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Background

Climates vary naturally at a range of scales, and Australia is often noted for its highly variable climate at the scale of years to decades. Modern anthropogenic climate change refers to the medium to long term trend in underlying climate caused by increases in concentration of greenhouse gases (GHGs) such as carbon dioxide, methane and nitrous oxide (IPCC, 2013). These increases are derived from global emissions of these and other gases from a variety of sources including fossil fuel burning, cement production, transport, removal and burning of vegetation, and agricultural sources such as methane from livestock. As a consequence the global carbon cycle is out of balance to such an extent that emissions outweigh storage (or sequestration) mechanisms, leading to a continued increase in GHG concentrations in the atmosphere. The result is a rise in overall average atmospheric temperature, and a disruption of natural climate processes.

The United Nation’s Intergovernmental Panel on Climate Change (IPCC), in conjunction with numerous academic bodies around the world (including Australia’s CSIRO, Australian Academy of Sciences, and Bureau of Meteorology) have characterised the modern trend in climate due to increased GHG emissions. Regardless of global and national efforts to mitigate these emissions, all regions will require some level of adaptation to projected changes in climate and consequent impacts. Climate change has the capacity to interact and impact on all social-ecological systems within the region. Opportunities do however exist within a changing climate, and although the Central West of NSW is predominantly hot and dry already, the region may benefit in some ways. Managing the expected impacts and potential opportunities will be a key role for the Central West LLS, in conjunction with other National, State and regional NRM and agricultural agencies (eg, Landcare).
Current Climate/Physiography of the Region

The region defined by the boundaries of Central West Local Land Service is generally described as the broad slopes and riverine plains emanating from the west of the central Eastern Highlands. The five (5) defined sub-regions are referred to as the Lachlan Plains, Southern Slopes, Northern Slopes, Western Plains and Floodplain local landscapes (Fig. 1).

Figure 1. Central West Local Landscapes

The east of the region contains some important high elevation plateaus (e.g. Coolah Tops/Liverpool Ranges) as well as other high ground associated with the Warrumbungle Range (highest elevation Mt Exmouth, 1206 metres ASL). However the majority of the LLS area is dominated by relatively low elevation broad slopes and riverine plains, all draining into the Murray-Darling Basin to the north and west. The region has a predominantly warm to hot climate relative to adjoining regions to the south and east. There is a marked gradation in annual average rainfall from approximately 700-750mm in the east to less than 450 mm to the west and northwest. This means that most of the region’s rivers flow into hotter and drier lands where evaporation greatly exceeds precipitation. Transeau’s ratios (Precipitation/pan evaporation) have been calculated as low as 0.2 on the western edges of the region (Packer et al, 2010). These western lands are therefore heavily reliant on river flows from the east. The Castlereagh and Talbragar rivers rise within the Northern Slopes Local Landscape, whereas the Macquarie and Lachlan rivers emanate from the Central Tablelands region to the southeast. All of these rivers supply critical irrigation water resources for the lower catchments. Therefore changes to climate and/or hydrology in the broader surrounding region (including the Central Tablelands) will likely impact on communities and ecological systems downstream.
The region is dominated by large areas of low recharge zones for the MDB (CSIRO & SKM, 2010), although some of the high elevation lands in the east of the region allow moderate recharge to the basin. A key result of the CSIRO modeling (CSIRO & SKM, 2010) indicates that below 600mm/yr annual average rainfall (most of the Central West LLS region) recharge under annual vegetation is an order of magnitude greater than perennial vegetation (including trees). This has meant that extensive historical clearing of native vegetation has increased recharge. The corollary of this is that restoration of perenniality will see more surface utilization of available water. CSIRO modeling of climate change impacts on recharge produced equivocal results, with some models predicting increases, and some decreases (CSIRO & SKM, 2010).

Groundwater resources are critical for the region, which contains many mapped local fractured rock and basalt aquifers including the Liverpool Ranges Basalt MDB, Lachlan Fold Belt MDB and Warrumbungles Basalt Groundwater Sources (NSW Office of Water, 2012). Many of these groundwater sources are considered as having a high risk of a change in groundwater levels (from overextraction or changes in rainfall), with consequent impacts on Groundwater Dependent Ecosystems (GDEs - generally associated with springs and wetlands) (NSW Office of Water, 2012). Indeed most of the identified high priority fractured rock GDEs in the MDB exist within the central west of NSW (NSW Office of Water, 2012).

**Current Monthly Temperature and Rainfall Distribution**

The modified Koeppen classification is used by climatologists to give a generalized picture of the prevailing climate of a region. The Koeppen climate varies across the Central West LLS region which is mostly classed as Temperate with no dry season (hot summer), with warm summers in the high elevations of the Northern Slopes, and Subtropical in the very north of the Floodplain Local Landscape. Some areas of Hot Grassland (persistently dry) exist in the Western Plains Local Landscape, whereas to the south west (western Lachlan Plains) the Koeppen classification indicates a Warm Grassland (summer drought) climate (BoM, 2015).

The Dubbo Airport weather station (Site ID 065070) at an elevation of 284 metres ASL is included in the key ACORN-SAT reference network maintained by the Australian Bureau of Meteorology (BoM, 2012). This network of high-quality ground based climate records is used to monitor long term climate change across the continent. Figure 2 gives the standard climatology (mean monthly max temperature and mean monthly rainfall) for this site.

![Figure 2. Dubbo (065070) Climatology](image-url)
Being an inland site, there is a marked seasonal and diurnal variation in temperature, with mild winters and hot summers. Rainfall (annual average for Dubbo of approx 570mm) is distributed fairly evenly throughout the year, with a slight summer increase, however there is a wide year to year variation driven largely by ENSO cycling (see Box 1).

Rainfall seasonality varies between a slight summer dominance in the north (eg. Coonamble, Figure 3), to a slight winter dominance in the south of the region (eg. Grenfell, Figure 4).

Figure 3. Coonamble (Site No. 051010) Climatology

Figure 4. Grenfell (Site No. 073014) Climatology
Box 1. Evidence of long term climatic change in the region
(Source: Australian Bureau of Meteorology)

Temperature trend for Dubbo
Figure B1.1 provides the long term trend in annual mean maximum temperature for Dubbo (065070). The black line indicates the 11 year running mean, which is a plot of the trend over time. Even though gaps appear in the trend line, the overall pattern suggests a marked similarity to the long term global temperature trend (Figure 5). Since the 1970s, a clearly perceptible rise in temperature of approx. 1 degree Celsius is noted, which is slightly above both the National and Global mean for this period.

Figure B1.1

Rainfall trend for the Murray-Darling Basin (MDB)
Figure B1.2 shows that over the period of record (1900-2015) there was no clear trend in rainfall for the Murray Darling Basin that can be directly attributable to anthropogenic climate change. The period prior to 1950 was relatively dry compared to the latter half of the 20th Century. It is likely that this shift is due to natural multi-decadal fluctuations of the Pacific Decadal Oscillation (PDO), and may not be due to anthropogenic climate change. Current multi-year variability is mostly driven by ENSO cycling in the Pacific (which tends towards hot, dry conditions during El Ninos, and cooler, moist conditions during La Ninas), and the Indian Ocean Dipole (IOD) which alternates between wetter (negative) and drier (positive) phases.

Figure B1.2
Observed Climate Change

Our climates have been changing for more than a century, primarily due to previous increases in concentration of atmospheric greenhouse gases (IPCC, 2013). As a result, many long term temperature records have been broken in recent years (Coumou et al, 2013). The Bureau of Meteorology/CSIRO State of the Climate 2016 Report (BoM and CSIRO, 2016) outlines the key changes that have already taken place in Australia:

Temperature:
- Australia’s climate has warmed by 1°C since 1910, and the frequency of extreme weather has changed, with more extreme heat and fewer cool extremes.
- 9 of the ten warmest years have occurred since 1998
- Global mean temperature has risen by 0.85°C from 1880 to 2012. See Figure 5 Note: 2016 was globally the hottest year on record (NOAA, 2016), the third year in a row that the heat record was broken.
- All of the warmest 20 years on record (globally) have occurred since 1990.

![Figure 5. Global mean surface temperature change since 1850 (Colman et al, 2015)](image)
Rainfall:

- Rainfall averaged across Australia has increased slightly since 1900, with the largest increases in the northwest of the country since 1970.
- Rainfall has declined since 1970 in the southwest, dominated by reduced winter rainfall.
- Autumn and early winter rainfall has mostly been below average in the southeast since 1990.

Related Phenomena:

- Extreme fire weather has increased, and the fire season has lengthened, particularly into Spring, across large parts of Australia since the 1970s. Several large fires in NSW and Victoria over the last 15 years have exceeded previous records for intensity and fire behaviour.
- Annual average global atmospheric carbon dioxide concentrations reached 399 parts per million (ppm) in 2015 and concentrations of the other major greenhouse gases are at their highest levels for at least 800,000 years. (Note: Current global atmospheric carbon dioxide concentrations have reached approx. 406 ppm (February 2017) and are rising at an average rate of between 2-3 ppm per year. 2015 saw the largest carbon dioxide growth rate on record (to 2.96 ppm/year), indicating that atmospheric carbon dioxide concentrations are still accelerating. Source: http://www.esrl.noaa.gov/gmd/ccgg/trends/).
Future Climate Change

Introduction
Attribution of the causes of modern climate change and their relationship to human emissions of greenhouse gases is now well established by successive iterations of the Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC). These reports summarise the now substantial scientific literature on climate change processes, causes, impacts, and adaptation responses. The latest (5th) report, published in late 2013/early 2014, reiterates with greater confidence the conclusions of previous reports that humans have had a considerable impact on the climate of the planet. The IPCC (2014) states:

- Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems.
- Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.
- The effects of Anthropogenic greenhouse gas emissions, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century.
- Continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems.
- Cumulative emissions of CO₂ largely determine global mean surface warming by the late 21st century and beyond. Projections of greenhouse gas emissions vary over a wide range, depending on both socio-economic development and climate policy.
- Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise.

Modelling the Future
Future projections of climate change are contingent on changes in the global greenhouse gas emissions profile. Future net emissions are therefore dependent on global population changes, emissions intensity, fossil fuel usage, land management, technological improvements, potential efficiencies in energy generation and global efforts to curb emissions of the primary greenhouse gases. Previous iterations of the IPCC Assessment Reports have presented a range of socio-economic scenarios that underpin climate modeling. There are around 40 General Circulation Models (GCMs) currently used to simulate the Earth’s climate. The Coupled-Model Intercomparison Project (CMIP) provides standard protocols for the analysis of these models. Phase three of the project (CMIP3) underpinned the IPCC 4th Assessment Report (AR4) and used a set of possible future emissions scenarios based on a suite of socio-economic assumptions. The AR5 (IPCC, 2013) used CMIP5 modeling based on a set of Representative Concentration Pathways (RCPs) that delivered set radiative forcing levels by 2100. For example RCP 8.5 is a pathway that produces extra radiative forcing equivalent to 8.5 Watts per square metre by 2100. To put this into perspective, the 11 year solar output cycle varies by only 1 W/m². (It is important to note that both CMIP3 and CMIP5 modeling are equally valid modeling frameworks, however their base assumptions and underlying architecture are slightly different. Both model suites are used by Australian authorities.)
Figure 6 shows that since the beginning of the 21st Century, global emissions have increased dramatically to a level of approximately 10Pg carbon per year. This is equivalent to 10 trillion kilograms per year, and places the current emissions trajectory along or above the RCP8.5 line, which would see an increase of 3.2-5.4 degrees C in global mean temperature by 2100. Again, to put this into perspective, this change is equivalent to the difference in temperature between an interglacial (e.g., current climates) and a glacial era (ice age). The change would however occur over the period of a century, rather than the many thousands of years usually taken between ice age cycles. As a result, many earth system and biological processes will receive change at a pace that is unprecedented in nature, and places many communities and ecosystems at great risk.

![Figure 6. Possible Trajectories of global carbon emissions (source: Global Carbon Project 2016)](http://www.globalcarbonproject.org/)

Even if global mitigation efforts increase substantially over the coming decades, Figure 6 indicates that the Earth’s atmosphere and oceans will continue to heat at an unprecedented rate. Ultimately, global temperature levels in the latter half of the 21st Century will be determined by mitigation actions now.
Model Projections for the Central West LLS Region

As the Central West LLS is a relatively recently defined region, all currently available mapping and reporting on climate change follows previous Catchment Management Authority (CMA) boundaries, and no single report is yet available that focuses on this LLS region alone. Therefore the following is a précis of climate change projections for the Central West LLS region based on:

- IPCC 5th assessment reports (IPCC, 2013)
- CMIP3 NARClM outputs for the Orana/Central West Region obtained from AdaptNSW (http://www.climatechange.environment.nsw.gov.au/) (Evans et al., 2014; OEH, 2014a,b).
- CSIRO/BoM Central Slopes and Murray Basin Cluster Reports containing mostly CMIP5 modelling for the SE Aust Region (Ekström, M. et al. 2015; Timbal, B. et al. 2015)
- Climate Change adaptation tools and outputs via Terranova (https://terranova.org.au/), in particular biodiversity planning modeling (Drielsma et al., 2014).

Please note that all the following maps incorporate both Central West and Central Tablelands LLS areas, however discussion of them is confined to the Central West. There is broad agreement between CSIRO/BoM Central Slopes Cluster and NARClM outputs, however NARClM maps are used for illustration here primarily as they have a finer resolution enabling a better regional-scale indication of projected changes. NARClM outputs are based on an average of 12 GCMs chosen for their skill at modeling current climate in SE Australia (Evans et al., 2014; OEH, 2014a,b).

All projections are expressed as changes relative to a 20 year reference period (1990-2009) centred on 2030 (2020-2039) and 2070 (2060-2079) for clarity.

Temperature

There is a very high confidence that all temperature indices (max, min, seasonal, annual, extremes) will continue to increase over the coming decades. Both mean maximum and mean minimum temperatures are expected to rise in the Central West of NSW by around 0.7 degrees C by 2030, and 2.1 degrees by 2070 (OEH, 2014b). This represents a significant acceleration in the rate of temperature rise by comparison to the 20th Century rises.

Daily maximum temperature rises will be greatest in spring and summer for the Central West for both 2030 (Figure 7) and 2070 (Figure 8). Greatest changes for the region appear to exist for the Northern Slopes and eastern Southern Slopes in Summer (2030) and the Western Plains and Northern Slopes local landscapes in Spring and Summer (2070).

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**CW and Orana Daily Max Temp Change (2030)**

![Figure 7.](image-url)
Minimum temperatures will also rise across the region (Figures 9 and 10), although less pronounced in winter, which will still remain cool to mild for much of the region. Increases in overnight temperatures, particularly in summer, will likely impact on personal comfort in some areas, with the potential for little respite from the heat of the day. Air conditioner usage is expected to rise sharply, considerably impinging on affordability as well as generally contributing to energy demand and ultimately, greenhouse gas emissions from the NSW community.
The overall impact of the projected temperature changes will see a progressive expansion of the Hot Grasslands and Subtropical Koeppen climates further into the Central West LLS region, and a gradual removal of the Warm Grasslands (summer drought) climate from the Lachlan local landscape. Using the CSIRO/BoM Climate Change in Australia Analogues Explorer (http://www.climatechangeinaustralia.gov.au/en/climate-projections/climate-analogues/analogues-explorer/), Dubbo is projected to have a climate similar to inland SE Queensland (eg. Kingaroy, Roma, Chinchilla) by mid-century, regardless of which emissions scenario is followed.

**Extreme Temperatures**

Of particular concern for this region is the projected increase in the number of hot days (greater than 35 degrees C) for both the near term (Figure 11) and long term (Figure 12).

![Figure 10. CW and Orana Daily Min Temp Change (2070)](image)

![Figure 11.](image)
Most of the Western Plains and Floodplain Local Landscapes will receive on average between 10 and 20 more days per year above 35 deg C by 2030, and around 30-40 days by 2070. These landscapes are already exceedingly hot in summer, and it is expected that similar extreme temperatures will spread into spring and autumn as well. New high temperature records in the very high 40s and even 50s may be possible in the northwestern parts of the region by mid-century (Nyngan’s current record high temperature is 47 deg C on 12 Jan 2013). Lack of respite from extreme temperatures may lead to increased mortality in the elderly or otherwise infirm in the community.

Heatwaves are defined by the Bureau of Meteorology as three or more days of high maximum and minimum temperatures above an agreed threshold temperature that is unusual for a location. In line with global projections (Coumou et al, 2013) heatwaves are expected to increase in length, frequency and intensity for the entire region, however the Western Plains, Floodplain and western Lachlan Local Landscapes are most at risk for the severest impacts. Native fauna and livestock loss can be expected from extended extreme temperatures especially when combined with reductions in available water resources.
Rainfall

There is less confidence in projections for rainfall change, due to the highly complex nature of atmospheric processes that govern specific rainfall totals, timing and intensity. On average, a global increase in atmospheric temperature should lead to a slight increase in atmospheric humidity and ultimately to increases in precipitation. However global climate changes also impact on processes that govern rainfall distribution patterns. For example, a combination of global warming and ozone depletion may be shifting circulation and atmospheric pressure patterns leading to a sharp decline in rainfall in SW Australia (CSIRO/BoM, 2015). For the SE Australian region, a 15% decline in rainfall across late Autumn- early Winter has been noted (BoM/CSIRO, 2014), however its direct attribution to anthropogenic climate change is still to be determined.

When examining rainfall projections it is important to remain aware of the level of confidence in the modeled outcomes. As most of the models used here project varied outputs for rainfall, care should be taken with their interpretation. Trends can however still be determined by model agreement i.e. where more or most models agree with a particular outcome (CSIRO/BoM, 2015; OEH, 2014b). For the Central West region of NSW, there is medium confidence (based on model agreement) that mean rainfall will decrease in spring and increase in early autumn (Figure 13) although annual totals will remain similar to current (OEH, 2104b). The spring decreases will be most evident in the Lachlan, Southern Slopes and Western Plains local landscapes whereas autumn increases will be felt across the northern part of the region. By 2070, a clear shift towards Summer/Autumn dominance will become evident (Figure 14), with a possible slight increase (5-10%) in annual totals. The extra rainfall in Summer and Autumn is projected to be associated with increased intensity events (e.g. storm cells), which are likely to increase the risk of hail and wind damage. Flash flooding risk from these events is also likely to increase.

CW and Orana Rainfall Change (2030)

Figure 13.
Potential Evapotranspiration

There is a medium to high confidence that potential evapotranspiration will increase in all seasons as warming progresses (Ekström, M. et al. 2015; Timbal, B. et al. 2015). Pan evaporation will likely increase (from around 1800mm per annum at Dubbo) as temperatures rise, however the extent of this rise will be dependent on changes to wind speed and cloudiness.

Relative Humidity

A decline in average relative humidity is projected for winter and spring (high confidence) and summer and autumn (medium confidence), although changes in the near term are projected to be small (Ekström, M. et al. 2015; Timbal, B. et al. 2015). The specific impact on cloudiness is uncertain, however most models project increases in storm activity in summer and early autumn.

Drought and Soil Moisture Deficit

Increased temperatures, coupled with increases in potential evapotranspiration (PET) and changed distribution of rainfall has been shown at a global scale to indicate an overall landscape drying trend (Dai, 2011) which may lead to a worldwide agricultural drought by mid century. Increased effective aridity (eg. soil moisture deficit) is projected by most CMIP5 models primarily due to a global PET amplification effect (Cook et al, 2014; Scheff and Frierson, 2015), although prospects for Eastern Aust are yet to be determined. Landscape aridity not only impacts on the ability to maintain agricultural production, but has also been shown to affect the long term survival of many vulnerable fauna species in the Central West of NSW (Kerle et al, 2014).
Fire hazard in Australian conditions is usually determined by the McArthur Forest Fire Danger Index (FFDI), which is based on indices for dryness (calculated from rainfall and evaporation) and likely weather conditions (temperature, wind speed and humidity). This is a weather-based index and does not explicitly consider fuel loads. Bradstock (2010) demonstrated that climate change may alter the four key ‘switches’ (biomass growth, availability to burn, fire weather and ignition) that lead to increased fire activity. He concluded that in some semi-arid regions a drying climate may reduce fire hazard due to a reduction in available fuel, however in temperate forests (eg. Warrumbungle Ranges), fire hazards will increase.

Changes in mean and extreme fire weather conditions, based on NARCIM projections for 2030 and 2070 are given in Figures 15 - 18. These demonstrate that the most significant increases in fire weather will be in Summer and Spring, with potential reductions in FFDI in Autumn. These results are consistent with a recent trend towards an earlier onset of the fire season (now early- mid Spring) in Eastern Australia. Significantly higher fire weather risks projected by NARCIM for northern and western half of the Central West LLS region must be tempered by the potential for reduced fuel loads due to landscape drying in these regions (cf. Bradstock, 2010).
CW and Orana Severe FFDI Change (2030)

Figure 17.

CW and Orana Severe FFDI Change (2070)

Figure 18.
What are the Implications, Risks and Opportunities for Central West LLS Core Business Areas?

1. Agriculture

Over half of the Central West LLS region is used for grazing enterprises, and almost a third for broadacre crops, both irrigated and rainfed (Central West LLS, 2015). Agriculture is therefore the most dominant industry of the region in terms of interaction with the landscape. The NSW Dept of Planning and Environment's Central West Orana Agricultural Industries Report (2016) defines the key agricultural industry sectors as:

- Broadacre Cropping (cereal crops eg. wheat; non-cereal eg. canola)
- Livestock Meat/coarse wool (sheep, beef cattle, some goats, poultry, pigs)
- Fine wool
- Annual horticulture (nurseries, cut flowers, turf, vegetables)
- Perennial horticulture (stone fruits, citrus)
- Cotton

The region’s agricultural industries are highly dependent on climate. Many of the general impacts of climate change would be common across all agricultural industries, including possible water deficits, heat stress for both livestock and workers, shifting growing seasons and extreme effects such as hail, flooding and extended drought. Common climate change adaptation options at the farm level are provided in Box 2.
Box 2. Potential climate change adaptation options for agricultural operations
(adapted from Anwar et al., 2013; Stokes and Howden, 2010):

For a shift towards a hotter, drier climate, farm operations could consider the following adaptation options:

Modify farm management
- Timings (sowing, fertilization, spraying, harvest) to match the changed seasonal conditions
- Improve canopy management in horticultural crops
- Consider leasing or moving to alternative areas
- Increase scale of operation

Crop and livestock diversification
- Select new varieties/breeds to match conditions eg. shorter growing season varieties or those better adapted to hotter conditions
- Consider different food and fibre crops better suited to hot/dry conditions eg. bush foods

Improved animal husbandry and livestock management
- Reduce stocking rates
- Change feed sources including introduction of more adapted fodder crops eg saltbush
- Increase access to water and shelter

Optimise land management
- Better matching of soil, vegetation and water resources with farm production activities
- Shift production from marginal areas
- Conservation tillage techniques (eg. no till, controlled traffic, retained stubble) aimed at maintaining soil organic matter
- Shift from cropping to pasture to improve soil organic matter
- Incorporating agroforestry into overall farm operations
- Revegetate marginal areas and develop shelter belts
- Enhanced pest and weed management
- Develop farm plans

Figure B2.1 Retained stubble in paddock near Quambone (Floodplain Local landscape). Photo: A. Rawson.
The broader Central West Orana region (including the Central Tablelands) contains 19% of the gross value of agriculture production (GVAP) of NSW primarily because of relatively favorable soil and climatic conditions (Dept of Planning and Environment, 2016). Grazing enterprises are the most significant – the majority being improved dryland pastures with some unimproved pastures in the northern Floodplain and Western Plains Local landscapes. These enterprises are almost totally reliant on rainfall for pasture production.

Broadacre cropping (mostly cereal crops) is extensive across the region, but especially in the Floodplain, Southern Slopes, Western Plains and Lachlan Local Landscapes. As the majority of cropping is rainfed, future climate change has the potential to significantly alter yield outcomes, even beyond normal year to year variability. Dryland cropping in marginal, low rainfall areas of the Western Plains and Lachlan Local Landscapes will become increasingly difficult due to likely reductions in soil moisture, and yield reductions could be expected elsewhere. Of particular concern are the projected deficits in rainfall for winter and early spring which will impact on sensitive winter grains. Detailed crop production modeling would be needed to confirm whether enough soil moisture carryover from projected higher autumn rains would be sufficient to sustain cropping in these areas.

Some irrigated grain cropping is carried out along the Lachlan, Bogan and Macquarie floodplains especially around Narromine and between Forbes and Condobolin. Cotton is primarily centred on the Macquarie floodplain downstream from Narromine to the Macquarie Marshes, and is highly dependent on irrigation from the Macquarie River. Cotton production has also expanded into the Lachlan floodplain downstream of Condobolin. Current high demand for scarce irrigation water will continue and likely increase under projected hotter/drier conditions, and an increasing concern will be balancing this with environmental flows.

The prevalence of European type *Bos taurus* cattle (primarily adapted to cooler conditions) may contract in the region or shift to *Bos indicus* breeds or cross breeds to obtain heat resistance. There are over 800 breeds of beef or dairy cattle, some of which are bred for climatic extremes, however meat quality may differ from currently used breeds. Livestock enterprises may also shift from cattle into sheep to maintain production. Fine wool production is likely to continue in the region, however pasture availability, heat stress and disease pressures will increase. Access to suitable watering points and shade will become critical concerns.

Annual and perennial horticultural enterprises are tied to the major rivers, and their viability is directly linked to availability of irrigation water. Many vegetable crops shut down and stop producing flowers and fruit when temperatures are >30 degC, which will be a common occurrence in the region based on climate projections. Future climates in the region will therefore greatly limit the production of many of these crops, and may force a shift in production into cooler seasons. In South East Qld, no vegetable production occurs at all in summer (https://www.daf.qld.gov.au/plants/fruit-and-vegetables/vegetables/temperature-requirements-and-limitations). Careful matching of variety to future climate is warranted, and for annual crops this can occur incrementally. However perennial crops such as citrus may require more transformational change.
2. Natural Resource Management

The majority of the region has seen a long history of European occupation and consequently is considered a highly disturbed landscape. Although some areas of extensive native vegetation still exist, particularly in the Northern Slopes local landscape (Warrumbungles, Pilliga Scrub), these are rare in the region and also prone to fire. Indeed the Warrumbungles fire of January 2013 removed approximately 80% of extant vegetation, causing significant loss of habitat, as well as excessive post-fire erosion (McInnes-Clarke et al, 2014).

Habitat fragmentation, loss of landscape function, changes in soil condition and the overall drying of the landscape are seen as key driving processes for species loss and degradation since European occupation (Kerle et al, 2014). 64% of vertebrate fauna in the broader Central West and Lachlan catchments are considered to be declining (Kerle et al, 2014). Habitat fragmentation in this sense refers to a range of processes including: direct habitat loss, subdivision of remaining habitat, increased edge effects and disruption of species interactions or ecological processes (Lindenmayer and Fischer, 2006). Changing climates will almost certainly impose extra pressures on all these processes in an already degraded and fragmented landscape. Changes to the frequency, intensity and seasonality of rainfall, coupled with the high likelihood of increased temperatures across the region will impact on the survival capacity of many species, especially those already at the margins of their ranges or independently vulnerable.

Climate Change and Biodiversity

Biological responses to rapid climate change include:

- Species Extinction (Specialists, already vulnerable, isolated communities)
- Migration (Mobile, generalists, often weed species)
- Evolution (Rapid reproducers, R-type. Includes many insects including locusts)
- Withstand CC (Generalists, weeds, pests, large widespread populations)

Further research is required to define locally specific responses to changing climates, and whether species extinctions are likely in the region. Given the already highly fragmented landscape and limited opportunities for many native species to adapt to changes, extinctions (either localized or more broadly) are possible.
Being centrally located in NSW the Central West is a critical region for species migration, particularly from north to south, and from low to high elevation. Recent 3C biodiversity adaptation modeling (Drielsma et al, 2014) has indicated that high elevation parts of the nearby tablelands will become critical habitat and potential refugia for vulnerable species affected by rising temperatures (Figures 20 and 21), and links to lower elevations in the Central West LLS region will become important corridors in the future (Figure 21). Key refugia within the LLS area include the Warrumbungle Ranges, Pilliga Scrub and the Goobang National Park. Both structural and functional connectivity of the natural landscape will become increasingly important under changed climates (Doerr et al 2011). Continued engagement with the Great Eastern Ranges Initiative (GERI) will ensure a regionally strategic approach to corridor creation and maintenance. A strong north-south link from the Goobang National Park through to the Conimbla and Weddin Mts National Parks is evident from the modeling, and efforts should be made to enhance this (in conjunction with Central Tablelands LLS).

The imposition of climate change will undoubtedly increase the value of revegetation and corridor expansion initiatives. The 3C modeling (Drielsma et al 2014) has highlighted how the imposition of projected climate change has boosted the overall value of conservation efforts across a wide band of the Western Plains, Southern Slopes and Lachlan local landscapes, as well as the important Macquarie Marshes area within the Floodplain local landscape (Figure 22). Revegetation values are significantly enhanced in a similar band across the western half of the region, but most notably within the Lachlan local landscape. (Figure 23).

Balancing irrigation demands and environmental flows is expected to become a major concern over the coming decades, especially for the maintenance of sensitive and globally important wetlands such as the Macquarie Marshes (Jenkins et al, 2012). Smaller, less visible wetlands are perhaps more at risk.

![Figure 20. Vegetation Condition Central Slopes Cluster (Drielsma et al, 2014). Dark areas indicate vegetation in sufficiently good condition to enhance resilience to climate change, and to support range-shifting populations. Note: Central West LLS contains some key areas considered in good condition, especially within the reserve system (eg. Warrumbungles/Pilliga). Linkage into these regions may become increasingly important as climates change. However much of the central part of the region, especially the Lachlan Local Landscape remains in poor overall condition (lighter areas).](image-url)
Figure 21. Links (corridor) benefits based on 3C modelling (Drielsma et al, 2014). Dark areas indicate areas with a high link value, given impending climate change. The Central West LLS region contains many areas of high value as corridors, especially the Warrumbungle Ranges, Pillaga Scrub, Macquarie Marshes and the Goobang, Weddin Mts and Conimbla National Parks.
Figure 22. Climate influence on benefits of taking conservation action within the Central Slopes Cluster (Drielsma et al., 2014). Darker shading indicates areas where the benefits of conservation action are enhanced by the imposition of climate change. Critical zones for conservation action include the Macquarie Marshes and Warrumbungle Ranges.
Figure 23. Combined 1990-2050 Climate adaptation native vegetation benefits (Drielsma et al., 2014). Note the high link and conservation benefits in the Warrumbungles/Pilliga area and generally on the eastern and western boundaries of the region (purple) and the high revegetation benefit in a north-south strip through the centre of the region (green). Bright green zones in the Lachlan and Floodplain Local landscapes highlight the greater need for revegetation activities there in the light of climate change.
A search of the NSW Register of Threatened species indicates 133 species, populations, communities or habitats currently listed as being threatened by anthropogenic climate change in NSW. Many of these exist in the Central West LLS region or may rely on the region for migration. Key endangered populations include *Calyptorhynchus lathami* (Glossy Black Cockatoo) in the Lachlan local landscape; Fuzzy Box woodlands in Northern Slopes and Floodplain local landscapes; and *Myriophyllum implicatum* in the Pilliga area. It is expected that as climates change, further species, communities and habitats will be listed as vulnerable or endangered. Interactions between specific Key Threatening Processes as a result of changing climates will further exacerbate risks. For example, weed, disease and pest invasion, all Key Threatening Processes (KTPs), have the ability to expand under climate change. Cascading impacts are likely, where changes in one KTP will exacerbate others. Compounding of impacts will furthermore increase the rate at which species will become vulnerable.

**Soil Erosion**

A combination of a drying landscape, reduced groundcover and increased erosivity of future summer storms will cause an increased likelihood of sheet, rill and gully erosion in many areas of the State (Rawson and Murphy, 2011). The Central West local landscape is particularly vulnerable to increased gully erosion due to extensive areas of sodic subsoils which are prone to dispersal when wet. Sodic surface soils (eg. prevalent between Tottenham and Peak Hill in the Southern Slopes local landscape) are also prone to hardsetting and sheet and rill erosion. Maintenance of groundcover is essential to limit water movement, promote infiltration, and improve structure overall (Figure 24). However future limitations to pasture growth projected under climate change may increase soil erosion pressures in the Central West region.

![Figure 24. Poor groundcover, as shown by this paddock near Tottenham can exacerbate sheet and rill erosion. (Photo: A. Rawson)](image)
Using modeled changes to the Revised Universal Spoil Loss Equation (RUSLE) Yang et al (2013) found that projected increases in erosivity by 2050, coupled with reduced overall ground cover may significantly increase the risk of sheet and rill erosion. While most of these areas modeled are in National Parks outside of the Central West region and therefore mostly well protected by forest, they correspond to some of the world’s most fire prone regions. Significant post-fire erosion is likely when severe wildfire is followed by summer thunderstorms, as did occur following the catastrophic Warrumbungles fire of January 2013 (McInnes-Clarke et al, 2014). This fire also contributed both sediment and excess charcoal into surrounding waterways, potentially leading to damage of riparian habitats. Research is underway to determine the impact of this post-fire erosion on local biota.

Rawson and Murphy (2011) also highlighted the increased risk of salinity under future climate projections, primarily due to changes in soil water balance across seasons, and a more dynamic wetting/drying regime. Known occurrences of dryland salinity in the region are therefore most at risk of intensification and potential expansion of salinity. The risk of wind erosion is also likely to increase under hotter climates that hinder the production and maintenance of groundcover, particularly on the broad plains of the western half of the CWLLS region. Dust storms are generated by a combination of poor groundcover, dry conditions, storm type and intensity and agricultural land management. While many of the larger dust storms experienced in the region are generated from activity in the west of the State and central Australia, local generation of dust is still possible and can cause loss of topsoil condition and redistribution of nutrients to nearby waterways.
3. Biosecurity

Biosecurity threats (as outlined in the Central West LLS Strategic Plan 2016-2020) include:

Animal threats:
- Feral pigs
- Locusts
- Wild dogs
- Foxes
- (also rabbits, feral cats)

Disease threats:
- Anthrax
- Hendra virus
- Transmissible Spongiform Encephalopathies (TSEs or prion diseases such as scrapie, BSE, CJD or nvCJD)
- Ovine Johne’s Disease
- Bovine Johne’s Disease

Projected climate changes for the entire country will promote the spread of tropical and sub-tropical species into regions further south. Many of these will be pest and weed species, including insects, insect-borne livestock viruses, canetoads, cattle ticks, and ferals. Incidences of zoonotic diseases (e.g. Hendra, leptospirosis) are projected to increase in future as the movement of humans, livestock and wild animals is affected by changing climates (Australian Academy of Science, 2015). The rate at which these pests and diseases move south is largely unknown, however large stock numbers and movement throughout the Central West region are considered major challenges to the control of these threats (Central West LLS, 2016).

A recent report from the Australian Academy of Science (Australian Academy of Science, 2015) indicates that Australia’s risks of disease spread will be significantly increased under climate change projections. The types and frequencies of outbreaks will increase, especially many vector-borne diseases (e.g. dengue fever borne by mosquitoes), and heat related food-borne diseases such as salmonella, e.coli and Campylobacter. Water borne diseases such as Cholera and Giardia are also projected to rise in response to changes in water availability and temperature. Algal blooms in both rivers and reservoirs are projected to increase as water temperatures rise.

Projected climate change will affect the risk of weed threats in two ways: a) the suite of weed species in the region will change; and b) some weeds will become more invasive (Scott et al, 2014). In the case of the Central West, pest and weed invasion is expected via migration from warmer regions to the north and west. It is likely that species previously unrecognized in the Central West will begin to invade in the coming decades, and previously naturalized species may become increasingly difficult to control as climates change (Scott et al, 2014). Current dispersal mechanisms (including accidental dispersal via human activities) will remain the same, however the ability of some species to take root and reproduce will possibly increase in the region. Increased CO₂, in the future atmosphere may also preferentially advantage certain C4 species which may become weeds within the region.
4. Communities

Climate change has the capacity to affect all towns and villages in the region, although the specific impacts on many industries are not yet known. Integrated Regional Vulnerability Assessments (IRVA) in adjoining regions have highlighted the complexity of interactions between climate changes and human institutions (OEH, 2013). Emergency response, health and social services are most at risk of serious implications for their operations. Local tourism, mining, and retail services may be affected, but the specific impacts are unknown.

Future climate change is likely to affect built assets such as roads, drains, bridges etc. and will add to the range of hazards to infrastructure currently experienced. While the Central West LLS does not have a specific role in the maintenance of built infrastructure, it should be mindful of the emerging or cascading impacts on agricultural or native lands at the peri-urban fringes of centres like Dubbo.

Human health – numerous studies indicate a strong relationship between extreme temperatures and risks to human health, largely from heat stress of vulnerable people (particularly the elderly, previously unwell people, and those who work outdoors). As more people spend time indoors as a respite from extreme heat, the incidence of respiratory diseases (eg. whooping cough, influenza) is expected to rise (Australian Academy of Science, 2015).

Projected increased mean temperatures over the coming decades will almost certainly increase the frequency and severity of extreme high temperatures, often coupled with low humidity. Although the Central West LLS does not have a specific role in human health per se, the LLS should be aware of and prepare for increased incidence of heat stress amongst its own field staff, as well as the large number of its constituents who daily work outdoors in agriculture or land management. Although higher temperatures are likely across the entire region, the western and northern parts contain the greatest risk.
5. Emergency Management

All models suggest an increased risk of fire, flooding, storm damage (hail), heatwaves and drought for many regions within NSW, including the Central West. The key increases in climate-derived risks on a seasonal basis will be:

- **Summer**: flood, fire, heatwave, storm damage, hail, drought
- **Autumn**: flood
- **Winter**: drought
- **Spring**: drought, fire, heatwave

The Central West LLS role in emergency management is limited to the support of DPI and other emergency management agencies such as the Rural Fire Service, particularly where livestock and wildlife are threatened, and in major plague (e.g. locust) outbreaks. Staff training in emergency management should focus on understanding of renewed risks under climate change conditions, including changes to fire behaviour that increase the risk of injury or death. The 2009 Black Saturday fires in Victoria were driven by weather conditions not previously experienced in Australia, and are likely to have been exacerbated by climate change. The subsequent inquiry into the fires instigated a range of new management strategies, including the creation of a new fire risk category of ‘Catastrophic’. Under this category, fire behaviour is said to be directly life threatening and the best response is to leave the area promptly. Previous best management practice involved a ‘stay-and-save’ strategy under Extreme conditions. Identification of the correct response is critical to survival.
Recommended Adaptation Responses

General Recommendations

Many of the Goals, Strategies and Actions in the Central West Regional Strategic Plan (2016) are considered Best Management Practice for the long term sustainability of the local environment and maintenance of productive industries within it. As such, many of these practices will also help to build resilience to changes wrought by anthropogenic climate change. However climate change will also influence the details of these practices, and may determine the ultimate success or failure of investments with long term goals. For example, revegetation strategies need to be mindful of future climates which may be limiting for particular species currently used for rehabilitation. Similarly, species endemic to hotter, drier locations may soon become more important for rehabilitation upstream or in the south of the region. LLS field officers will need to remain aware of the changes as they occur, and to incorporate potential climate change into their operations.

A strategic approach is needed which captures broader regional solutions that can be implemented in specific localities. A key role for Central West LLS is in community engagement and education, and the Service should see themselves as an important broker of information and to provide guidance for on-ground adaptation activities. The Central West LLS can provide the link between “strategic” initiatives (eg. GERI,) down to the local or farm-scale. This link is extremely important for effective climate change adaptation, which requires medium - to long-term and catchment-wide responses which are often not obvious to landholders at the local scale.

Local Landscape Specific Impacts and Recommendations

The Central West LLS Transitional CAP (Central West LLS, 2014) identified a number of fragile or vulnerable ecosystems or natural areas within each of the five Local Landscapes. These range from threatened native flora and fauna communities, to fragile soils and waterways. The majority of these vulnerable systems and communities would come under increased threat from changes to climate, in particular changes in water availability, amounts, seasonality and rainfall intensity. It is likely that as climates change, more areas within the Central West LLS boundary will become vulnerable to degradation, and this list will expand.
Western Plains

Current systems of concern (from Central West LLS Transitional CAP)

- High fragility river reaches, for example Boggy Cowal
- Semi arid shrubby woodlands, for example Bimble Box Woodland
- Grassy woodlands and grasslands, for example south of Glenlyon
- Sodic surface and sub soil, for example Bulbodney floodplains
- Fragile red soils, for example around Hermidale

The Western Plains Local Landscape lies on the eastern edge of the Cobar Pediplain, and contains Early Paleozoic metasediments of the Girilambone Zone, which produce fragile red soils periodically suitable for opportunistic cropping when climatic conditions are suitable. Sheep and cattle grazing remain the primary agricultural enterprises here on both improved and unimproved pastures. The region is distinguished by large lot sizes and less extensively cleared areas compared to adjacent local landscapes. Although only one major nature reserve exists (Quanda Nature Reserve), significant native woodland remnants still exist in State Forest reserves, TSRs and on private or leasehold land. Good opportunities exist therefore to establish a series of vegetation corridors throughout the landscape to assist migration and maintain refugia for native species. This is highlighted by the high Link/Conserve value of the western half of the local landscape (see Figure 23).

This local landscape is the hottest and driest and the most sparsely populated in the region. Projected climate change is likely to exacerbate limitations to agriculture here by further reducing soil moisture availability at critical times of the year. A broad shift towards more summer/autumn dominance of rainfall is projected by climate models, however this will be offset by higher temperatures and potential rainfall deficits in winter/spring. Broadscale water ponding to capture and store rainfall is a new technique under trial in the region and shows promise for the improvement of soil organic matter condition and overall resilience to climate changes (Read et al, 2012). Techniques such as this may become essential to maintain agricultural productivity in what will be a marginal agricultural zone under future climates. Shading for stock, and access to suitable water reserves eg. groundwaters, will also become critical as overall and peak temperatures rise. The structure and species mix of native grasslands in the unimproved pasture zone in the north are likely to change as temperatures and atmospheric CO₂ levels shift to favour more C4 species.

CWLLS adaptation activities in this local landscape should focus on supporting landholders to maintain water and shade for stock, feral pest and weed control, and enhancement of wildlife corridors from the remaining native vegetation. Given historical concerns surrounding woody weed invasion (Invasive Native Scrub or INS), a pragmatic approach that considers the corridor potential of native vegetation should be advocated. In some instances, clearing of scrub may impact on this potential, whereas a strategic approach to clearing may allow INS removal in other less critical areas. As this local landscape is the hottest and driest in the region, LLS staff should be aware of the potential for heat-related health concerns for both their clients and themselves, especially during summer months.
Floodplain

Current systems of concern (from Central West LLS Transitional CAP)

- High fragility river reaches, for example Wareena Creek at Coonamble
- Moderate fragility river reaches, for example the Bogan River
- Semi arid floodplain swamps, for example Macquarie Marshes
- Bugwah duplex soils, for example clay pans around Marra Creek
- Sodic surface and sub soil, for example west of Collie
- Semi-arid grassy woodland, for example Weeping Myall communities
- Semi arid shrubby woodlands, for example Bimble Box Woodland
- Grassy woodlands and grasslands, for example Mitchell Grass Plains

The Floodplain local landscape is dominated by the alluvial plains of the Bogan, Macquarie and Castlereagh rivers. These consist of outwash fans, riverine plains, terraces and valley fills of primarily Quaternary age and include backswamps, oxbow lakes and depressions, intermittent cowals, floodplains, and riparian zones.

A very large proportion of the Floodplain local landscape contains highly productive grazing and cropped lands, including extensive areas of used for cereal crops and cotton production. As a result, this local landscape is heavily cleared, and few large areas of native vegetation (mostly Weeping Myall and Bimble Box woodlands, and native grasslands) remain. Those that do remain are generally degraded and quite fragmented. 3C biodiversity mapping of the region (Drielsma et al, 2014) indicates that the majority of the southern two thirds of the landscape requires revegetation to maintain or improve biodiversity values under future climates. Revegetation programs in this area need to focus on a balance between connectivity, agricultural needs, and potential for shade. Again, a strategic approach to vegetation planning is required.
The Macquarie Marshes, an iconic and internationally recognized RAMSAR wetland, is a significant feature of the local landscape, relying heavily on floodwaters of the regulated Macquarie river. Many bird and aquatic species are reliant on the Macquarie Marshes at some stage in their life cycle, and hence it is a critical feature in the landscape, especially for its refugia potential under hotter climates. A recent examination of climate change impacts on the Macquarie Marshes (Jenkins et al., 2012) noted that the key climate change related stressor on the Marshes was the potential loss of flooding, however losses from water regulation were of greater impact. Key adaptations highlighted by the Jenkins et al. (2012) report include a return of significant environmental flows to the system as soon as possible to buffer against projected climate change. However even this simple solution is not without considerable social resistance, and the report recognizes the need to educate the local community about the long term value of the Marshes. The CWLLS and its local staff should have a role in providing updated information on this value, and in brokering local solutions to water resource concerns.

This most northerly local landscape already has a sub-tropical climate that is warm to hot and with slight summer dominance in rainfall. Future climate projections indicate a further shift towards summer dominance, with potential deficits in winter compared to the current climate. Winter crops may suffer if soil moisture levels are not maintained into the cooler months. This region is mapped as a very low recharge zone (CSIRO and SKM, 2010) which suggests that most rainfall is currently intercepted by the ground surface and soils. If this is the case, there may be little or no capacity to improve capture of rainfall under a hotter and more seasonal climate. Evaporative losses may be extreme, which highlights the need to maintain good groundcover and to build soil organic matter. This can be achieved with conservative grazing and cropping management.
Northern Slopes

Current systems of concern (from Central West LLS Transitional CAP)

- Swamps and lakes – local rainfall and run-off, for example Old Harbour Lagoon
- Moderate fragility river reaches, for example Lower Talbragar River
- High fragility river reaches, for example Upper Marthaguy Creek
- Semi arid shrubby woodlands, for example Minore area
- Sodic surface and sub soil, for example Tonderbrine region
- Dry sclerophyll forest, for example Goonoo Forest
- Grassy woodlands and grasslands, for example south Jones Creek Reserve

In contrast to the Floodplain local landscape the Northern Slopes consists of rolling hills ridges and slopes with only minor floodplains along the major waterways (mainly the Castlereagh and Talbragar rivers). The geology consists of Jurassic to Cretaceous sediments of the Surat Basin, with extensive areas of volcanic intrusions of Jurassic and Cainozoic age. The Warrumbungle Range is a notable feature popular with tourists, and hosts the internationally significant Siding Springs Observatory. Soils in the region vary according to their source geology, with sedimentary rocks producing sandier soils and very sandy floodplains (eg. the Castlereagh). More productive soils are found associated with the volcanics and alluvium derived from them. These rocks support the majority of cropping activities in the local landscape, and can be highly productive.

There is a larger proportion of remnant native vegetation in the Northern Slopes landscape than elsewhere in the CWLLS region. Important reserves exist, including National Parks (Warrumbungle, Yarrigan, Coolah Tops, Goonoo) State Conservation Areas (Ukerbarley, Cooleburba, Goonoo), Nature Reserves (Binnaway, Pilliga, Weetalibah, Coolbaggie), and State Forests (Breelong, Eura, Boyben, Goonoo, Lincoln, Biddon, Mogriguy, Yearinan, Wittenbra and Cobbora). Vegetative cover on private land is also high relative to other local landscapes. This combined with the local landscape’s relatively higher rainfall and lower evaporation give these native vegetation remnants a very high link (corridor) potential and conservation values under future climates (Drielsma et al., 2014). Efforts to maintain and enhance this conservation value should be a high priority for the Local Land Service, and programs that enhance corridors here will have the best chance of success. In partnership with the Great Eastern Ranges Initiative (GERI) the Local Land Service has an important role in developing local projects that enhance resilience to climate change in this area. Links to other nearby projects (for example the Hunter Valley Partnership) will ensure the link potential identified by biodiversity modeling is realized.
Future climate changes in this local landscape include shifts to greater summer/autumn dominance in rainfall, more intense storms in summer, higher temperatures overall and likelihood of enhanced fire threat. The extreme fire activity in the Warrumbungles National Park and surrounding areas in January 2013, where approximately 80% of the Park was affected, has left a considerable scar on the region. More than 54000ha were burnt, and at least 53 homes destroyed. Both native forest and grazing lands were affected, leaving many farms without feed for surviving stock, and most natural habitats destroyed. While dry sclerophyll forests are well adapted to periodic fire activity, large scale and intense burns such as the 2013 fire have the ability to significantly modify local ecosystems. This is especially so when these ecosystems are independently vulnerable due to fragmentation and weed and pest invasion. Climate change will have a dual effect by impacting on this intrinsic vulnerability as well as increasing fire risk and fire behaviour. Fire management plans must take into consideration the potential changes in fire activity (frequency, intensity) that a changing climate is likely to bring.
Southern Slopes

Current systems of concern (from Central West LLS Transitional CAP)

- High fragility river reaches, for example Cox’s Creek
- Moderate fragility river reaches, for example Little River
- Dry sclerophyll forest, for example Mount Frome and Mount Knowles
- Semi arid floodplain swamps, for example Three Mile Creek Wetlands
- Sodic surface and sub soil, for example between Tullamore and Peak Hill
- Semi arid shrubby woodlands, for example Bimble Box Woodlands
- Grassy woodlands and grasslands, for example Home Rule Common

The Southern Slopes local landscape spans across a wide range of climatic conditions, from relatively high rainfall/lower evaporation zones in the east, to semi-arid and hot climates in the west. Important watercourses include the Bogan, Bell and Macquarie rivers, although broad expanses of floodplain are rare apart from the upper Bogan area. The landscape is linked primarily by similar geology and soils, which support a diverse range of broadacre cropping and grazing enterprises. The geology is primarily early to Middle Paleozoic metasediments and volcanics associated with the Cowra Trough, Mt Foster – Parkes Zone, Molong Rise and Girilambone Zone, as well as Late Devonian terrestrial sediments south of Dubbo. These rocks commonly generate soils of productive potential that underpin rain-fed beef cattle, sheep and wheat enterprises. Some soils, especially those between Tullamore and Peak Hill have problems with surface and subsoil sodicity, which can be prone to surface sealing and erosion.
The landscape is heavily cleared for agricultural activities, and remnant vegetation is largely confined to poorer soils on ridges. These ridges are often oriented approximately north-south, and will be important corridors in the future. Remnant native vegetation on the more productive soils are rare and are mainly found along watercourses, road corridors and TSRs. The Goobang National Park straddling the range between this local landscape and the Central Tablelands LLS contains a significant stand of remnant woodland and forest linking the Sappa Bulga Range in the north to the Nangar National Park in the south. The very high link value of this range is clear from the 3C biodiversity modeling (Drielsma et al., 2014), and the Local Land Service, in partnership with Central Tablelands LLS, should consider prioritizing this region for investment in enhancing native vegetation linkages across private lands. This would require building partnerships with Landcare groups and individuals along the range. Similar linkage potential exists for the vegetated range to the north, west and southwest of Tullamore.

Future climate change will impact differently across the landscape. While increasing temperatures, shifts in seasonality and higher intensity summer storms are likely across the entire area, the already hot and relatively dry western third of the landscape will become increasingly marginal for agricultural production. Soil water deficits, especially in winter, may limit dryland cropping here to only the wettest seasons. Grazing will still be viable, however shade and access to water will be increasingly important over the coming decades, and graziers could consider more drought tolerant stock breeds in order to maintain productivity.
Lachlan Plains

Current systems of concern (from Central West LLS Transitional CAP)

- High fragility river reaches
- Moderate fragility river reaches
- Dry sclerophyll forest
- Semi arid floodplain swamps
- Sodic surface and sub soil
- Semi arid shrubby woodlands, for example Bimble Box communities
- Grassy woodlands and grasslands
- Threatened fauna eg. Bush Stone-curlew, Spotted Harrier, Glossy Black Cockatoo, Malleefowl, Curly-bark Wattle, Austral Pillwort

The Lachlan Plains local landscape incorporates some of the most extensively cleared areas in the entire LLS region. The long history of agricultural production here followed early gold discoveries that brought many people into the region. Highly productive alluvial plains of the Lachlan River and tributaries have supported a wide range of cropping enterprises, especially wheat and barley, and some vegetables. 38% of the landscape is cropped, some of which is irrigated from the Lachlan River directly or via irrigation schemes such as the Jemalong Irrigation District. The Lachlan River, as the primary water resource, flows from the Central Tablelands and is heavily regulated via dams and weirs (eg. Wyangala Dam and Jemalong Weir). The flow is driven by higher rainfall in the tablelands and any changes in climate there will impact on the volume and timing of flows downstream. Much of the lowland inflow is captured by cropped lands on primarily clayey soils. These clayey alluvial backplain soils are prone to waterlogging and gilgai formation, making trafficability an issue in wet seasons. As a result of river regulation, irrigation offtake and lower rainfall/higher evaporation, the volume of flow of the western Lachlan River diminishes westwards. Highly sinuous and anastomosing channels across the western plains further divide the flow.
The few native vegetation remnants in this local landscape are confined primarily to hard rock ridges (eg. Jemalong Ridge), TSRs, riparian areas and minor State Forests (eg. Manna, Weelah, Euglo, Nerang Cowal, Warraderry, Priddle, Maudry, Bimbi). The Lachlan Valley National Park preserves small segments of important floodplain, riverine and backplain ecosystems, however it is highly fragmented. The largest areas of original vegetation exist in the Weddin Mountains and nearby Cominbla National Parks and along the eastern edge of the local landscape between Grenfell and Goolagong. The ridges are a relic of geological folding that has exposed harder rocks that produce poor soils. These areas have not been extensively cleared as their agricultural potential is low, and the north-south orientation of many vegetated ridges gives them good link potential between hotter areas in the north and relatively cooler regions in the south. The whole local landscape has a high revegetation value under future climates (Drielsma et al., 2014).

The Lachlan Plains local landscape also contains a number of important ephemeral lakes that are significant as bird and aquatic habitats. Lake Cowal, Nerang Cowal, Bogandillon Swamp and surrounding low-lying areas are periodically inundated and support fluctuating populations of over 270 bird species. Lake Cowal is the largest natural inland lake in NSW, and supports a wide diversity of terrestrial, aquatic and avian species. It is listed on the Register of the National Estate, and is an iconic feature of the local landscape. However this important inland ephemeral wetland system is threatened by weed and pest invasion, declining water quality and salinisation. Increased temperatures under future climates will undoubtedly impact on these relatively shallow and exposed wetlands by increasing the rate of evaporative losses from the larger water bodies. Changes to the timing of inflows may also modify breeding habits of the many species that rely on these wetlands.

Apart from the general increase in temperatures across all seasons, this region will notice a significant shift from slight winter dominance in rainfall to slight summer/autumn dominance. This shift in seasonality may impact on retained soil moisture so critical for winter cropping in the area. While the grains production here will still be highly viable over the coming decades, yields may decline in some areas if winter and spring rains are insufficient to maintain soil moisture. Farming enterprises in this landscape can adapt readily to climate changes by monitoring soil moisture and modifying timing of sowing and harvest. Grazing enterprises will need to focus more on shade protection and access to water, as well as modifying grazing management and stocking rates in line with trending temperatures and rainfall.

Summary

It is envisaged that managing native species survival will eventually become a key activity of all NRM, regional development and local Govt agencies in the region. The LLS must play a key role in helping to preserve the natural and cultural amenity of the landscapes where conflicts occur. For example, increased pressure for irrigation expansion in the Floodplains local landscape must be balanced against the need to maintain equitable environmental flows for the Macquaries Marshes. Soil erosion risks will continue to increase and careful management of new landuses and users will be critical to ensure sustainability of soil resources. Of particular concern is the expansion of lifestyle blocks where the owners may not have the land management experience necessary to restrict land degradation or for adequate pest and weed control. The Central West LLS must have a role in educating any new landholders about impending climate change and their role in a strategic adaptation framework.
Where should the Central West LLS be investing to address the impact of Climate Change?

Adaptation Planning

The Central West LLS, as a primary land management agency, will have a critical role in the future management of climate change adaptation in the region. Of particular importance will be:

- Education and translation of up-to-date research on climate change and adaptation responses, particularly to the farming community;
- Promotion and brokering of Federal and State Government initiatives focused on adaptation;
- Extension advice to farmers dealing with climate change;
- Direct investment in on-ground activities which help support climate change adaptation responses, for example riparian zone revegetation, corridor planting, habitat enhancement;
- Regulation of native vegetation removal to take into account impacts on climate change adaptation.

Incremental climate change or climate variability usually leads to autonomous and reactive responses (Stokes and Howden, 2010), often at the local, or farm scale. Nevertheless there is a likely need for planned transformational change to manage larger climatic shifts expected this century; however the transformation required is specific to a region and the ultimate vulnerability of the system (Kates et al, 2012). Not enough is known about the specific vulnerabilities of industries and communities in the Central West LLS region, however it is reasonable to expect that projected climate change will impinge on all activities here. Of particular concern in an already hot and relatively dry climate will be the shift towards hotter conditions that may push many systems beyond physiological heat thresholds. Even though projected rainfall change is equivocal, likely deficits in winter and little overall change in annual figures will, in concert with higher evapotranspiration rates, lead to reductions in soil moisture, and an overall drier landscape. It is likely that farm productivity will decline as a result, unless modifications are made to water resource access, crop selection and/or land management.

Anwar et al (2013) identified a range of barriers to adaptation which would need to be overcome if farmers (as primary land managers) are to deal with climate change. These “constraints to adaptation”, including a) misinformation about climate change; b) lack of partnership co-ordination; c) farmer skepticism; and d) uncertainty of effective solutions, are all areas where the LLS can contribute to solving.

Building resilience, (eg. in soils, vegetation and water resources; in businesses; in farms and agricultural industries) should be a key driver of all Central West LLS activities. It is inevitable that the landscapes of the Central West LLS will change in response to climate change drivers, and it is critical that the Service maintains an adaptive management approach to NRM. In conjunction with Govt agencies (DPI, OEH), monitoring change as well as success of investments should become a key activity of the Service.

Given the often restricted resources for NRM activities in the region, a multiple benefits approach should drive all LLS investments aimed at adaptation to climate change. For example, revegetation of riparian corridors adjacent to grazing lands has the multiple benefit of improved aquatic ecology, a cross-elevation migration corridor for species affected by changing climates, shade and shelter for stock, increased carbon sequestration in biomass and soils, and potential sites for rehabilitation of endangered or vulnerable species affected by changing climates.

There should be continued investment in pest and weed control, including monitoring and control of new invasions as they occur. Planned responses to invasions, including research on which species to expect, and when, should guide activities. Fire management will become increasingly important, even in cooler, moist areas where the risk of fire has previously been low. The prospect of agricultural grass fires reaching into towns is increasing, and temperate forested areas (eg Warrumbungles, Pilliga area) are most at risk of increased fire threat (see Bradstock, 2010).
The main factors driving native species vulnerability to climate change have been identified as a) dependence on a particular disturbance regime (often fire), b) reliance on a particular moisture regime or habitat, and c) low genetic variation (Lee et al., 2015). The LLS cannot on its own ensure the survival of all vulnerable species in the region, however in partnership with other agencies eg. OEH, Landcare, universities, CSIRO, NGOs, local ecologists, the LLS can help promote actions that at least provide some protection, and reduce further degradation. The OEH Save Our Species program could be used as a vehicle to identify vulnerable species and conserve critical habitat. Activities already underway in nearby regions that will become increasingly important include the Kanangra-Boyd to Wyangala link under the Great Eastern Ranges Initiative (GERI). Similar links (especially north-south and cross-elevation) within the region should be targeted for future initiatives. The GERI and its partners can guide the location of suitable wildlife corridors for on-ground works.

CSIRO has produced broad guidelines (Prober et al, 2015) for biodiversity adaptation planning, which include these principles:

- Optimise ecological processes
- Maintain Evolutionary character
- Maintain regional character
- Minimise species loss
- Promote cross-sectoral planning

Some key adaptation principles that support the above suggestions are (adapted from Measham et al 2014):

- Importance of local scale meshing with regional scales – Local NRM is crucial for on-ground adaptation, but needs to be effectively linked to regional or national scale planning. This is critical for GERI linkages and native vegetation planning overall.
- Importance of multiple partnerships – Multiple partnerships are necessary to manage multiple drivers, and new partnerships are needed between government, science, private sector and local communities to support local adaptation.
- Local leadership needs to be strong, and sufficient resources to underpin this leadership are critical.
- Managing “climate change” needs to focus on locally relevant specific events
- Limited information about vulnerability of municipalities to climate impacts can be a constraint.
- Institutional limitations, resource constraints and competing agendas can limit adaptation responses – The policy framework, financial capacity and competition for finite resources all limit adaptation responses. Policy makers need to be aware of potential mismatches between current organisational roles and scale of adaptation and institutional support.

As a consequence of the above, it is recommended that the Central West Local Land Service become actively involved in Integrated Regional Vulnerability Assessments (IRVA) (now known as Enabling Regional Adaptation – ERA) as this process (driven by OEH) comes to the region. Climate change impacts are by definition multi-faceted and complex, and only a detailed multi-agency assessment of sensitivities, exposure and ultimate vulnerability will inform ultimate adaptation responses. Building a repository of critical NRM data for the region hence becomes a critical need to inform this process.

It is important to ensure that the LLS is an organization that captures trust within the community, and is able to respond positively to climate change concerns. Education, both of the staff and the community, is critical to building a collaborative adaptation response.
Local Land Service Staff Training

As a consequence of the high likelihood of significant climate changes over the coming decades, Local Land Service staff will need to be aware of the implications of these changes, not only to the landscape and people living within the region, but also for LLS activities and priorities. Staff will need to understand the medium to long term implications of any action, as well as be able to recognize any symptoms of change. Climate change impacts are often hard to identify, but are likely to become more obvious over time. Staff should be trained to recognize climate change impacts, act strategically rather than reactively, and prepare for the changes.

Training, especially for frontline and field-based staff should include:

- Basic understanding of climate change and its broad implications
- Recognition of stresses within the environment attributable to climate change
- Recognition of stresses within the community (particularly the agricultural community) as a consequence of climate change.
- Conflict resolution training
- Extension and compliance training that incorporates climate change adaptation

Mitigation Opportunities

Global climate change has a global cause, driven largely from the Northern Hemisphere where the majority of industrial emissions exist. Regardless of Australia's lower relative total GHG emissions, we do have a role and a global responsibility to reduce our net emissions over the long term.

Opportunities exist to provide some GHG mitigation benefits through the net increase in production of biomass across the region. This carbon sequestration in biomass is matched by consequent potential long term C sequestration in soils. Revegetation/rehabilitation activities encouraged by the LLS will have the multiple benefit of improving many ecosystem services, including carbon sequestration. Federal Govt initiatives under the Emissions Reduction Fund (ERF) and Carbon Farming Initiative (CFI) give access to funds for land-based carbon sequestration to offset National GHG emissions. Both soil carbon and biomass sequestration activities are supported by the CFI, and there are methodologies specifically relevant to the Central West region.

Agricultural emissions of other GHGs such as methane (CH₄) and nitrous oxide (N₂O) are important contributors to climate change. Methane from livestock can be reduced with a combination of genetic manipulation, stock management and husbandry methods. Given the very high populations of ruminant livestock in the region, significant potential exists for the promotion of methods aimed at methane emission mitigation. Similarly, efficiencies and improvements in crop and irrigation management can reduce nitrogen loss to rivers and deep drainage while concurrently reducing N₂O emissions, which can be significant from high N-dependent crops in the region such as cotton (eg. Macdonald et al., 2016).

Central West LLS should have a support role to provide local expertise and guidance to encourage landholders to engage in these initiatives and build projects with a likelihood of funding.
Partnerships

Key partners relevant to climate change: NSW Govt agencies, specifically OEH and DPI, local councils, BoM, CSIRO, Landcare, Aboriginal Lands Councils. All State and Federal guidelines dealing with climate change adaptation stress the importance of cross-sectoral and multi-agency partnerships as an effective way to identify and deal with regional vulnerabilities. The recently signed MoU between the LLS and Landcare is a positive step towards this process, but a climate change adaptation agenda must be explicit in the agreement.

Knowledge Gaps and Future Work

Many climate change impacts on local natural resources and native ecological communities are surmised by previous studies, but detailed responses and interactions with climate changes are largely unknown for the Central West region. Access to new modeling products such as NARClim climate mapping and 3C Biodiversity mapping provides a great opportunity to derive useful new products on specific species and ecological community responses to climate change.

CSIRO’s recent Guide to implications of climate change on biodiversity (Williams et al, 2014) has produced a set of climate change analyses that are critical to understand biodiversity adaptation to changing climates. These are analyses of:

- Potential degree of ecological change
- Change in effective area of similar ecological environments
- Extremes of ecological change such as potentially novel or disappearing environments
- Degree to which ecological environments are becoming novel or tending to disappear

In conjunction with improved climate change modeling, the Central West LLS now has access to much of the information it needs to deliver a strategic plan for climate change adaptation and mitigation activities. It is critical that all this information is collated and used for local modeling purposes. Adjoining regions such as the Eastern Zone Cluster (North Coast, Hunter and Greater Sydney Local Lands Services) have initiated mapping of risks to biodiversity and carbon within their regions (Turner et al, 2015). MCAS-S modeling (ABARES, 2011) has been used to develop maps of priority areas for adaptation and mitigation action (some of which extend into the eastern edge of the Central West LLS region). An extension of this methodology into the rest of the Central West LLS region is warranted, requiring a re-casting of current spatial data layers into a MCAS-ready format.

Further research needs include:

- a) specific details about interactions between environmental change and ecological needs of vulnerable species within the region
  - Threshold heat and water stresses
  - Reproductive capacity and limitations
  - Evolutionary capacity
  - Preservation potential of habitat

- b) detailed modelling of specific habitats within the region, both for their refugia and temporary corridor potential.

- c) an inventory of the degradation status of all high value habitats, with options for their rehabilitation

- d) the use of fire as a management tool requires further investigation in the region. Fire ecology is a primary driver of biodiversity in the region (Graham et al, 2013), and can also be used as a weed reduction and land rehabilitation tool (Milton Lewis pers. comm.). Aboriginal cultural use of fire is receiving increased recognition in recent years, and many local rehabilitation projects are starting with cultural cool burns (eg. Parissi et al 2015). Projected changes in FFDI will also undoubtedly influence the available window for fuel reduction burns.

- e) details of structural changes needed in all relevant agricultural industries in the region, on a case-by-case, or by industry basis.
List of useful internet sites on Climate Change Science, Projections, Impacts and Adaption

Intergovernmental Panel on Climate Change (IPCC)
http://www.ipcc.ch/

Adapt NSW (NSW Office of Environment and Heritage)

Climate Change in Australia (CSIRO/Bureau of Meteorology)

Terranova (Australian Climate Change Adaptation Hub)
https://terranova.org.au/

NCCARF
https://www.nccarf.edu.au/

AdaptNRM (Commonwealth Dept of Environment/CSIRO/NCCARF)
http://adaptnrm.csiro.au/

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