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Climate change adaptation pressures for SA land based Primary Industries

This document is a work in progress.

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Future Drought Fund
SA DROUGHT HUB
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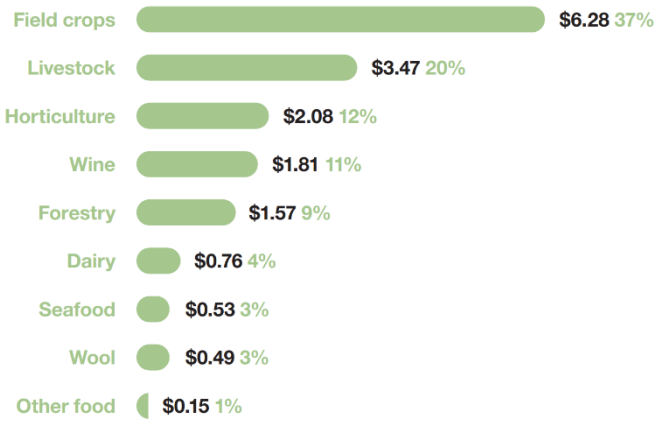
This project received funding from the Australian Government's Future Drought Fund and the Government of South Australia

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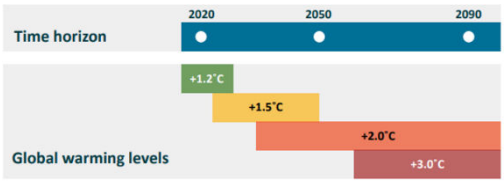
Introduction

Decreased productivity, quality and profitability of primary industries due to climate change was one of the 11 priority risks identified by the National Climate Risk Assessment (NCRA) and addressed by the primary industries chapter of the National Adaptation Plan. Primary industries are a major sector considered in the South Australian state risk assessment and adaptation planning process.

The purpose of this document is to provide a succinct assessment of the impacts, management options and residual adaptation pressure of the four most important land based primary industries in South Australia (field crops, extensive livestock, horticulture and wine grapes). Just as ecologists talk about keystone species, these are keystone industries that underpin the agricultural and rangeland regions of South Australia.



Consistent with the National Climate Change Risk Assessment we are considering Global Warming Levels of up to 2°C by 2050 and up to 3°C by 2090. Because the planet has already warmed by 1.2°C, a GWL of 2°C is 0.8°C warmer than the present.



Time horizon of GWL (NCRA 2025)

Primary producers in South Australia have continuously adapted their practices to stay economically viable. Many producers have experienced the challenge of starting farming in a new region and almost all producers have dealt with changes to climate over recent decades. In coming decades, further changes to the climate will be a headwind. We have used the term adaptation pressure to avoid a fatalistic report of loss and damage. The more severe end of projected warming and drying will damage agriculture, along with most human activities in SA. Even at global net zero emissions, the locked in changes to the climate will make it more difficult to grow crops and produce livestock. Adapting to the changed climate usually comes at a cost, and this might challenge the viability of financially stressed enterprises. Because this report focuses on production risk within the farm gate, we don't address broader questions of supply chains or the viability of rural communities.

We consider six main risks from climate change: warmer mean temperature, extreme heat, changes to frost, changes to seasonal rainfall, increased intensity of rain events and increased levels of carbon dioxide. We assess the vulnerability of the different industries to the risk based on conversations with producers and researchers. Any broad ranking is controversial and there will be many exceptions due to the substantial regional differences within each industry and even different businesses on neighbouring farms. Nevertheless, a useful question is whether there are broadly comparable crop or livestock enterprises in a warmer and drier location in the current climate. It is generally possible to find areas where similar crops are grown and livestock produced in warmer regions than South Australia, but fewer cases where it is drier. The climate gradients within Australia and within short distances in South Australia allow farmers to 'visit the future' and learn from farmers dealing with different climates.

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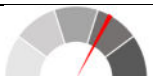
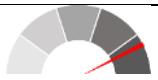
	Climate science confidence	***Field crops***	***Viticulture***	***Horticulture***	***Extensive livestock***
*Almost certain that **mean temperatures** will increase over next decades.*		*Moderate adaptation pressure*	*High adaptation pressure*		*Low adaptation pressure*
*High confidence that weather systems bringing **heatwaves** will be hotter.*		*High adaptation pressure*	*Extreme adaptation pressure*		*High adaptation pressure*
*Low confidence to changes in **frost** frequency in coming decades*		*Extreme adaptation pressure*	*Moderate adaptation pressure*		*Very low adaptation pressure*
*Worrying but uncertain reduction to autumn winter and spring **rainfall** and water for **irrigation**.*		*Extreme adaptation pressure*			*High adaptation pressure*
*High confidence that **intensity of rainfall** will increase*		*Relatively low adaptation pressure because SA currently has very low intensity of rainfall compared to NSW & Qld.*			
*Certain that **carbon dioxide** will increase*		*Mostly beneficial although expect a reduction in quality of some products.*			

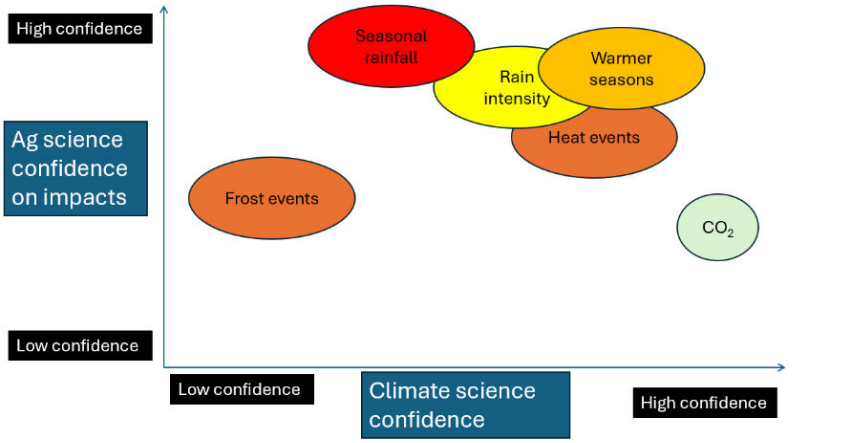
Table 1. A high-level summary that ranking the impact of the six main climate risks between four key primary industries. Extreme adaptation pressure- major challenge to current production system, high adaptation pressure- challenge requiring substantial and costly changes, moderate adaptation pressure – requiring some changes to current system, low adaptation pressure – requiring relatively minor changes to the current system.

Table 1 highlights rainfall and/or access to water for irrigation as the greatest risk. Recent droughts in SA have highlighted the extreme vulnerability to rainfall. Heat waves are assessed as the second most important source of adaptation pressure and the damage from heatwaves is much greater when soils are dry or animals short of water. This indicates the importance of considering combinations of adaptation pressures. Ranking the adaptation pressure of industries will always be controversial. The sensitivity of premium wine grapes to warmer vintages and heat waves and chilling requirements for much of the perennial horticulture industry are reasons for the higher adaptation pressure of viticulture and horticulture. There is no doubt that livestock reproduction and productivity in all regions of SA are affected by heat and the rangelands have prolonged periods of heat stress. However, it is rare for SA heat events in the agricultural zone to be associated with the combination of heat and humidity that even a location like Wagga might experience. The desiccating dry heat events can be catastrophic for wine grapes and premium horticulture and are more damaging for a wheat crop than livestock.

We have estimated the confidence from climate science for SA agricultural regions with a simple dial and series of confidence statements. Changes to carbon dioxide and consequent increases in mean temperature are guaranteed for the near future. Heat events and frost events are influenced by the underlying trends in climate but also a dynamic weather component which slightly moderates the confidence. Confidence in how frost will change in the coming decades is highly uncertain as the weather patterns that contribute to radiation frosts interact with an overall warming trend. While warming is a first order response to changes to the radiative properties of the atmosphere, responses of the weather systems that bring rainfall to SA vary between seasons. Although there is more consistency in the trends and modelled projections for drying in the autumn, winter and spring

than summer, models still range from minor changes that are well within a coping range and major drying that would substantially challenge farming systems. A warmer atmosphere will increase the intensity of rain events and increase the evaporation from soil, plants and animals. It is important to note that 0.8°C (2 degrees GWL by 2050) will lead to modest increase in intensity and evaporation.

The two-page summaries for each of the industries also includes an assessment of the confidence from agricultural sciences in the impacts of the six aspects of climate change. The high confidence in the impact of moisture stress on crop and pasture growth is due to the substantial RD&E programs that is evident industry manuals and quantified in simulation models. The impact of extreme temperature on crops, pasture and livestock is an ongoing area of research and less well quantified in simulation models. While climate science is more confident in changes to temperature than rainfall, the confidence from agricultural science lies in the impact of changes to rainfall.



Confidence from climate science of exposure and agricultural science of sensitivity. Colours represent risk; extreme for seasonal rainfall, high for heat and frost events, moderate for warmer seasons, low risk for increased intensity of rainfall and very blow for direct impact of elevated CO_2.

SA Primary Industries are well served with climate science information funded by the Future Drought Fund from the CSIRO and BoM delivered in My Climate View designed to provide Australian farmers with tailored insights into their changing climate at a local scale. There is also an abundance of international and national research from agricultural science on the impact of climate change on crops and livestock. The most valuable asset is the practical experience and knowhow of croppers, wine grape growers, horticulturists and livestock producers in dealing with the challenges of a variable and changing climate from farmers and their advisers.

Key references

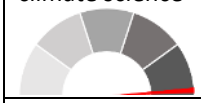
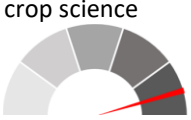
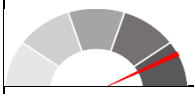
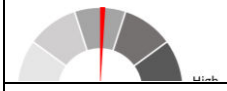
National Climate Risk Assessment | Australian Climate Service Website

Detailed reporting on climate risks for key primary industries in *Darbyshire et. al. 2025 Technical Report for National Climate Risk Assessment: Primary Industries*. *https://publications.csiro.au/publications/publication/PIcsiro:EP2024-6309*

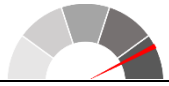
A reference with the climate risk framework *Hayman et. al. 2020 Australian Agronomy in the Anthropocene: the challenges of climate*. *Australian Agriculture in 2020 Pt6Ch25.pdf*

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Field Crops

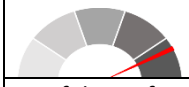
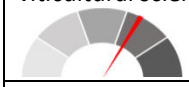
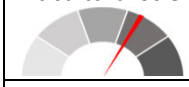
1. Increased mean temperature	
Confidence from climate science 	**Very high** All parts of South Australia have warmed and are expected to warm in the future. Because inland regions are drier, they are expected to warm faster than coastal regions. The greatest trends in warming across much of South Australia has been in spring, this may be largely due to a decline in spring rainfall.
Confidence on impacts from crop science 	**High** confidence warming will speed up crop development. Faster development reduces potential yield in most cases. Each degree of warming increases potential evapotranspiration by about 4 to 5%. Crop emergence conditions will be more challenging in early autumn but improved in early winter. Higher mean temperature will change the spectrum of pests, weeds and diseases. Warmer conditions could increase foliar diseases in above average seasons.
Management options	Understanding the drivers of crop development can be used to better match varieties to the changing climate. Stubble retention will reduce evaporation and keep the seedbed cooler. Long coleoptile wheat varieties will play a role.
Moderate adaptation pressure	**Moderate adaptation pressure** due to warning over coming decades, providing grain growers have access to crops with appropriate development. Adaptation pressure of warmer seasons will be greatly increased if growing season rainfall declines, and warming is associated with heat waves.
2. More frequent and intense heat events	
Confidence from climate science 	**High** confidence that in a warmer world the weather patterns that bring heat to the grains belt will result in more intense heat waves. Confidence is lower on how the weather patterns that set up the hot spells will change.
Confidence of impacts from crop science 	**Moderate** understanding of the impact of heat on different phenological stages and thresholds for crops grown in the field and how these impacts are modified by soil moisture. Spring heat events are more damaging when combined with low soil moisture. The impact of heat spells at critical stages of cereals and pulses is an active area of national and international research.
Management options	Optimising flowering time of available winter crops and breeding crops that can tolerate high heat loads.
High adaptation pressure	**High adaptation pressure** due to an increase in spring heat events for all dryland winter crops but especially pulse crops.
3. Changes to frost frequency and intensity	
Confidence from climate science 	**Low** confidence for the coming decades– a perceived paradox that, despite warming, the frequency and intensity of frost has increased in some regions of the SA grains belt. It remains unclear whether this trend is due to decadal variability or increased greenhouse gases. The more rapid crop development due to warmer conditions can contribute to frost adaptation pressure.
Confidence of impact from crop science 	**Moderate to low –** although the impact of extreme frost at critical times is obvious, the exact link between minimum temperature recorded in the Stevenson screen and damage to crops is noisy. Frost damage is not well represented in simulation models. There is limited international R&D on post head emergence frost damage because it isn't a major issue in US and Europe.
Management options	Understanding the frostier parts of the landscape and matching land use (e.g. livestock on river flats). Using the small amount of variation in frost susceptibility between wheat varieties and greater variation between winter crops (e.g. barley as less susceptible than wheat). Sow frost prone areas last and/or use slower varieties.
Extreme adaptation pressure	Although there is low confidence in the changes to frost, an increase in severity and frequency would lead to **extreme adaptation pressure** for frost prone regions of the grains belt. Agronomists working with frost affected farmers refer to a direct cost of frost damage and an indirect psychological impact on decision making.

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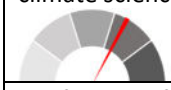
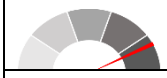
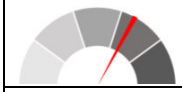
4. Changes to seasonal rainfall	
Confidence from climate science 	**Moderate** confidence in drying in southern winter growing season. **Lower** confidence for other seasons. Most Global Climate Models show drying in the cool wet season in Mediterranean regions of the northern and southern hemisphere. The amount of drying projected by the models ranges from mild to severe.
Confidence of impact from crop science 	**Very high.** There are extensive studies that provide a good basis for understanding water productivity of major crops. Growers and agronomists are highly aware of the impact that the timing and amount of rainfall has on yield and profitability.
Management options Adaptive capacity to counter impacts.	More effective storage of water prior to the growing season and then using the water as efficiently as possible by matching sowing time and cultivar to the environment. SA grain farmers have improved their water use efficiency by summer weed control, stubble retention and timely sowing.
Extreme adaptation pressure	**Extreme adaptation pressure.** Although SA grain growers are highly skilled at managing low rainfall environments recent dry autumns and failed springs highlight the adaptation pressure of reduced rainfall.
5. Changes in the intensity of rainfall	
Confidence from climate science 	**High.** A warmer atmosphere contains more energy and will hold more water. This leads to intensification of the hydrological cycle which further increases variability. There is lower confidence in changes to weather systems that bring high or low intensity of rainfall.
Confidence of impact from crop science 	**High** confidence in the impacts of changes to daily intensity. The SA grains belt has numerous low intensity falls (< 5mm) which wet the surface soil and are lost in evaporation. A moderate increase in intensity will improve efficiency of soil water gains. An increase in large falls (>20mm) is likely to lead to runoff and erosion and cause problems for operations such as sowing and harvest. Localised flooding causes damage to crops and infrastructure.
Management options	Stubble retention and other erosion management especially on sloping sites. Many grain growers are using short term weather forecasts to plan operations.
Low adaptation pressure	**Low adaptation pressure.** A modest increase in the intensity of rainfall will be beneficial. There are adaptation pressures to water erosion, but these can be managed with stubble retention which has high levels of adoption and co-benefits of reducing wind and water erosion adaptation pressure and increasing productivity
6. Elevated levels of carbon dioxide	
Confidence from climate science 	**Very High.** Future emissions depend on policy and technology. Although the exact concentration is difficult to predict, there is high confidence that future levels will be higher than present
Confidence of impact from crop science 	**High** for growth and yield of crops but **lower** for longer term cropping systems (soil C and N) and grain quality components e.g., protein and its various end use requirements. The growth rate of weeds, pests and disease will also change with elevated CO_2.
Management options	Higher levels of CO_2 will improve WUE of crops with adequate nutrition. Monitoring of changes to pests and disease and revising nutrition will be essential.

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Viticulture

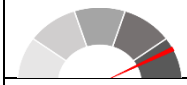
1. Increased mean temperature	
Confidence from climate science 	**Very high.** All South Australian wine regions have warmed and are expected to warm in the future. The inland regions are expected to warm faster than coastal regions. The greatest trends in warming across much of South Australia has been in spring, this may be largely due to a decline in spring rainfall.
Confidence of impact from viticultural science 	**High** confidence key development stages will continue to shift earlier. Warming is expected to further compress vintages whereby longer season varieties such as shiraz and cabernet advance faster than earlier varieties such as chardonnay. Experimental heating of whole vines have hastened development but not changed yield. The main diseases of grapevines (powdery and downy mildew and botrytis) tend to be less damaging in hot dry seasons. Potential evapotranspiration is expected to increase by 4-5% per degree warming.
Management options (Adaptive capacity)	Early pruning can delay ripening with no detrimental effect on yield and a neutral or beneficial effect on quality. A warmer future will change wine styles and may lead to some varieties being unsuited to where they are currently grown. Warming will also present opportunities for new varieties, especially in cool regions.
High adaptation pressure	**High adaptation pressure** to warming over coming decades, especially for cool regions that may lose their cool climate status. **Medium adaptation pressure** for warm and inland hot regions in coming decades providing there is sufficient water.
2. Changes to heatwave frequency and intensity	
Confidence from climate science 	**High** confidence that in a warmer world the weather patterns that bring heat to wine regions will result in more frequent and intense heat waves. Confidence is lower on how the weather patterns that set up the hot spells will change.
Confidence from viticultural science 	**Moderate to high** understanding of the impact of extreme heat events on grape quality and vine development from industry experience over the last decade and a series of field heating chamber experiments. Lower confidence in exact thresholds and impacts on wine quality for a given ambient temperature.
Management options	Industry experience of coping with heat waves highlights the value of water in the root zone prior to the event and keeping berries shaded by the canopy. Although much hotter, the inland regions have the irrigation infrastructure and a higher level of canopy shade than the cool regions. Industry is experimenting with kaolinite clays and overhead sprinkling systems.
Extreme adaptation pressure	**Extreme adaptation pressure** caused by heat events, especially when water is scarce. Heat events create problems at the vineyard and the winery level
3. Changes to frost frequency and intensity	
Confidence from climate science 	**Low.** A perceived paradox that, despite warming, the frequency and intensity of spring frost has increased in some wine regions. It remains unclear whether this trend is due to decadal variability or increased greenhouse gases. Earlier budburst due to warmer conditions can contribute to frost adaptation pressure.
Confidence from viticultural science 	**High.** Grapevines are susceptible to frost after budburst. There tends to be more opportunities for compensation from frosts immediately following budburst than later frosts that damage vegetative shoots.
Management options	Site selection is the most effective way to manage frost. Where large parts of regions are frost prone (eg Limestone coast) sprinklers and frost fans are commonly used. Considerable investment in frost fans has occurred in regions that are experiencing higher frost incidence e.g. the Barossa. Pruning to delay budburst and maturity may be beneficial to frost management.
Moderate adaptation pressure	Although there is less confidence on the likelihood of frost, there is **moderate adaptation pressure** of any increase in frost severity.

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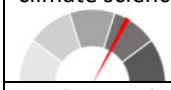
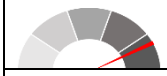
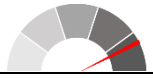
4. Changes to rainfall and quality and quantity of water for irrigation	
Confidence from climate science 	**Moderate** confidence in less rainfall over winter. **Lower** confidence for other seasons. Moderate confidence in reduction to inflow of water to the MDB and other catchments but high confidence in the increased demand for irrigation water from competing crops and competing uses (eg environmental flows).
Confidence of impact from viticultural science 	**Very high.** Research on water relations of vines to guide irrigation and the impact of winter drought have been supported by extensive grower experience and experimentation. Drier winters have an impact on yield under all conditions and are especially damaging where the winter rain is required to wash salts from the root zone.
Management options	The South Australian wine grape industry has a history of managing water efficiently. All regions are examining ways to supplement irrigation.
Extreme adaptation pressure	**Extreme adaptation pressure -** compared to most other irrigated crops, vineyards use relatively low amounts of water; however, as a perennial crop, there is a requirement every year and productivity suffers if this requirement is not met. The risk is especially high in regions with limited supplies of surface water and limited or expensive opportunities to import water from outside of the region.
5. *Changes in the intensity of rainfall*	
Confidence from climate science 	**High.** A warmer atmosphere contains more energy and will hold more water. This leads to intensification of the hydrological cycle which further increases variability. There is lower confidence in changes to weather systems that bring high or low intensity of rainfall.
Confidence of impact from viticultural science 	**High** confidence in the impacts of changes to daily intensity. If the annual rainfall remained the same, a modest increase in intensity is likely to improve soil water storage over winter. Numerous low intensity falls (< 5mm) tend to be inefficient as most of the rainfall wets the surface and is lost in evaporation. An increase in large falls (>20mm) is likely to lead to runoff and erosion, especially in sloping vineyards.
Management options	Mulch and inter-row management especially on sloping sites. Many viticulturists use short term weather forecasts to plan operations. This planning leads to improved efficiency and reduces the likelihood of runoff of agricultural chemicals
Low adaptation pressure	**Low adaptation pressure.** A modest increase in the intensity of rainfall will be beneficial. There are adaptation pressures to water erosion on sloping sites and unseasonal rainfall increasing disease pressure.
6. Elevated levels of carbon dioxide	
Confidence from climate science 	**Very High.** Future emissions depend on policy and technology. Although the exact concentration is difficult to predict, there is high confidence that future levels will be higher than present.
Confidence from viticultural science 	**Moderate** In chamber experiments elevated CO_2 caused a small improvement in yield. Elevated CO_2 alone and in combination with warmer air increased photosynthesis but not water use by vines. The growth rate of weeds, pests and disease will also change with elevated CO_2. Free Air Carbon Dioxide
Management options	Variation in vine performance due to elevated CO_2 is well within the bounds of seasonal variation that is currently observed; but good crop management practices need to be maintained.

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Horticulture

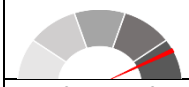
1. Increased mean temperature	
Confidence from climate science 	**Very high.** All South Australian horticultural regions have warmed and are expected to warm in the future. The inland regions are expected to warm faster than coastal regions. The greatest trends in warming across much of South Australia has been in spring, this may be largely due to a decline in spring rainfall.
Confidence of impact from horticultural science 	**Very high** confidence that key development stages will continue to shift earlier. The requirement for chilling is lower in citrus and olives than most pome, stone and berry fruit, but the impact on synchronicity of flowering for effective pollination and quality of flowers and subsequent fruiting can limit yield potential in most crops. Annual horticulture offers greater management flexibility to choice of crop type, variety and the planting and maturity date. Potential evapotranspiration is expected to increase by 4-5% per degree warming.
Management options (Adaptive capacity)	Warming will present opportunities for new varieties more suited to warm conditions. Chemical treatments offer some assistance in low chill situations. Artificial covers / netting likely to become more important, particularly for the higher value commodities; preliminary studies have also suggested that covers reduce irrigation requirements.
High adaptation pressure	**High adaptation pressure** due to warming over coming decades as chilling declines and water requirements increase. Adaptation pressure of warmer seasons will be greatly increased under water constrained situations.
2. ***Changes to heatwave frequency and intensity***	
Confidence from climate science 	**High** confidence that in a warmer world the weather patterns that bring heat to horticultural regions will result in more frequent and intense heat waves. Confidence is lower on changes to weather patterns that set up the hot spells.
Confidence of from horticultural science 	**Moderate to High** understanding of the impact of extreme heat conditions on most commodities from industry experience over the last decade.
Management options	Water in the root zone prior to and during the event is essential. Shading of the saleable product by the canopy is an important requirement to limiting sun and heat damage in many crops. Covered cropping (glasshouse, shade-house, netting) is likely to become more important. Industry is experimenting with kaolinite clays but these products are not suited to all crops.
Extreme adaptation pressure	**Extreme adaptation pressure of** an increase in heat events, especially when water is scarce. Heat events create quality issues with most crops.
3. Changes to frost frequency and intensity	
Confidence from climate science 	**Low.** A perceived paradox that, despite warming, the frequency and intensity of spring frost has increased in some wine regions. It remains unclear whether this trend is due to decadal variability or increased greenhouse gases. Earlier budburst due to warmer conditions can contribute to frost adaptation pressure.
Confidence of from horticultural science 	**High.** Most crops are susceptible to frost. Annual cropping regimes may avoid frosts through time of sowing. Deciduous perennial crops are more sensitive after budburst. Frosts that damage floral and fruiting organs of fruiting crops as opposed to vegetative organs will to lead to greater economic loss.
Management options	Site selection is the most effective way to manage frost. Sprinklers and frost fans are used in some regions. Delaying bud burst will reduce the likelihood of frost damage. In some crops this can be achieved by late pruning.
Moderate adaptation pressure	Although there is less confidence on the likelihood of frost, there is **moderate adaptation pressure of** any increase in frost severity.

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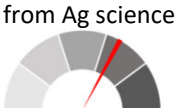
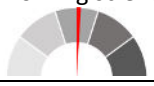
4. Changes to rainfall and quality and quantity of water for irrigation	
Confidence from climate science 	**Moderate** confidence in less rainfall over winter. **Lower** confidence for other seasons. Moderate confidence in reduction to inflow of water to the MDB and other catchments but high confidence in the increased demand for irrigation water from competing crops and competing uses (eg environmental flows)
Confidence from horticultural science 	**Very high.** There have been many studies on water relations of horticultural crops to guide irrigation. Experience and some experiments from the Millennium drought (2002 -2009) provide guidance on the impact and recovery from severe water stress.
Management options	The South Australian perennial tree industry has a high level of water management and efficiency. Further improvements were made during the Millennium drought.
Extreme adaptation pressure	**Extreme adaptation pressure.** Perennial horticultural crops have a high requirement for quality and quantity of water every year and productivity reduces markedly if these irrigation requirements are not met. Annual horticultural crops are also irrigated and have continual requirements for high quality irrigation water.
5. Changes in the intensity of rainfall	
Confidence from climate science 	**High** A warmer atmosphere contains more energy and will hold more water. This leads to intensification of the hydrological cycle which further increases variability. There is lower confidence in changes to weather systems that bring high or low intensity of rainfall.
Confidence from horticultural science 	**High** confidence in the impacts of changes to daily intensity. If the annual rainfall remained the same, a modest increase in intensity is likely to improve soil water storage over winter. Numerous low intensity falls (< 5mm) tend to be inefficient as most of the rainfall wets the surface and is lost in evaporation. An increase in large falls (>20mm) is likely to lead to runoff and erosion, especially in sloping orchards. These intense rainfall events may lead to crop damage, particularly if they occur at sensitive stages of crop development.
Management options	Many horticulturists use short term weather forecasts to plan operations. This planning leads to improved efficiency and reduces the likelihood of runoff of agricultural chemicals. Inter-row management reduces the adaptation pressure of erosion.
Low adaptation pressure	**Low adaptation pressure.** A modest increase in the intensity of rainfall will be beneficial. There are adaptation pressures of crop damage at certain crop stages, especially in the lead up to harvest. There are adaptation pressures to water erosion on sloping sites.
6. Elevated levels of carbon dioxide	
Confidence from climate science 	**Very High.** Future emissions depend on policy and technology. Although the exact concentration is difficult to predict, there is high confidence that future levels will be higher than present.
Confidence from horticultural science 	**Moderate.** There are few field experiments at elevated CO_2 although numerous glasshouse studies indicate increased biomass and yield under higher CO_2 regimes.
Management options	Variation in plant performance due to elevated CO_2 is well within the bounds of variation due to season and management decisions; but good crop husbandry practices need to be maintained. Monitoring of changes to pests and disease and revising nutrition will be essential.

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Pasture and Livestock

1. Increased mean temperature	
Confidence from climate science 	**Very high** All parts of South Australia have warmed and are expected to warm in the future. Because inland regions are drier, they are expected to warm faster than coastal regions. The greatest trends in warming across much of South Australia has been in spring, this may be largely due to a decline in spring rainfall.
Confidence of impact from Ag science 	**High** confidence that the growth rate of pasture will change. For the same rainfall expect increased winter growth rates in cooler locations and cooler months of the year to increase. Higher temperatures in autumn and spring are likely to shorten the growing season due to quicker development. Hot conditions can contribute to more challenging conditions to establish pasture. Hotter summers are likely to have detrimental effects on animal growth rates and fertility
Management options (Adaptive capacity)	Selecting appropriate pasture species to minimize the adaptation pressures and maximize the opportunities. Considering changing the species and breeds of livestock. Shifting mating times
Low adaptation pressure	**Low adaptation pressure of** mean warning over coming decades providing graziers have access to appropriate pasture species. Adaptation pressure of warmer seasons will be greatly increased if growing season rainfall was to decline, and warming is associated with increasingly severe and frequent heat waves.
2. Changes to heatwave frequency and intensity	
Confidence from climate science 	**High** confidence that in a warmer world the weather patterns that bring heat to the SA livestock regions will result in more intense heat waves. Confidence is lower on how the weather patterns that set up the hot spells will change.
Confidence from agricultural science 	**Moderate** understanding of the impact of extreme heat waves on different introduced and natural pasture species. **Moderate to high** understanding of extreme temperature on cattle and sheep growth rates and reproduction. This is an active area of research.
Management options	Species selection for pasture. Providing access to water and shade trees for livestock, changing mating times to avoid high adaptation pressure of heat waves. Changing supplements to reduce the impact of heat stress on reproduction.
High adaptation pressure	**High adaptation pressure** due to the impact of heat events on many introduced pasture species. The fertility rates of livestock appear to be reduced at relatively mild temperatures of 32^{o} C and feed intake is likely to be reduced prior to this time. Livestock require large amounts of high quality water during heatwaves.
3. Changes to seasonal rainfall	
Confidence from climate science 	**Moderate** confidence in drying in southern winter growing season. **Lower** confidence for other seasons. The trends and projections for rainfall are less clear in the Rangelands than further south.
Confidence from Ag science. 	**Very high.** The carrying capacity of dryland grazing systems are largely determined by the amount and timing of rainfall. Any decrease in rainfall will reduce the carrying capacity and/or increase the requirement for supplementary feeding. Providing water for livestock can be difficult during droughts.
Management options	Adjusting stocking rates to seasonal conditions. Containment feeding during droughts. Changing pasture species to benefit from rainfall at all times of the year and/or increase the hard-seed component of the pasture to deal with false breaks. Some livestock producers are adjusting the time of lambing and calving.
Extreme adaptation pressure	**Extreme adaptation pressure.** Although SA livestock producers are highly efficient at dealing with dry conditions, stocking rates and profitability are closely linked to rainfall. In extended dry periods not only is there a greater requirement for hay and grain, but as supply tightens, prices increase. In many regions there is a problem of water supply as well as feed supply.

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4. *Changes in the intensity of rainfall*	
Confidence from climate science 	**High.** A warmer atmosphere contains more energy and will hold more water. This leads to intensification of the hydrological cycle which further increases variability. There is lower confidence in changes to weather systems that bring high or low intensity of rainfall.
Confidence from Ag science 	**High** confidence in the impacts of changes to daily intensity. Much of the agricultural region of SA has numerous low intensity falls (< 5mm) which tend to be inefficient as most of the rainfall wets the surface and is lost in evaporation. A moderate increase in intensity will improve efficiency of soil water gains. An increase in large falls (>20mm) is likely to lead to runoff and erosion and localized flooding.
Management options	Maintaining pasture cover, especially on sloping sites. Where possible to move stock from low lying areas to minimise the damage to soil and conditions
Low adaptation pressure	**Low adaptation pressure.** A modest increase in the intensity of rainfall will be beneficial. There are adaptation pressures to water erosion, but these can be managed with maintenance of pasture cover. Localised flooding and washouts can cause costly repairs.
5. *Elevated levels of carbon dioxide*	
Confidence from climate science 	**Very High.** Future emissions depend on policy and technology. Although the exact concentration is difficult to predict, there is high confidence that future levels will be higher than present.
Confidence from Ag science 	Expect increased pasture growth, especially of C3 species (most temperate pasture spp.). Elevated CO_2 will reduce protein content and digestibility. The direct impact of higher CO_2 on livestock health is minimal but there is likely to be an impact on weeds and pests.
Management options	Monitoring pasture quality and changes to species composition, monitoring changes in weeds and pests.

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