WORKING DRAFT

Wheatbelt

Drought Resilience Situational Analysis

Cover to come

Australian Government
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Future Drought Fund

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South-West WA Drought Resilience Adoption and Innovation Hub

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Working Draft

Wheatbelt

Figure 1: Geographic spread of the Western Australian wheatbelt and its port zones.

Key messages

- Growing season rainfall across the WA wheatbelt has dropped by as much as 50–60mm or 20% in some areas over the past 90 years.
- The traditional ‘break of season’ has become later and more variable across the wheatbelt, especially on heavier soils.
- The drop in growing season rainfall has been associated with a one degree warming trend and the amount of heat during flowering and grain fill (August to October) has increased since 2000.
- Southwest WA has lost a third of its 10mm and 25mm rainfall events and many of the estimated 200,000 farm dams across the wheatbelt no longer capture enough run-off – making them unreliable during low rainfall years.
- Crop yields have continued to increase despite the drying trend, but yields have become increasingly variable since 2000 and the gap between potential and observed grain yields is beginning to close.
- Improved on-farm water supplies and efficiency gains in cropping and livestock systems will be needed to cope with the projected reductions in rainfall and increases in temperature expected with future climate change.

Location and size

The Western Australian wheatbelt covers 25 million hectares and runs from north of Geraldton, to the south coast at Albany, east along the coast to Esperance and inland to the east of Merredin. About 70% of the wheatbelt (17.5 million hectares) is cleared for agriculture and the area contains about 5725 agricultural holdings across four port zones – Geraldton, Kwinana, Albany and Esperance (Figure 1).

Annual rainfall across the wheatbelt varies widely from 700–900mm in the southwest through to 200mm in the northeast.

Of the cleared 17.5 million hectares, about half (7–8 million hectares) is cropped each year with the remaining area used for livestock. The wheatbelt carries most of WA’s 14 million-head sheep flock (80–90%) and about a fifth of the State’s two million cattle herd. Wheat is the dominant crop grown (55%)[1] followed by barley (28%), canola (10.5%), lupins (<5%) and oats (<3%). Pulse production (field peas, faba beans lentils, chickpeas) is relatively low but increasing, especially in the Esperance Port Zone. Canola has grown from a low base to become a crop of major significance.

About $6.5 billion in production value is generated from the wheatbelt each year with about $5 billion coming from crops and $1.5 billion from sheep meat and wool.

Ongoing property consolidation has resulted in average farm size across the wheatbelt increasing considerably over the past 50 years. In 1966 there were 22,900 farms with an average size of 546 hectares while now there is about a quarter of this number (5,725) with an average size of more than 3,000 hectares. About 70% of properties larger than 3,000 hectares are managed by 30% of the region's farmers who collectively produce about two thirds of the production.

Crop production

Over the past 100 years, average crop production across the wheatbelt has increased from about two million tonnes to more than 10 million tonnes each year. For much of the State's farming history this crop production has been driven by an expanding cropping area, but since 1980 increasing crop yield has been the main driver (Figure 2). This increase in average yield has occurred despite growing season rainfall across the southwest of WA dropping by up to 20% since the mid-1970s.

Improvements in technology, agronomy and crop varieties have effectively increased the rainfall use efficiency of wheat at a greater rate than rainfall has declined in WA. It is estimated that wheat yields from dryland farms in southern Australia increased from about 35% of their maximum attainable water-limited yield in 1980 to about 60% of attainable yield by 2021.[3]

A range of factors have contributed to the yield increases:

- genetically superior crop varieties
- a better understanding of how crops grow and interact with their environment
- enhanced sowing technology enabling dry sowing
- more effective weed, disease and pest management
- more efficient fertiliser use
- soil amelioration.

If today's WA growers were using the same crop varieties and management practices as their predecessors 50 years ago, the State's average wheat yield would be about half of today's at just over 0.75t/ha.

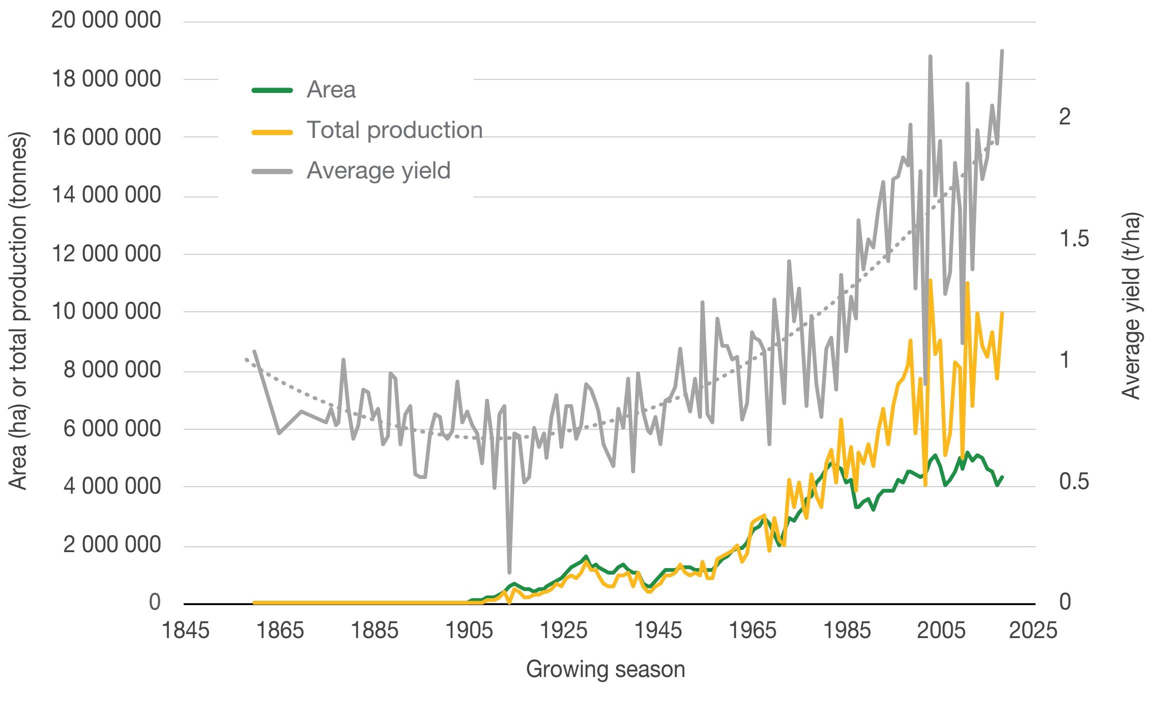


Figure 2. Change in average (grey line) and total (yellow line) crop yield vs total area of production (green line) in Western Australia from 1865 to present day.

Source: Re-drawn from Angus (2011). Variety yield data from Perry and D'Antuono (1989)[2]. This version of the graph originally appeared in the 2021 DPIRD Research Highlights.

Livestock production

WA manages about 20% of the national sheep flock with numbers across the wheatbelt having dropped by more than half in the past 30 years – from about 32 million in 1992 to 14 million today (Figure 3). Over the same period, cropping area has increased from about 6 to 8 million hectares.

WA has 4000 sheep producers with about 80% of these managing flocks of 500 or more sheep. The number of breeding ewes sits at about 7 million head and about 6 million head of sheep are currently turned-off each season for domestic slaughter, live export, or transfer interstate (Figure 4). Merinos constitute about 85% of the WA flock – the highest ratio in Australia with the remainder of the flock Merino crossbreds, dual purpose and specialist meat breeds. Wool production (2021) from the WA flock accounts for 20% of national wool production (67.5M kg).

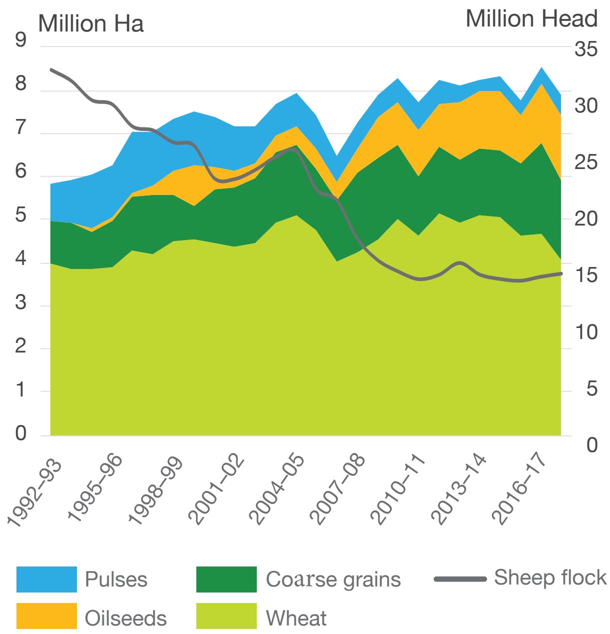


Figure 3. Change in Western Australian crop area (hectares) and sheep flock numbers over the past 30 years. Source: Agar et al (2020)[4]

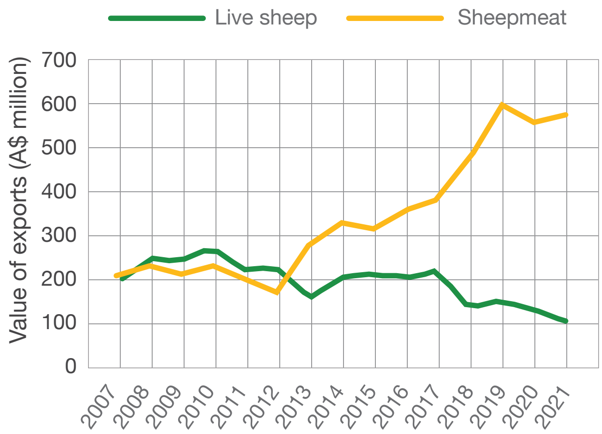


Figure 5. Value of sheep meat exports (2007–2021). Value of sheep meat exports has almost trebled since 2011. Over the same period, the value of live sheep exports has declined by 50%.
Source: Kate Pritchett, DPIRD

China is WA's largest market for sheep meat (45%) with volumes exported increasing over the past five years due to an outbreak of African swine fever in the Chinese pig population, which has caused a significant protein deficit in the country.

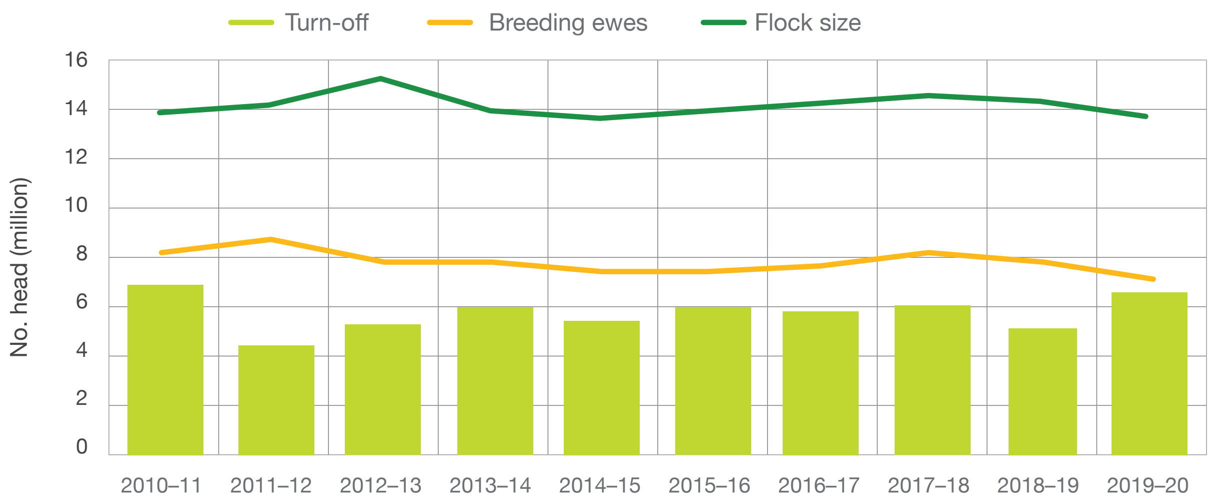


Figure 4. Size of the WA sheep flock (green line) has hovered around the 14M head mark for the past decade. The number of breeding ewes (orange line) sits at about 7M head. About 6M head of sheep (green bars) are currently turned-off each season for domestic slaughter, live export, or transfer interstate. Ewes and lambs make up between 80–90% of the flock. Source: Kate Pritchett DPIRD

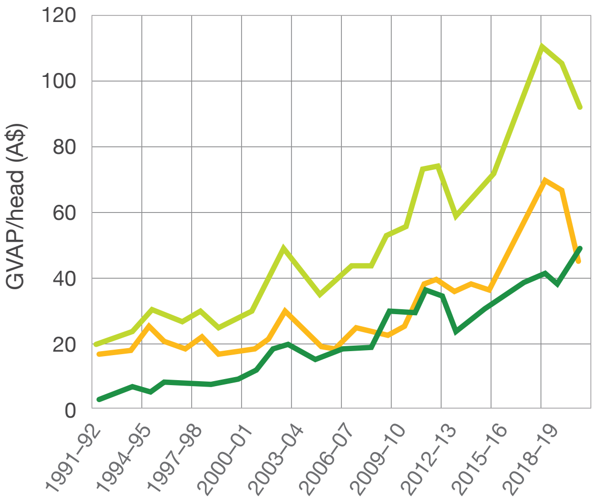


Figure 6. Gross value of sheep meat and wool production has increased significantly over the past 30 years, from about $25/head in 1990 to $93/head in 2021. Source: Kate Pritchett DPIRD

The WA sheep flock has restructured over the past 30 years with the breeding ewe proportion of the flock increasing and the proportion of wethers decreasing largely in response to increasing sheep meat vs wool production. Despite the fall in sheep numbers over the past few decades, productivity of the WA flock has increased with weight of lamb produced per ewe mated increasing from 4 to 8kg during the past 20 years. The value of sheep meat exports has almost trebled in the past 15 years while the value of live sheep exports has halved (Figure 5).

Over the past 30 years, WA's wool production has declined in line with the drop in total sheep numbers but wool production per head has increased and this, along with a decrease in average fibre diameter and an increase in price, has seen the value of wool production increase significantly (Figure 6).

Recent climate

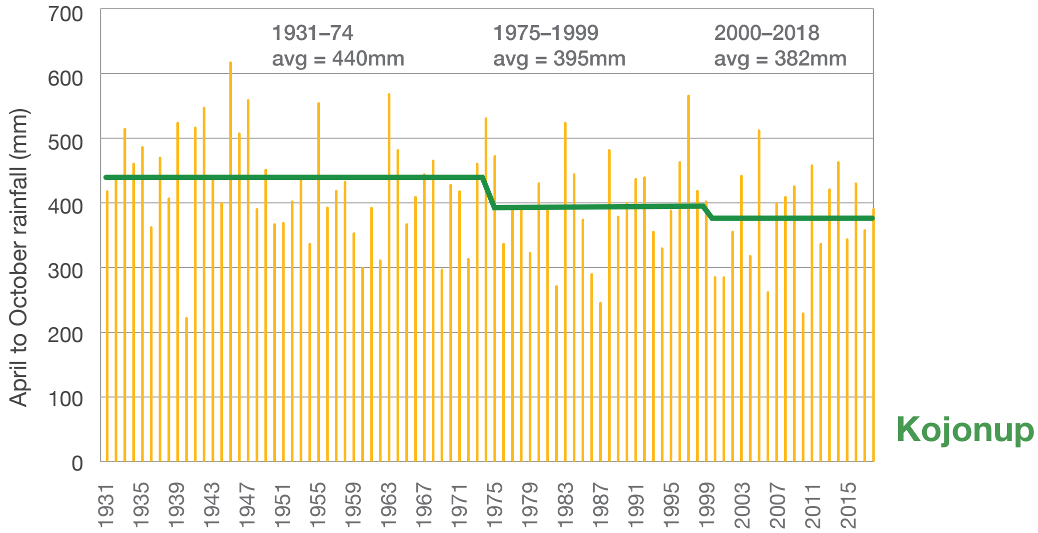
Given its vast geographic spread, growing season rainfall (May–Oct) varies widely across the wheatbelt and can range from as little as 200mm in the north-east to 500–700mm in the south (Table 1). As a result, the growing season can be as short as four months in the north-eastern extremities and as long as seven months in the far south-west.

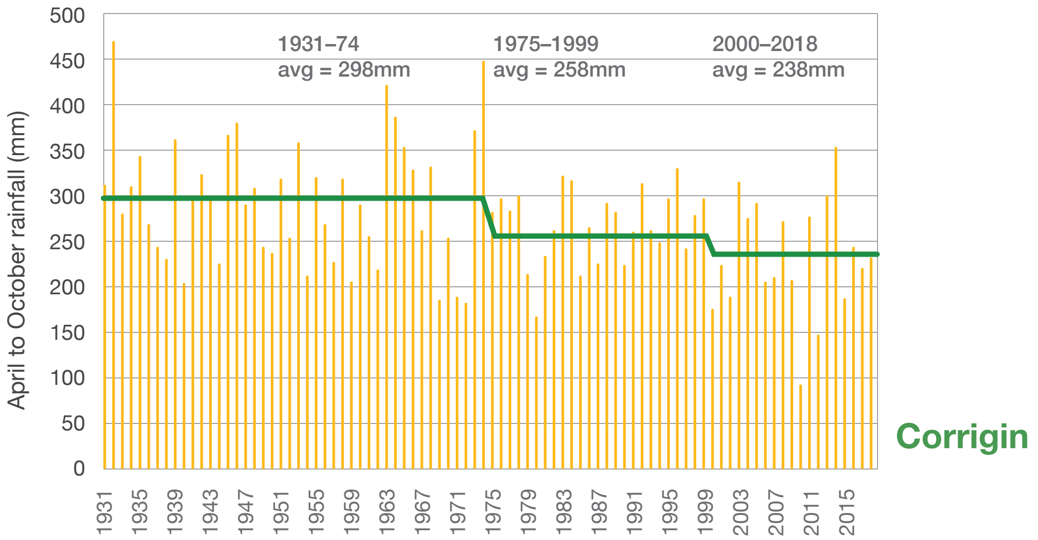
Cropping dominates the southeast coastal

Table 1: Change (%) in average annual rainfall across the WA wheatbelt between 1961–1990 and 1991–2021

	Rainfall 1961–1990			Rainfall 1991–2021		
	Annual average	May–Oct	Nov–April	Annual average	May–Oct	Nov–April
Albany Port Zone						
Albany	906	671	235	868 (-4%)	646 (-4%)	222 (-6%)
Katanning	474	341	132	449 (-5%)	321 (-6%)	127 (-4%)
Geraldton Port Zone						
Geraldton	437	362	74	385 (-12%)	320 (-12%)	65 (-12%)
Moora	450	348	102	407 (-10%)	305 (-12%)	102 (0%)
Kwinana Port Zone						
Northam	434	333	98	403 (-7%)	299 (-10%)	103 (+5%)
Merredin	328	220	106	326 (-0.5%)	206 (-6%)	120 (+13%)
Lake Grace	348	234	114	385 (+11%)	206 (-12%)	134 (+18%)
Esperance Port Zone						
Esperance	646	471	175	613 (-5%)	428 (-9%)	185 (+6%)
Salmon Gums	342	207	135	378 (+10%)	200 (-3%)	178 (+32%)

*Data in brackets indicates change in rainfall over the past 30 years. Source: BOM data via Dr Meredith Guthrie DPIRD





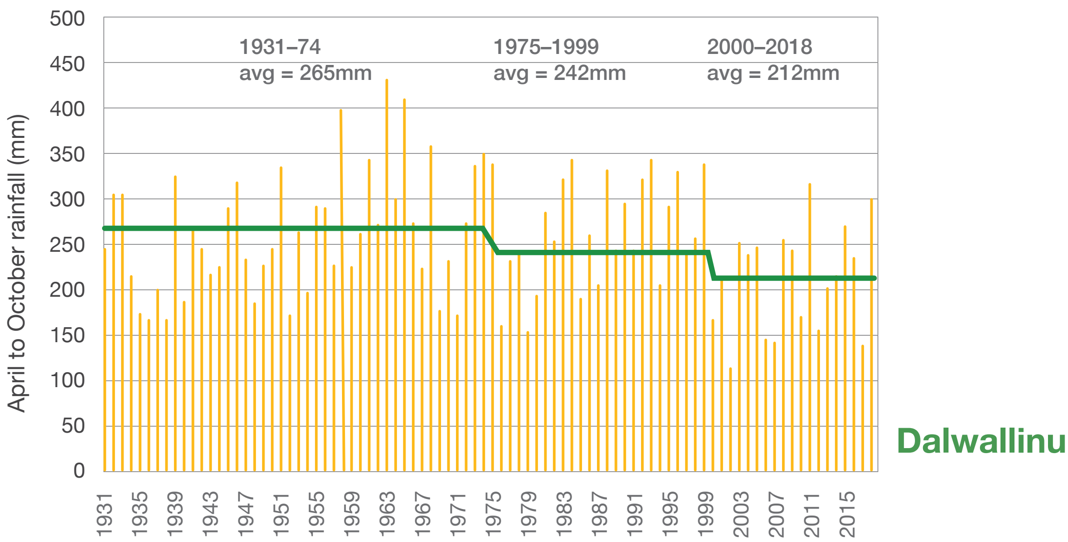


Figure 7. Change in annual rainfall across the Western Australian wheatbelt at Kojonup, Corrigin and Dalwallinu over the past 90 years. Source: Dr Meredith Guthrie DPIRD

(Esperance Port Zone) and northern (Geraldton Port Zone) regions while the central (Kwinana Port Zone) and southern (Albany Port Zone) agricultural regions are more mixed cropping-livestock.

Rainfall decline

In the mid-1970s the southwest of WA experienced a noticeable drop in winter rainfall compared to the previous few decades, and this was followed by another, smaller, downward shift in the 2000s. As a result, growing season rainfall has dropped by as much as 50–60mm or 20% in some areas over the past 90 years (Figure 7).

Crop yields

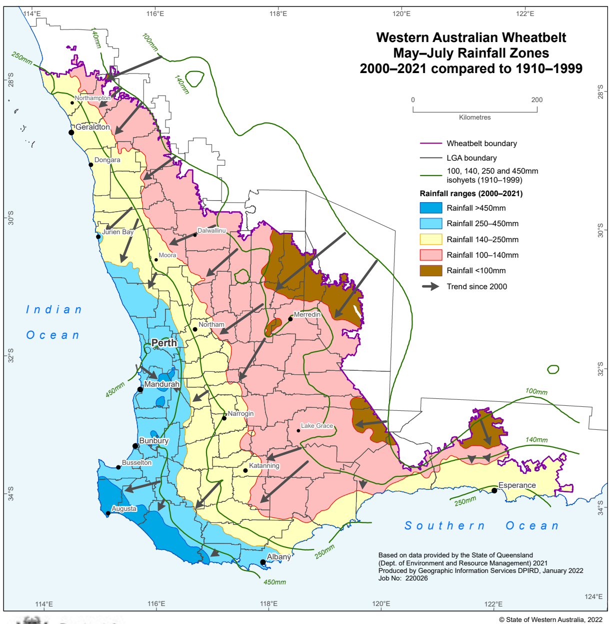
The decline in growing season rainfall has caused a shift in rainfall isohyets and the historical 3t/ha wheat yield potential line now sits 40 kilometres towards the southwest (Figure 8). Figure 8 shows the shift in 175, 225, 450 and 700mm growing season rainfall isohyets for the period 1900–1999 compared with their location during 2000–2018. As a result, some areas in the north-eastern wheatbelt such as Mukinbudin now receive just 175mm (on average) of growing season rain for crop production while the percentage area cropped in the western and south coastal regions has expanded as the threat of waterlogging has declined.

The decline in rainfall has resulted in fewer wet years and many more smaller rainfall years across the wheatbelt with the traditional 'break of season' (defined as 15mm of rain over three days) becoming later and more variable across some of the wheatbelt – especially on heavier soils. The number of rain days above 2mm during the growing season (April to July), have also declined across the wheatbelt and crop yields have become more variable since 2000 (Figure 9).

> ***The traditional 'break of season' (defined as 15mm of rain over three days) has become later and more variable across the wheatbelt – especially on heavier soils.***

Temperature

The drop in growing season rainfall across the wheatbelt has been associated with a one degree warming trend – an anomaly compared to the long-term average (Figure 10). The amount of heat during flowering and grain fill (Aug–Oct) has increased since 2000 and a wider area of the wheatbelt is now experiencing 5-6 days of frost on average.



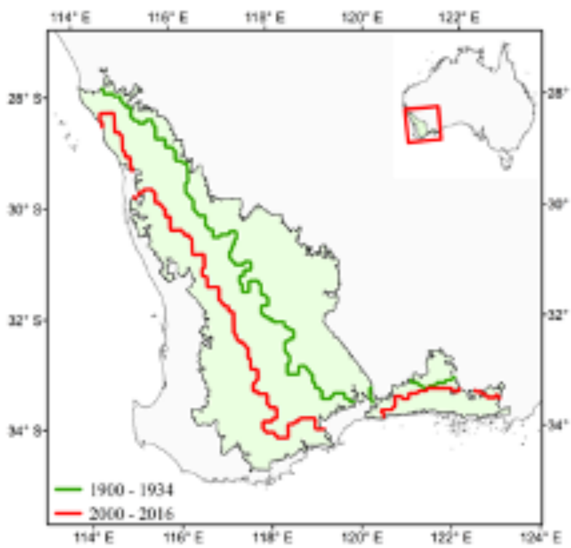


Figure 8. Shift in rainfall isohyets (left) and the 3t/ha potential yield line (right) over the past 100 years as the climate has dried across southwest Western Australia. Sources: left: DPIRD and right: Fletcher et al (2020)[5]

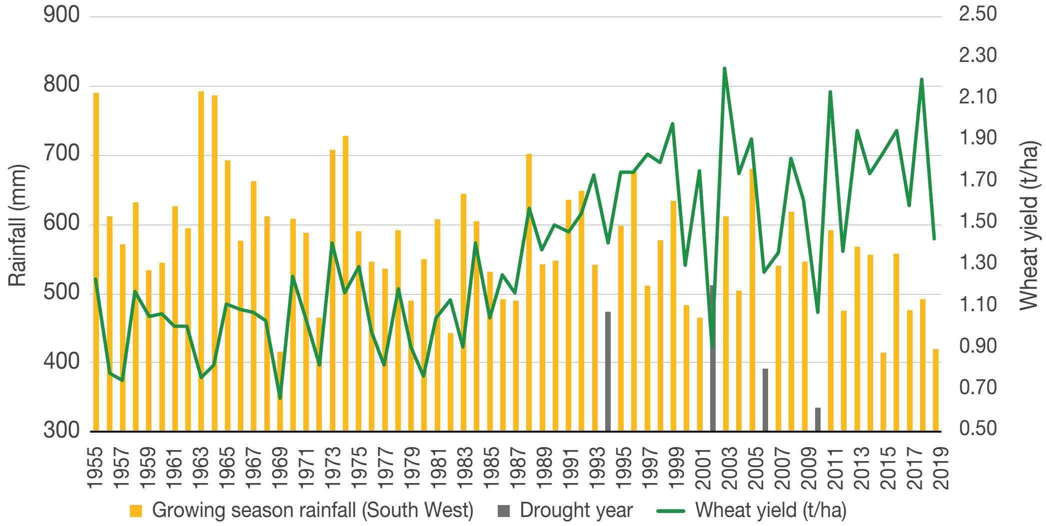


Figure 9. Western Australian wheat yields and annual rainfall (1955-2019). Source: DPIRD

In WA, average wheat yields have doubled over the past 30 years, but since the end of the 1990s yield variability has increased and the rate of yield increase has flattened. Yield increases have been greatest in southern and northern areas and least in central and eastern areas, while yield variability has been greatest in eastern and northern areas.

Since 2000, the amount of heat during flowering and grain fill (August–October) has increased.

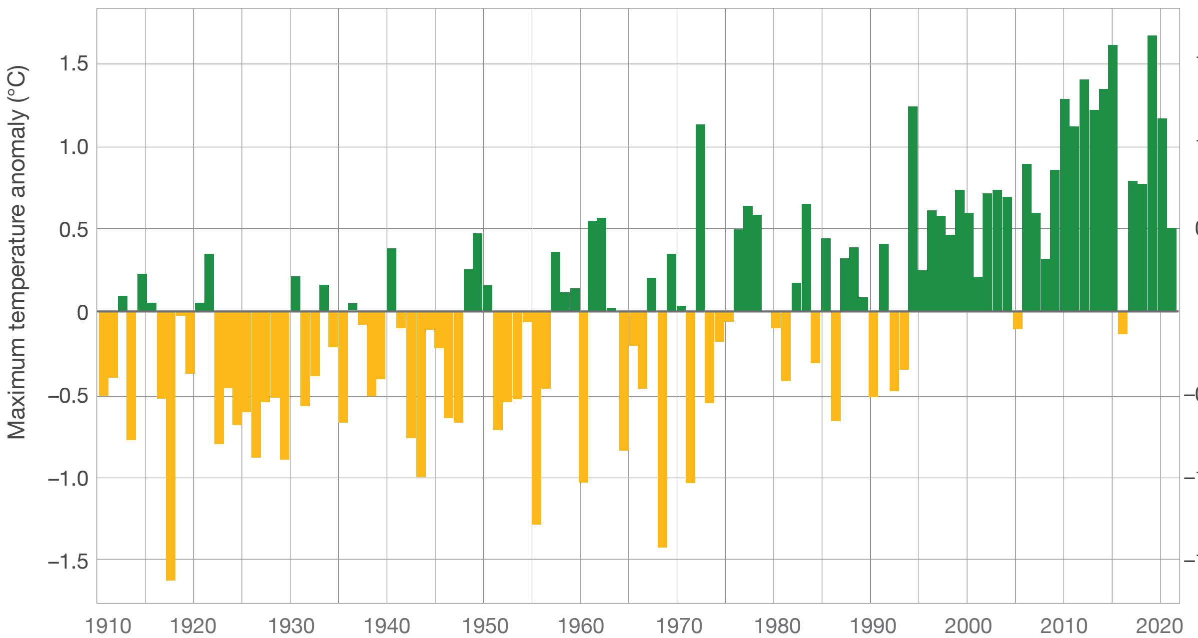


Figure 10. Annual maximum temperature anomaly in southwest Australia (1910–2021). Source: Bureau of Meteorology

Run-off and farm water supplies

Compared with 40 years ago there is now significantly less runoff and streamflow across southwest Western Australia (Figure 11).

The region has lost a third of its 10mm and 25mm rainfall events making its natural catchments less effective. Modelling studies at the large water supply catchment scale have shown that for every one millimetre of lost rainfall about three millimetres of run-off are lost – making it harder to fill dams.[6]

A 'water deficiency declaration' is a government response to safeguard the commercial interests of farmers during very dry periods. A declaration occurs when a group of five or more farmers, within a 20-kilometre radius, require water from an off-farm source and must travel greater than a 40-kilometre radius from their farm to get this. During 2020, a record 12 water deficiency declarations were issued for wheatbelt towns in the southeast and on the south coast. Most farms in the region were down by 75% of their dam water capacity and some had lost 100% of supply and were forced to feedlot or off-load their sheep flock. Without the rainfall that arrived in 2021, many farmers would have had to completely de-stock their properties.[7]

Farm water needs

Dryland agriculture across the wheatbelt is estimated to require between 30 to 50GL of water each year for cropping and livestock needs. About 5.5GL of this comes from scheme water with the remainder (80–90%) needing to come from on-farm supplies. The average large cropping farm (6000 hectares) requires an estimated 3 million litres of spraying water each year while the average farm dam might contain about four million litres of water when full. Farms south of a line from Mandurah to Corrigin have significantly less access to scheme water than northern towns and must rely on farm supplies alone. East of Hyden and Newdegate and south of Nyabing and Kojonup and out to Esperance there is no access to scheme water. In 2020 it was this area (and beyond) for which the water deficiency declarations were made.

Many of the estimated 200,000 farm dams across the wheatbelt no longer capture enough run-off – making them unreliable during low rainfall years. In addition, minimum tillage has significantly lifted the efficiency with which rainfall is captured for crop use, which in turn has increased the rainfall threshold required for run-off to >25mm (a figure less likely given the drying climate). With rainfall expected to drop even further across the wheatbelt over the next few decades, there is a need to re-engineer farm dams to make them more efficient at capturing run-off and minimise evaporation losses. Technology such as polymers on roaded catchments have been shown to lower the run-off threshold to 4–6mm while plastic-covered catchments can result in run-off at just 0.4mm of rainfall.[7] Suspended and floating covers to reduce evaporation losses are currently being investigated by the WA Water Corporation.

Groundwater

Many thousands of gigalitres of groundwater exist beneath the wheatbelt, and with favourable economics and desalination, some of this could form an important future source of agricultural and community water. A growing number of farmers across the region are trialling desalination units and there is a project underway to investigate community-scale desalination units in several wheatbelt towns. It is estimated that about 50% of the wheatbelt has access to water suited to desalination. The challenge is to develop systems that are economically viable, and which can out-compete the cost of accessing emergency water ($8–9/KL) and ultimately scheme water ($2.50/KL). If this cost barrier could be overcome, desalination could secure farm water supplies across the wheatbelt.

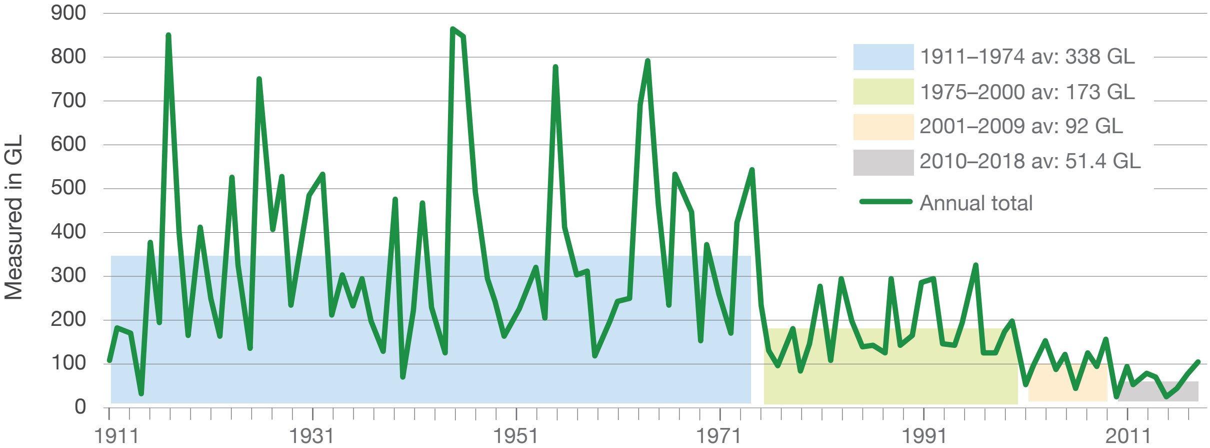


Figure 11: Annual streamflow data (GL) across southwest Western Australia over the past 100 years

Dual crops lift stocking rates and margins

Frost and dry seasons are the key profit drivers of Simon Wallwork's 3700-hectare mixed farming operation at Corrigin. Wheat has been dropped from the system entirely and sheep and cattle introduced along with more frost-tolerant barley, which is grazed in lieu of regenerative annual pastures. The new approach has enabled higher stocking rates and this, combined with higher livestock prices in recent years, has resulted in his sheep and cattle enterprises generating higher gross margins than his crops. Lifting his soil water holding capacity is a major focus and Simon has been mouldboard ploughing since 2014 to mitigate non-wetting and increase rooting depth. EM38 surveys have been done to map soil types across the entire property. Soil amelioration has generated significant yield responses – up to 900kg/ha in the first year and 500kg/ha six years after the initial plough.

Corrigin farmers Simon Wallwork and Cindy Stevens

Financial confidence hedges against dry years

Drought is a severe risk to Dylan Hirsch's northern wheatbelt cropping operation with return on capital averaging 10% but ranging between –25 and +35 year-on-year. Traditionally this has been managed by ensuring the business has enough cash and unleveraged assets to cope with successive poor seasons.

The Hirsch's sow 100% of the cropping operation dry and have done so since 2016 – getting the crop in early has been the main driver of economic return along with chasing moisture through deep seeding and removing livestock from the system. Early sowing also helps avoid the production risks of heat stress in spring. The cropping system is based on a range of yields and Dylan aims to produce somewhere between 1-3t/ha. Canola and lupins are important components of the cropping rotation and Dylan is excited about the breeding traits and technologies coming through for crops in the low rainfall area. Deep ripping combined with lime is used to increase soil water holding capacity and rooting depth and mitigate the region's drier winters. Summer rainfall is conserved through stubble retention. Average paddock size is 300 hectares, which has created economies of scale.

While land prices and profitability are increasing so are input costs and the risk of crop failure. The underlying philosophy of the farming business is to do 'more with less' by improving efficiencies and increasing productivity. High business equity and frugal expenditure have worked to date but with more erratic seasons expected, Dylan has been investigating financial risk management products to hedge against dry years. In the last few years, the Hirsch's have purchased weather derivatives which insure against poor seasons using a predictive crop water use efficiency that Dylan accesses via a nearby Bureau of Meteorology weather station. The insurance hedges against a dry year and pays a premium in a better rainfall year. The scheme is expensive – requiring an upfront cost of $200,000 and averaging about $10/ha but Dylan believes it provides greater financial certainty for dry sowing, borrowing capital and grain marketing decisions.

Northern wheatbelt farmer Dylan Hirsch

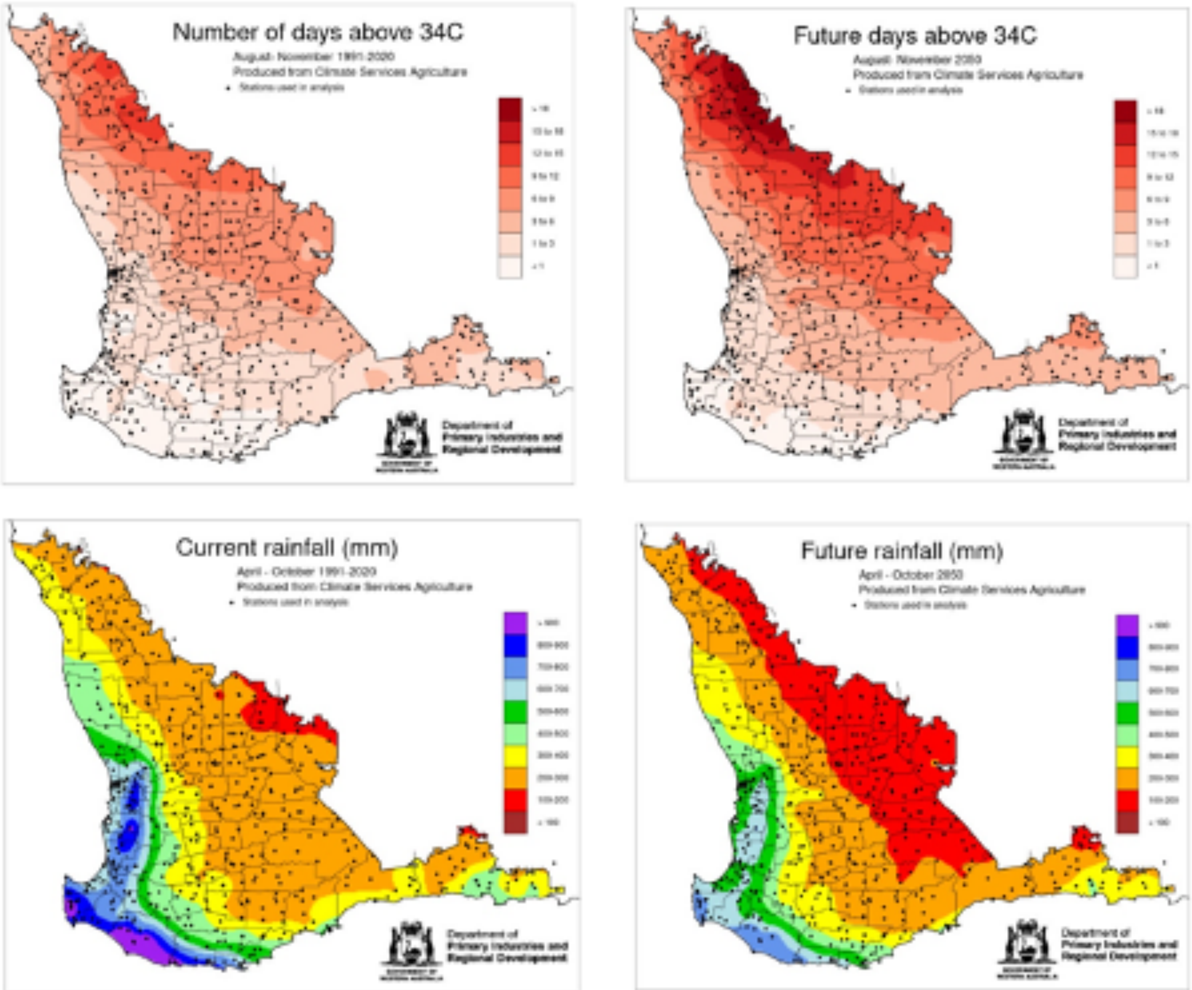


Figure 12: Projected change in days above 34°C (top) and growing season rainfall (bottom) across southwest Western Australia by 2050 compared with the past 30 years (1991–2020) Source: DPIRD

Table 2: Projected rainfall and maximum temperatures across the wheatbelt by 2050 under medium and high emissions scenarios compared with recent climate (1991–2020)

	Annual rainfall (mm)		Summer rainfall (mm)		Heat risk: days >35°C*	
Emissions scenario	Medium	High	Medium	High	Medium	High
Katanning	391 (–10%)	353 (–19%)	47 (–4%)	40 (–18%)	23.0 (+5.8)	26.1 (+8.9)
Moora	395 (–4%)	347 (–16%)	47 (+2%)	37 (–20%)	61.9 (+15.1)	69.3 (+22.5)
Merredin	296 (–11%)	268 (–20%)	54 (–8.5%)	47 (–20%)	59.2 (+12.3)	67.0 (+20.1)
Salmon Gums	329 (–20%)	309 (–11%)	73 (–13%)	67 (–20%)	29.2 (+6.1)	32.7 (+9.6)

Medium emissions: Greenhouse gas emissions reduced substantially by end of the century, but not enough to stop continued warming. Adaptation continues to become increasingly harder over time. High emissions: Rapid increases in greenhouse gases continue towards the end of the century. Some systems are unlikely to be able to adapt to the large changes in climate.
*Jan-Dec. Source: Climate Services for Agriculture

Each day with temperatures over 35°C during grain fill can reduce wheat yield by 5%. In extreme temperatures sheep and cattle can consume up to 80% more water.

Future climate

Climate change has already occurred across the WA wheatbelt and even the most optimistic emissions reduction scenario is expected to deliver a further 1–2°C rise in average temperature by 2050 (Figure 12 and Table 2). The drying trend experienced across the wheatbelt since the mid-1970s is expected to continue with rainfall projected to decline by 5–20% depending on location (Figure 12 and Table 2).

The climate models have high confidence that there will be less rainfall in winter and spring and that annual rainfall will decline, but changes to autumn and summer rainfall remain unclear.

As the atmosphere warms, it can hold more water vapour, potentially leading to higher rainfall rates from weather systems. While overall rainfall will decline, there is medium confidence that the intensity of heavy rainfall events will increase, but low confidence in the magnitude of the change.

Drought

Under all emissions reduction scenarios there is high confidence that the duration and frequency of droughts in southwest WA will increase compared to the present climate. Agricultural drought months (defined as a month of extremely low soil moisture) are projected to increase by up to 20% over most of Australia by 2030 and up to 80% in the southwest by 2070.

Run-off and stream flow

Projected climate change is expected to reduce streamflow into dams and groundwater recharge in western and south-western areas of WA. Surface water and groundwater resources are very sensitive to climate change and recharge is expected to be greatly reduced. Projections are for median streamflow to decline by 24% by 2030 and 45–64% by 2090 depending on emissions reduction scenario. By 2030, potential evaporation is expected to increase by about 2.5%. By 2090, potential evaporation is expected to increase by 5–10% depending on emissions reduction scenario.

Future climate impacts

Across the wheatbelt, business and production risks associated with future climate variability are expected to increase, particularly in drier marginal areas.

In a 2020 social benchmarking survey of 180 farmers in the northern wheatbelt, led by Southern Cross University and jointly funded by the Soil CRC and the West Midlands Group, the top two issues for the region were identified as weather patterns (86%) and water security (77%).[8] Survey participants were specifically concerned about temperature extremes on farm productivity (74%) and the impact of uncertain or low returns on their capacity to invest in the property (73%).

Table 3 outlines the major impacts of a drier, hotter climate on cropping and livestock enterprises across the wheatbelt. Table 4 summarises RD&E done to date to address these impacts and the unresolved issues requiring further work.

Roaded catchment can cause water to run after just 8–10mm of rainfall and with chemical treatment the threshold for runoff can be as low as 4–6mm. Source: South West Catchments Council

Table 3. Potential impacts of projected climate on cropping and livestock enterprises across WA wheatbelt.
Source: Adapted from Sudmeyer et al (2016)

Enterprise	Impact of a hotter, drier climate
Crops	Crop yield is most affected by changes in rainfall, particularly its timing. Declining growing season rainfall and lighter rainfall events will make evaporation losses more significant, and less water will be stored deep in the soil.
	Plant available water capacity of soils will become increasingly important in determining yield; yield declines will be greater on clay soils compared to sands, particularly in drier eastern areas.
	Dry autumn conditions can delay sowing and limit potential yield. Dry spring conditions can limit water available for grain filling and result in small, pinched grain.
	Higher temperatures, and to a lesser extent declining rainfall, will hasten development times and reduce the flowering period.
	Each day with temperatures over 35°C during grain filling can reduce wheat yield by 5%. Temperatures above 32°C during canola flowering can cause flower abortion.
	Crop yields may be largely unchanged or increase in wetter western and southern areas where higher temperatures and reduced waterlogging will benefit crops.
	Reduced rainfall and run-off = less captured water and water quality for spraying could be compromised.
Livestock	A later and more variable start to the growing season will increase production risk for pastures. Deferred grazing of pastures at the break of season will likely become more important. Supplementary feeding costs could increase.
	Reduction in reliability of run-off into farm dams. Roaded and natural catchments will need to be larger or amended with polymers or plastic to increase run-off and fill existing dams. Stock water quality could become an issue.
	Reduced rainfall and higher temperatures could reduce forage production by up to 10%. Flexible lot-feeding or confined feeding systems will be needed to maintain or finish livestock in dry years.
	In the higher rainfall areas of the south-west, increased temperature in winter and early spring and reduced waterlogging could benefit livestock production by increasing forage production.
	Increased temperatures during summer could increase heat stress of livestock leading to poorer reproductive rates and increasing livestock water requirements.

Kingwell (2002) commented on crop-dominant farming systems in Australia that:

> “. . .a switch into more cropping means a more capital-intensive business with greater demands for working capital. With such a business structure a few poor seasons, especially if coupled with poor prices, can rapidly cripple a farm business.”

Consistent with this view were findings by Lawes and Kingwell (2012) who found that the consecutive years of drought in 2006 and 2007 greatly challenged the profitability of farm businesses in the northeast part of the wheatbelt of Western Australia. Almost two-thirds of farms experienced a decline in business equity over the period 2004 to 2009.

What innovations and technology interventions are needed across the low, medium and high rainfall zones of the wheatbelt to maintain and grow business equity in the face of a drier, hotter more variable climate?

Table 4. Summary of drought adaptation levers available to the WA wheatbelt and the RD&E gaps needing attention to better equip the industry in the face of projected climate change

Drought adaptation lever	What's worked?	What's needed?
Water use efficiency From Harries M et al. (2022): "Studies benchmarking the yield of wheat in southern Australia report a wide variation in water-limited yield compared to farm yield achieved, which is commonly termed the yield gap. Recent surveys report leading farmers achieving about 80% of water-limited yield potential (van Rees et al. 2014; Lawes et al. 2021) compared to estimates of 50–60% based on mean industry level data and simulation analyses (Hochman et al. 2016; Anderson et al. 2017; Hochman and Horan 2018) and estimates ranging from 35–70% at the local government level (Hochman et al. 2021)."	**Soil water holding capacity** Multiple soil constraints can reduce crop yields by 40–50%. Crop roots often constrained to 40cm in soils with multiple constraints but in deep sandy soils with no constraints, roots can grow to 200cm. Soil amelioration: removing physical and chemical constraints to water infiltration and storage can lift wheat yields by 0.6–1.4t/ha when soil moisture available during grain fill. When multiple constraints are ameliorated, crops have been shown to access an additional 10-40mm water, depending on soil texture and structure. Soil amelioration can increase water use efficiency in cereals by 5-8kg/ha for every millimetre of additional water accessed by the crop.	Current soil amelioration practices work within the top 40cm of soil – accessing deeper subsoil water potentially has huge benefits. This work is underway (DPIRD). DPIRD research underway to determine how to manage impact of soil amelioration on herbicide efficacy, seedling establishment, erosion risk, soil biology and weed population dynamics. Soil amelioration best done in moist soil – drier autumns make this problematic and increase erosion risk. Investigations underway (DPIRD) into benefits and consequences of amelioration during winter/spring. Soil amelioration benefits proven for low rainfall areas – need to translate benefits for medium and high-rainfall areas.
	Controlled traffic When controlled traffic is used after deep ripping there is an additional yield benefit of 10% ($50/ha for 2t/ha yield + $300/tonne grain price) and better grain quality. When subsoil constraints have been controlled effectively controlled traffic farms in WA have shown water use efficiencies better than 20 kg/mm.	Controlled traffic adoption on the rise – from 21% of 89 surveyed WA growers in 2016 to 25% in 2019. Half of all growers surveyed indicated they intended to implement a form of controlled traffic in the future.
	Maximise rainfall to yield **1. Coleoptile length:** Early dry sowing when coupled with sowing at depth can lead to poor crop establishment, particularly in varieties with short coleoptiles. Genes that increase coleoptile length have been identified and tagged with molecular markers to facilitate their use in breeding programs. These genes are expected to play an important role in improving emergence from depth. Matching new genetics with appropriate agronomy and technologies such as moisture seeking, will help improve the emergence and establishment of deep-sown wheats, particularly when sown early in warmer soil conditions or when sown deep when chasing soil water when the top 100+mm of soil has dried out.	**Coleoptile length:** "Many growers are keen to see the development of long coleoptile wheats, particularly for seeding into marginal moisture or when there is moisture at depth." Maximising Crop Potential in a Drying Environment – An Initiative of the Regional Cropping Solutions Network (2019) **Seeding systems:** Wesley Wheel – designed to harvest moisture from inter-row furrows. Possible adaptation could include incorporation of heavier, angled rubber-tyred rolled system + polymer to create a permanently compacted, barren environment in the inter-row to harvest and direct rainfall to plants. Identify or develop a low-cost polymer suitable for the cropping industry; ideally sprayed onto inter-row to enable water harvesting.

Drought adaptation lever	What's worked?	What's needed?
	2. Transpiration efficiency: Selection of crops with high transpiration efficiency (e.g., Scout) has increased water use efficiency of Australian cereals. **3. Heat tolerance:** Wheat: University of Sydney plant breeders evaluated 23 Australian wheat cultivars and two breeding lines for heat-tolerance. Seven classified as heat tolerant and nine heat susceptible. Heat tolerant genotypes are candidates for further breeding and selection to improve adaptation to a changing climate. Barley: Western Crop Genetics Alliance has identified 100 genes in the barley genome controlling flowering time and/or yield. These have been digitally marked and breeding lines developed to counter impacts of climate change. **4. Root disease resistance:** breeding for resistance to cereal cyst nematodes **5. Tolerance of soil toxicities:** soil salinity, aluminium, and boron tolerance **6. Early vigour:** increase ground cover to reduce soil water evaporation **7. Harvest index:** stem carbohydrates and reduced tillers to drive more sugars into grain development	
Rainfall capture + storage Reduced rainfall over SW WA mean dams on natural catchments no longer reliable for animal production in low rainfall years. Minimum tillage highly efficient at intercepting water and stopping run-off; need rainfall events of 20-50mm to get overland flow. Climate projections 90% confidence of less rainfall so run-off will decline even further.	**Roaded catchments** above dam can reduce rainfall threshold for run-off from 20-30mm to 8-12mm **Polymer-sprayed catchment:** run-off reduced to 4-6mm **Plastic covered catchment:** run-off reduced to 0.4mm	Audit of farm dams across wheatbelt to determine proportion with roaded catchments (work underway via WaterSmart Dams – Richard George et al). Need a 'back-to-basics' extension campaign to encourage adoption and maintenance of roaded catchments and skilling up of dam contractors and consultants. Dam diggers retiring – not enough skill in industry for dam location/design. Investigations underway (WaterSmart Dams) re plastic/polymer coated catchments – economics and effectiveness need to be quantified. Long-term research projects needed to secure farm water supplies into the future and encourage adoption of technologies to reduce evaporation (tanks storage/dam covers) and increase water capture. Largest water loss is from evaporation – need to store water in tanks for dry times or stop from evaporating using dam cover technology. Water budgeting needs to be part of farm planning process.

Drought adaptation lever	What's worked?	What's needed?
Groundwater Dryland agriculture in wheatbelt estimated to need about 30-50GL of water for livestock/cropping each year. About 80% of this currently comes from farm dams and bores but many thousands of gigalitres of water underneath wheatbelt – about 10% immediately suitable for livestock. Desalination could make 50% available and secure farm water supplies into the future.	About 50 farms investigating desalination as a water source for livestock and cropping purposes. Purity of desalinated water excellent for spraying – spray effectiveness increased. Some operating on solar – others on AC.	Desalination units in rural towns being investigated for capacity to supply community water and potentially scale up for new industry development. If enough water can be desalinated economically towns could attract new industries – e.g., feedlots. Blue sky R&D = drilling into base rock across wheatbelt to find fractured systems with access to small aquifers. Such volumes, once desalinated, could supply whole communities. How to make economics of desalination more attractive and competitive with emergency and scheme water?
Best practice agronomy Early dry sowing when coupled with sowing at depth can lead to poor crop establishment, particularly in varieties with short coleoptiles. There has been increasing interest in deep sowing systems (typically at 50-200mm) to use summer rainfall and ensure earlier establishment (Rich et al 2021). However, the shorter coleoptile of modern wheat varieties limits their suitability for deeper sowing. In turn, many crops are sown dry to accommodate large sowing programs. An ability to germinate and establish wheat crops from seed placed 100mm or deeper in the soil would be beneficial in situations where the subsoil is moist but the surface soil dry (Rebetzke et al 2007; Rich et al 2021). To increase crop yield per unit of scarce water requires both better cultivars and better agronomy. The challenge is to better manage the crop and/or improve its genetic	**Variety choice:** Grower interest and demand for winter wheats has increased in WA due to recent early sowing opportunities and the logistics of sowing larger cropping programs on time coupled with research highlighting the benefits of winter varieties (Hunt et al. 2019). **Sowing time:** To maximise yield potential, the maturity of a variety must be matched with sowing date so that flowering and grain fill occur after highest frost risk but before late-season water limits and high temperatures. Yield gains from early sowing have been estimated at 10–30%. Wheat: delaying sowing until June compared with sowing in May can reduce average yield potential by 26kg/ha/day in the northern ag region, 28kg/ ha/day in the central ag region, 23kg/ha/day in the Great Southern and 13kg/ha/day on the south coast (Zaicou-Kunesch et al., 2018). Canola: (Harries et al., 2014) have demonstrated that early sowing is the key to maximising canola yields in the northern ag region. Yields were lower for all varieties when sowing was delayed from 14 April to 29 April, with average yield losses of 43kg/ha/day between these two times of sowing. **Row spacing:** Wide row spacings for canola and lupins appear to be better suited to areas where conditions are warm during grain fill. Wheat and barley establishment and yields are improved with narrow row spacing.	Identify eastern wheatbelt growers successfully navigating drying climate and increased seasonal variability to promote approach to broader cropping industry. Seeding systems that promote water harvesting Quality water for spraying: poor water quality can adversely impact the results for many farm chemicals Increase subsidy to complete Farm Water Audit currently being offered by WA Government. Use of precision agriculture + camera spraying technology to create efficiencies in spraying operations and weed management. Use of variable rate technology to distribute fertiliser inputs more effectively and save on input costs. Improved break crop agronomy + management packages.

Working Draft

Drought adaptation lever	What's worked?	What's needed?
makeup to capture more of the water supply for use in transpiration; exchange transpired water for CO_2 more effectively in producing biomass; and convert more of the biomass into grain or other harvestable product.	**Sowing depth:** Increased adoption of early and deep sowing has seen a push for wheat breeders to investigate the wheat traits that enable greater seedling vigour and ability to emerge from depth. Lines with long coleoptiles have been distributed to breeding companies, where breeding programs will begin a lengthy process to select suitable varieties. It will take approximately 8 to 10 years to get these varieties through to the GRDC National Variety Testing program. On-farm, deep-sowing studies at Southern Cross WA showed the benefits of new dwarfing genes in increasing coleoptile length and seedling emergence at sowing depths of up to 140mm. **Tillage & residue management:** Precision seeding systems under control traffic and with disk openers for minimum disturbance. Stubble retention to minimise soil evaporation and maximise infiltration **Optimise fertiliser inputs:** soil testing and variable rate application can better match fertiliser rates to crop demand and improve efficiency of fertiliser use. **Rotation diversity:** minimise disease, weeds, pests, N deficiency to sustain yields in high intensity cereal cropping systems	
New cropping technology Robertson et al (2016) propose some of the emerging technologies that are likely to contribute to yield gain in the medium (10–20 years) term. "With a conservative assumption about maintaining the current rate of genetic progress at 0.5% per year, ongoing adoption of current and new agronomic technologies, continuing investment in R&D, and farm consolidation, at a whole industry level, annual gains in wheat yields of around 20 kg/ha (0.8–1.0%) are feasible over the next 20 years."	Emerging and future cropping technologies capable of lifting crop yields in a drying climate (from Robertson et al 2016) **Timely sowing:** Seed coatings to delay imbibition under marginal moisture Cultivars with appropriate phenology and long coleoptiles to allow deep sowing Cultivars tolerant to frost at flowering Further improvements in seasonal climate forecasts Real-time sensors for plant available soil water Fertiliser efficiency: Improved fertiliser formulations to release available nutrients matched to crop demand On-the-go proximal soil sensing **Fertiliser efficiency:** Improved fertiliser formulations to release available nutrients matched to crop demand On-the-go proximal soil sensing	

<table>
<tr><th>Drought adaptation lever</th><th>What's worked?</th><th>What's needed?</th></tr>
<tr><td></td><td colspan="2">Subsoil constraints:
Low-cost and easy means to map and diagnose constrained soils
Mechanical and chemical means to increase rate of penetration of ameliorants into sub-soils
Cultivars with tolerance to aluminum, salinity and boron
Rotation diversity:
Technologies for managing seasonal risks and opportunities (opportunity cropping, relay cropping or sowing of sacrifice inter-row mulches)
Low-input break options that minimise input costs and maximise N and weed-control benefits (break crop used for hay or green/brown manure)
Novel intercropping facilitated by precision technology
Widely adapted high-value grain legume (as pasture area declines and the cost of fertilizer N increases, there will be an increasing need for a profitable legume break-crop similarly adapted to the larger areas of acid soils where lupin was formerly grown to complement profitable oilseed break crops such as canola). Could genetic oil modification create a high-oil lupin (more like soybean) for human consumption?
Tillage and residue management:
Further advances in precision seeding systems to sow under marginal moisture, maximise benefits and minimise negatives of on/off previous row sowing
Sprayable biodegradable plastic mulches to suppress soil evaporation</td></tr>
<tr><td>Best practice livestock management
CSIRO scientist Dr Dean Thomas modelled climate change scenarios in a traditional self-replacing Merino sheep flock in the low rainfall zone. Profitability of the system drops as the climate scenarios become more extreme. The degree to which adaptation can help offset these declines as the climate scenario becomes more severe - new livestock systems may be needed with a drying, hotter climate.</td><td>Lifetime Ewe: professional development course run over 12 months to increase understanding of the influence of ewe nutrition and management on overall reproductive rates and lamb and ewe survival. The course also explores the economics of supplementary feeding and pasture management to review stocking rates. On average, participants report an increase in stocking rate of 9.3%, increase in marking and weaning percentage by 7% and a 25% reduction in ewe mortality.
Sheep flock composition calculator: assists livestock producers to compare selling scenarios and models the consequences of selling or retaining different age classes of ewes over six years.
Feed calculators: on average about 20% of the season feedbase comes from crop stubble. Around 60% comes from green and dry pastures, and the remainder comes from forage crops, dual-purpose crops, perennial forage species, or supplementary feeding.</td><td>Water: dams on natural catchments in SW WA no longer reliable for animal production in low rainfall years. Enhanced roaded catchments needed to capture more rainfall. What are the future needs, and can we meet it?
Heat: projections are for an extra 6–22 heat risk days above 35°C per year across the wheatbelt by 2050. What will this mean for livestock production and welfare?
Forage: How can the seasonal feed gaps be filled economically and reliably and integrated easily with cropping systems?
Focus extension efforts on finishing sheep as quickly as possible in recognition of increasing value of sheepmeat over wool. Investigate potential of semi-permanent confinement feeding systems.</td></tr>
</table>

Drought adaptation lever	What's worked?	What's needed?
	The Stubble Grazing Calculator predicts liveweight gain or loss in adult ewes based on their size, condition and reproductive status, the type and condition of crop stubble (wheat, barley or canola), and the provision of supplementary feed. **Twin and summer sowing of hard-seeded legume pastures:** pasture sowing does not interfere with cropping program and seed is easily harvested. **FEED 365:** aims to re-design livestock forage systems for grazing all-year round in Mediterranean environments minimising supplementary feeding. The focus is sheep grazing systems in southwest WA challenged by climate change with increasingly hotter, drier and more variable seasons.	
Business management Top 25% of Farmanco clients in the low rainfall zone of WA are achieving a 5-year average 'return on assets managed' of 8.84% from an average 176mm GSR. The top 25% of Planfarm north-eastern wheatbelt clients achieved 15.1% return on capital 2009-2019 compared with an average for the region of 9.1%.	'Growing and strong farms, when compared to less secure or secure farms have, on average, made greater use of leasing, contractors, superannuation funds, succession planning, Farm Management Deposits (FMDs), and off-farm assets. They also, on average, adopt and make greater use of farm business software, marketing strategies, decision support tools, precision technology, electronic paddock recording and GPS technology' – Kingwell et al (2013). DPIRD's **Plan, Prepare, Prosper workshops** – 2000 participants over the 8-year life of the program. Full course materials still available – covers financial management, risk management, strategic planning, sales and marketing, succession planning.	How do the top 25% of farmers manage seasonal and market variability? What insurance options are available to farmers in a drying, more variable climate? Why are FMDs not used more widely? Decision trigger tools around offloading livestock and committing to a crop
Digital agriculture	**Internet of Things (IoTs)** Monitors for water troughs, weather stations, soil moisture probes Enables instant picture of rainfall across large area and suitability for spraying operations. Monitoring of livestock water troughs and tanks Demonstration site established at DPIRD's Katanning Research Station	Poor connectivity and data speeds an issue for IoT What does best practice use of IoTs look like for wheatbelt farms? How can IoTs be used to better manage seasonal variability and create production efficiencies in a drying climate?
Weather forecasting + decision tools	Many forecasting and decision tools available – not all used to capacity. Why?	Promotion and demonstration of risk management tools needed at farm level to lift predictive ability of yield as season progresses and match inputs accordingly.

Drought adaptation lever	What's worked?	What's needed?
Climate projections	Climate change has already occurred across the WA wheatbelt and even the most optimistic emissions reduction scenario is expected to deliver a further 1–2°C rise in average temperature by 2050. The drying trend experienced across the wheatbelt since the mid-1970s is expected to continue with rainfall projected to decline by 5–20% depending on location.	Scaled-down projections coupled with adaptation/mitigation opportunities to communicate climate change impacts at local levels and translate the economic impacts of 2–3 poor seasons in a row.

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