Key messages

1. Drought has long been regarded as a key recurring feature of the Australian landscape with impacts on our agriculture and food systems and, especially in the past, on the nation's income (recent Australian Bureau of Agricultural Resources and Sciences (ABARES) data predict a 74% decrease in farm cash receipts for FY20 compared to FY 19 attributable to the drought (Martin and Topp, 2020). Severe droughts (in terms of the land covered and length of below average rainfall) are part of our folklore and have led to significant impacts on livelihoods, health, and the national economy. It has also led to major infrastructure investment, including so-called 'drought proofing' schemes and similar attempts to withstand future droughts. But each drought still seems to come as a new surprise (in part because no two droughts affect the same areas for the same period of time - each having some unique characteristics).
2. Some key areas of impact recur including urban and peri-urban water supply, reduced yield, productivity and profitability from cropping systems and especially rainfed systems, major and prolonged impact on rangelands and livestock with accompanying land degradation, and irrigation system shortfalls and allocation dilemmas.
3. The societal and policy response leads to trade-offs including:

1) Infrastructure investment that includes a funding transfer between sectors and across generations (future generations benefit from large investments now)
2) Tax and investment and arrangements for some specific sectors (even in the FMD[1] scheme if a certain proportion of income is off-farm you are ineligible)
3) Mitigation arrangements not uniformly adopted – those that have not used them may be more likely to receive aid. Government policy has changed away from in-drought support to encouraging preparedness.

4. The underlying system is changing due to climate change. In Australia, we have observed:

1) Step reductions in growing season rainfall in southern Australia particularly WA, SA and to a lesser extent Victoria;
2) Rainfall increases in north-western Australia; and
3) A technology / adaptation response that has then followed

5. There is evidence of effective financial adaptation to drought risk:

1) Higher level of use of financial instruments prior to last drought
2) Better debt structure across Australian farms prior to last drought

6. Each drought sees significant off-site impacts and transferred risks

1) Increased loss of soil from wind erosion, sedimentation and pollution of wetlands, reef systems, estuaries
2) Blue-green algal blooms
3) Wild fire
4) Value chain / supply chain impacts –

a) destocking and delays in restocking impact on the supply into abattoirs and delivery to and maintenance of export markets
b) Assured supply expectations (eg. from farm or farm businesses to supermarkets) fail or weaken and/or there is a transfer of opportunity between suppliers
c) Failure of regional non-farm businesses due to less capacity to buy in the region and/or downturn in regional industries such as tourism.

2. Physical and Socio-economic Characteristics of the Case Study

Australia is a small country on the smallest continent with a low average population density concentrated on the higher rainfall fringe. It has both a relatively low rainfall and, for a given level of average rainfall, a higher level of variability than is common on other settled continents or most world regions (Nicholls et al., 1997). Thus, drought is a frequently observed feature of the Australian climate and the experience of most Australians many of whom recognise the description of the nation as one of ". . . drought and flooding rains" from Dorothea Mackellar's 19th century poem "My Country".

While most parts of Australia experience seasonal drought, this is seen as part of the annual cycle; the droughts that reach national consciousness are intense and may often be protracted events, although short term 'flash' droughts can be damaging locally (Nguyen et al., 2019). While it is a frequently stated truism that no two droughts are the same, there is now a body of evidence from studying previous droughts that the differences are significant and the nature of the impacts and the societies and economies impacted vary greatly (Freund et al., 2017); Figure 1.

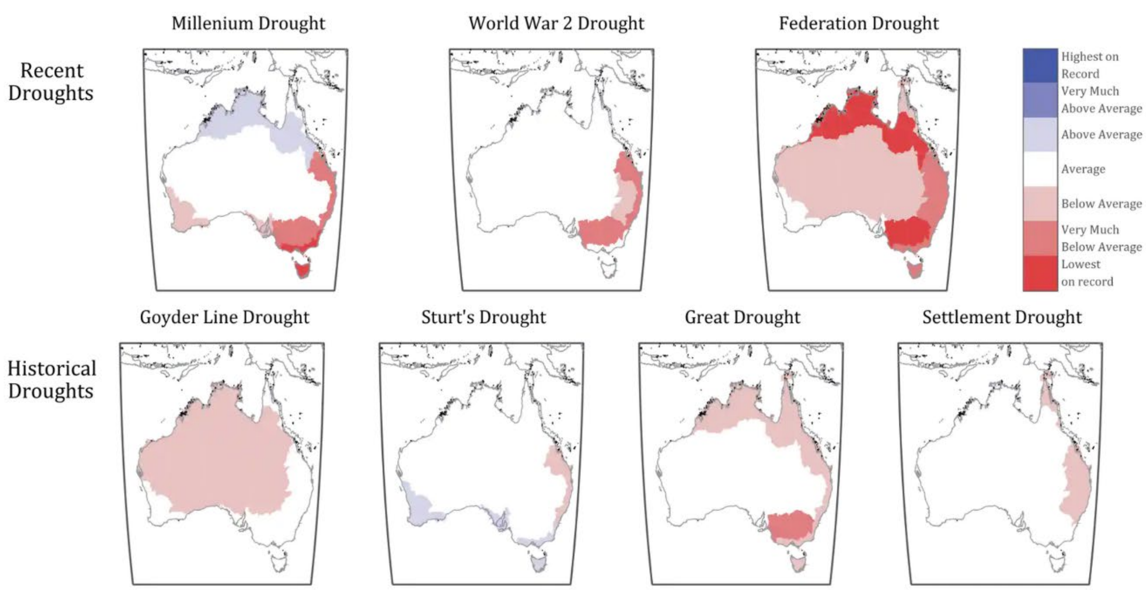

Figure 1 Maps of a selection of major Australian droughts illustrating variety in intensity and coverage. Adapted from Freund et al. 2017. Dates of droughts: Settlement (1790-93), Great Drought (1809-14), Sturt's drought (1809-30), Goyder Line (1861-66), Federation Drought (1895-1903), World War 2 (1939-45), Millenium (1997-2009).

There are interactive databases available to explore both the rainfall and soil moisture dynamics associated with the development and progress of drought (http://www.bom.gov.au/climate/drought/; https://portal.tern.org.au/cosmoz-australian-cosmic-sensor-network/2177.

In addition to this rainfall and extent variability, droughts have led to a wide variety in impacts on the environment, productivity and economy and on society. Notable experiences include:

a) Series of degradation events connected to drought, overstocking and rangeland deterioration (McKeon et al., 2004); Dust storm across Sydney (Leys et al., 2011)
b) Significant and prolonged irrigation water shortages in Australia's largest irrigation system (the Murray-Darling Basin) and the subsequent development of a $AUD10 billion plan to share water more effectively (Horne, 2016);
c) Urban water shortages in major cities Melbourne, Perth and Brisbane leading to policy changes to urban water management (Lindsay and Supski, 2017);
d) Changes to the state and dynamics of many aspects of ecosystems (Kuglerová et al., 2019; Siebert et al., 2019); and
e) a range of effects on various aspects of agricultural production and profitability (Fennell et al., 2016; Sheng and Xu, 2019; Stafford Smith and McKeon, 1998; Thomas et al., 2018; Wang et al., 2020).

Responding to drought before, during and after significant events has been a continuing challenge to both the public and private sector in Australia; there have been difficulties both in reaching consensus on appropriate settings and then maintaining that consensus as new drought events occur (Berbel and Esteban, 2019; Crase, 2011; Kath et al., 2019; Kosovac and Davidson, 2020; Nelson et al., 2008; Stone, 2014). Despite the difficulty the aim of Government through the National Drought Agreement is to move from in drought support to preparedness.

3. Highlight the specific drought characteristics of the area and exemplify with a specific case:

Droughts are an irregular but recurring feature of the Australian continent. Several major, widespread droughts (and many less extensive in coverage) have been recorded since European settlement (Freund et al., 2017). Two lines of evidence point to the potential for worse and more frequent droughts in the future. Australia only has instrumented records of rainfall from around 1900. Historical Australian climate (rainfall) has, however, been reconstructed from paleoclimate proxies such as ice cores from Antarctica (Freund et al., 2017; Kiem et al., 2020) and tree rings and coral records (Freund et al., 2017). These studies suggest that there have been greater droughts in the last 1000 years than the last 200. In addition to evidence of more severe historical droughts using the latest climate projection from the Coupled Model Intercomparison Projects (CMIP6) future droughts in Australia are predicted to increase in both duration and intensity (Ukkola et al., 2020).

Given the potential for prolonged disastrous impacts it is surprising protracted drought events and the climate systems responsible for such protracted events have not received greater attention in both the climate science literature and in drought policy needs. This is despite the knowledge that protracted droughts are responsible for some of Australia's worst known ecological and grazing systems disasters (see https://www.longpaddock.qld.gov.au/rainfall-poster/ (Stone, 2018; Stone et al, 2019).

It is known that the El Nino/Southern Oscillation (ENSO), through its El Niño (warm) and La Niña (cool) sea surface temperatures (SST) extremes in the equatorial Pacific, drives much of Australian drought and flooding extremes respectively. While ENSO events generally occur every 2-7 years (and usually last up to a year) importantly, some 'protracted' episodes can last for many years (Allan et al, 2019). One of the main characteristics of protracted El Niño episodes is that they are characterized by positive (warm) SST anomalies in the central western equatorial Pacific Ocean (rather than in the eastern equatorial Pacific, common in many 'normal' El Nino events), and which leads to enhanced atmospheric convection in the central equatorial Pacific region. This convection then leads to the generation of a teleconnection which suppresses rainfall across eastern Australia (UKMO, 2020) (https://www.metoffice.gov.uk/research/news/2020/causes-of-extreme-fire-weather-in-australia). This type of pattern has been particularly evident in the more recent protracted drought event impacting eastern Australia, commencing 2017.

We also focus here on the Millenium drought (1997-2009, Australia's Bureau of Meteorology timescale) but because the issue of drought is as much about the nature of recurring droughts and the notion of preparedness, resilience, response, we draw more general observations. In addition, there is now clear evidence in Australia that climate change is altering the base on which drought acts. Additionally, there is increasing evidence that severe protracted droughts in Australia may become more frequent due to central equatorial Pacific warming (Liu et al., 2017).

The Millenium drought was both widespread and protracted. It had prolonged impact on both the south-east and south-west of the continent and reduced urban water supplies in all capital cities except Darwin (van Dijk et al., 2013; Verdon-Kidd et al., 2017) Figure 2.

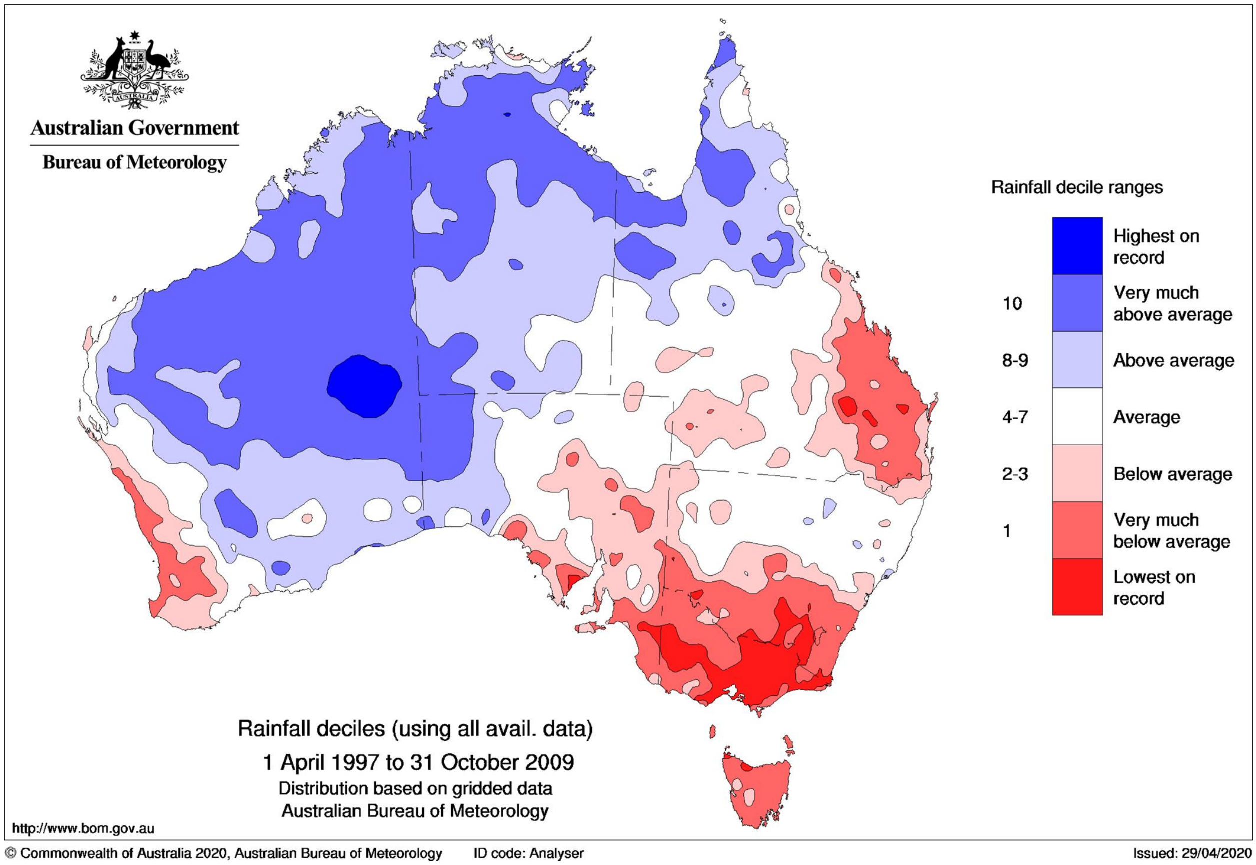

Figure 2 Rainfall deciles 2001 to 2009 characterising the Millenium drought in Australia - source Bureau of Meteorology http://www.bom.gov.au/climate/drought/knowledge-centre/previous-droughts.shtml

A substantial literature now exists exploring the impacts of that drought. We list below some salient features relevant to risk assessment more generally.

a) The impact was broad and varied and included disruption to agricultural profitability and persistence, national irrigation water supply systems to agriculture, the environment and cities, environmental systems, urban water supplies and, notably, to rural, peri-urban and urban communities.
b) As well as the expected direct and indirect socio-economic and environmental impacts (e.g. wetlands, biodiversity, land degradation), there were impacts in the near region and globally (e.g. markets). Failures in yields of exported crops (eg. wheat in Australia) have been associated with more general global food price spikes (Jayasuriya et al., 2012; Tadesse et al., 2014).
c) The length of the disruption led to stress on drought support measures that were able to cope with shorter term events.
d) The drought contributed to vulnerability to other hazards including wind erosion events, significant wildfire outbreaks, and with the breaking of the

drought, extreme flooding leading to loss of life, major infrastructure damage and extensive soil erosion.

The higher rainfall hiatus since the Millenium drought was short lived and over the last 4-5 years (since 2016) another significant, protracted drought has impacted eastern Australia although the areas of overlap do not include southern and south-west Australia.

This experience with the Millenium drought and with droughts before and since leads to important discussion points on the nature of risk management needed.

Climate change:

The Millennium drought was the first major event that occurred on top of the emerging impacts of climate change. In southern Australia, there has been a long lasting and continuing step decline in growing season rainfall. This has led to adaptive changes in urban and rural settings, for example there have been sustained change in farmer decisions, urban water planning and so on. Elsewhere in northwestern Australia, rain increases have occurred and variability increased.

Progress on measuring, communicating and responding to drought:

There are continuing challenges to our capacity to measure, evaluate and respond to risk arising from drought. When does a drought start? When will it end (when you are in drought and looking ahead)? Does return of some rain signify an end to drought or transitory relief? Are any past droughts indicative of future droughts? Does policy support the community and individuals through this cycle? The opportunity under the National Drought Agreement is - to look at things differently and get greater consistency given the continuing disparate approaches across the states and territories. The emphasis on defining whether an area is in drought goes away if the available response measures do not need a declaration. For example in NSW they have definitions (by area) of areas in drought, intense drought, drought (intensifying), drought (weakening) (based on rainfall, soil moisture, plant growth), whilst SA concentrate on financial, social and environmental factors with rainfall a contribution factor to decide upon assistance. As in the future we will have less water available at most points in southern Australia; it is how we manage better with less water available in every year irrespective of where it is along the rainfall gradient that is key.

Sustaining a policy / governance / financing / preparedness stance:

Are we still constrained in maintaining awareness (in policy, governance, financing systems and even on farms) during quiescent periods – even when we are aware and have measured the costs of historic events? Australia has established a Future Drought Fund with enduring capital base and $100 million a year spend an attempt to overcome this (https://www.agriculture.gov.au/ag-farm-food/drought/future-drought-fund).

Can we harness the IT and genetic revolutions:

What is the most effective way to deploy these transformative tools to reduce risk and to increase the effectiveness of response when drought strikes. Informed farmers / equipped farmers (near real time knowledge of threats and opportunities and the points of potential intervention; a set of solutions available in near real time) would be responsive and resilient.

Impact on natural capital (the basis for resilience?)

There are at least three dimensions of natural capital impacts relevant to drought –

1. direct impacts on the production systems,
2. measurable impacts on off-site assets and
3. the more general (commons) benefits described under ecosystem services.

1 and 2 are increasingly seen as being (at least in concept) capable of becoming endogenous to the financing of agricultural systems. The challenge is in measuring and monitoring over time the key elements of natural capital that drive sustainability and productivity. With prolonged drought, there is a deterioration to natural capital; on the other hand, there are expected benefits from healthy natural capital on resilience of the natural, productive and economic systems (at least in the early stages of drought). A focus area?

Measures of economic costs and social impacts

The economic and social impacts of drought are broad, experienced at the individual, societal and environmental levels both by those directly affected and those remote form the area in drought. Estimates and modelling of the economic impacts on agriculture are relatively well developed (Hughes et al., 2019). Measuring the economic impacts upon society and the environment are less comprehensive. One example is the estimate of the cost of the 2009 dust storm at $299 million (Tozer and Leys, 2013). A recent whole of economy estimate of the effect of the drought in the state of New South Wales reported a drop in GDP of 1.3% ($5.5 billion) in 2018-9 (Wittwer, 2020). Further development in characterising the different costs of drought will inform the most prospective points of intervention to reduce the impacts of drought.

4. Explain existing and/or potential management/mitigation and adaptation options:

a. Do drought policies and legislation/ and/or drought management plans exist?

The Australian government's approach to drought has evolved over time. Initially development of water resources and irrigation schemes was the focus that changed in the 1970s when drought was treated as a natural disaster and so assistance packages were provided. Several reviews of the way in which support was delivered resulted in the end of "exceptional circumstances payments" in 2012 heralding a shift towards a policy of drought preparedness. Australia has both federal and state- based governments. A new National Drought Agreement was signed in 2018 that replaced the 2013 Intergovernmental agreement on National Drought.

b. If yes, have they been useful

The more targeted (case by case) approach to deciding on who is eligible for support, it is families rather than the business that has been the focus of these changes (although some business subsidies remain) the change in emphasis to preparedness and resilience rather than support and bail out during an event has helped encourage industry to think about how it needs to adapt and plan both strategically (what activities happen) and tactically (how they happen) to changed and variable circumstances.

c. Which steps have been taken to mitigate droughts in case of an event?

The federal government has a range of measures in place to help individuals and communities during drought such as withdrawal of funds that may have been previously paid into a Farm Management Deposit; direct payments of $3000 per household of farmers, farm workers, contractors and suppliers; and up to $25,000 rebate on emergency water infrastructure for watering animals and permanent plants . The effects of drought on the broader community is recognised through payments directly to affected local councils and regions to fund improvement activities generating employment and to local businesses for financial planning.

Some of the State Governments provide other measures including subsidised transport for fodder and de-stocking in drought and to transport animal for re-stocking in recovery; waive various government charges, provide support for emergency water infrastructure and social and health support.

d. Discuss possible options/pathways to increase the resilience and minimize the risk from droughts (now and in the future)

In addition to the measures in place for support within drought the Australian Federal Government is also investing significantly in preparedness and resilience. The $100 million per year Future Drought Fund became operational on July 1 2020 to prepare the rural sector to become more resilient through planning and actions. There is a research component of this fund. The $150 million per year National Water Infrastructure Development Fund is for partnering with the states and territories to develop water resources that improve the security and availability of water for industry including agriculture.

One pathway to improved resilience in the face of reducing rainfall is research that improves the adaptation of farming systems. Comparing the trend of potential wheat yields at 50 sites across Australia between 1990 and 2015 Hochman et al (2017) showed that temperature increase (0.04oC yr-1) and rainfall reduction (2.8 mm yr-1) over the period have reduced the potential yield by 27%. However, when comparing the actual yield obtained, the application of science and technology had maintained yields and closed the yield gap (the difference between water-limited potential yield and actual yield).

In a more detailed study for Western Australia between 1900 and 2016, Fletcher et al (2020) showed the effect of an average reduction in 70 mm of rain and an increase of 1.17oC on moving the potential yield isoline (3.2 t ha-1) 70 km towards the west coast. The effect of increased CO2 negated half of this movement. However, the actual yields have been increasing and consequently the actual (rather than potential isoline) is not moving. Improved use of N fertiliser, sowing earlier and improved harvest index have accounted for significant improvements in actual yields. However, in order for wheat production to continue at the lowest rainfall margin of the area, continuous improvement in crop genetics and agronomic practice are required. Whilst Hochman and Horan (2018) highlight how the yield gap can be further reduced, there needs to be improvements in yield potential.

An Australian example of where the extent of an industry has moved because of changing climate is grapevines. The primary reason for this was increased temperatures but similar strategies will be deployed to hedge against increased frequency of drought. Geographical spread of properties for large crop producers and graziers is currently practiced to balance risk of seasonal effects such as drought. If adaptation strategies do not keep up with altered climate, resilience will need to be built around either changes in activity or alternate revenue streams (e.g. biodiversity/carbon payments).

Beyond the biophysical there are other strategies to combat the effects of drought on primary producers. There are a range of both options currently available and possibilities for the future. There are ways of using financial instruments to spread income from good to less good (e.g. drought) years. The federal government administers a scheme (Farm Management Deposits) where income generated in one year can be deposited with favourable tax treatment for withdrawal in a later year. There is however, evidence that this scheme may not be being used for the intended purpose and tax management being a bigger driver than income smoothing.

Insurance has been used to manage yield losses, including climate induced losses for decades, but faces several challenges (e.g. Goodwin, 2001). In many parts of the world, certain types of insurance, such as full coverage of all losses (Multi-peril crop insurance (MPCI) or Named-peril crop insurance) are too expensive and unviable without subsidies. The extensive use of crop insurance by farmers in the United States is only possible because of extensive government subsidies. In countries without subsidies, such as Australia, the prohibitive costs of MPCI insurance mean that most farmers do not purchase insurance and thus remain exposed to significant climate risks (Odening and Shen, 2014).

In Australia, one possibility to address the low uptake of insurance and thus farmer's high exposure to climate risks, is index insurance. Index insurance products are a potentially more cost-effective means of insuring farmers against particular aspects of climate risk (Barnett and Mahul, 2007). Index insurance (also referred to as parametric, weather index or index-based insurance) pays the holder of the insurance contract when a certain value on an index (e.g. a percentile of rainfall) is realized (Barnett and Mahul, 2007).

Index insurance typically has cheaper premiums than yield based insurance or revenue-based insurance, as it does not require expensive on-ground assessments and limits moral hazard resulting from information asymmetries or false reporting of losses (World Bank, 2007). Index insurance thus has the potential to offer a cheap and effective way for farmers to transfer climate risks (Kath et al, 2019). Despite its potential benefits the successful application of index insurance requires extensive research. In particular research is needed to ensure basis risk (i.e. payouts may occur when losses do not, or vice versa) is not high and that farmers obtain a product that efficiently supplements their income during adverse climatic conditions, such as drought. In summary, index-based insurance may be coupled with further, cost-saving approaches, to enhance uptake use of drought insurance through:

- Better quantification of climate at fine scales to inform more targeted and affordable insurance products,
- Development of new and innovative approaches to maximise cost-effective penetration & adoption of insurance products (e.g. industry-led mutual approaches and funds),
- Development of more fully integrated risk management and risk transfer approaches - involving re/insurance - to maximise resilience to climate extremes and drought (Kath, et al., 2019; Mushtaq, et al., 2020).

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