	3954
	257	7667	7151	6267	7639	7123	6245	7273	6744	5861	5661	5121	4338
	267	7896	7391	6484	7872	7367	6465	7538	7021	6112	6013	5479	4653
	277	8125	7631	6701	8104	7610	6685	7803	7297	6362	6366	5838	4969
	287	8354	7872	6918	8336	7853	6905	8068	7573	6612	6718	6196	5285
	297	8583	8112	7135	8569	8097	7125	8333	7849	6862	7071	6555	5600
	307	8812	8352	7352	8801	8340	7345	8598	8126	7113	7424	6913	5916
	317	8973	8523	7505	8963	8513	7500	8774	8311	7283	7637	7137	6139
	327	9134	8694	7659	9125	8685	7655	8951	8497	7453	7851	7360	6362
	337	9294	8865	7813	9287	8857	7810	9128	8683	7624	8065	7584	6585
	347	9455	9036	7966	9449	9030	7965	9305	8868	7794	8279	7807	6808
	357	9616	9208	8120	9611	9202	8120	9482	9054	7964	8493	8031	7031
	367	9737	9335	8234	9731	9329	8234	9610	9190	8091	8665	8226	7216
	377	9858	9462	8348	9851	9456	8347	9738	9326	8219	8838	8420	7401
	387	9980	9589	8462	9970	9584	8460	9867	9461	8346	9010	8615	7586
	397	10101	9717	8576	10090	9711	8573	9995	9597	8473	9183	8810	7771
	407	10223	9844	8690	10210	9838	8686	10123	9733	8600	9355	9005	7956
	417	10299	9933	8760	10288	9926	8756	10208	9830	8675	9465	9129	8066
	427	10375	10021	8831	10366	10015	8826	10292	9927	8750	9574	9252	8177
	437	10451	10110	8902	10444	10103	8895	10377	10024	8824	9683	9376	8287
	447	10527	10199	8972	10522	10192	8965	10461	10122	8899	9792	9500	8397
	457	10604	10287	9043	10600	10280	9035	10545	10219	8974	9902	9624	8507
120	177	4423	4048	3492	4372	3999	3444	3833	3477	2972	1915	1626	1289
	187	4895	4473	3867	4853	4428	3823	4312	3903	3341	2360	2050	1656
	197	5368	4898	4241	5334	4857	4202	4791	4328	3710	2805	2475	2024
	207	5841	5322	4616	5814	5286	4581	5270	4754	4079	3250	2900	2391
	217	6274	5738	4976	6249	5705	4944	5727	5190	4460	3774	3361	2793
	227	6708	6154	5336	6683	6124	5307	6183	5627	4841	4298	3821	3194
	237	7142	6570	5697	7118	6542	5670	6640	6063	5222	4822	4281	3596
	247	7575	6986	6057	7552	6961	6033	7097	6500	5603	5346	4742	3998
	257	8009	7401	6417	7987	7379	6396	7554	6936	5984	5870	5202	4399
	267	8307	7703	6681	8288	7684	6662	7884	7271	6275	6268	5617	4741
	277	8605	8005	6945	8589	7990	6929	8214	7605	6566	6666	6032	5083
	287	8902	8307	7208	8890	8295	7195	8544	7940	6857	7063	6447	5424
	297	9200	8609	7472	9191	8600	7461	8874	8274	7147	7461	6862	5766
	307	9498	8911	7736	9492	8905	7727	9204	8609	7438	7859	7277	6108
	317	9720	9123	7913	9716	9119	7906	9440	8839	7632	8130	7542	6357
	327	9943	9334	8090	9939	9333	8084	9676	9069	7826	8401	7808	6607
	337	10165	9546	8266	10163	9546	8262	9913	9299	8020	8672	8074	6857
	347	10388	9758	8443	10387	9760	8441	10149	9529	8214	8943	8340	7107
	357	10610	9969	8620	10611	9974	8619	10385	9759	8408	9214	8606	7357
	367	10777	10135	8740	10775	10139	8740	10561	9934	8546	9444	8855	7578
	377	10943	10301	8860	10940	10304	8860	10737	10109	8683	9673	9104	7800
	387	11109	10467	8980	11105	10470	8981	10913	10284	8821	9903	9353	8021
	397	11275	10633	9100	11269	10635	9102	11088	10459	8958	10133	9602	8242
	407	11441	10799	9220	11434	10800	9223	11264	10634	9096	10363	9851	8464
	417	11547	10907	9315	11541	10907	9316	11379	10751	9193	10518	9994	8579
	427	11653	11016	9409	11649	11015	9410	11494	10868	9291	10673	10137	8693
	437	11758	11124	9504	11757	11122	9504	11609	10985	9388	10829	10280	8808
	447	11864	11233	9598	11864	11229	9597	11723	11102	9485	10984	10423	8923
	457	11969	11341	9692	11972	11336	9691	11838	11219	9583	11140	10566	9038

(ii) Simulated long-term average Post-Harvest Biomass (kg/ha) – CLIMATE CHANGE: 5% REDUCED RAINFALL

PAWC (mm)	Ave GSR (mm)	3.75			7.5			15			30			% Surface Clay
		11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	Ave GS Temp (°C)
40	177	3856	3387	2858	3805	3345	2825	3291	2849	2373	1438	1160	906	
	187	4225	3729	3154	4170	3682	3117	3688	3211	2680	1838	1505	1185	
	197	4594	4071	3449	4536	4019	3408	4085	3573	2987	2239	1850	1464	
	207	4963	4413	3745	4902	4357	3700	4482	3934	3294	2639	2195	1743	
	217	5237	4666	3976	5179	4615	3934	4789	4222	3549	3002	2523	2033	
	227	5511	4920	4208	5457	4874	4167	5096	4510	3804	3365	2851	2324	
	237	5786	5173	4439	5734	5133	4401	5403	4798	4060	3728	3180	2614	
	247	6060	5427	4671	6012	5391	4635	5710	5086	4315	4091	3508	2904	
	257	6334	5680	4903	6289	5650	4869	6017	5374	4570	4454	3836	3194	
	267	6500	5861	5079	6460	5833	5049	6217	5573	4766	4734	4090	3409	
	277	6666	6041	5256	6630	6017	5229	6417	5773	4962	5013	4345	3624	
	287	6832	6222	5433	6801	6200	5410	6617	5973	5158	5293	4600	3839	
	297	6998	6403	5610	6971	6384	5590	6817	6173	5354	5572	4854	4054	
	307	7164	6583	5787	7142	6567	5770	7017	6373	5550	5851	5109	4270	
	317	7242	6684	5887	7223	6670	5871	7120	6497	5671	6018	5293	4453	
	327	7320	6785	5987	7304	6772	5972	7224	6621	5791	6184	5477	4636	
	337	7398	6886	6087	7386	6874	6074	7328	6745	5912	6350	5661	4819	
	347	7476	6987	6187	7467	6977	6175	7431	6869	6033	6517	5845	5002	
	357	7554	7088	6287	7548	7079	6276	7535	6993	6154	6683	6029	5185	
	367	7592	7167	6373	7591	7162	6364	7588	7088	6250	6777	6168	5312	
	377	7630	7246	6458	7633	7244	6452	7641	7183	6346	6872	6306	5440	
	387	7668	7324	6544	7675	7327	6541	7694	7277	6441	6966	6445	5567	
	397	7706	7403	6630	7717	7410	6629	7748	7372	6537	7060	6583	5695	
	407	7744	7481	6715	7760	7493	6717	7801	7467	6633	7155	6722	5822	
	417	7748	7514	6761	7766	7527	6764	7814	7510	6691	7224	6816	5942	
	427	7753	7547	6807	7773	7561	6811	7827	7554	6748	7293	6909	6062	
	437	7757	7580	6853	7779	7596	6858	7841	7597	6806	7361	7003	6182	
	447	7761	7613	6899	7786	7630	6905	7854	7640	6863	7430	7096	6301	
	457	7766	7645	6945	7792	7665	6952	7867	7684	6920	7499	7190	6421	
60	177	4034	3506	2942	3989	3474	2919	3428	2946	2445	1486	1198	945	
	187	4475	3904	3283	4425	3864	3253	3881	3348	2781	1931	1571	1242	
	197	4916	4302	3624	4861	4254	3587	4334	3750	3117	2376	1943	1540	
	207	5358	4700	3966	5297	4644	3921	4787	4151	3453	2821	2316	1837	
	217	5717	5021	4240	5661	4971	4199	5178	4503	3754	3246	2690	2166	
	227	6076	5343	4515	6025	5298	4477	5569	4855	4055	3671	3064	2496	
	237	6435	5665	4790	6389	5624	4755	5959	5207	4356	4096	3438	2825	
	247	6795	5987	5064	6753	5951	5033	6350	5559	4657	4521	3812	3154	
	257	7154	6309	5339	7116	6278	5311	6741	5910	4957	4945	4187	3483	
	267	7384	6533	5540	7349	6505	5515	7002	6159	5181	5302	4507	3736	
	277	7614	6757	5740	7583	6733	5719	7262	6407	5404	5659	4827	3989	
	287	7844	6981	5941	7816	6960	5923	7522	6655	5627	6016	5148	4242	
	297	8074	7206	6141	8049	7188	6127	7783	6904	5850	6373	5468	4495	
	307	8304	7430	6342	8282	7415	6331	8043	7152	6074	6730	5789	4748	
	317	8465	7581	6463	8445	7568	6453	8225	7322	6215	6960	6019	4955	
	327	8626	7733	6584	8608	7721	6576	8408	7493	6356	7190	6248	5162	
	337	8787	7884	6705	8772	7874	6698	8590	7664	6497	7420	6478	5369	
	347	8949	8036	6826	8935	8026	6821	8772	7834	6638	7650	6707	5576	
	357	9110	8187	6948	9098	8179	6943	8954	8005	6780	7880	6937	5783	
	367	9234	8323	7043	9223	8315	7038	9090	8156	6887	8045	7110	5931	
	377	9358	8458	7138	9348	8451	7133	9225	8306	6994	8209	7283	6080	
	387	9483	8594	7233	9473	8587	7228	9361	8457	7101	8373	7456	6229	
	397	9607	8729	7329	9598	8723	7323	9496	8608	7208	8537	7630	6377	
	407	9731	8864	7424	9722	8860	7418	9632	8759	7315	8701	7803	6526	
	417	9798	8943	7484	9789	8938	7478	9705	8843	7381	8825	7953	6657	
	427	9865	9021	7544	9856	9016	7538	9778	8927	7446	8949	8102	6789	
	437	9931	9099	7604	9923	9094	7599	9851	9011	7511	9073	8252	6920	
	447	9998	9178	7664	9989	9172	7659	9924	9096	7577	9197	8402	7052	
	457	10064	9256	7724	10056	9250	7719	9997	9180	7642	9321	8552	7183	

PAWC (mm)	Ave GSR (mm)	3.75			7.5			15			30			% Surface Clay
		11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	Ave GS Temp (°C)
80	177	4056	3509	2947	4015	3483	2922	3438	2949	2445	1488	1198	944	
	187	4521	3926	3308	4474	3891	3277	3912	3364	2796	1942	1576	1246	
	197	4985	4342	3669	4934	4299	3633	4385	3779	3147	2397	1954	1547	
	207	5450	4759	4030	5393	4707	3989	4859	4195	3498	2851	2332	1849	
	217	5857	5123	4332	5804	5076	4294	5290	4582	3822	3305	2730	2194	
	227	6263	5487	4634	6215	5445	4599	5722	4969	4147	3759	3129	2539	
	237	6670	5852	4935	6626	5815	4904	6154	5356	4472	4213	3527	2884	
	247	7076	6216	5237	7037	6184	5209	6585	5743	4797	4666	3925	3229	
	257	7483	6580	5539	7449	6553	5513	7017	6130	5122	5120	4323	3574	
	267	7751	6841	5759	7720	6818	5737	7319	6417	5365	5513	4679	3846	
	277	8019	7102	5979	7992	7082	5960	7622	6704	5609	5906	5035	4118	
	287	8287	7363	6199	8264	7347	6184	7924	6992	5852	6298	5391	4390	
	297	8555	7624	6419	8535	7611	6407	8226	7279	6095	6691	5748	4662	
	307	8823	7884	6640	8807	7876	6630	8529	7566	6339	7084	6104	4934	
	317	9013	8060	6775	8999	8052	6767	8740	7765	6499	7352	6367	5161	
	327	9203	8235	6910	9191	8229	6904	8952	7965	6660	7620	6629	5389	
	337	9393	8410	7046	9384	8405	7040	9164	8164	6820	7887	6892	5616	
	347	9583	8585	7181	9576	8582	7177	9376	8364	6981	8155	7155	5843	
	357	9773	8761	7316	9768	8758	7313	9587	8563	7141	8423	7418	6071	
	367	9927	8909	7416	9922	8907	7414	9751	8727	7250	8618	7624	6236	
	377	10081	9058	7516	10076	9057	7514	9915	8891	7360	8813	7829	6402	
	387	10235	9207	7616	10229	9206	7615	10079	9055	7469	9008	8035	6567	
	397	10389	9356	7716	10383	9355	7715	10243	9220	7578	9203	8241	6733	
	407	10543	9504	7815	10537	9504	7816	10407	9384	7687	9398	8447	6898	
	417	10638	9582	7877	10631	9580	7878	10510	9468	7758	9550	8594	7032	
	427	10732	9660	7939	10725	9656	7939	10613	9552	7829	9703	8742	7166	
	437	10827	9737	8001	10819	9732	8001	10716	9636	7899	9855	8889	7300	
	447	10921	9815	8063	10913	9808	8062	10818	9720	7970	10007	9036	7434	
	457	11016	9892	8125	11008	9884	8124	10921	9804	8041	10160	9183	7567	
120	177	4040	3498	2942	4005	3477	2922	3416	2931	2434	1460	1171	917	
	187	4520	3925	3311	4479	3895	3284	3898	3352	2788	1910	1547	1216	
	197	5000	4352	3680	4954	4313	3645	4380	3773	3142	2360	1923	1516	
	207	5481	4779	4049	5429	4730	4007	4862	4194	3495	2810	2299	1815	
	217	5923	5170	4357	5877	5127	4319	5326	4607	3826	3287	2713	2166	
	227	6366	5562	4666	6324	5523	4631	5790	5020	4156	3764	3126	2517	
	237	6809	5953	4975	6772	5919	4943	6254	5432	4486	4241	3540	2868	
	247	7251	6345	5283	7220	6315	5255	6718	5845	4817	4718	3954	3219	
	257	7694	6736	5592	7668	6711	5566	7182	6258	5147	5195	4367	3569	
	267	8026	7044	5842	8005	7022	5819	7544	6582	5415	5632	4747	3852	
	277	8359	7351	6092	8342	7333	6072	7905	6905	5684	6070	5127	4135	
	287	8691	7659	6342	8678	7644	6325	8267	7229	5952	6508	5507	4418	
	297	9024	7966	6592	9015	7954	6578	8629	7553	6220	6946	5887	4701	
	307	9356	8274	6842	9352	8265	6831	8991	7876	6489	7383	6267	4984	
	317	9597	8477	7005	9594	8471	6996	9254	8107	6677	7705	6565	5240	
	327	9838	8681	7169	9837	8676	7161	9517	8337	6865	8027	6863	5495	
	337	10079	8884	7332	10079	8882	7327	9780	8568	7054	8349	7160	5751	
	347	10320	9088	7495	10322	9087	7492	10043	8799	7242	8671	7458	6006	
	357	10561	9291	7659	10564	9292	7657	10306	9029	7430	8993	7756	6262	
	367	10763	9456	7770	10767	9457	7769	10521	9213	7553	9251	8005	6451	
	377	10965	9620	7881	10969	9622	7880	10736	9397	7676	9508	8254	6641	
	387	11167	9784	7992	11172	9787	7992	10951	9581	7799	9766	8503	6830	
	397	11369	9948	8103	11374	9952	8103	11166	9765	7922	10024	8752	7020	
	407	11571	10113	8215	11577	10117	8215	11380	9948	8044	10281	9001	7209	
	417	11693	10214	8286	11697	10218	8287	11507	10056	8125	10463	9168	7346	
	427	11815	10316	8357	11817	10319	8358	11633	10164	8206	10644	9335	7483	
	437	11937	10417	8429	11937	10419	8430	11760	10272	8286	10826	9501	7620	
	447	12059	10519	8500	12057	10520	8501	11886	10380	8367	11008	9668	7757	
	457	12181	10620	8571	12178	10621	8573	12013	10488	8448	11189	9835	7894	

(iii) Simulated long-term average Post-Harvest Biomass (kg/ha) – CLIMATE CHANGE: 10% REDUCED RAINFALL

PAWC (mm)	Ave GSR (mm)	3.75			7.5			15			30			% Surface Clay
		11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	Ave GS Temp (°C)
40	177	3453	3013	2534	3407	2986	2513	2886	2482	2047	1072	871	665	
	187	3846	3379	2853	3793	3344	2824	3305	2862	2378	1455	1186	911	
	197	4238	3744	3172	4178	3702	3135	3725	3243	2710	1837	1501	1158	
	207	4630	4110	3491	4563	4059	3447	4144	3623	3041	2220	1816	1404	
	217	4895	4354	3706	4836	4310	3668	4441	3898	3275	2543	2118	1678	
	227	5159	4598	3920	5109	4561	3889	4738	4172	3510	2867	2419	1951	
	237	5424	4842	4135	5382	4813	4110	5035	4447	3744	3190	2721	2225	
	247	5688	5086	4350	5655	5064	4331	5332	4721	3978	3513	3023	2499	
	257	5953	5330	4564	5928	5315	4553	5629	4996	4213	3837	3324	2773	
	267	6153	5531	4761	6130	5514	4747	5856	5212	4425	4155	3605	3012	
	277	6353	5733	4958	6332	5714	4941	6083	5428	4637	4473	3886	3251	
	287	6553	5934	5155	6535	5913	5136	6311	5644	4850	4791	4167	3489	
	297	6753	6135	5351	6737	6113	5330	6538	5859	5062	5110	4447	3728	
	307	6953	6337	5548	6940	6312	5524	6765	6075	5274	5428	4728	3967	
	317	7057	6458	5666	7044	6436	5645	6893	6222	5414	5648	4945	4164	
	327	7160	6579	5785	7148	6559	5766	7020	6368	5554	5869	5161	4362	
	337	7264	6700	5903	7252	6683	5887	7148	6515	5695	6089	5377	4559	
	347	7368	6821	6021	7356	6806	6009	7275	6662	5835	6310	5594	4757	
	357	7472	6942	6139	7460	6930	6130	7403	6808	5975	6530	5810	4954	
	367	7517	7022	6228	7508	7014	6220	7467	6908	6076	6624	5940	5083	
	377	7563	7103	6317	7557	7098	6310	7531	7008	6177	6718	6069	5212	
	387	7608	7183	6406	7605	7182	6400	7595	7108	6278	6812	6199	5341	
	397	7654	7264	6495	7653	7266	6490	7660	7208	6379	6905	6328	5470	
	407	7699	7344	6584	7701	7350	6581	7724	7307	6480	6999	6458	5599	
	417	7711	7391	6635	7716	7399	6633	7747	7365	6543	7081	6573	5714	
	427	7723	7438	6686	7731	7449	6686	7771	7423	6607	7162	6688	5828	
	437	7735	7485	6737	7746	7498	6738	7794	7481	6670	7244	6802	5942	
	447	7747	7531	6788	7761	7547	6791	7817	7538	6733	7325	6917	6056	
	457	7758	7578	6839	7776	7596	6843	7841	7596	6797	7406	7032	6171	
60	177	3576	3100	2593	3538	3082	2582	2976	2548	2094	1100	899	690	
	187	4030	3511	2946	3984	3483	2924	3446	2964	2451	1518	1231	951	
	197	4484	3922	3299	4431	3884	3266	3916	3379	2808	1935	1564	1212	
	207	4939	4333	3652	4877	4285	3607	4385	3794	3165	2353	1896	1474	
	217	5284	4637	3912	5230	4596	3875	4757	4124	3443	2727	2240	1781	
	227	5629	4941	4173	5582	4907	4143	5129	4454	3720	3101	2583	2087	
	237	5974	5244	4433	5935	5219	4411	5500	4783	3998	3475	2927	2394	
	247	6319	5548	4693	6288	5530	4679	5872	5113	4276	3849	3270	2701	
	257	6664	5851	4954	6640	5842	4947	6244	5442	4554	4222	3614	3008	
	267	6923	6102	5175	6902	6089	5167	6531	5709	4794	4612	3952	3276	
	277	7183	6353	5397	7163	6337	5387	6819	5975	5033	5001	4290	3545	
	287	7442	6604	5618	7424	6585	5607	7107	6242	5273	5390	4628	3814	
	297	7701	6855	5840	7686	6832	5826	7395	6508	5512	5779	4966	4083	
	307	7961	7105	6062	7947	7080	6046	7683	6775	5752	6169	5304	4351	
	317	8146	7272	6202	8133	7250	6188	7886	6966	5915	6461	5574	4584	
	327	8332	7439	6343	8318	7421	6330	8090	7157	6078	6753	5844	4816	
	337	8517	7606	6484	8504	7591	6472	8294	7349	6242	7045	6114	5049	
	347	8703	7773	6624	8689	7761	6614	8497	7540	6405	7338	6384	5282	
	357	8889	7940	6765	8875	7932	6757	8701	7731	6568	7630	6654	5514	
	367	9013	8074	6867	8999	8066	6858	8838	7882	6681	7778	6818	5662	
	377	9137	8208	6968	9123	8201	6960	8975	8033	6795	7926	6981	5810	
	387	9261	8342	7069	9247	8336	7062	9112	8184	6908	8073	7145	5958	
	397	9385	8477	7171	9371	8471	7163	9249	8335	7021	8221	7309	6106	
	407	9510	8611	7272	9496	8606	7265	9386	8486	7134	8369	7473	6254	
	417	9589	8705	7336	9576	8700	7329	9473	8587	7207	8516	7633	6386	
	427	9668	8800	7399	9656	8794	7393	9560	8688	7280	8663	7794	6519	
	437	9748	8894	7463	9736	8888	7457	9647	8789	7352	8811	7955	6652	
	447	9827	8988	7526	9816	8982	7521	9733	8890	7425	8958	8116	6784	
	457	9906	9083	7590	9896	9077	7584	9820	8991	7498	9105	8276	6917	

PAWC (mm)	Ave GSR (mm)	3.75			7.5			15			30			% Surface Clay
		11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	Ave GS Temp (°C)
80	177	3582	3098	2590	3547	3085	2581	2975	2543	2087	1098	897	688	
	187	4055	3524	2956	4014	3500	2937	3462	2969	2452	1521	1233	952	
	197	4528	3949	3323	4480	3915	3292	3948	3394	2817	1944	1570	1216	
	207	5002	4374	3690	4947	4330	3648	4434	3819	3182	2367	1907	1480	
	217	5384	4707	3975	5336	4670	3941	4834	4172	3482	2762	2266	1799	
	227	5766	5040	4260	5725	5010	4234	5234	4524	3783	3157	2626	2118	
	237	6149	5373	4545	6114	5350	4527	5634	4876	4084	3552	2985	2437	
	247	6531	5706	4830	6503	5690	4819	6034	5228	4385	3947	3345	2756	
	257	6913	6039	5115	6891	6030	5112	6435	5580	4686	4342	3704	3075	
	267	7216	6335	5357	7197	6324	5352	6768	5893	4945	4766	4080	3361	
	277	7519	6631	5600	7502	6618	5592	7101	6206	5204	5189	4456	3648	
	287	7822	6927	5842	7807	6912	5833	7434	6519	5464	5613	4831	3935	
	297	8125	7224	6084	8112	7207	6073	7767	6832	5723	6036	5207	4221	
	307	8428	7520	6326	8417	7501	6313	8100	7145	5983	6460	5583	4508	
	317	8641	7713	6486	8631	7697	6474	8334	7366	6166	6791	5881	4758	
	327	8854	7905	6645	8845	7892	6634	8567	7587	6350	7122	6179	5007	
	337	9067	8098	6804	9060	8088	6795	8801	7808	6534	7453	6477	5257	
	347	9280	8291	6963	9274	8284	6956	9035	8030	6718	7784	6775	5507	
	357	9493	8483	7123	9488	8480	7117	9268	8251	6902	8115	7074	5756	
	367	9643	8636	7228	9637	8634	7223	9432	8420	7021	8293	7271	5926	
	377	9792	8789	7333	9786	8787	7329	9595	8590	7140	8471	7468	6096	
	387	9942	8942	7439	9935	8941	7435	9759	8759	7260	8649	7665	6266	
	397	10091	9095	7544	10085	9095	7541	9922	8928	7379	8826	7862	6436	
	407	10241	9248	7649	10234	9248	7646	10086	9098	7498	9004	8059	6606	
	417	10352	9342	7716	10345	9341	7713	10204	9203	7575	9177	8232	6742	
	427	10462	9436	7782	10456	9434	7780	10322	9307	7653	9351	8404	6879	
	437	10573	9529	7849	10566	9527	7848	10440	9412	7730	9524	8576	7015	
	447	10684	9623	7916	10677	9620	7915	10559	9517	7807	9697	8749	7152	
	457	10795	9717	7982	10788	9713	7982	10677	9622	7885	9871	8921	7288	
120	177	3564	3093	2586	3533	3080	2581	2944	2525	2071	1055	863	658	
	187	4045	3519	2956	4008	3497	2940	3434	2952	2438	1479	1198	920	
	197	4526	3945	3326	4482	3914	3299	3924	3379	2804	1903	1534	1182	
	207	5007	4371	3695	4957	4331	3657	4414	3806	3171	2327	1870	1444	
	217	5412	4730	3987	5368	4697	3955	4835	4180	3478	2735	2240	1770	
	227	5817	5089	4278	5779	5063	4253	5256	4554	3784	3142	2610	2097	
	237	6221	5448	4569	6191	5429	4551	5677	4928	4091	3550	2980	2424	
	247	6626	5807	4860	6602	5795	4849	6098	5302	4397	3957	3350	2750	
	257	7030	6167	5151	7013	6161	5146	6519	5677	4704	4365	3720	3077	
	267	7399	6494	5415	7384	6487	5408	6906	6012	4977	4837	4118	3374	
	277	7767	6822	5679	7755	6813	5670	7292	6348	5250	5310	4515	3671	
	287	8135	7150	5942	8127	7139	5931	7679	6684	5524	5782	4913	3968	
	297	8503	7478	6206	8498	7465	6193	8065	7019	5797	6254	5310	4266	
	307	8871	7806	6469	8869	7791	6455	8452	7355	6071	6727	5708	4563	
	317	9141	8040	6661	9139	8026	6648	8743	7620	6288	7108	6039	4830	
	327	9410	8273	6853	9408	8261	6842	9035	7885	6505	7488	6370	5097	
	337	9679	8507	7044	9678	8497	7035	9326	8150	6722	7869	6702	5364	
	347	9948	8740	7236	9947	8732	7229	9617	8415	6939	8250	7033	5631	
	357	10217	8973	7428	10217	8968	7422	9909	8680	7157	8631	7364	5898	
	367	10406	9146	7543	10407	9142	7539	10115	8870	7289	8849	7589	6091	
	377	10594	9318	7659	10597	9316	7655	10322	9061	7422	9067	7813	6283	
	387	10782	9490	7775	10787	9490	7772	10529	9251	7555	9284	8038	6475	
	397	10971	9662	7891	10977	9664	7888	10736	9442	7688	9502	8262	6668	
	407	11159	9834	8006	11167	9838	8005	10942	9633	7821	9720	8486	6860	
	417	11308	9942	8089	11314	9946	8089	11099	9754	7915	9946	8693	7015	
	427	11457	10051	8172	11462	10054	8172	11255	9875	8008	10172	8900	7170	
	437	11607	10159	8255	11609	10162	8256	11411	9996	8101	10398	9107	7325	
	447	11756	10268	8338	11757	10270	8339	11567	10117	8195	10625	9314	7479	
	457	11905	10376	8421	11904	10378	8423	11723	10238	8288	10851	9521	7634	

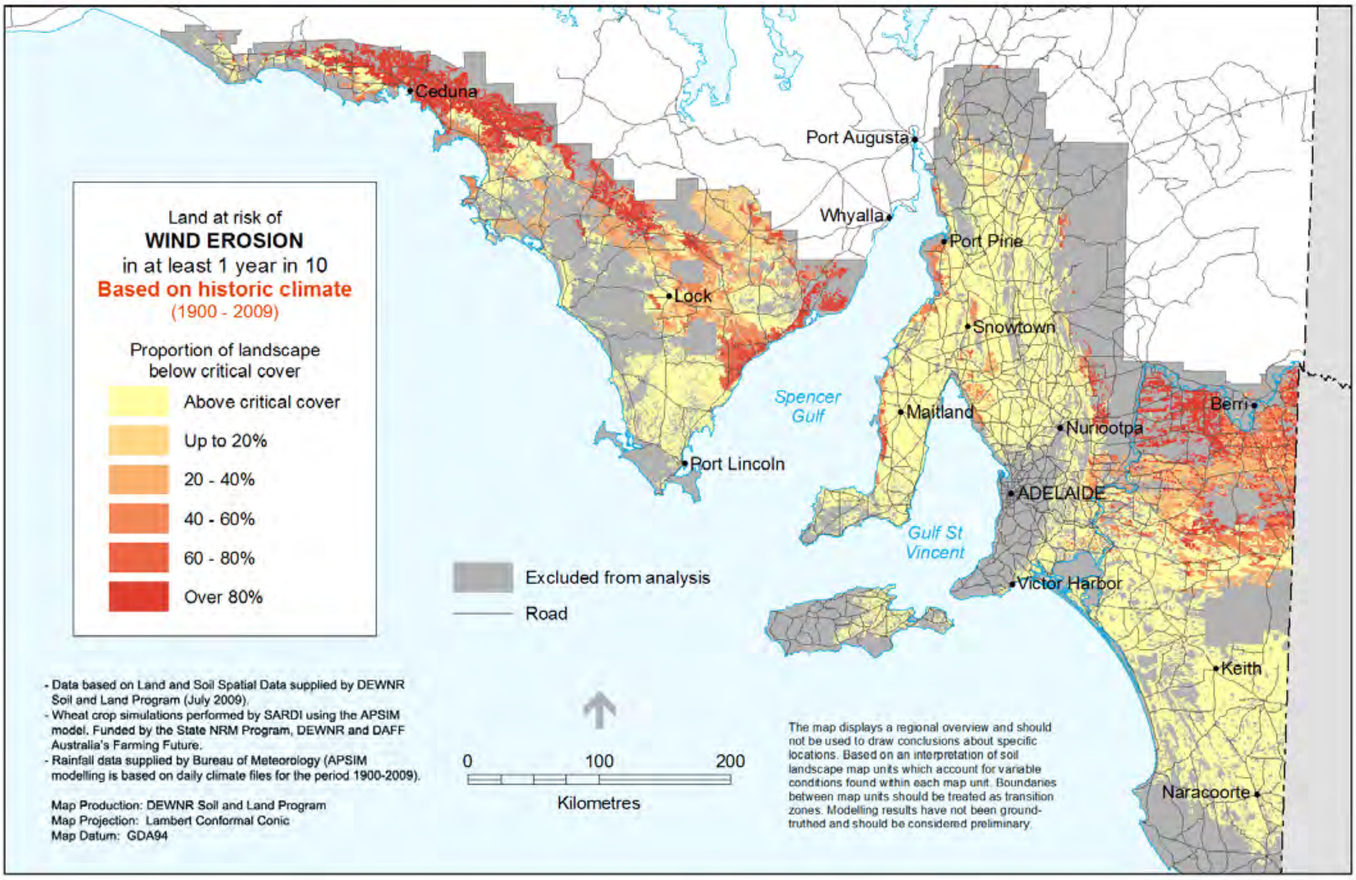
(iv) Simulated long-term average Post-Harvest Biomass (kg/ha) – CLIMATE CHANGE: 20% REDUCED RAINFALL

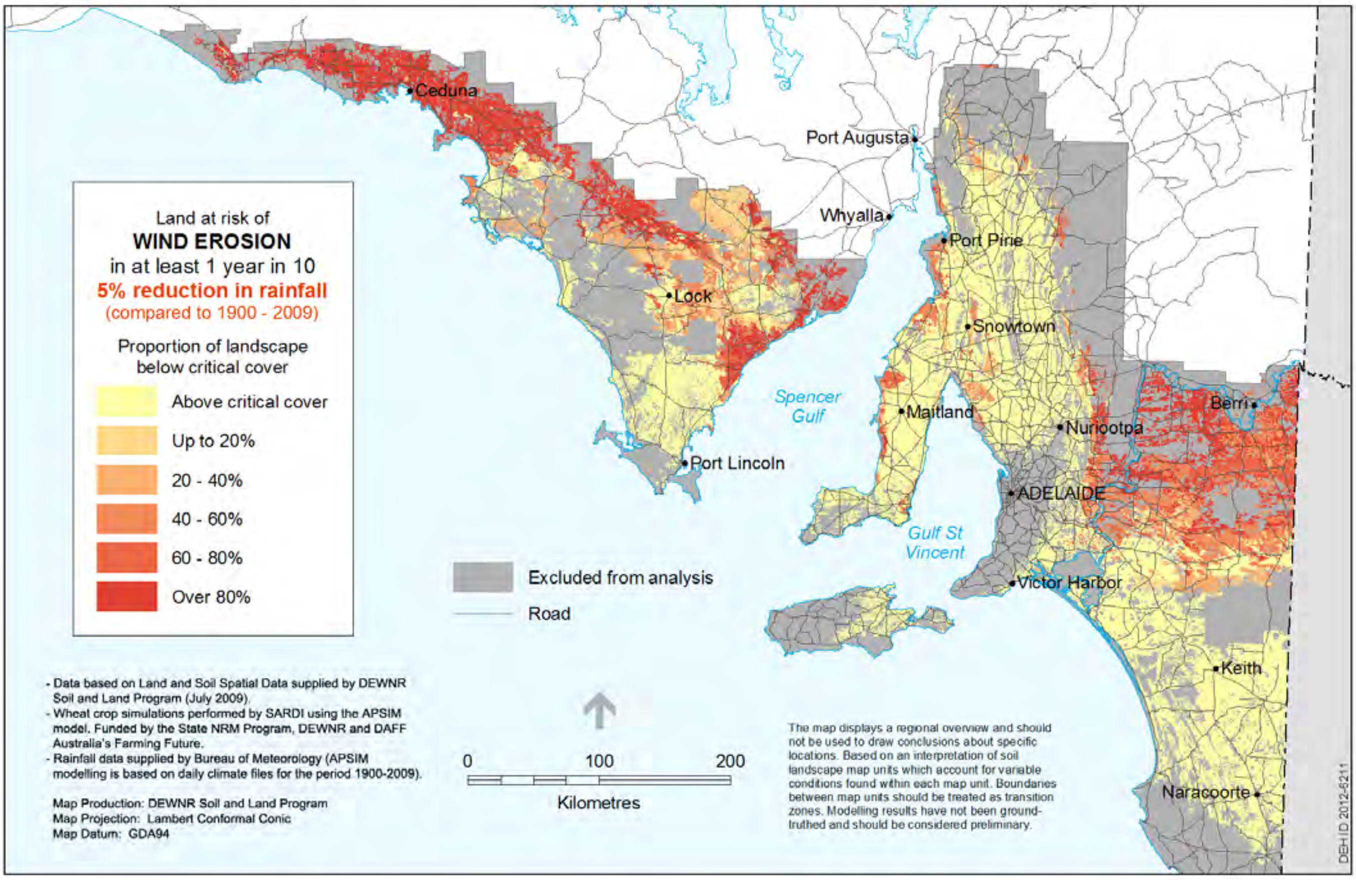
PAWC (mm)	Ave GSR (mm)	3.75			7.5			15			30			% Surface Clay
		11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	11.5	13.0	14.5	Ave GS Temp (°C)
40	177	2574	2228	1864	2515	2179	1819	1976	1649	1325	550	455	363	
	187	2961	2574	2160	2906	2528	2124	2368	2008	1638	808	658	515	
	197	3348	2920	2456	3296	2877	2428	2760	2367	1951	1067	861	667	
	207	3736	3266	2752	3686	3226	2732	3152	2726	2264	1325	1065	819	
	217	4038	3551	2999	3989	3510	2975	3479	3026	2522	1657	1361	1063	
	227	4340	3836	3246	4292	3794	3218	3806	3327	2781	1990	1657	1307	
	237	4642	4121	3493	4595	4078	3461	4133	3627	3039	2322	1953	1551	
	247	4944	4406	3740	4898	4362	3704	4460	3927	3298	2654	2249	1796	
	257	5246	4691	3986	5201	4646	3947	4787	4228	3556	2987	2546	2040	
	267	5464	4889	4170	5419	4847	4131	5033	4457	3759	3280	2804	2271	
	277	5681	5086	4353	5636	5048	4315	5279	4686	3962	3574	3062	2502	
	287	5899	5284	4536	5854	5248	4500	5525	4915	4165	3867	3320	2733	
	297	6117	5482	4719	6071	5449	4684	5771	5144	4368	4161	3578	2963	
	307	6334	5680	4903	6289	5650	4869	6017	5374	4570	4454	3836	3194	
	317	6482	5840	5061	6442	5814	5032	6194	5546	4743	4700	4051	3377	
	327	6629	5999	5219	6594	5977	5195	6371	5719	4916	4945	4267	3560	
	337	6777	6159	5377	6747	6141	5357	6549	5892	5088	5191	4482	3743	
	347	6925	6318	5535	6900	6305	5520	6726	6065	5261	5436	4697	3926	
	357	7072	6478	5694	7052	6469	5683	6904	6238	5433	5682	4913	4109	
	367	7155	6576	5789	7138	6566	5779	7010	6362	5551	5853	5102	4291	
	377	7238	6675	5884	7223	6664	5874	7115	6485	5668	6025	5291	4474	
	387	7322	6773	5979	7308	6762	5970	7221	6609	5785	6197	5479	4656	
	397	7405	6871	6074	7394	6860	6066	7327	6732	5903	6368	5668	4839	
	407	7488	6970	6170	7479	6958	6161	7433	6856	6020	6540	5857	5021	
	417	7530	7045	6253	7523	7036	6245	7491	6946	6112	6632	5977	5137	
	427	7572	7120	6335	7568	7115	6329	7549	7037	6204	6724	6098	5252	
	437	7615	7194	6418	7612	7193	6413	7607	7127	6296	6816	6218	5368	
	447	7657	7269	6501	7657	7272	6497	7666	7217	6388	6907	6338	5484	
	457	7699	7344	6584	7701	7350	6581	7724	7307	6480	6999	6458	5599	
60	177	2611	2255	1885	2555	2207	1841	1995	1663	1334	561	463	371	
	187	3037	2628	2199	2986	2586	2166	2421	2047	1665	829	674	531	
	197	3463	3002	2514	3418	2966	2492	2848	2430	1997	1097	886	690	
	207	3890	3375	2828	3850	3345	2818	3274	2813	2328	1366	1098	849	
	217	4258	3708	3115	4218	3676	3099	3654	3152	2619	1739	1421	1113	
	227	4627	4042	3403	4585	4007	3381	4033	3490	2910	2111	1744	1376	
	237	4996	4375	3690	4952	4337	3663	4413	3828	3200	2484	2068	1640	
	247	5365	4708	3978	5319	4668	3945	4793	4166	3491	2857	2391	1904	
	257	5733	5042	4265	5686	4999	4226	5172	4504	3782	3230	2714	2168	
	267	6017	5295	4480	5972	5255	4443	5486	4785	4017	3573	3009	2431	
	277	6301	5548	4695	6258	5510	4660	5800	5067	4252	3916	3303	2694	
	287	6585	5802	4910	6544	5766	4877	6114	5348	4487	4259	3598	2957	
	297	6870	6055	5124	6830	6022	5094	6427	5629	4722	4602	3892	3220	
	307	7154	6309	5339	7116	6278	5311	6741	5910	4957	4945	4187	3483	
	317	7355	6506	5518	7321	6479	5495	6970	6126	5154	5257	4457	3698	
	327	7557	6704	5698	7526	6680	5679	7198	6341	5352	5568	4727	3913	
	337	7759	6901	5877	7731	6881	5863	7427	6556	5549	5879	4997	4128	
	347	7960	7099	6057	7936	7083	6047	7655	6771	5746	6190	5267	4344	
	357	8162	7296	6236	8141	7284	6232	7884	6987	5943	6501	5537	4559	
	367	8317	7435	6349	8297	7423	6344	8057	7148	6077	6732	5773	4765	
	377	8471	7574	6462	8453	7563	6457	8230	7309	6211	6963	6009	4970	
	387	8626	7712	6575	8609	7702	6570	8403	7470	6345	7194	6245	5176	
	397	8781	7851	6689	8765	7841	6682	8576	7631	6479	7425	6481	5382	
	407	8935	7990	6802	8921	7981	6795	8749	7792	6613	7656	6717	5588	
	417	9050	8114	6896	9036	8106	6889	8877	7931	6718	7799	6868	5721	
	427	9165	8238	6990	9151	8231	6983	9004	8070	6822	7941	7019	5854	
	437	9280	8362	7084	9266	8356	7077	9131	8208	6926	8084	7170	5987	
	447	9395	8487	7178	9381	8481	7171	9259	8347	7030	8226	7322	6121	
	457	9510	8611	7272	9496	8606	7265	9386	8486	7134	8369	7473	6254	
80	177	2599	2245	1875	2549	2203	1836	1988	1657	1329	560	462	370	
	187	3035	2622	2193	2990	2585	2164	2419	2042	1661	829	673	529	
	197	3470	2999	2511	3430	2968	2491	2849	2427	1993	1097	885	689	
	207	3906	3376	2830	3871	3351	2819	3280	2812	2325	1366	1097	848	
	217	4297	3725	3132	4260	3697	3116	3679	3161	2627	1750	1426	1116	
	227	4687	4074	3435	4649	4043	3413	4077	3511	2930	2133	1756	1385	
	237	5078	4423	3737	5038	4388	3711	4475	3860	3232	2517	2085	1653	
	247	5469	4771	4039	5427	4734	4008	4874	4209	3534	2901	2415	1921	
	257	5859	5120	4342	5816	5080	4305	5272	4558	3837	3285	2744	2189	
	267	6184	5412	4581	6142	5374	4547	5621	4872	4094	3652	3060	2466	
	277	6509	5704	4821	6469	5669	4788	5970	5187	4351	4019	3376	2743	
	287	6833	5996	5060	6795	5964	5030	6319	5501	4608	4386	3691	3020	
	297	7158	6288	5300	7122	6258	5272	6668	5816	4865	4753	4007	3297	
	307	7483	6580	5539	7449	6553	5513	7017	6130	5122	5120	4323	3574	
	317	7717	6812	5736	7687	6789	5715	7282	6382	5337	5461	4628	3807	
	327	7952	7044	5933	7925	7025	5917	7546	6634	5552	5803	4934	4040	
	337	8187	7276	6131	8163	7261	6119	7811	6885	5766	6144	5239	4273	
	347	8422	7508	6328	8401	7497	6321	8075	7137	5981	6486	5544	4506	
	357	8657	7740	6525	8639	7733	6523	8340	7389	6196	6827	5850	4738	
	367	8836	7899	6652	8820	7893	6649	8538	7574	6347	7093	6109	4959	
	377	9014	8059	6780	9001	8053	6776	8737	7760	6499	7358	6369	5179	
	387	9193	8218	6907	9182	8213	6902	8935	7946	6650	7623	6629	5400	
	397	9372	8377	7034	9363	8373	7029	9133	8132	6802	7889	6888	5620	
	407	9551	8537	7162	9544	8533	7155	9331	8317	6954	8154	7148	5840	
	417	9689	8679	7259	9682	8676	7253	9482	8474	7063	8324	7330	5993	
	427	9827	8821	7357	9820	8819	7352	9633	8630	7171	8494	7512	6146	
	437	9965	8963	7454	9958	8962	7450	9784	8786	7280	8664	7695	6300	
	447	10103	9106	7552	10096	9105	7548	9935	8942	7389	8834	7877	6453	
	457	10241	9248	7649	10234	9248	7646	10086	9098	7498	9004	8059	6606	
120	177	2592	2245	1875	2542	2201	1834	1962	1638	1312	541	443	353	
	187	3025	2619	2192	2981	2583	2162	2393	2024	1646	805	651	509	
	197	3458	2993	2509	3420	2964	2490	2823	2411	1980	1069	860	665	
	207	3891	3367	2826	3859	3346	2818	3254	2798	2313	1334	1068	821	
	217	4291	3727	3136	4259	3703	3122	3662	3154	2620	1717	1397	1088	
	227	4691	4087	3446	4660	4060	3427	4069	3510	2927	2100	1727	1356	
	237	5092	4447	3755	5060	4417	3731	4477	3867	3234	2483	2056	1623	
	247	5492	4806	4065	5461	4775	4036	4885	4223	3541	2866	2386	1891	
	257	5892	5166	4375	5862	5132	4340	5293	4579	3848	3249	2715	2158	
	267	6253	5480	4619	6223	5448	4585	5671	4915	4108	3638	3045	2440	
	277	6613	5794	4862	6584	5764	4831	6048	5251	4368	4027	3376	2723	
	287	6973	6108	5105	6945	6080	5076	6426	5587	4627	4417	3706	3005	
	297	7334	6422	5349	7307	6395	5321	6804	5922	4887	4806	4037	3287	
	307	7694	6736	5592	7668	6711	5566	7182	6258	5147	5195	4367	3569	
	317	7987	7008	5814	7964	6987	5793	7499	6540	5381	5576	4695	3810	
	327	8279	7280	6036	8260	7263	6019	7817	6822	5615	5958	5022	4051	
	337	8572	7552	6259	8556	7539	6246	8135	7103	5850	6339	5349	4292	
	347	8864	7824	6481	8852	7815	6473	8452	7385	6084	6721	5676	4533	
	357	9157	8096	6703	9148	8091	6699	8770	7667	6318	7102	6003	4774	
	367	9383	8284	6858	9376	8279	6854	9014	7884	6498	7417	6293	5018	
	377	9609	8471	7013	9603	8466	7008	9258	8101	6677	7731	6583	5263	
	387	9836	8659	7168	9831	8654	7163	9502	8318	6857	8046	6872	5507	
	397	10062	8847	7323	10058	8842	7318	9746	8535	7036	8360	7162	5752	
	407	10288	9034	7478	10286	9030	7473	9990	8752	7216	8675	7451	5996	
	417	10462	9194	7584	10462	9191	7579	10180	8928	7337	8884	7658	6169	
	427	10637	9354	7690	10638	9353	7686	10371	9104	7458	9093	7865	6342	
	437	10811	9514	7795	10814	9515	7792	10561	9280	7579	9302	8072	6515	
	447	10985	9674	7901	10991	9677	7899	10752	9457	7700	9511	8279	6688	
	457	11159	9834	8006	11167	9838	8005	10942	9633	7821	9720	8486	6860	

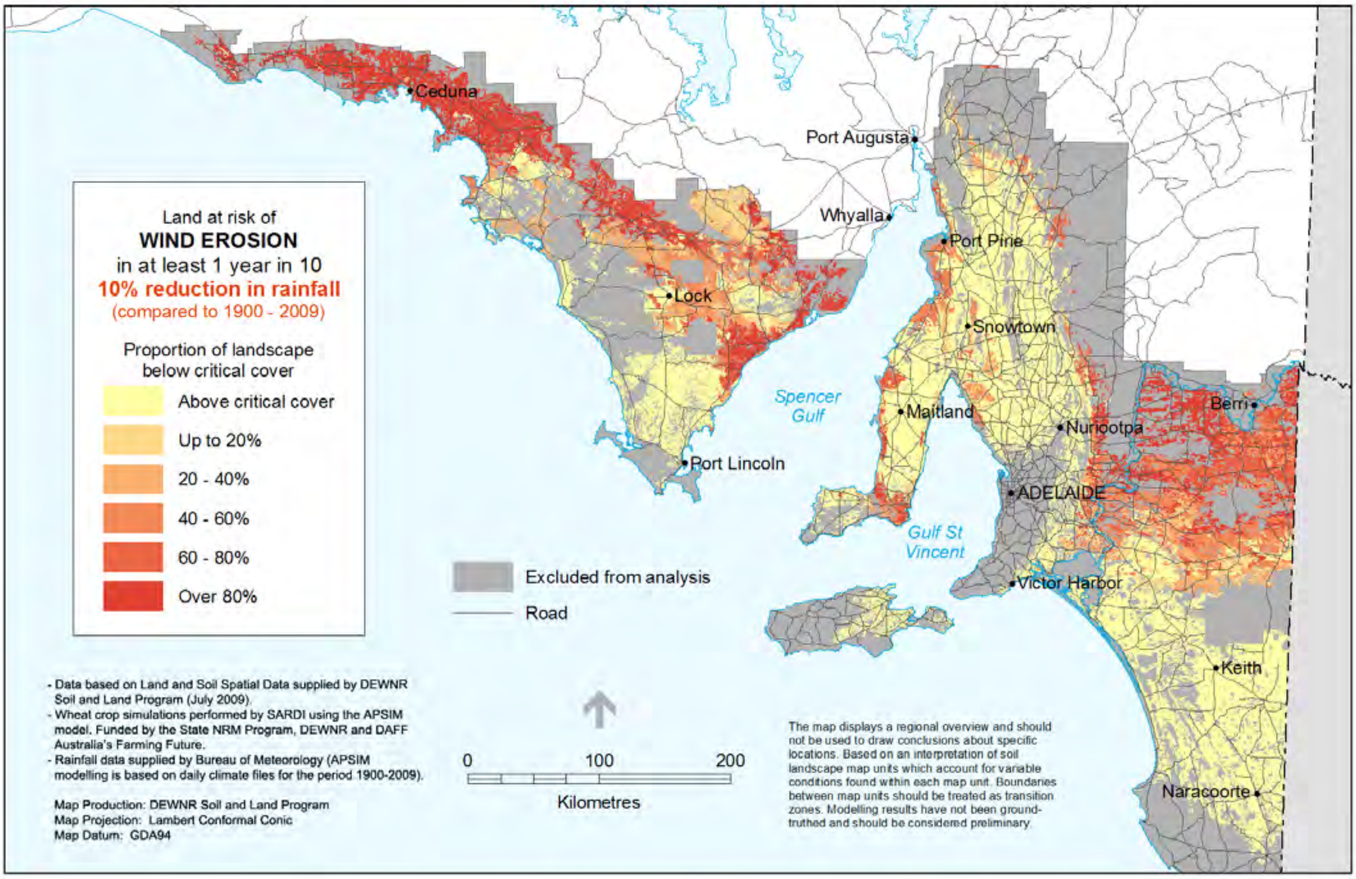
Appendix L – List of available map products

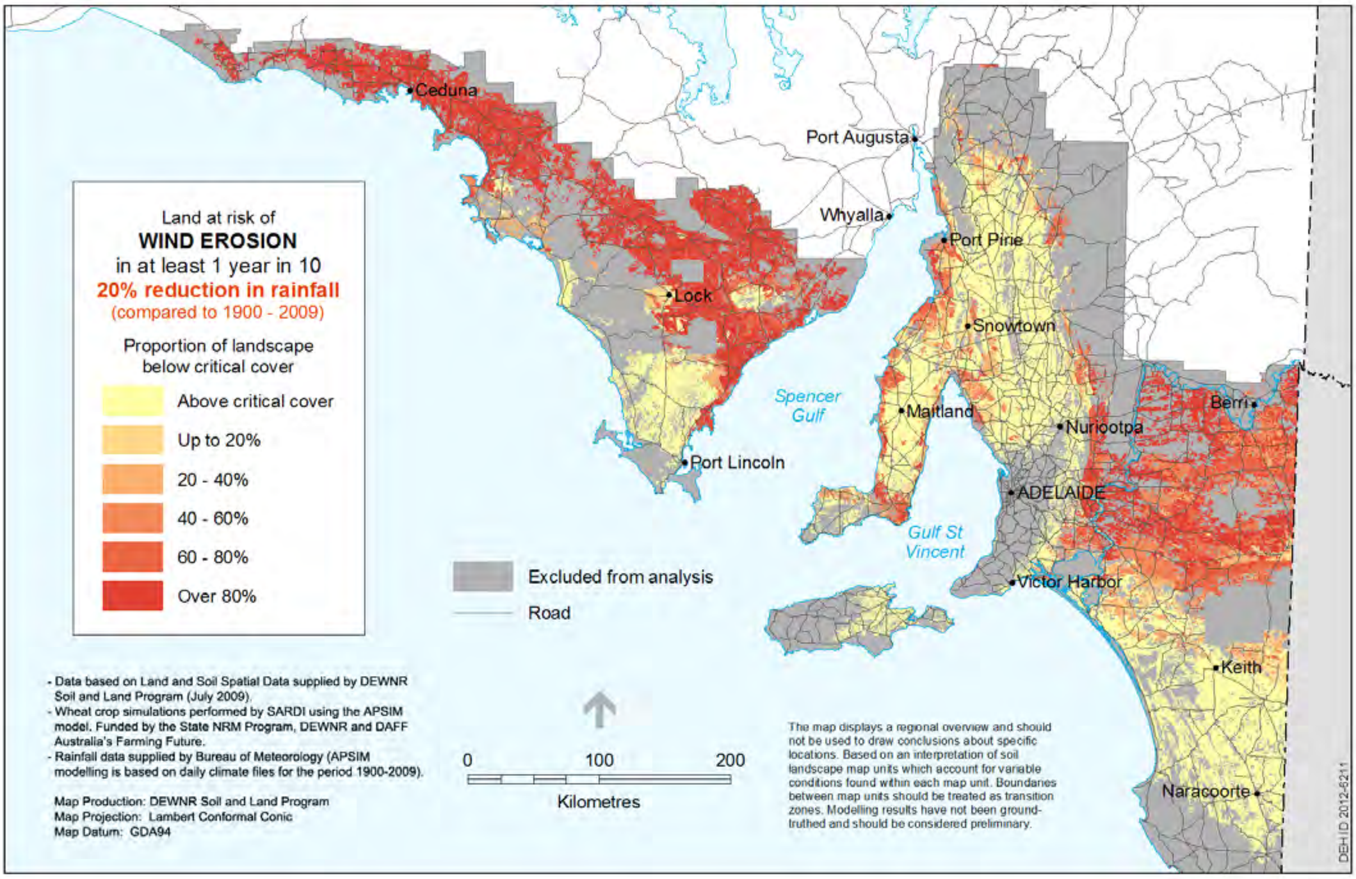
Indicator	Frequency (for erosion risk only) "areas with belowcritical cover in at least ..."	Climate Scenario	State-wide	Separately by NRM Regions (AMLR, EP, KI, NY, SAMDB, SE)
Average Wheat Grain Yield (t/ha)		Historic	✓	✓
		-5% rainfall	✓	✓
		-10% rainfall	✓	✓
		-20% rainfall	✓	✓
Average Post-Harvest Biomass (t/ha)		Historic	✓	✓
		-5% rainfall	✓	✓
		-10% rainfall	✓	✓
		-20% rainfall	✓	✓
Erosion Risk – Area of below critical cover (indicating increased risk of ***Wind*** erosion)	4 years in 10	Historic	✓	✓
	2 years in 10	Historic	✓	✓
	1 year in 10	Historic	✓	✓
	1 year in 100	Historic	✓	✓
	4 years in 10	-5% rainfall	✓	✓
	2 years in 10	-5% rainfall	✓	✓
	1 year in 10	-5% rainfall	✓	✓
	1 year in 100	-5% rainfall	✓	✓
	4 years in 10	-10% rainfall	✓	✓
	2 years in 10	-10% rainfall	✓	✓
	1 year in 10	-10% rainfall	✓	✓
	1 year in 100	-10% rainfall	✓	✓
	4 years in 10	-20% rainfall	✓	✓
	2 years in 10	-20% rainfall	✓	✓
	1 year in 10	-20% rainfall	✓	✓
	1 year in 100	-20% rainfall	✓	✓
Erosion Risk – Area of below critical cover (indicating increased risk of ***Water*** erosion)	4 years in 10	Historic	✓	✓
	2 years in 10	Historic	✓	✓
	1 year in 10	Historic	✓	✓
	1 year in 100	Historic	✓	✓
	4 years in 10	-5% rainfall	✓	✓
	2 years in 10	-5% rainfall	✓	✓
	1 year in 10	-5% rainfall	✓	✓
	1 year in 100	-5% rainfall	✓	✓
	4 years in 10	-10% rainfall	✓	✓
	2 years in 10	-10% rainfall	✓	✓
	1 year in 10	-10% rainfall	✓	✓
	1 year in 100	-10% rainfall	✓	✓
	4 years in 10	-20% rainfall	✓	✓
	2 years in 10	-20% rainfall	✓	✓
	1 year in 10	-20% rainfall	✓	✓
	1 year in 100	-20% rainfall	✓	✓
Erosion Risk – Area of below critical cover (indicating increased risk of ***Wind or Water*** erosion)	4 years in 10	Historic	✓	✓
	2 years in 10	Historic	✓	✓
	1 year in 10	Historic	✓	✓
	1 year in 100	Historic	✓	✓
	4 years in 10	-5% rainfall	✓	✓
	2 years in 10	-5% rainfall	✓	✓
	1 year in 10	-5% rainfall	✓	✓
	1 year in 100	-5% rainfall	✓	✓
	4 years in 10	-10% rainfall	✓	✓
	2 years in 10	-10% rainfall	✓	✓
	1 year in 10	-10% rainfall	✓	✓
	1 year in 100	-10% rainfall	✓	✓
	4 years in 10	-20% rainfall	✓	✓
	2 years in 10	-20% rainfall	✓	✓
	1 year in 10	-20% rainfall	✓	✓
	1 year in 100	-20% rainfall	✓	✓

Appendix M – Land with below critical cover (simulation results) indicating increased risk of <u>wind erosion</u>, in at least 1 year in 10, for historic and climate change scenarios

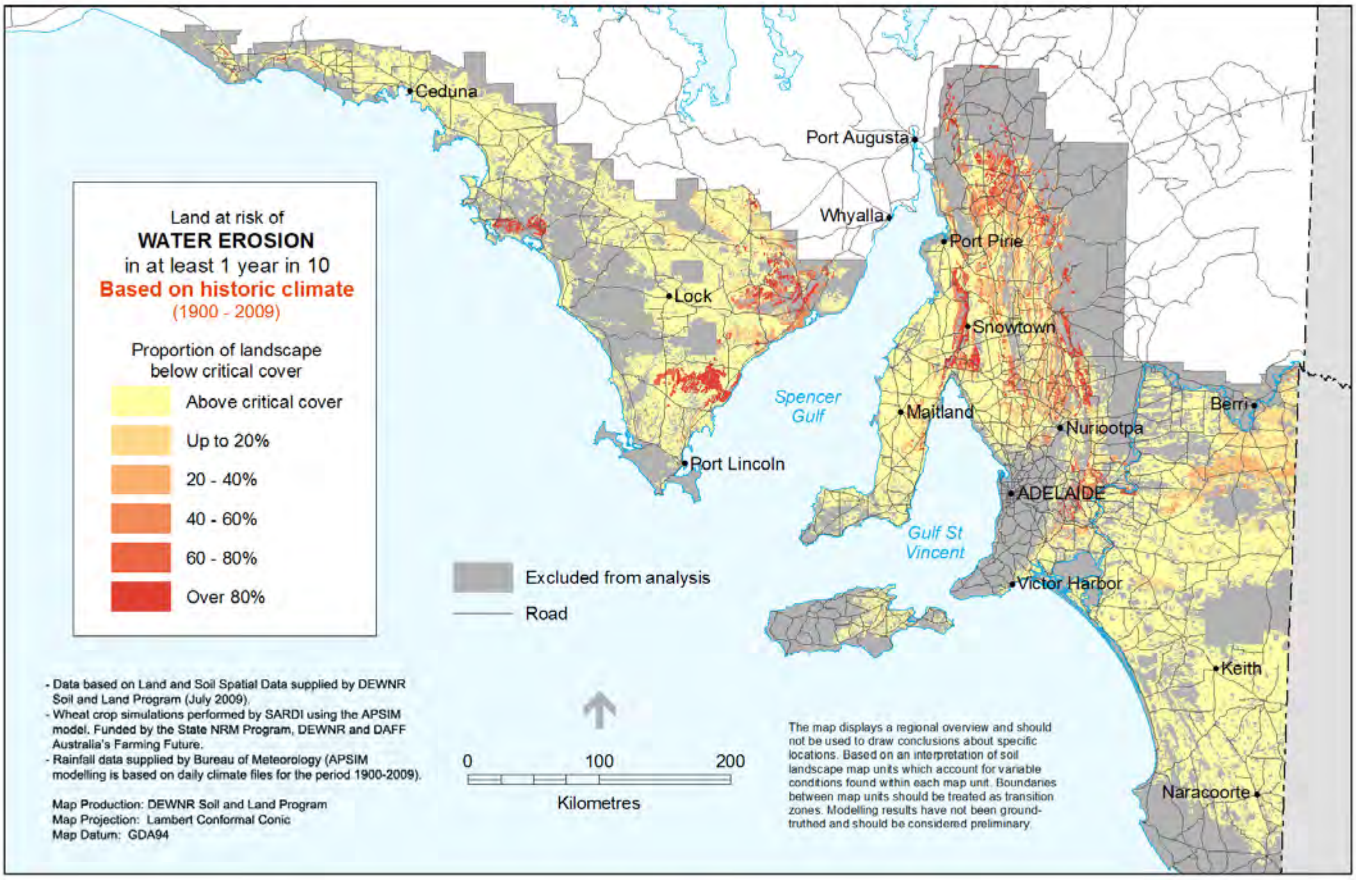


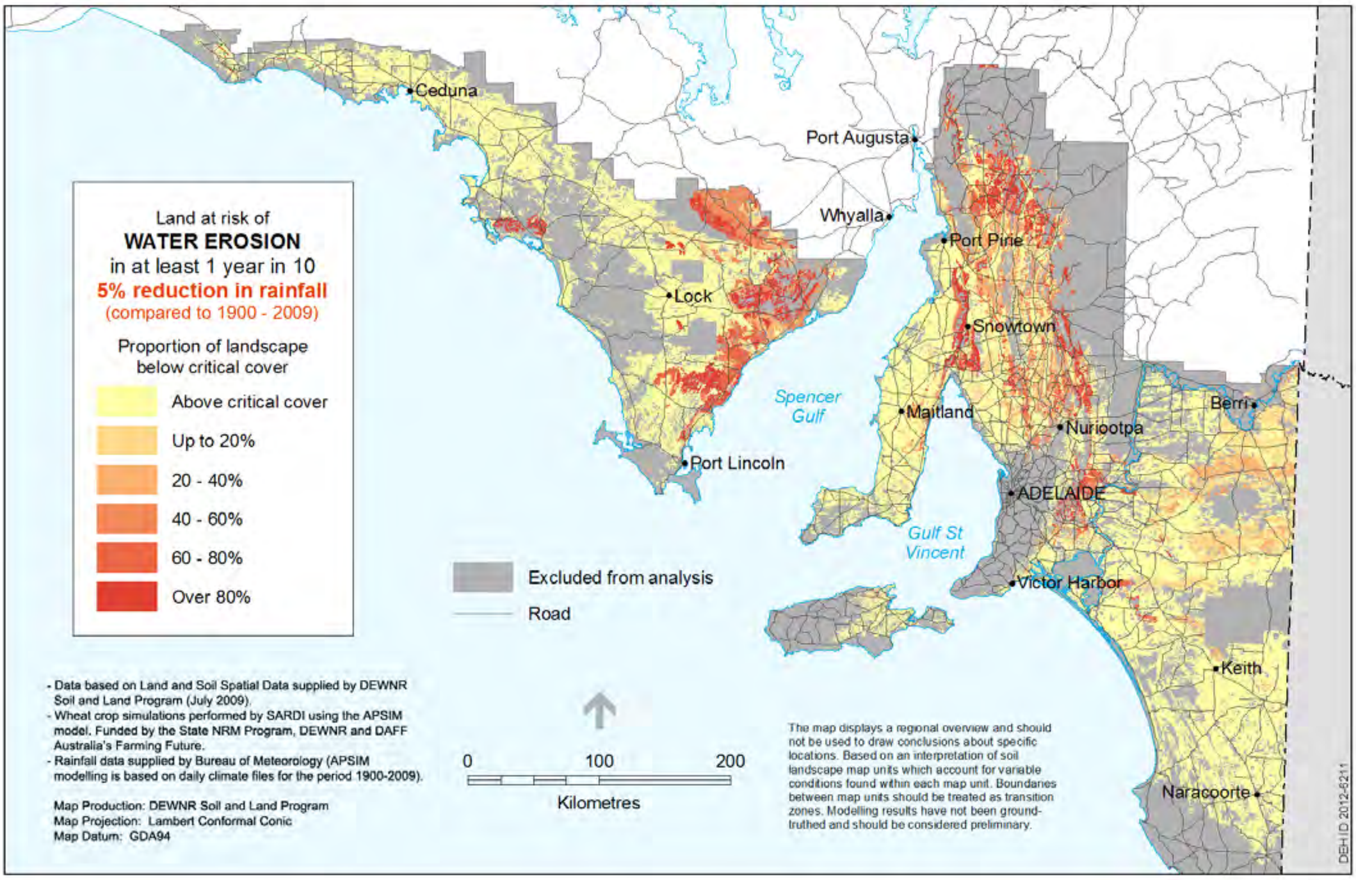


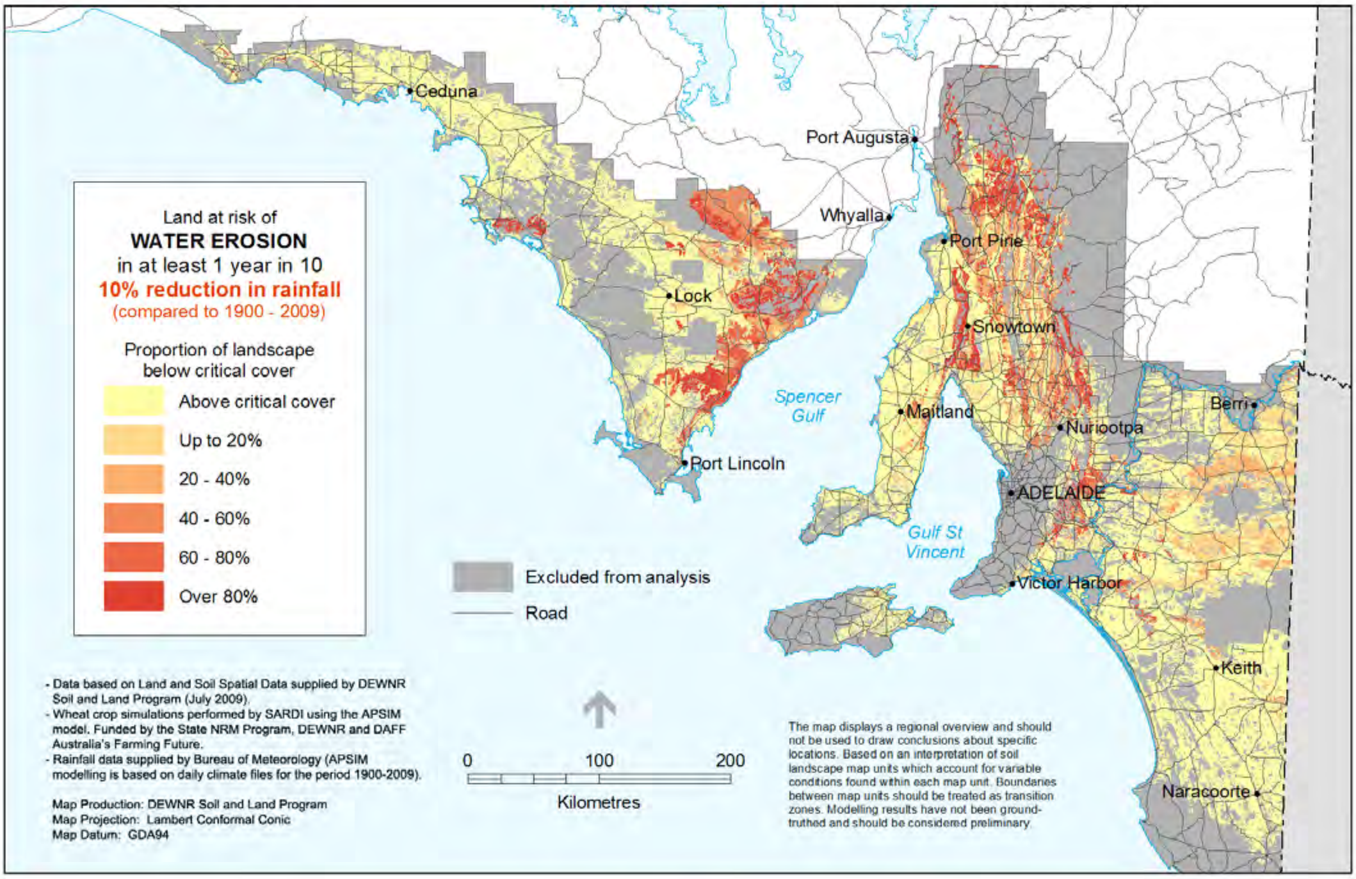

Land at risk of
WIND EROSION
in at least 1 year in 10
10% reduction in rainfall
(compared to 1900 - 2009)
Proportion of landscape below critical cover
Above critical cover
Up to 20%
20 - 40%
40 - 60%
60 - 80%
Over 80%
Excluded from analysis
Road
Ceduna
Port Augusta
Whyalla
Port Pirie
Lock
Snowtown
Spencer Gulf
Maitland
Nuriootpa
Berri
Port Lincoln
ADELAIDE
Gulf St Vincent
Victor Harbor
Keith
Naracoorte
0
100
200
Kilometres
- Data based on Land and Soil Spatial Data supplied by DEWNR Soil and Land Program (July 2009).
- Wheat crop simulations performed by SARDI using the APSIM model. Funded by the State NRM Program, DEWNR and DAFF Australia's Farming Future.
- Rainfall data supplied by Bureau of Meteorology (APSIM modelling is based on daily climate files for the period 1900-2009).
Map Production: DEWNR Soil and Land Program
Map Projection: Lambert Conformal Conic
Map Datum: GDA94
The map displays a regional overview and should not be used to draw conclusions about specific locations. Based on an interpretation of soil landscape map units which account for variable conditions found within each map unit. Boundaries between map units should be treated as transition zones. Modelling results have not been ground-truthed and should be considered preliminary.

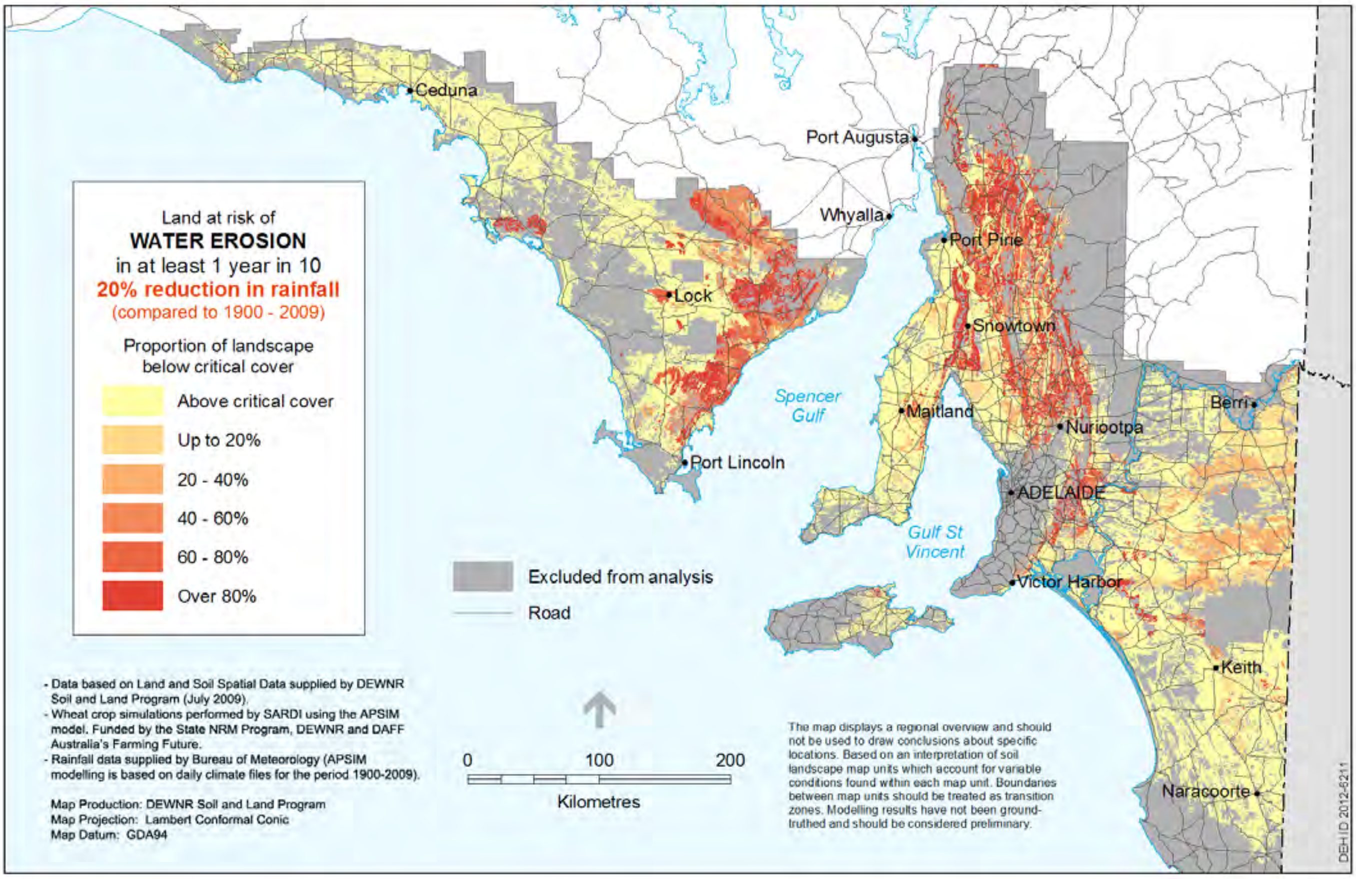

Land at risk of
WIND EROSION
in at least 1 year in 10
20% reduction in rainfall
(compared to 1900 - 2009)
Proportion of landscape below critical cover
Above critical cover
Up to 20%
20 - 40%
40 - 60%
60 - 80%
Over 80%
Excluded from analysis
Road
Ceduna
Port Augusta
Whyalla
Port Pirie
Lock
Snowtown
Spencer Gulf
Maitland
Nuriootpa
Berri
Port Lincoln
ADELAIDE
Gulf St Vincent
Victor Harbor
Keith
Naracoorte
0
100
200
Kilometres
- Data based on Land and Soil Spatial Data supplied by DEWNR Soil and Land Program (July 2009).
- Wheat crop simulations performed by SARDI using the APSIM model. Funded by the State NRM Program, DEWNR and DAFF Australia's Farming Future.
- Rainfall data supplied by Bureau of Meteorology (APSIM modelling is based on daily climate files for the period 1900-2009).
Map Production: DEWNR Soil and Land Program
Map Projection: Lambert Conformal Conic
Map Datum: GDA94
The map displays a regional overview and should not be used to draw conclusions about specific locations. Based on an interpretation of soil landscape map units which account for variable conditions found within each map unit. Boundaries between map units should be treated as transition zones. Modelling results have not been ground-truthed and should be considered preliminary.
DEH ID 2012-6211

Appendix N – Land with below critical cover (simulation results) indicating increased risk of water erosion, in at least 1 year in 10, for historic and climate change scenarios






Land at risk of
WATER EROSION
in at least 1 year in 10
10% reduction in rainfall
(compared to 1900 - 2009)
Proportion of landscape below critical cover
Above critical cover
Up to 20%
20 - 40%
40 - 60%
60 - 80%
Over 80%
Excluded from analysis
Road
0
100
200
Kilometres
Ceduna
Port Augusta
Whyalla
Port Pirie
Lock
Snowtown
Spencer Gulf
Maitland
Nuriootpa
Berri
Port Lincoln
ADELAIDE
Gulf St Vincent
Victor Harbor
Keith
Naracoorte
- Data based on Land and Soil Spatial Data supplied by DEWNR Soil and Land Program (July 2009).
- Wheat crop simulations performed by SARDI using the APSIM model. Funded by the State NRM Program, DEWNR and DAFF Australia's Farming Future.
- Rainfall data supplied by Bureau of Meteorology (APSIM modelling is based on daily climate files for the period 1900-2009).
Map Production: DEWNR Soil and Land Program
Map Projection: Lambert Conformal Conic
Map Datum: GDA94
The map displays a regional overview and should not be used to draw conclusions about specific locations. Based on an interpretation of soil landscape map units which account for variable conditions found within each map unit. Boundaries between map units should be treated as transition zones. Modelling results have not been ground-truthed and should be considered preliminary.


Land at risk of
WATER EROSION
in at least 1 year in 10
20% reduction in rainfall
(compared to 1900 - 2009)
Proportion of landscape below critical cover
Above critical cover
Up to 20%
20 - 40%
40 - 60%
60 - 80%
Over 80%
Excluded from analysis
Road
0
100
200
Kilometres
Ceduna
Port Augusta
Whyalla
Port Pirie
Lock
Snowtown
Spencer Gulf
Maitland
Nuriootpa
Berri
Port Lincoln
ADELAIDE
Gulf St Vincent
Victor Harbor
Keith
Naracoorte
- Data based on Land and Soil Spatial Data supplied by DEWNR Soil and Land Program (July 2009).
- Wheat crop simulations performed by SARDI using the APSIM model. Funded by the State NRM Program, DEWNR and DAFF Australia's Farming Future.
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DEH ID 2012-6211

Appendix O – Boundaries of ABS Statistical Local Areas and PIRSA crop reporting districts

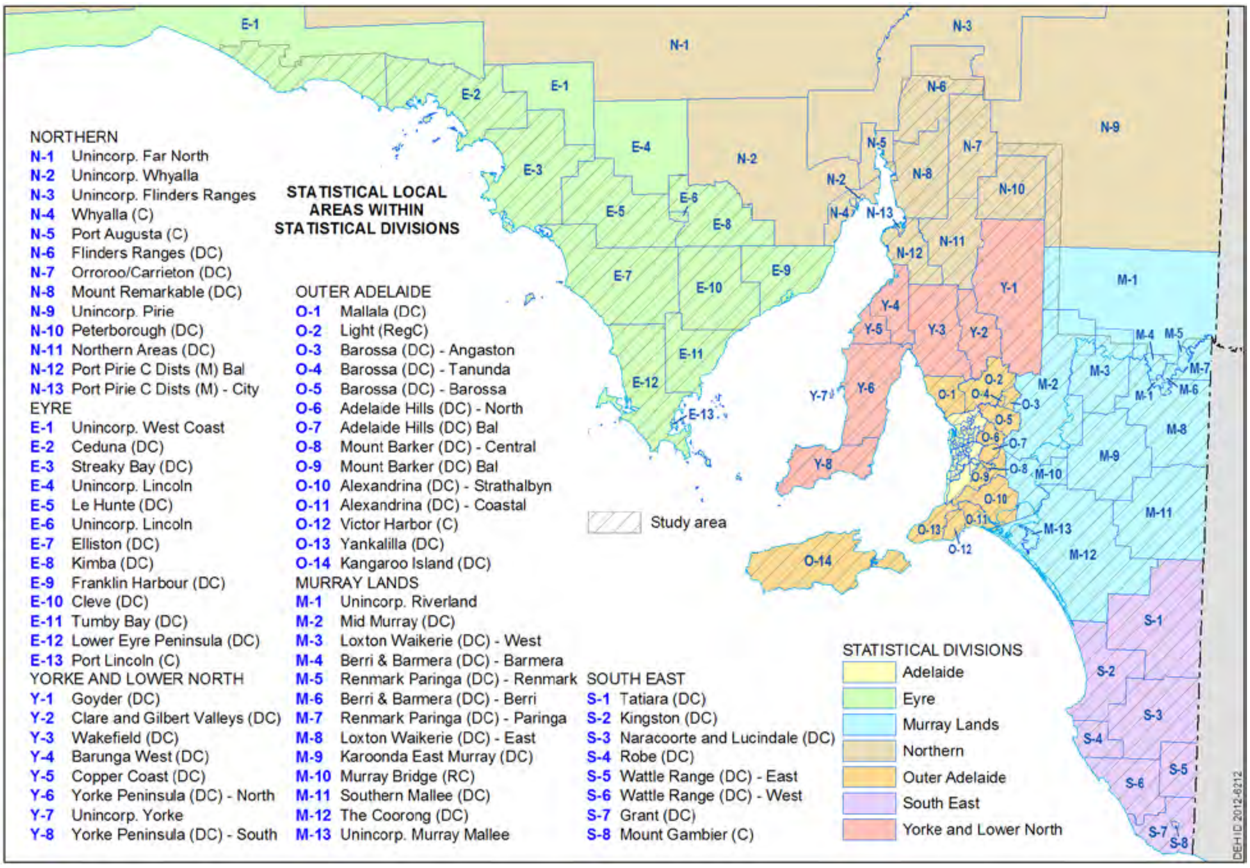


Figure O-1. Australian Bureau of Statistics (ABS) 'Statistical Local Areas', within 'Statistical Divisions'

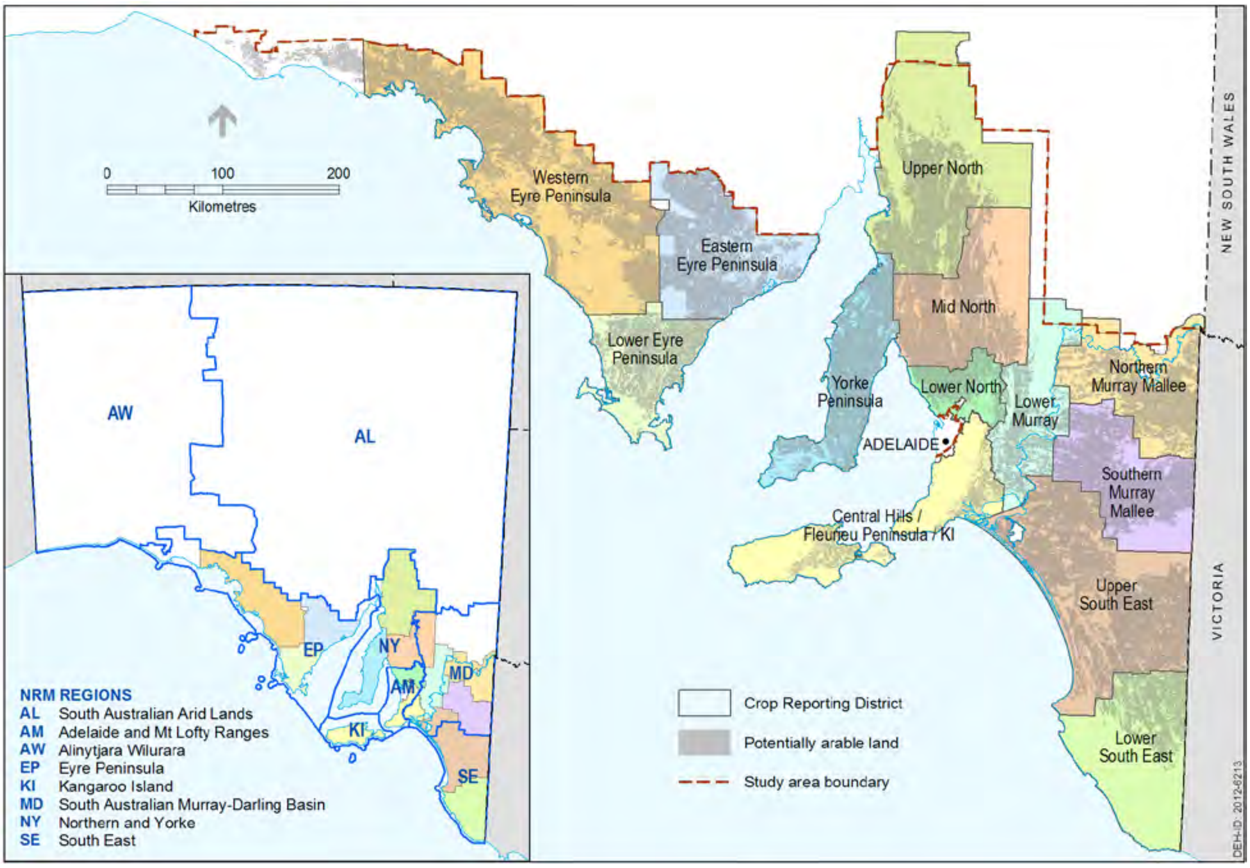


Figure O-2. PIRSA Crop Reporting Districts and NRM Regions

Appendix P – PIRSA Crop and Pasture Report 10 year average (2002/03 – 2011/12) datasets [Source: PIRSA 2003-2012]

PIRSA (Rural Solutions SA) Crop Report Data - WHEAT CROPS - for 10 years (2002/03 - 2011/12)

		Western Eyre Peninsula	Lower Eyre Peninsula	Eastern Eyre Peninsula	Yorke Peninsula	Upper North	Mid North	Lower North	Kangaroo Island	Central Hills & Fleurieu	Lower Murray	Nth Murray Mallee	Sth Murray Mallee	Upper South East	Lower South East	SA	Report Ref.
2002-03	Area (ha)	308,000	142,000	365,000	152,000	240,000	208,000	37,000	6,100	7,000	42,000	120,000	100,000	66,400	16,000	1,809,500	Jan '03
	Prod (t)	215,000	241,000	350,000	210,000	165,000	375,000	70,000	12,200	10,000	16,800	8,000	42,000	73,000	48,000	1,836,000	
	Yield (t/ha)	0.70	1.70	0.96	1.38	0.69	1.80	1.89	2.00	1.43	0.40	0.07	0.42	1.10	3.00	1.01	
2003-04	Area (ha)	308,000	145,000	400,000	152,000	245,000	208,000	38,100	6,000	7,000	44,000	170,000	100,000	67,000	16,000	1,906,100	Jan'04
	Prod (t)	340,000	435,000	680,000	304,000	300,000	550,000	102,900	12,000	17,500	70,000	285,000	170,000	169,500	49,000	3,484,900	
	Yield (t/ha)	1.10	3.00	1.70	2.00	1.22	2.64	2.70	2.00	2.50	1.59	1.68	1.70	2.53	3.06	1.83	
2004-05	Area (ha)	308,000	147,000	380,000	155,000	255,000	208,000	39,000	5,000	7,000	44,000	180,000	100,000	67,000	11,000	1,906,000	Jan'05
	Prod (t)	360,000	338,000	260,000	349,000	280,000	334,000	106,000	9,500	10,500	35,000	135,000	120,000	140,000	34,700	2,511,700	
	Yield (t/ha)	1.17	2.30	0.68	2.25	1.10	1.61	2.72	1.90	1.50	0.80	0.75	1.20	2.09	3.15	1.32	
2005-06	Area (ha)	285,000	154,000	350,000	155,000	243,000	218,000	39,000	3,500	5,000	47,000	185,000	110,000	69,000	11,000	1,874,500	Jan'06
	Prod (t)	370,000	420,000	520,000	420,000	390,000	570,000	119,000	8,700	10,500	75,000	300,000	198,000	180,000	33,000	3,614,200	
	Yield (t/ha)	1.30	2.73	1.49	2.71	1.60	2.61	3.05	2.49	2.10	1.60	1.62	1.80	2.61	3.00	1.93	
2006-07	Area (ha)	300,000	154,000	380,000	125,000	248,000	218,000	38,500	4,500	4,000	41,500	190,000	115,000	65,000	8,000	1,891,500	Feb '07
	Prod (t)	150,000	246,000	230,000	150,000	146,000	258,000	54,000	6,500	6,000	27,000	125,000	35,000	39,000	11,000	1,483,500	
	Yield (t/ha)	0.50	1.60	0.61	1.20	0.59	1.18	1.40	1.44	1.50	0.65	0.66	0.30	0.60	1.38	0.78	
2007-08	Area (ha)	309,000	155,000	393,000	155,000	255,000	240,000	41,000	4,500	6,000	47,000	190,000	131,000	73,000	13,500	2,013,000	Feb '08
	Prod (t)	170,000	256,000	267,000	318,000	230,000	456,000	94,000	10,000	12,000	45,000	140,000	118,000	145,000	44,000	2,305,000	
	Yield (t/ha)	0.55	1.65	0.68	2.05	0.90	1.90	2.29	2.22	2.00	0.96	0.74	0.90	1.99	3.26	1.15	
2008-09	Area (ha)	465,000	129,000	363,000	148,000	208,000	216,000	42,000	5,000	6,000	63,000	190,000	115,000	69,000	24,000	2,043,000	Feb '09
	Prod (t)	274,000	244,000	360,000	288,000	183,000	378,000	97,000	9,000	9,000	63,000	161,000	92,000	127,000	62,000	2,347,000	
	Yield (t/ha)	0.59	1.89	0.99	1.95	0.88	1.75	2.31	1.80	1.50	1.00	0.85	0.80	1.84	2.58	1.15	
2009-10	Area (ha)	465,000	133,000	370,000	158,000	220,000	227,000	44,000	5,500	6,600	63,000	200,000	125,000	69,000	25,000	2,111,100	Mar '10
	Prod (t)	767,000	439,000	592,000	483,000	370,000	581,000	125,000	14,000	14,500	76,000	160,000	163,000	165,000	83,000	4,032,500	
	Yield (t/ha)	1.65	3.30	1.60	3.06	1.68	2.56	2.84	2.55	2.20	1.21	0.80	1.30	2.39	3.32	1.91	
2010-11	Area (ha)	470,000	135,000	375,000	174,000	270,000	240,000	47,000	5,500	6,600	66,000	220,000	131,000	72,000	25,000	2,237,100	Mar '11
	Prod (t)	892,000	520,000	820,000	695,000	590,000	840,000	180,000	16,500	18,000	150,000	473,000	300,000	234,000	90,000	5,818,500	
	Yield (t/ha)	1.90	3.85	2.19	3.99	2.19	3.50	3.83	3.00	2.73	2.27	2.15	2.29	3.25	3.60	2.60	
2011-12	Area (ha)	470,000	135,000	375,000	165,000	250,000	223,000	44,000	5,500	6,600	66,000	200,000	131,000	72,000	25,000	2,168,100	Jan '12
	Prod (t)	658,000	432,000	562,000	495,000	422,000	580,000	132,000	13,800	14,500	100,000	180,000	180,000	170,000	85,000	4,024,300	
	Yield (t/ha)	1.40	3.20	1.50	3.00	1.69	2.60	3.00	2.51	2.20	1.52	0.90	1.37	2.36	3.40	1.86	
AVE	Area (ha)	368,800	142,900	375,100	153,900	243,400	220,600	40,960	5,110	6,180	52,350	184,500	115,800	68,940	17,450	1,995,990	
AVE	Prod (t)	419,600	357,100	464,100	371,200	307,600	492,200	107,990	11,220	12,250	65,780	196,700	141,800	144,250	53,970	3,145,760	
AVE	Yield (t/ha)	1.09	2.52	1.24	2.36	1.25	2.22	2.60	2.19	1.96	1.20	1.02	1.21	2.08	2.98	1.55	

PIRSA (Rural Solutions SA) Crop Report Data - TOTAL FIELD CROP AREA - for 10 years (2002/03 - 2011/12)

		Western Eyre Peninsula	Lower Eyre Peninsula	Eastern Eyre Peninsula	Yorke Peninsula	Upper North	Mid North	Lower North	Kangaroo Island	Central Hills & Fleurieu	Lower Murray	Nth Murray Mallee	Sth Murray Mallee	Upper South East	Lower South East	SA	Report Ref.
2002-03	Area (ha)	429,000	317,500	503,900	513,100	448,350	484,900	107,150	22,350	25,300	125,650	158,708	245,250	214,220	71,250	3,666,628	Jan '03
2003-04	Area (ha)	428,500	323,700	541,700	520,100	444,500	480,450	109,600	23,650	25,300	130,800	235,000	245,500	212,200	71,900	3,792,900	Jan'04
2004-05	Area (ha)	427,000	312,300	539,000	514,600	453,500	478,500	109,300	22,750	23,600	130,150	245,500	246,750	212,200	62,000	3,777,150	Jan'05
2005-06	Area (ha)	398,800	318,700	493,800	519,500	425,800	493,500	109,600	19,250	22,100	135,500	250,100	264,800	210,300	62,070	3,723,820	Jan'06
2006-07	Area (ha)	420,100	319,150	526,300	471,400	417,400	483,400	107,600	19,050	17,600	129,250	269,200	270,700	211,600	58,600	3,721,350	Feb '07
2007-08	Area (ha)	433,200	335,500	554,000	538,400	449,200	517,600	112,800	20,050	26,600	146,350	275,350	297,750	229,600	73,100	4,009,500	Feb '08
2008-09	Area (ha)	609,200	315,800	508,500	505,600	417,750	455,600	118,500	18,000	23,700	142,900	275,200	296,100	244,700	76,900	4,008,450	Feb '09
2009-10	Area (ha)	607,400	318,400	504,200	503,500	433,100	463,500	119,000	18,500	23,600	143,200	280,200	289,000	244,200	76,900	4,024,700	Mar '10
2010-11	Area (ha)	590,700	315,600	494,200	511,500	451,300	461,600	119,800	18,200	23,000	141,000	294,200	285,000	243,100	73,800	4,023,000	Mar '11
2011-12	Area (ha)	605,200	321,400	509,900	538,500	460,900	462,600	119,900	19,000	24,500	143,000	307,000	292,900	247,400	77,300	4,129,500	Jan '12
AVE	Area (ha)	494,910	319,805	517,550	513,620	440,180	478,165	113,325	20,080	23,530	136,780	259,046	273,375	226,952	70,382	3,887,700	As above
*Potential arable land identified in this study (ha)		1,048,408	373,359	692,418	563,204	632,959	649,322	192,386	86,934	81,716	240,789	415,082	553,397	1,046,765	262,555	6,839,296	See Section 3.8
*10yr Ave Total Field Crop Area as a % of identified potential arable land area		47	86	75	91	70	74	59	23	29	57	62	49	22	27	57	

*Note: The bottom 2 rows are derived values from this study

Appendix Q – Supporting data for comparison of simulated historic average wheat grain yields with Australian Bureau of Statistics (ABS) data for (i) Statistical Local Areas and (ii) Statistical Divisions

(i) ABS 'Statistical Local Area' data 1991/92-2000/01 (10 years)

The period 1991/92 – 2000/01 represents the most recent consecutive 10 year period with availability of ABS data at the smaller Statistical Local Area reporting level. 10 year average values of wheat grain yield (t/ha) for SLAs are shown in Table Q-1. This is compared against simulated historic average wheat yield data (see Table Q-3) as shown in the scatterplot presented in Figure 33a (Section 4.5). These datasets can also be compared through mapping within SLA boundaries as shown in Figures Q-1 and Q-2.

Table Q-1. Wheat yield data by Statistical Local Areas, calculated from ABS data (1991/92-2000/01).

Statistical Local Area (SLA)	Statistical Division (SD)	Australian Bureau of Statistics 1991/92 - 2000/01 Average Wheat Yield (t/ha)
Ceduna (DC)	Eyre	0.94
Cleve (DC)	Eyre	1.45
Elliston (DC)	Eyre	1.55
Franklin Harbour (DC)	Eyre	1.21
Kimba (DC)	Eyre	1.4
Le Hunte (DC)	Eyre	1.2
Lower Eyre Peninsula (DC)	Eyre	2.33
Streaky Bay (DC)	Eyre	1.12
Tumby Bay (DC)	Eyre	1.93
Unincorp. West Coast	Eyre	0.98
Karoonda East Murray (DC)	Murray Lands	1.26
Loxton Waikerie (DC) - East	Murray Lands	1.25
Loxton Waikerie (DC) - West	Murray Lands	1.02
Mid Murray (DC)	Murray Lands	1.43
Murray Bridge (RC)	Murray Lands	1.49
Renmark Paringa (DC) - Paringa	Murray Lands	1.26
Southern Mallee (DC)	Murray Lands	1.72
The Coorong (DC)	Murray Lands	1.87
Flinders Ranges (DC)	Northern	1.14
Mount Remarkable (DC)	Northern	1.53
Northern Areas (DC)	Northern	2.4
Orroroo/Carrieton (DC)	Northern	1.4
Peterborough (DC)	Northern	1.27
Port Pirie C Dists (M) Bal	Northern	2.15
Alexandrina (DC) - Coastal	Outer Adelaide	2.01
Alexandrina (DC) - Strathalbyn	Outer Adelaide	1.83
Barossa (DC) - Angaston	Outer Adelaide	1.69
Barossa (DC) - Barossa	Outer Adelaide	2.82
Kangaroo Island (DC)	Outer Adelaide	2.44
Light (RegC)	Outer Adelaide	2.69
Mallala (DC)	Outer Adelaide	2.18
Naracoorte and Lucindale (DC)	South East	2.77
Tatiara (DC)	South East	2.53
Wattle Range (DC) - East	South East	2.78
Barunga West (DC)	Yorke and Lower North	2.4
Clare and Gilbert Valleys (DC)	Yorke and Lower North	3.13
Copper Coast (DC)	Yorke and Lower North	2.65
Goyder (DC)	Yorke and Lower North	1.95
Wakefield (DC)	Yorke and Lower North	2.46
Yorke Peninsula (DC) - North	Yorke and Lower North	2.91
Yorke Peninsula (DC) - South	Yorke and Lower North	2.42

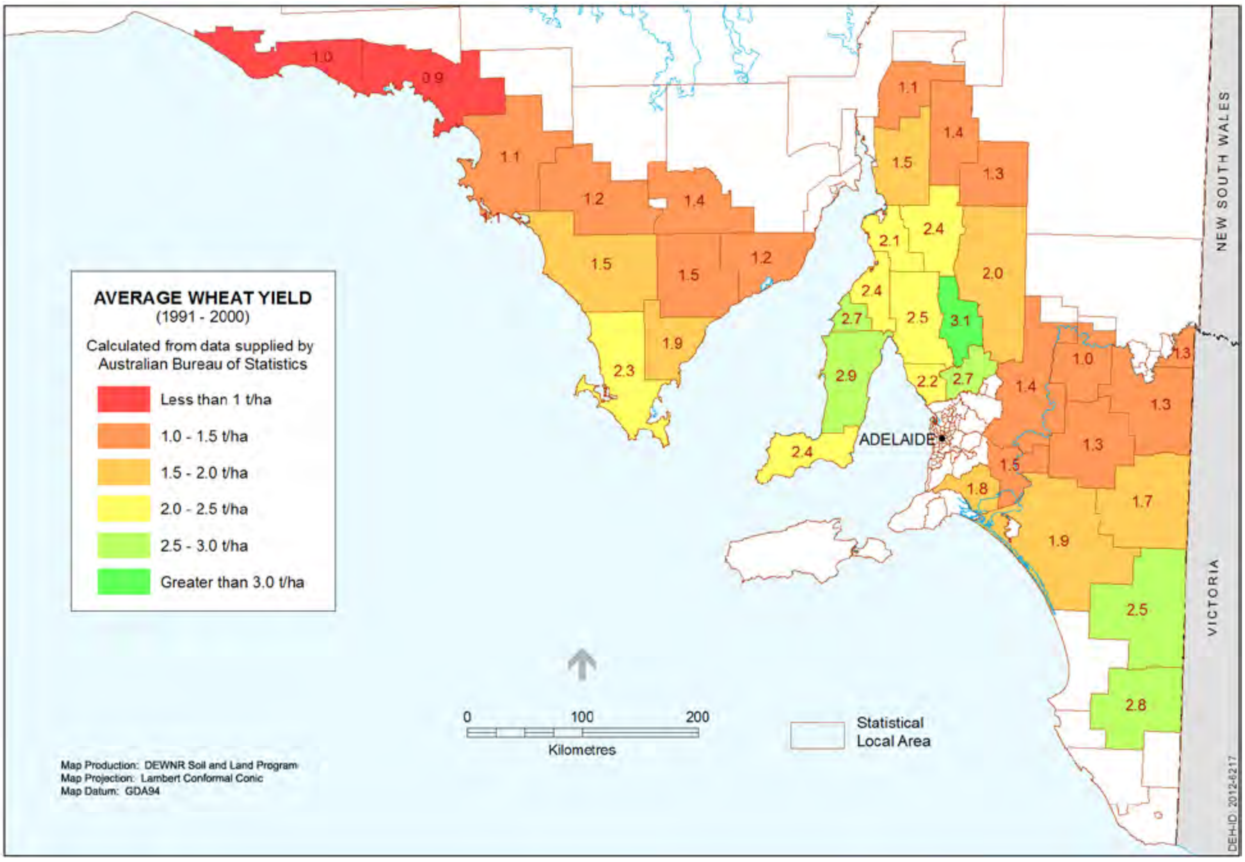


Figure Q-1. Average wheat grain yields (t/ha) by Statistical Local Areas from ABS data (1991/92-2000/01).

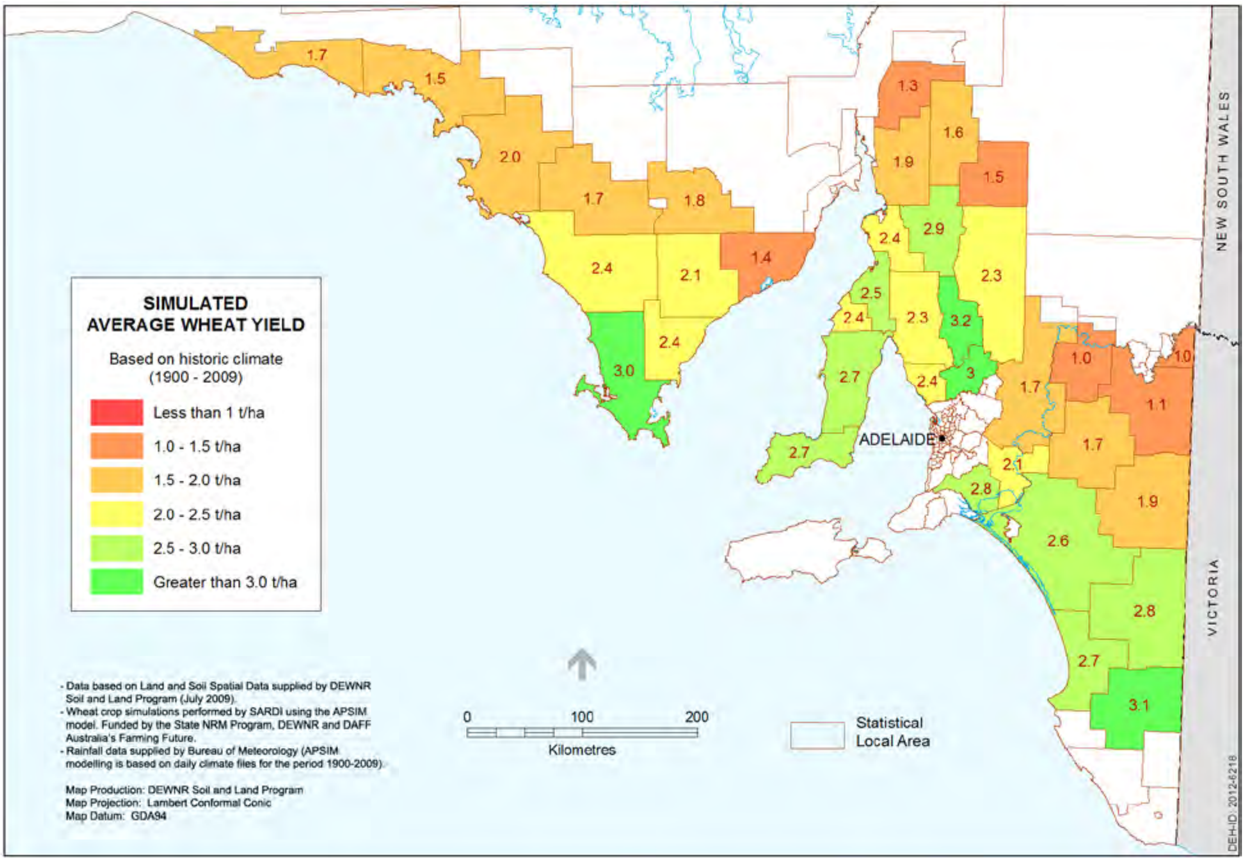


Figure Q-2. Simulated historic average wheat grain yields (t/ha) spatially averaged for each Statistical Local Area (based on APSIM modelling of modern practices under historic climate on arable soils identified within the State Land & Soil Information Framework).

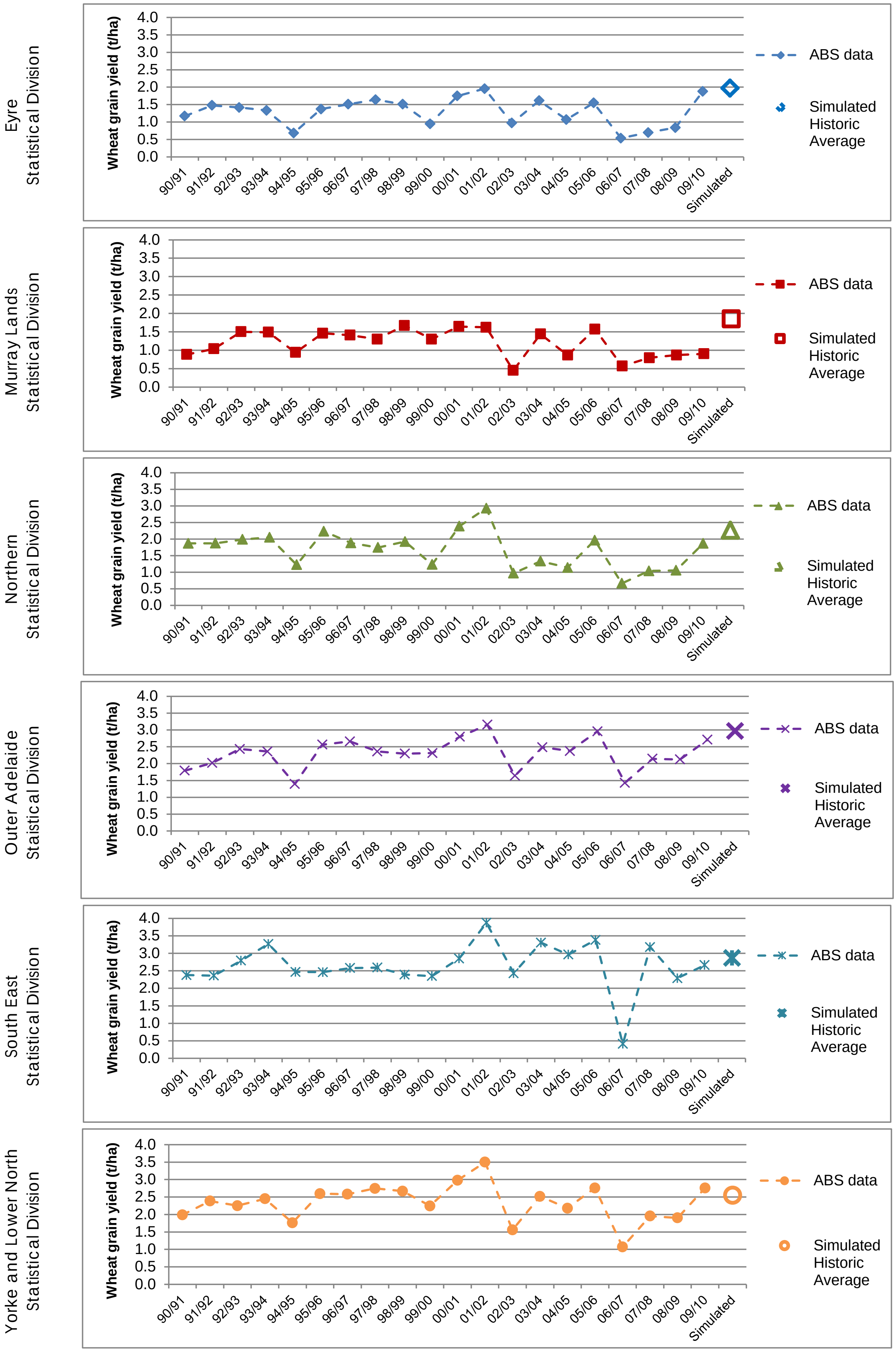
(ii) ABS 'Statistical Division' data 1990/91-2009/10 (20 years)

ABS wheat yield data for this 20 year period is shown in Table Q-2. This is compared against simulated historic average wheat yield values, calculated by SD (refer to Table Q-3), as shown in the scatterplot Figure 33b (Section 4.5). RMSE values of 0.55t/ha suggest a relatively close association between the ABS SD data and simulated results. However it is possible that ABS data collected over 20 years may be subject to changing uptake of no-till and other modern practices, and/or climate conditions that are on average different to 100+ year average conditions. Figure Q-3 presents time series plots showing ABS wheat grain yield data, separately for each SD, with simulated historic average values shown on the far right of each plot. Values have been calculated on the basis of total tonnes produced / total hectares, within each SD.

Table Q-2. Wheat yield statistics by Statistical Divisions (Source: ABS data 1990/91 – 2009/10)

Year	Indicator	Eyre	Murray Lands	Northern	Outer Adelaide	South East	Yorke and Lower North	SA
90/91	Wheat - Area (ha)	735,386	204,975	181,510	32,784	24,523	255,095	1,435,437
	Wheat - Production (t)	860,160	181,233	339,318	58,764	58,289	507,416	2,007,299
	Wheat - Yield (t/ha)	1.17	0.88	1.87	1.79	2.38	1.99	1.40
91/92	Wheat - Area (ha)	644,958	195,215	161,518	30,992	18,933	236,563	1,288,911
	Wheat - Production (t)	953,799	202,248	302,905	62,676	44,751	564,247	2,132,303
	Wheat - Yield (t/ha)	1.48	1.04	1.88	2.02	2.36	2.39	1.65
92/93	Wheat - Area (ha)	677,981	229,314	181,774	35,377	26,738	259,728	1,411,720
	Wheat - Production (t)	961,080	344,301	361,579	86,082	74,632	585,373	2,415,176
	Wheat - Yield (t/ha)	1.42	1.50	1.99	2.43	2.79	2.25	1.71
93/94	Wheat - Area (ha)	547,692	193,881	163,337	35,038	26,227	243,355	1,210,303
	Wheat - Production (t)	729,329	288,690	335,173	82,764	85,676	596,777	2,120,211
	Wheat - Yield (t/ha)	1.33	1.49	2.05	2.36	3.27	2.45	1.75
94/95	Wheat - Area (ha)	633,066	223,797	185,894	39,528	29,060	276,488	1,388,738
	Wheat - Production (t)	432,128	210,379	227,862	55,201	71,746	487,503	1,485,812
	Wheat - Yield (t/ha)	0.68	0.94	1.23	1.40	2.47	1.76	1.07
95/96	Wheat - Area (ha)	688,691	250,799	194,634	43,622	31,830	301,038	1,511,518
	Wheat - Production (t)	945,016	366,392	434,806	111,781	78,370	782,396	2,720,678
	Wheat - Yield (t/ha)	1.37	1.46	2.23	2.56	2.46	2.60	1.80
96/97	Wheat - Area (ha)	659,585	268,999	191,721	47,608	40,663	314,855	1,524,585
	Wheat - Production (t)	995,675	378,596	361,493	126,708	104,939	812,649	2,782,325
	Wheat - Yield (t/ha)	1.51	1.41	1.89	2.66	2.58	2.58	1.82
97/98	Wheat - Area (ha)	753,068	252,322	117,530	44,608	37,009	286,582	1,493,253
	Wheat - Production (t)	1,234,959	328,305	205,215	105,272	95,955	787,756	2,763,001
	Wheat - Yield (t/ha)	1.64	1.30	1.75	2.36	2.59	2.75	1.85
98/99	Wheat - Area (ha)	869,267	612,729	405,220	36,734	36,236	887,338	2,848,517
	Wheat - Production (t)	1,312,915	1,024,024	780,218	84,414	86,625	2,368,507	5,658,624
	Wheat - Yield (t/ha)	1.51	1.67	1.93	2.30	2.39	2.67	1.99
99/00	Wheat - Area (ha)	795,502	312,995	243,195	52,222	47,763	395,185	1,850,019
	Wheat - Production (t)	754,145	406,882	299,696	120,831	112,158	886,890	2,585,543
	Wheat - Yield (t/ha)	0.95	1.30	1.23	2.31	2.35	2.24	1.40
00/01	Wheat - Area (ha)	890,146	355,242	234,568	57,714	43,494	391,742	1,973,409
	Wheat - Production (t)	1,556,697	584,309	560,082	161,571	124,035	1,167,326	4,155,271
	Wheat - Yield (t/ha)	1.75	1.64	2.39	2.80	2.85	2.98	2.11
01/02	Wheat - Area (ha)	888,342	353,204	240,581	58,191	44,019	401,223	1,985,561
	Wheat - Production (t)	1,739,251	572,931	705,174	183,648	170,432	1,403,836	4,775,272
	Wheat - Yield (t/ha)	1.96	1.62	2.93	3.16	3.87	3.50	2.40
02/03	Wheat - Area (ha)	905,081	320,389	220,432	61,088	45,627	399,214	1,956,540
	Wheat - Production (t)	877,714	143,816	213,421	100,045	110,792	621,937	2,071,833
	Wheat - Yield (t/ha)	0.97	0.45	0.97	1.64	2.43	1.56	1.06
03/04	Wheat - Area (ha)	878,476	371,791	230,124	54,966	38,790	381,546	1,959,521
	Wheat - Production (t)	1,416,509	535,309	306,947	136,773	128,271	960,857	3,490,430
	Wheat - Yield (t/ha)	1.61	1.44	1.33	2.49	3.31	2.52	1.78
04/05	Wheat - Area (ha)	924,484	340,154	242,325	50,951	31,896	389,066	1,979,206
	Wheat - Production (t)	987,402	293,529	276,164	120,945	94,501	847,902	2,620,787
	Wheat - Yield (t/ha)	1.07	0.86	1.14	2.37	2.96	2.18	1.32
05/06	Wheat - Area (ha)	965,210	393,969	204,794	52,002	40,339	377,949	2,034,943
	Wheat - Production (t)	1,495,740	619,134	402,564	153,971	136,465	1,042,945	3,852,776
	Wheat - Yield (t/ha)	1.55	1.57	1.97	2.96	3.38	2.76	1.89
06/07	Wheat - Area (ha)	1,035,233	454,910	210,327	38,851	42,329	389,678	2,172,512
	Wheat - Production (t)	555,504	258,331	139,653	55,591	17,372	416,631	1,445,984
	Wheat - Yield (t/ha)	0.54	0.57	0.66	1.43	0.41	1.07	0.67
07/08	Wheat - Area (ha)	982,734	442,652	174,107	86,523	35,135	393,126	2,120,820
	Wheat - Production (t)	684,035	350,746	181,188	185,657	111,621	769,110	2,295,971
	Wheat - Yield (t/ha)	0.70	0.79	1.04	2.15	3.18	1.96	1.08
08/09	Wheat - Area (ha)	1,003,189	390,639	216,166	48,738	45,080	395,441	2,103,872
	Wheat - Production (t)	840,900	339,335	228,369	103,618	103,228	753,300	2,376,094
	Wheat - Yield (t/ha)	0.84	0.87	1.06	2.13	2.29	1.90	1.13
09/10	Wheat - Area (ha)	986,565	413,204	231,996	43,969	50,089	395,780	2,122,416
	Wheat - Production (t)	1,850,079	372,025	433,023	119,188	133,372	1,091,512	4,001,296
	Wheat - Yield (t/ha)	1.88	0.90	1.87	2.71	2.66	2.76	1.89

Figure Q-3. Comparison between 20 year ABS time trends (1990/91 – 2009/10) and simulated historic average wheat yields, by Statistical Divisions



(iii) Simulated historic results for ABS SLA and SD boundaries

Simulated historic average yields assume modern practices and are calculated from the average production results after simulating the historic climate record (based on 1900-2009 data). This is discussed in detail in the Method (Section 3). When reporting simulated historic average yields by SLA or SD, results are averaged across all potentially arable soils identified within this study (see Section 3.9). That is, total production (t)/ total; arable area (ha) is evaluated to determine yield (t/ha) values, for both SLA and SD boundaries (see Table Q-3).

Table Q-3. Simulated historic average (total annual) wheat crop production statistics based on wheat cropping on all potentially arable land (as defined in Section 3.9). {Note that simulated average total annual production data statistics (tonnes) presented elsewhere in this report are scaled down from the values in this table according to varying regional wheat crop areas. This is described further in Section 4.4.}

Statistical Division (SD)	Statistical Local Area (SLA)	Total Arable Area (ha) [ie. all land with potential for cropping]	Simulated Historic Average Total Wheat Grain Production (t), if all arable land is cropped	Simulated Historic Average Total Post-Harvest Biomass Production (t), if all arable land is cropped	Simulated Historic Average Wheat Grain Yield (t/ha)
Eyre	Ceduna (DC)	304,982	470,312	1,324,536	1.54
Eyre	Cleve (DC)	296,149	610,950	1,799,162	2.06
Eyre	Elliston (DC)	162,799	386,619	1,085,516	2.37
Eyre	Franklin Harbour (DC)	129,742	185,596	589,639	1.43
Eyre	Kimba (DC)	266,508	468,492	1,457,297	1.76
Eyre	Le Hunte (DC)	261,786	453,526	1,273,607	1.73
Eyre	Lower Eyre Peninsula (DC)	183,807	554,222	1,535,057	3.02
Eyre	Streaky Bay (DC)	318,847	627,358	1,653,273	1.97
Eyre	Tumby Bay (DC)	189,414	456,636	1,293,668	2.41
Eyre	Unincorp. West Coast	112,145	188,037	518,282	1.68
Eyre SD TOTAL		**2,226,177**	**4,401,748**	**12,530,037**	**1.98**
Murray Lands	Karoonda East Murray (DC)	253,860	423,961	1,345,770	1.67
Murray Lands	Loxton Waikerie (DC) - East	299,491	337,898	1,194,632	1.13
Murray Lands	Loxton Waikerie (DC) - West	80,823	83,973	305,977	1.04
Murray Lands	Mid Murray (DC)	166,828	275,578	879,581	1.65
Murray Lands	Murray Bridge (RC)	73,982	153,951	461,673	2.08
Murray Lands	Renmark Paringa (DC) - Paringa	32,120	32,654	119,402	1.02
Murray Lands	Southern Mallee (DC)	299,465	579,242	1,791,104	1.93
Murray Lands	The Coorong (DC)	474,461	1,234,727	3,545,727	2.60
Murray Lands SD TOTAL		**1,681,030**	**3,121,983**	**9,643,865**	**1.86**
Northern	Flinders Ranges (DC)	19,970	25,312	83,426	1.27
Northern	Mount Remarkable (DC)	154,938	301,299	934,464	1.94
Northern	Northern Areas (DC)	219,238	634,376	1,874,109	2.89
Northern	Orroroo/Carrieton (DC)	76,635	121,710	419,060	1.59
Northern	Peterborough (DC)	40,255	59,077	209,611	1.47
Northern	Port Pirie C Dists (M) Bal	121,131	292,503	785,967	2.41
Northern SD TOTAL		**632,167**	**1,434,277**	**4,306,638**	**2.27**
Outer Adelaide	Alexandrina (DC) - Coastal	14,179	44,122	123,116	3.11
Outer Adelaide	Alexandrina (DC) - Strathalbyn	49,644	137,151	384,164	2.76
Outer Adelaide	Barossa (DC) - Angaston	9,114	30,752	90,187	3.37
Outer Adelaide	Barossa (DC) - Barossa	16,408	53,949	154,343	3.29
Outer Adelaide	Kangaroo Island (DC)	86,934	286,468	786,489	3.30
Outer Adelaide	Light (RegC)	95,896	291,255	802,688	3.04
Outer Adelaide	Mallala (DC)	64,840	158,574	448,447	2.45
Outer Adelaide SD TOTAL		**337,015**	**1,002,271**	**2,789,433**	**2.97**
South East	Kingston (DC)	137,965	367,273	1,130,126	2.66
South East	Naracoorte and Lucindale (DC)	233,131	712,571	2,150,058	3.06
South East	Tatiara (DC)	434,333	1,229,182	3,698,030	2.83
South East	Wattle Range (DC) - East	29,364	88,386	268,329	3.01
South East SD TOTAL		**834,793**	**2,397,412**	**7,246,543**	**2.87**
Yorke and Lower North	Barunga West (DC)	123,915	309,974	842,355	2.50
Yorke and Lower North	Clare and Gilbert Valleys (DC)	132,257	423,308	1,217,703	3.20
Yorke and Lower North	Copper Coast (DC)	44,853	107,678	299,382	2.40
Yorke and Lower North	Goyder (DC)	230,414	523,787	1,627,131	2.27
Yorke and Lower North	Wakefield (DC)	286,663	666,417	1,918,118	2.32
Yorke and Lower North	Yorke Peninsula (DC) - North	291,718	791,501	2,160,261	2.71
Yorke and Lower North	Yorke Peninsula (DC) - South	102,715	279,856	768,219	2.72
Yorke and Lower North SD TOTAL		**1,212,535**	**3,102,521**	**8,833,169**	**2.56**

Appendix R – Supporting data for comparison of simulated historic average wheat grain yields with PIRSA Crop Report data

Table R-1 presents simulated historic average wheat grain yield values calculated for PIRSA Crop Reporting Districts. Simulated historic average yields assume modern practices and are calculated from the average production results after simulating the historic climate record (based on 1900-2009 data). This is discussed in detail in the Method (Section 3). When reporting simulated historic average yields by PIRSA Crop Reporting Districts, results have been averaged across all potentially arable soils identified within this study (see Section 3.9). That is, total production (t)/ total arable area (ha) is evaluated to determine yield (t/ha) values. Table R-1 also shows recent 10 year average PIRSA Crop and Pasture wheat yield data (as derived from the more detailed records shown in Appendix P.)

A scatterplot of simulated historic average yield against PIRSA Crop Report 10 year average yield values is shown in Figure 33c (Section 4.5). A RMSE value of 0.52 t/ha indicates a relatively close association between these two datasets. As a further comparison, simulated historic average yield values were re-calculated with a simplified modelling approach that considered only 'most common' (or dominant) soil components (refer to Section 3.1). A larger discrepancy arose, when comparing simulation results to observed records (RMSE = 0.63 t/ha) using this approach, supporting the argument that greater predictive accuracy can be achieved when all available soil and land information is utilised (rather than a simplified approach).

Table R-1. Simulated historic average wheat yield values calculated for PIRSA Crop Reporting Districts.

PIRSA Crop Reporting District	Simulated Historic Average Wheat Grain Yield (t/ha)	Simulated Historic Average Wheat Grain Yield (t/ha) **Considering dominant soils only**	PIRSA Crop Report 10yr Average (2002/03-2011/12) Wheat Grain Yield (t/ha)
Central Hills & Fleurieu	2.67	2.95	1.96
Kangaroo Island	3.20	3.33	2.19
Eastern Eyre Peninsula	1.79	1.80	1.24
Lower Eyre Peninsula	2.55	2.65	2.52
Lower Murray	1.51	1.77	1.20
Lower North	2.72	2.87	2.60
Lower South East	2.80	3.05	2.98
Mid North	2.37	2.49	2.22
Northern Murray Mallee	1.01	1.03	1.02
Southern Murray Mallee	1.64	1.73	1.21
Upper North	2.17	2.30	1.25
Upper South East	2.49	2.68	2.08
Western Eyre Peninsula	1.77	1.85	1.09
Yorke Peninsula	2.46	2.63	2.36
TOTAL	2.23	2.23	1.55
	*RMSE = 0.52 t/ha	*RMSE = 0.63 t/ha	

*Note: RMSE values compare simulated historic results to PIRSA Crop Report 10yr average results

Appendix S – Anecdotal wheat yield estimates

These Indicative yields associated with example district soil types and rainfall assume a 'good operator' and moderate nutrition (*also see notes below).

Major soil types (Hall et al. 2009)

Subgroup soil class	Description	Typical (anecdotal) yield for:								
		300 mm annual rainfall			350 mm annual rainfall			400 mm annual rainfall		
		poor year (t/ha)	median year (t/ha)	good year (t/ha)	poor year (t/ha)	median year (t/ha)	good year (t/ha)	poor year (t/ha)	median year (t/ha)	good year (t/ha)
A6	Calcareous gradational clay loam	0.4	1.3	2.8	1	2	3.5	1.5	2.5	4
		Mambray Creek			Crystal Brook			Brinkworth		
A4	Calcareous loam	0.5	1.3	2.5	1.2	1.9	3.2	1.6	2.5	3.6
		Mambray Creek			Port Broughton flats			Blyth / Crystal Brook		
A5	Calcareous loam on clay	0.5	1.3	2.5	1.2	1.9	3.2	1.6	2.5	3.6
		Mambray Creek			Port Broughton flats			Blyth / Crystal Brook		
D2	Loam over red clay	0.3	1.4	3	0.8	2.2	3.6	1.6	2.7	4
		Willowie			Warnertown			Crystal Brook / Redhill		
C3	Friable gradational clay loam	0.3	1.4	3.2	0.8	2.2	3.7	1.5	2.8	4.5
		Willowie			Balaklava			Snowtown		
H2	Siliceous sand	1	1.6	2.2	1.3	2	2.7	1.8	2.7	3.2
		Mambray Creek			Port Broughton / Warnertown			Bismarck (between Snowtown & Pt Wakefield)		
B2	Shallow calcareous loam on calcrete	0.2	0.8	2	0.5	1.2	2.5	1	2	3
		Wallaroo			Kadina			Agery		
A2	Calcareous loam on rock	0.4	1.3	2.5	1	1.8	2.8	1.4	2.2	3
		East of Wilmington			West of road Wilmington to Quorn			Barunga Gap		
L1	Shallow soil on rock	Non arable – not cropped								
D3	Loam over poorly structured red clay	0	1	2.5	1	1.6	2.6	1.2	2.2	3
		Mambray Creek			Condowie (rain shadow)			South of Brinkworth		
D4	Loam over pedaric red clay	0	0.8	3	0	1.1	3.2	(Not applicable)		
		Mambray Creek			Port Wakefield					
N2	Saline soil	Non arable – not cropped								
D1**	Loam over clay on rock	(Not applicable)			1.1	2	3	(Not applicable)		
					South of Quorn					
D7**	Loam over poorly structured clay on rock	(Not applicable)			(Not applicable)			1.4	2.5	3.2
								Wirrabara (450-500 mm)		

*Notes: Indicative yields for each broad soil type (with an example district and rainfall zone) were estimated to provide a ball-park guide to wheat grain yield modelling in the Northern & Yorke pilot project (Liddicoat et al. 2011). Estimates were derived in a workshop attended by cropping, soil and land management consultants (from Rural Solutions SA and DEWNR) including, Brian Hughes, Barry Mudge, Michael Wurst, David Maschmedt, James Hall and Tim Herrmann. A "poor" year is considered representative of decile 2 yield, median year = decile 5 and a "good" year is represented by decile 8 yield.

**Examples of water erosion prone soils.

Soils were selected due to their high frequency of occurrence within the N&Y pilot study area.

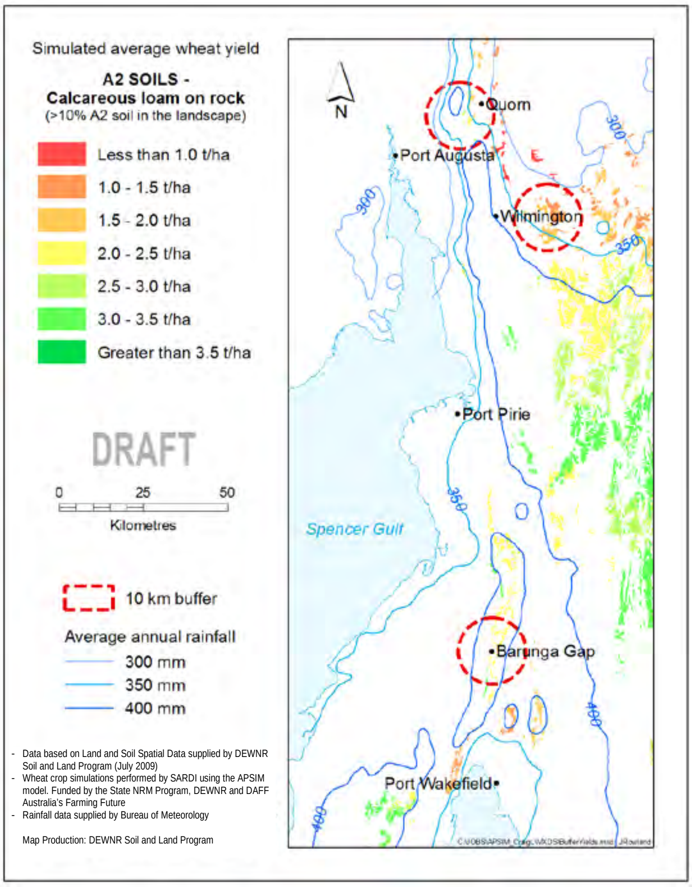
Appendix T – Comparison of simulated average wheat grain yield outcomes with anecdotal estimates (from Appendix S)

A comparison was performed between simulated historic average wheat grain yields and anecdotal yield estimates on the basis of subgroup soil classes, as mapped by the State Land & Soil Mapping Program (Hall et al. 2009). Particular localities and subgroup soils, as outlined in Appendix S, were investigated.

10km buffer zones were drawn in the localities described in Appendix S ('Anecdotal wheat yield estimates'). Each buffer zone typically contained a number of variants of the particular 'subgroup soil class' under investigation – and it was necessary to obtain summary data (including the area-weighted simulated average yield) for the purpose of comparison with anecdotal estimates. All relevant subgroup soil variants in each buffer zone were identified to report on: the number of occurrences (soil landscape map unit polygons), the area of landscape occupied, simulated average yields, and Ave GSR. Ranges of values encountered, the area-weighted simulated average yield (refer to *below) and anecdotal median yield estimates are also reported in table format for each subgroup soil and locality (buffer zone).

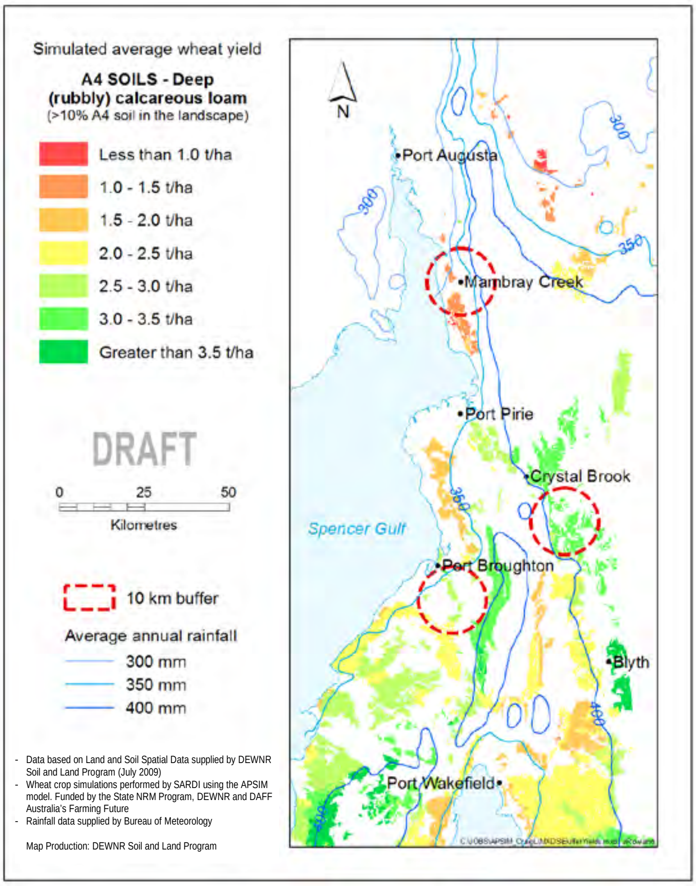
A scatterplot of simulated historic average yield results (calculated within 10km buffers, as presented in this Appendix) against the expert anecdotal yield estimates (see previous Appendix) is shown in Figure 33d (Section 4.5).

(i) ***Simulated wheat yields on 'A2' (calcareous loam on rock) soils, with summary results for reference localities***



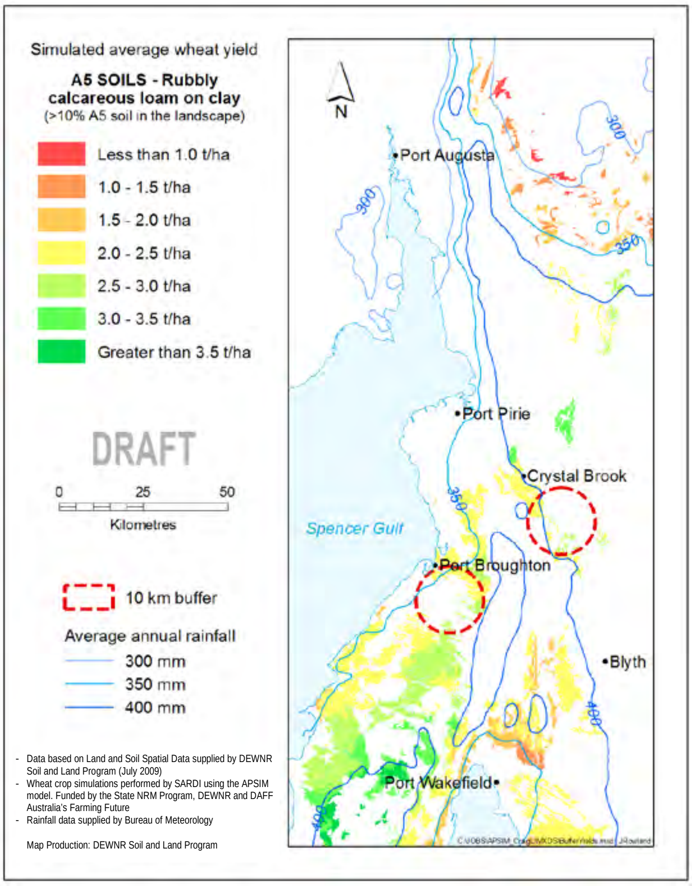
Locality (10 km buffer)	East of Wilmington	West of road Wilmington to Quorn	Barunga Gap
No of LANSLU map polygons with >10% of soil type	11	10	4
Range of Simulated Ave Yield (t/ha)	0.93-1.83	1.13-2.99	2.01-3.01
Ave GSR range (mm)	177-237	217-347	287-307
Total area (ha) occupied by soil type within the 10km buffer	1269	428	287
***Simulated (area-weighted) Average Yield (t/ha)**	1.41	2.18	2.27
Anecdotal Estimate Median Yield (t/ha)	1.3	1.8	2.2

(ii) ***Simulated wheat yields on <u>'A4' (calcareous loam)</u> soils, with summary results for reference localities***



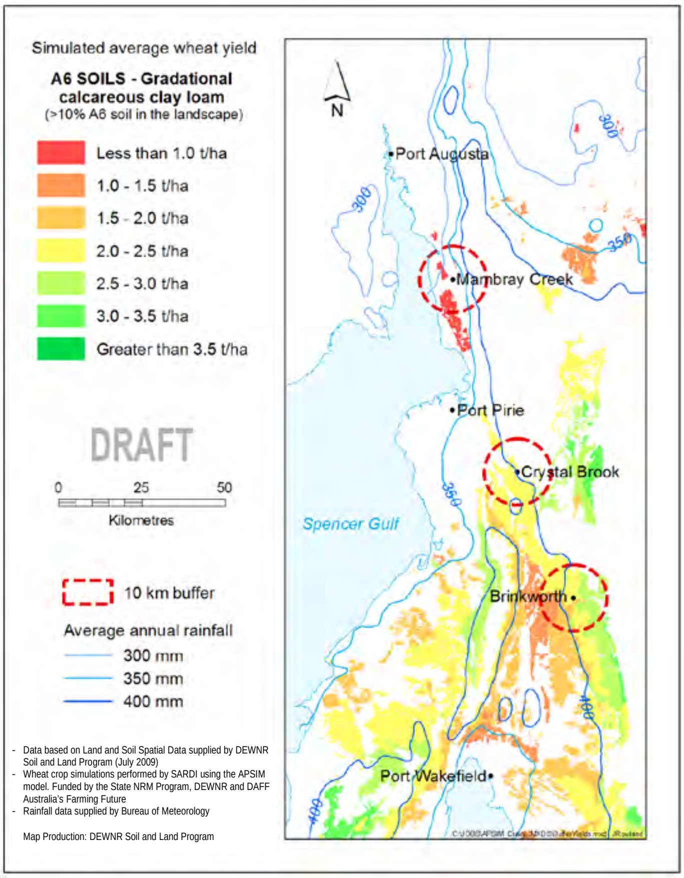
Locality (10 km buffer)	Mambray Creek	Port Broughton Flats	Blyth / Crystal Brook
No of LANSLU map polygons with >10% of soil type	4	13	12
Range of Simulated Ave Yield (t/ha)	0.96 – 1.626	2.19-3.42	2.72-3.44
Ave GSR range (mm)	187-217	247-297	287-357
Total area (ha) occupied by soil type within the 10km buffer	484	1915	1758
***Simulated (area-weighted) Average Yield (t/ha)**	1.26	2.60	3.15
Anecdotal Estimate Median Yield (t/ha)	1.3	1.9	2.5

(iii) ***Simulated wheat yields on <u>'A5' (calcareous loam on clay)</u> soils, with summary results for reference localities***



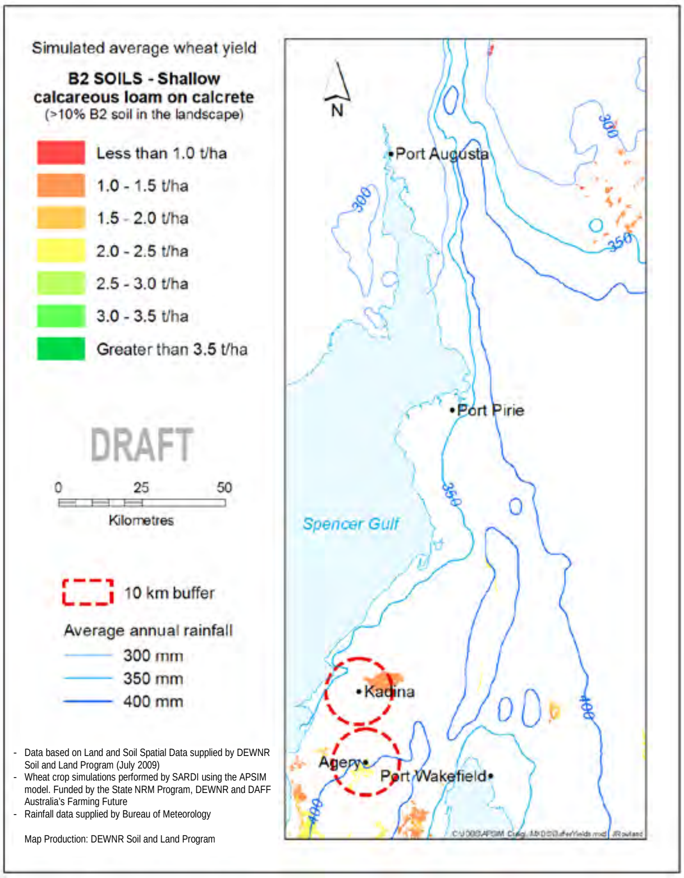
Locality (10 km buffer)	Port Broughton Flats	Blyth / Crystal Brook
No of LANSLU map polygons with >10% of soil type	15	4
Range of Simulated Ave Yield (t/ha)	2.13-2.58	2.19-2.60
Ave GSR range (mm)	247-277	287-317
Total area (ha) occupied by soil type within the 10km buffer	1745	1050
***Simulated (area-weighted) Average Yield (t/ha)**	2.47	2.38
Anecdotal Estimate Median Yield (t/ha)	1.9	2.5

(iv) ***Simulated wheat yields on 'A6' (calcareous gradational clay loam) soils, with summary results for reference localities***



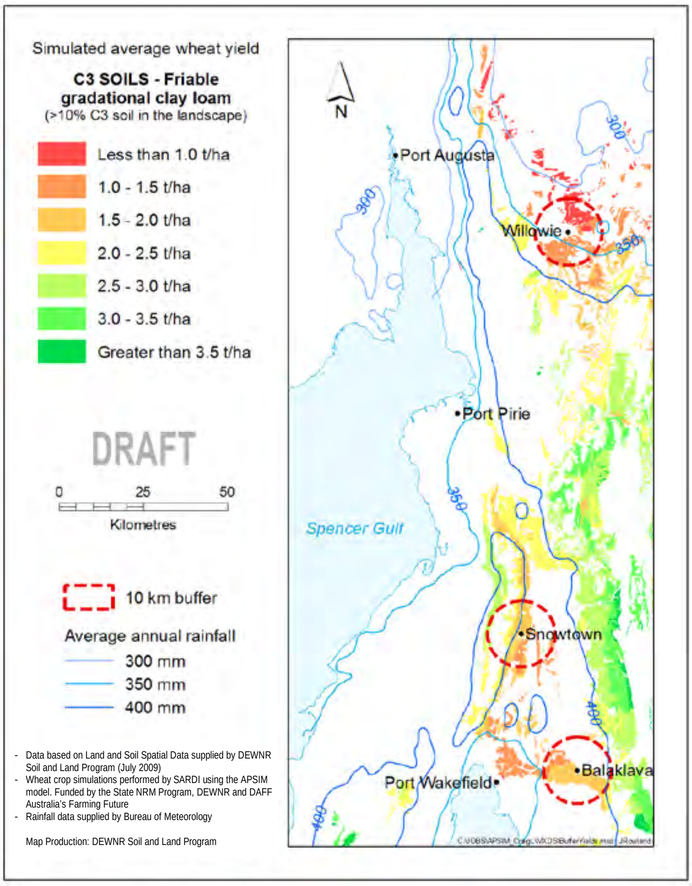
Locality (10 km buffer)	Mambray Creek	Crystal Brook	Brinkworth
No of LANSLU map polygons with >10% of soil type	5	17	25
Range of Simulated Ave Yield (t/ha)	0.68 -0. 96	1.87-2.84	1.23-3.14
Ave GSR range (mm)	197-217	267-337	237-407
Total area (ha) occupied by soil type within the 10km buffer	1290	5200	12,186
***Simulated (area-weighted) Average Yield (t/ha)**	0.70	2.29	2.11
Anecdotal Estimate Median Yield (t/ha)	1.3	2	2.5

(v) ***Simulated wheat yields on 'B2' (shallow calcareous loam on calcrete) soils, with summary results for reference localities***



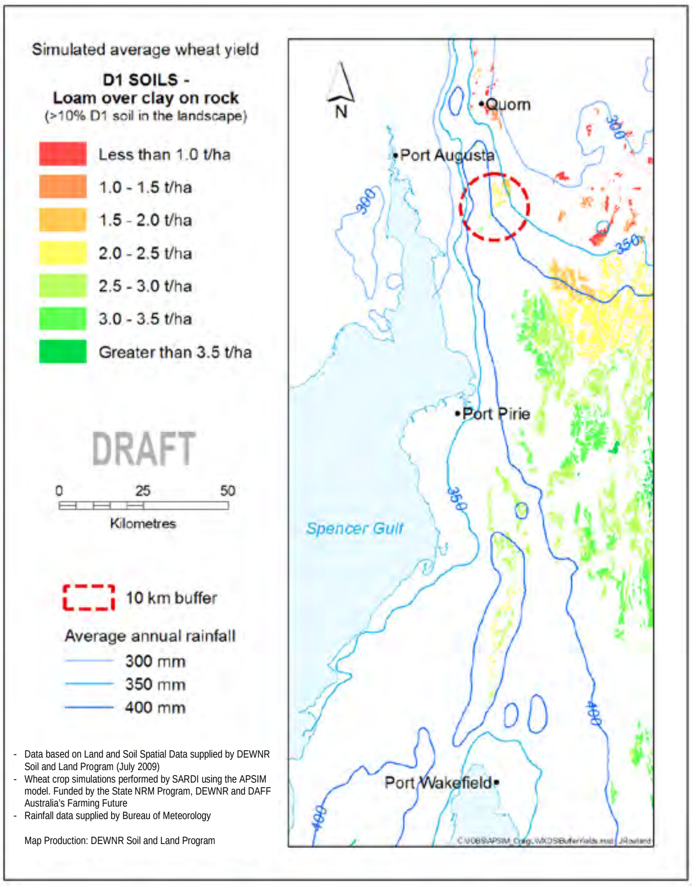
Locality (10 km buffer)	Kadina	Agery
No of LANSLU map polygons with >10% of soil type	1	16
Range of Simulated Ave Yield (t/ha)	1.45	2.06-2.32
Ave GSR range (mm)	267	297-327
Total area (ha) occupied by soil type within the 10km buffer	2666	930
***Simulated (area-weighted) Average Yield (t/ha)**	1.45	2.23
Anecdotal Estimate Median Yield (t/ha)	1.2	2.0

(vi) *Simulated wheat yields on <u>'C3' (friable gradational clay loam)</u> soils, with summary results for reference localities*



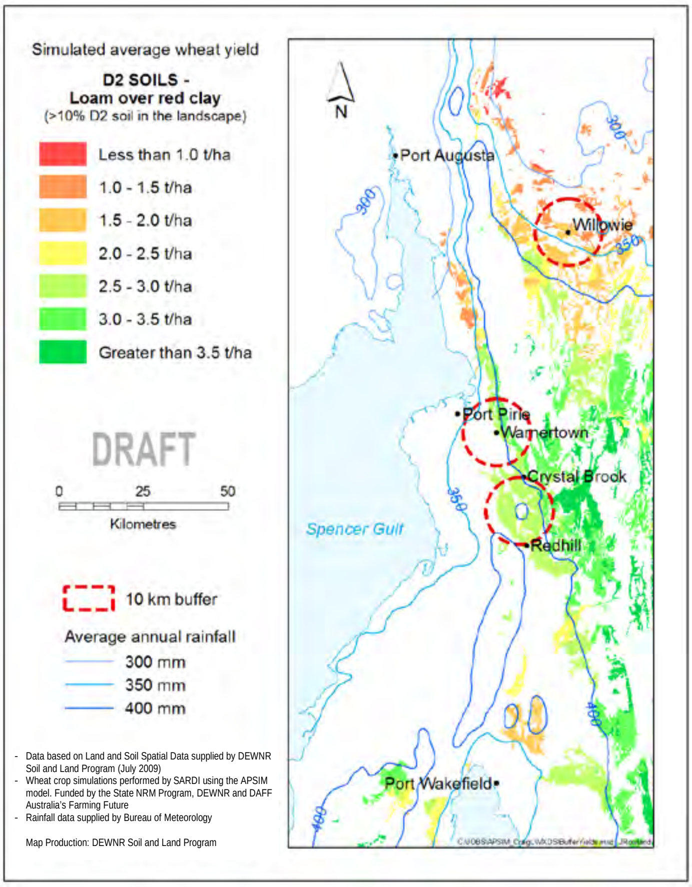
Locality (10 km buffer)	Willowie	Balaklava	Snowtown
No of LANSLU map polygons with >10% of soil type	22	7	17
Range of Simulated Ave Yield (t/ha)	0.59-1.95	1.11-2.28	1.20-2.86
Ave GSR range (mm)	187-267	227-307	227-327
Total area (ha) occupied by soil type within the 10km buffer	5874	3725	3399
***Simulated (area-weighted) Average Yield (t/ha)**	0.97	1.68	1.85
Anecdotal Estimate Median Yield (t/ha)	1.4	2.2	2.8

(vii) *Simulated wheat yields on <u>'D1' (loam over clay on rock)</u> soils, with summary results for reference localities*



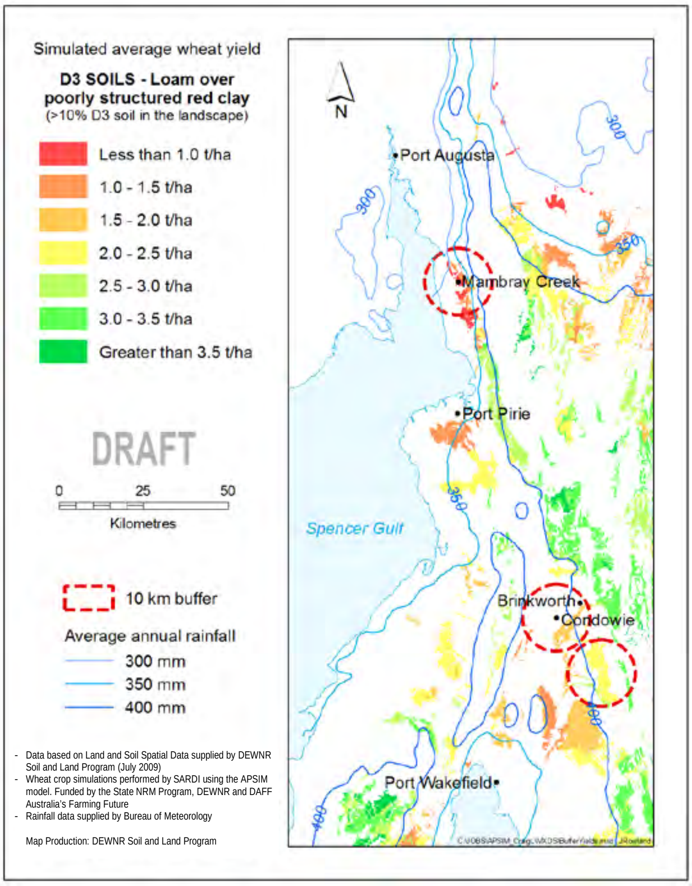
Locality (10 km buffer)	South of Quorn
No of LANSLU map polygons with >10% of soil type	8
Range of Simulated Ave Yield (t/ha)	1.68-3.33
Ave GSR range (mm)	227-417
Total area (ha) occupied by soil type within the 10km buffer	810
***Simulated (area-weighted) Average Yield (t/ha)**	2.02
Anecdotal Estimate Median Yield (t/ha)	2.0

(viii) Simulated wheat yields on <u>'D2' (loam over red clay)</u> soils, with summary results for reference localities



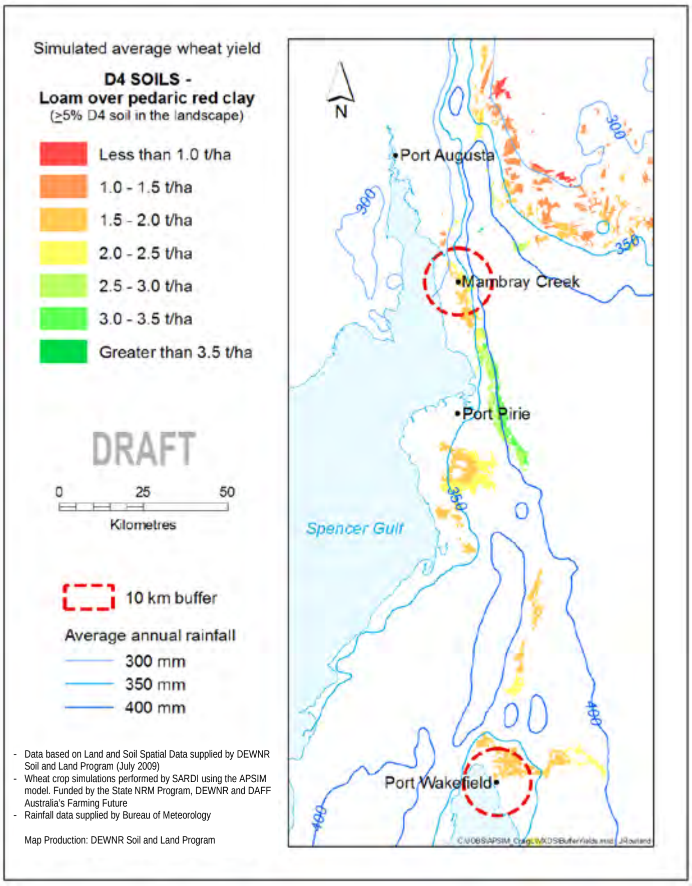
Locality (10 km buffer)	Willowie	Warnertown	Crystal Brook / Redhill
No of LANSLU map polygons with >10% of soil type	28	3	21
Range of Simulated Ave Yield (t/ha)	1.07-2.36	2.19-2.60	2.06-3.66
Ave GSR range (mm)	187-277	317-397	267-347
Total area (ha) occupied by soil type within the 10km buffer	4620	2230	6415
***Simulated (area-weighted) Average Yield (t/ha)**	1.63	2.94	2.91
Anecdotal Estimate Median Yield (t/ha)	1.4	2.2	2.7

(ix) Simulated wheat yields on <u>'D3' (loam over poorly structured red clay)</u> soils, with summary results for reference localities



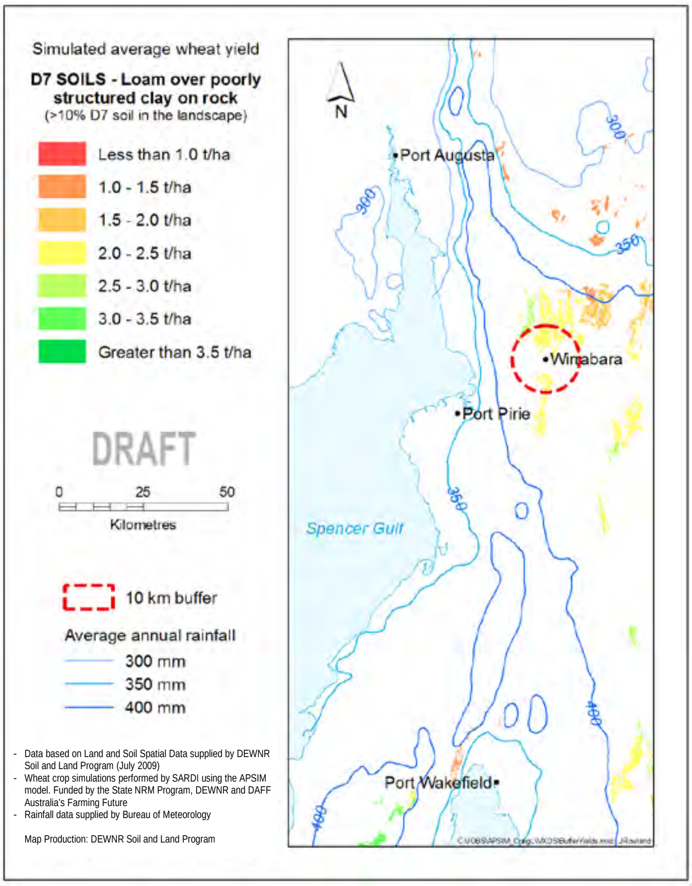
Locality (10 km buffer)	Mambray Creek	Condowie (rain shadow)	South of Brinkworth
No of LANSLU map polygons with >10% of soil type	8	3	13
Range of Simulated Ave Yield (t/ha)	0.73-1.65	1.23-2.03	1.54-3.45
Ave GSR range (mm)	197-297	247-277	247-417
Total area (ha) occupied by soil type within the 10km buffer	842	1909	1653
***Simulated (area-weighted) Average Yield (t/ha)**	1.18	1.74	2.53
Anecdotal Estimate Median Yield (t/ha)	1.3	1.8	2.2

(x) ***Simulated wheat yields on 'D4' (loam over pedaric red clay) soils, with summary results for reference localities***



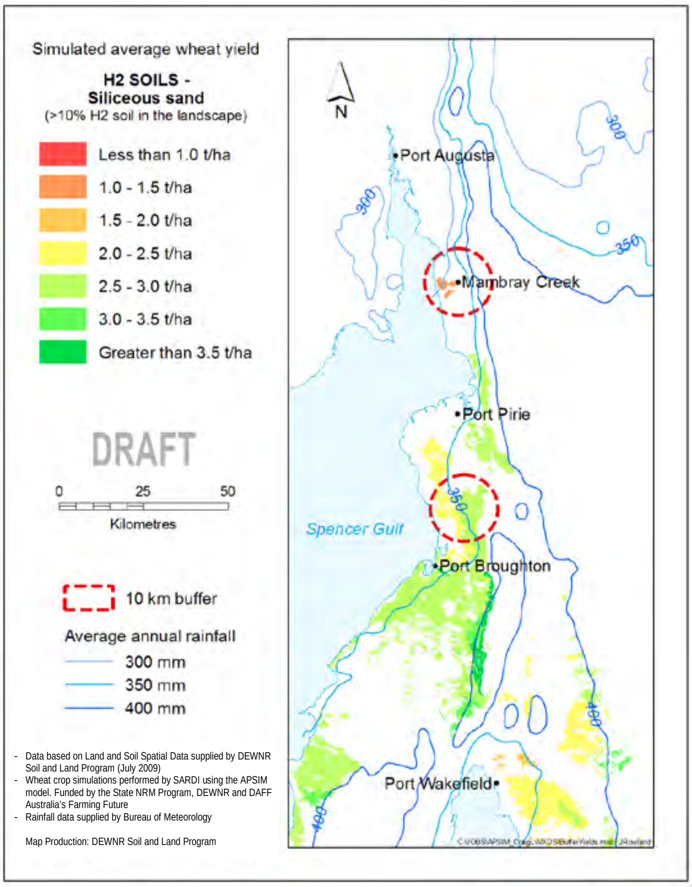
Locality (10 km buffer)	Mambray Creek	Port Wakefield
No of LANSLU map polygons with >10% of soil type	9	5
Range of Simulated Ave Yield (t/ha)	1.68-2.92	1.68
Ave GSR range (mm)	227-337	227
Total area (ha) occupied by soil type within the 10km buffer	212	3536
***Simulated (area-weighted) Average Yield (t/ha)**	1.90	1.68
Anecdotal Estimate Median Yield (t/ha)	0.8	1.1

(xi) ***Simulated wheat yields on 'D7' (loam over poorly structured clay on rock) soils, with summary results for reference localities***



Locality (10 km buffer)	Wirrabara
No of LANSLU map polygons with >10% of soil type	9
Range of Simulated Ave Yield (t/ha)	2.01-2.79
Ave GSR range (mm)	257-387
Total area (ha) occupied by soil type within the 10km buffer	1787
***Simulated (area-weighted) Average Yield (t/ha)**	2.33
Anecdotal Estimate Median Yield (t/ha)	2.5

(xii) Simulated wheat yields on <u>'H2' (siliceous sand)</u> soils, with summary results for reference localities



Locality (10 km buffer)	Mambray Creek	Port Broughton / Warnertown
No of LANSLU map polygons with >10% of soil type	1	11
Range of Simulated Ave Yield (t/ha)	1.09	2.22-2.77
Ave GSR range (mm)	177	237-267
Total area (ha) occupied by soil type within the 10km buffer	1429	5887
***Simulated (area-weighted) Average Yield (t/ha)**	1.09	2.60
Anecdotal Estimate Median Yield (t/ha)	1.6	2.0

Units of Measurement

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

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

Glossary / Acronyms

ABS — Australian Bureau of Statistics

APSIM — **A**gricultural **P**roduction **S**ystems s**IM**ulator

Arable — used to describe land that is able to be cropped (or suitable for dryland cropping in the case of this study)

ASRIS — Australian Soil Resource Information System

Ave — Average

CSIRO — Commonwealth Scientific and Industrial Research Organisation

DAFF — Department of Agriculture, Fisheries and Forestry (Australian Government)

DEWNR — Department of Environment, Water and Natural Resources – South Australian Government (predecessors of this department of relevance to the work presented in this report include: DWLBC [see below], and the Department of Environment and Natural Resources [DENR])

Dryland — Used to describe agricultural land use that is 'rain-fed' or dependent on rainfall only

DWLBC — Department of Water, Land and Biodiversity Conservation

FFI CRC — Future Farm Industries Cooperative Research Centre

GIS — Geographic Information System, computer software based systems for spatial mapping and modelling.

GRDC — Grains Research and Development Corporation

GSR — Growing season rainfall. This is typically assumed to be the sum of rainfall within the months of April to October. However in some crop simulation models GSR is taken as the sum of rainfall over the exact duration of crop growth.

GS Temp — Growing season temperature (expressed in this report as Ave GS Temp). Ave GS Temp is the average of daily minimum and maximum temperatures, averaged across the growing season, or multiple growing seasons.

Landscape component — In the context of the SL&SIF, this term is used when referring to distinct landscape elements (e.g. dune, swale, sandhill) which form the basis for SA-format soil and land attribute datasets. The word 'component' makes reference to the nature of soil and land mapping whereby the smallest map units (soil landscapes) may contain spatially undefined components (ie. multiple landscape components to one map unit). Refer to Section 2.5 for further information.

Model — A conceptual or mathematical means of understanding elements of the real world that allows for predictions of outcomes given certain conditions.

N&Y — Northern and Yorke (agricultural region)

NRM — Natural resource management, defined as "caring for our natural resources – balancing people's needs with those of nature" (Government of South Australia 2012). Also used in the context of 'NRM Regions' (describing regional NRM groups or Boards, as below).

NYNRM — Northern and Yorke Natural Resources Management (Region)

PAWC — Plant available water-holding capacity. In layman's terms this is the size of the bucket for holding soil-water that is able to be filled by rainfall and is available for plant uptake. This refers to moisture that is additional to the unavailable soil-water held tightly in a soil matrix (ie. above the lower limit or wilting point, WP) and is limited by gravitational drainage (field capacity, FC). The total PAWC represents the sum of (FC-WP) x depth, factoring out the coarse fraction (stone), for each layer down the soil profile until the impeding depth for plant root growth for that crop species is reached.

Percentile — A way of describing sets of data by ranking the dataset and establishing the value for each percentage of the total number of data records. The 90th percentile of the distribution is the value such that 90% of the observations fall at or below it.

PIRSA — Primary Industries and Regions South Australia (South Australian Government)

RMSE — Root mean square error, a statistical measure of how well a set of values derived from a predictive model agree with observed records.

SANTFA — South Australian No-Till Farmers Association

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

SL&SIF (State Land & Soil Information Framework) — refer to Section 2.5 and the DEWNR website, http://www.environment.sa.gov.au/Knowledge_Bank/Information_data/soil-and-land

Soil component — In the context of the SL&SIF (see above), this term is used when referring to the conceptual soil profile types that form the basis for National-format soil and land attribute datasets. These are based on SA-format 'subgroup soil' classes (see below) but have been further differentiated following consideration of conditions present in each land system. The word 'component' makes reference to the nature of soil and land mapping whereby the smallest map units (soil landscapes) may contain spatially undefined components (ie. multiple soil components to one map unit). Refer to Section 2.5 for further information.

Subgroup soil — Is a conceptual 'soil type' attribute with sixty one classes that capture the variation found within soil profiles across South Australia and highlight features of importance for land use and management. Subgroup soils were developed by the DEWNR Soil & Land Program as part of the State Land and Soil Mapping Program. Subgroup soils form part of the SA-format soil and land attributes (see Section 2.5) and are recorded based on their occurrence in association with distinct landscape elements (also see 'landscape component' above). Subgroup soils are described in detail in the reference book Hall et al. 2009.

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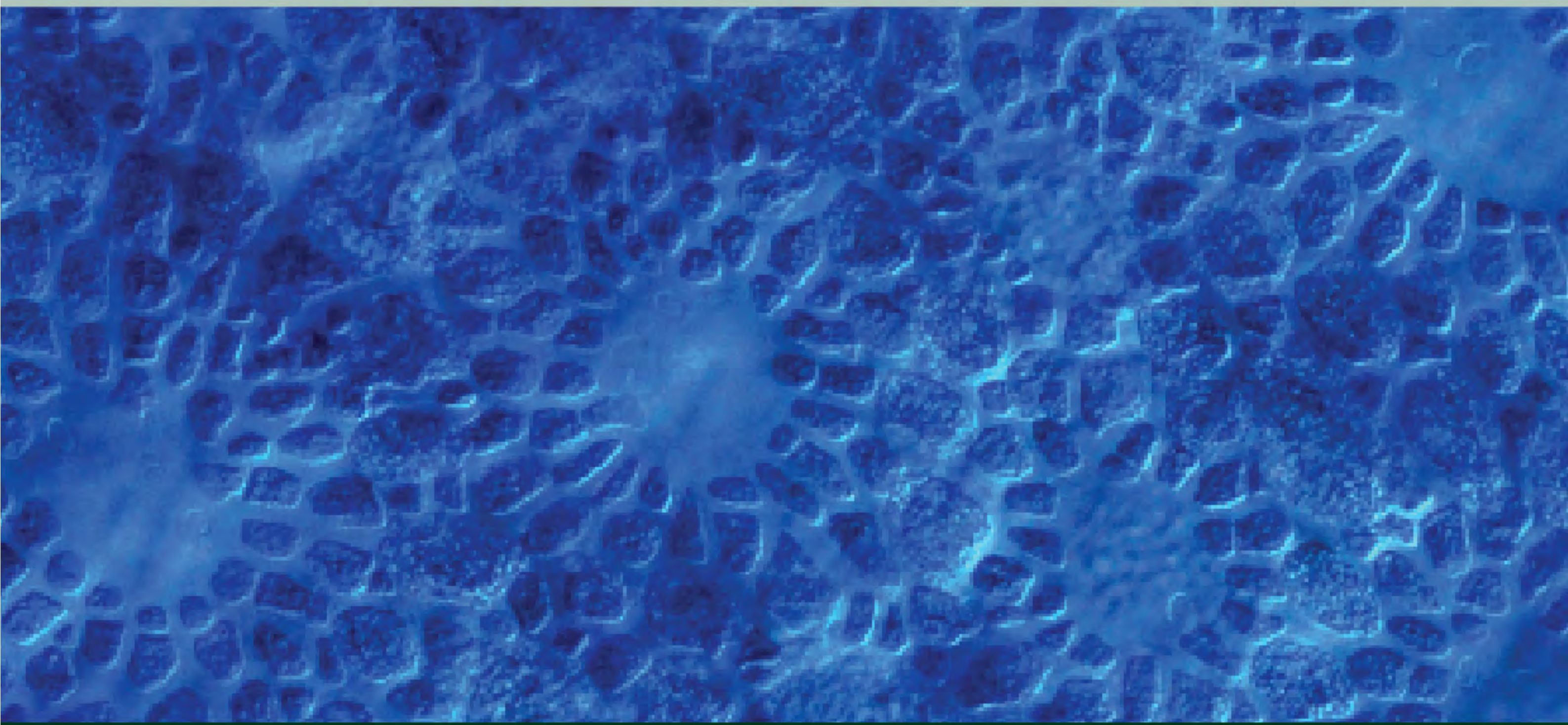

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