Australian Government
Bureau of Meteorology

Trends and historical conditions in the Murray-Darling Basin

A report prepared for the Murray-Darling Basin Authority by the Bureau of Meteorology.

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Foreword

The Murray-Darling Basin Authority (MDBA) is undertaking a Climate Change Research Program to improve the MDBA's capacity to respond to climate risk. This will entail an updated assessment of climate change impacts on Basin water management, identifying adaptation opportunities, and determining how best to direct future resources and investment via a 5-year climate change research program to inform the Basin Plan review in 2026.

The Bureau of Meteorology was asked by the MDBA to support this program by providing an updated assessment of climate and hydrological conditions across the northern and southern Basins.

The Bureau of Meteorology maintains observational records of temperature, rainfall amounts, streamflow in rivers and groundwater extending back many decades. These observational records are complemented by modelled estimates of land surface conditions across the Basin in areas where no direct observations exist. Assessment of these observational records and of the modelled output by scientists identifies trends which are important considerations for the future management of water resources across the Basin.

This report represents a synthesis of the current available information relating to observed trends and historical conditions across the Murray-Darling Basin. Trends reported in this report represent natural – or unmanaged – conditions arising from changes in the climate system. It is important to note that in many catchments which make up the Murray-Darling Basin human intervention in the form of irrigation, regulation and river management may have a greater influence on changes in streamflow patterns and trends beyond changes in rainfall.

High level summary of conditions in the Murray-Darling Basin

- Temperatures have been rising over the Basin and this is expected to continue into the future.
- The entire Basin has experienced a decline in rainfall, particularly in the winter months across the Southern Basin, which has been partly attributed to anthropogenic climate change.
- The decline in rainfall is amplified as a decline in winter and annual streamflow and runoff in the Southern Basin (most of the runoff in the Southern Basin occurs in winter and early spring).
- Variability in rainfall is large both spatially and temporally across the Basin and will continue to be a significant feature of the region's climate, with very wet years and very dry years possible into the future.
- Declining trends in soil moisture content as well as runoff are evident across the Basin particularly in the south, with most drying occurring since the Millennium Drought.
- Analysis of hydrological reference stations across the Basin reveals that most locations have experienced a step change in streamflow during the late 1990s, with the change coincident with the Millennium Drought.
- Rainfall-runoff relationships across the Basin have been shown to have changed in recent decades and some catchments in the Southern Basin have not yet fully recovered from the Millennium Drought.

Background

The MDBA is undertaking a Climate Change Research Program to improve the MDBA's capacity to respond to climate risk. This will entail an updated assessment of climate change impacts on Basin water management, identifying adaptation opportunities, and determining how best to direct future resources and investment via a 5-year climate change research program to inform the Basin Plan review in 2026.

Given recent advances in climate science and its application to water resources management, the MDBA is seeking CSIRO's assistance to update the climate scenarios used to inform future Basin water availability and provide advice on the MDBA's application of climate science to Basin water management. As part of the Climate Change Research Program the MDBA are working with CSIRO to develop a long-term climate research strategy to improve the use of hydroclimate knowledge for climate risk management in the Basin. The hydroclimate scenarios are described by a combination of temperature, rainfall, and flow characteristics. Climate scenarios are developed to better understand the sensitivity of the water systems under a range of plausible future climate conditions. They are useful tools for capturing the range of risks of water systems to climate change. However, it should be clear that they are not predictions of future climate, rather plausible futures of what might happen

The Bureau of Meteorology is supporting this work with a description of how the historical conditions are changing across the Northern and Southern Basins to contextualise these future hydroclimate scenarios. Trends as well as long-term average historical conditions will be described for the period of observational record for temperature and rainfall, runoff, soil moisture and streamflow indicators. A map of the Basin is shown in Figure 1.

Figure 1 The Murray-Darling Basin showing the Northern and Southern Basin regions.

Baseline climatology of the Murray-Darling Basin

A summary of the conditions in the Murray-Darling Basin:

- The Basin region's climate ranges from sub-tropical in the north, to semi-arid in the west, to temperate in the south.
- Average rainfall across the region ranges from more than 2,100 mm in the highland areas in the southeast to less than 300 mm in the semi-arid areas in the west.
- Typically, streamflow in the northern part of the region reflects the sub-tropical rainfall distribution with higher streamflows in the late summer–early autumn months (January–March) following the higher summer rainfall period.
- Flow in the southern part of the region reflects the more temperate climate with higher flows in the late winter–early spring months (August–October) following winter rainfall. Flow regimes across the Basin experience large year to year variability on top of seasonal differences.
- Variability in rainfall and streamflow is large both spatially and temporally across the Basin with multi-year dry spells a regular occurrence.

To paint a full picture of the natural variability in conditions across the Basin the Bureau of Meteorology has evaluated long-term, high quality observational records as well as analyses and simulations from operational products such as the gridded climate analysis, AWAP, and the gridded landscape water balance model, AWRA-L. Table 1 provides an overview of data sources and period of analysis for the evaluation.

Variable	Record Length	Data Source
Temperature	1910 – 2019	From the Bureau of Meteorology's high-quality station-based dataset (AWAP).
Rainfall	1900 – 2019	From the Bureau of Meteorology's high-quality station-based dataset (AWAP).
Runoff	1911 – 2019	Simulated using the Bureau of Meteorology's Australian Water Resources Assessment – Landscape (AWRA-L) landscape water balance model.
Soil Moisture	1911 – 2019	Simulated using the Bureau of Meteorology's Australian Water Resources Assessment – Landscape (AWRA-L) landscape water balance model.
Streamflow	Various	Observations of streamflow at Hydrologic Reference Stations (HRS) have been evaluated over all available records up to Feb. 2019 for 75 catchments within the Murray Darling Basin. A hydrologic reference station is a streamflow gauging station in an unregulated catchment with minimal land-use change and other anthropogenic influences such as extractions. Sites were selected to be representative of catchment conditions across the Basin.
Groundwater	1997-2019	From bore observations delivered to the Bureau's under the regulations 2008 cat 2a. Sites were selected that match the period of the "Record Length" and other criteria as per trends and peak analysis methodology

Table 1 Long term observational records from across Australia have been analysed to provide a picture of historical variability across the Basin as well as an assessment of long-term trends.

Temperature and rainfall trends in the Murray Darling Basin

Rainfall patterns across the Basin vary widely, ranging from sub-tropical in the north, to semi-arid in the west, to temperate in the south. Typically, streamflow in the northern part of the region reflects the sub-tropical rainfall distribution with higher streamflows in the late summer–early autumn months (January–March) following the higher summer rainfall. Flow in the southern part of the region reflects the more temperate climate with higher flows in the late winter–early spring months (August–October) following the peak in winter rainfall; however this rainfall, is also highly variable from year to year and is strongly influenced by phenomena such as the Indian Ocean Dipole (IOD), El Niño and La Niña and shorter-lived phenomenon such as the Southern Annular Mode (SAM). This variability now takes place against long-term trends in Australia's climate due to climate change. Recent years have seen declining rainfall in the Basin and on the western slopes of the Great Dividing Range during the cool season, as well as rising temperatures including increased frequency and intensity of extreme heat events, and worsening fire seasons. The western slopes of the Great Dividing Range are the most important runoff-generating region for the Basin.

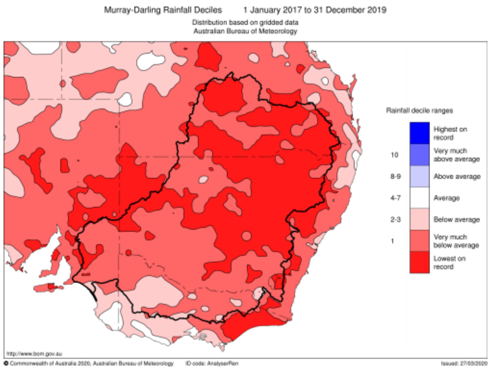
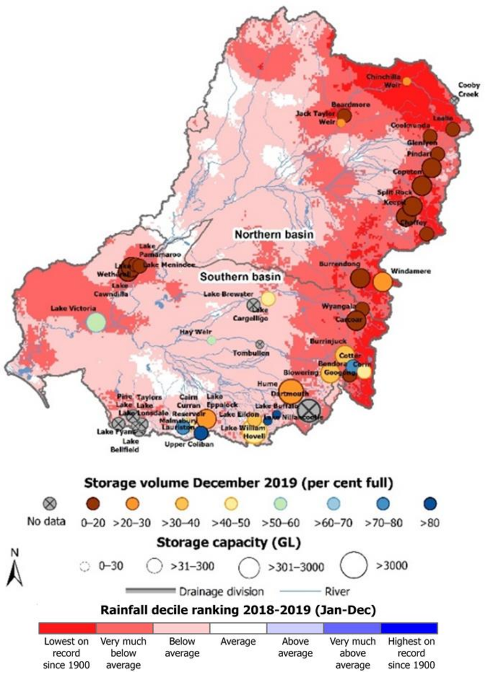


Figure 2 Rainfall deciles for the last 3 calendar years (2017–2019). A decile map shows where rainfall is above average, average or below average for the recent period, in comparison with the entire rainfall record from 1900.

Figure 3 December 2019 root zone soil moisture expressed as deciles against 1908-2019 timeseries. Storage volumes as percentages of capacity are overlaid. Most of the basin is characterised by below average root zone soil moisture, meaning many months of above average rainfall is needed to generate runoff needed to replenish severely depleted storages, particularly in the north.



Recent drought across the Basin

Rainfall deficiencies have affected most of the New South Wales, Queensland and South Australian parts of the Murray–Darling Basin since early 2017. Some of the largest rainfall deficiencies have occurred in the upper catchments of major tributaries of the Darling, including the Macquarie, the Namoi–Peel, and the Border Rivers. The location of the poor rainfall has meant it has particularly impacted water supplies.

Area-average rainfall in the Murray-Darling Basin in the three years from January 2017 to December 2019 (Figure 2) was the lowest on record. Average rainfall across the basin was more than 170mm lower than the driest three-year period during the Federation Drought. This has occurred concurrently with an extended period of well above average and record temperatures for the same period.

The dry conditions of the last three years have been particularly acute during the cool season from April−September. Lack of rainfall in those parts of the basin that generate runoff has had a significant impact on water storage levels. The very much below average October and November rainfall in 2019 over most of the main water catchments of New South Wales and the Murray–Darling Basin further exacerbated the effect of low inflows to storages by the end of 2019 (Figure 3).

The record low rainfall was associated with record high temperatures. During droughts, above average daytime temperatures are usually offset by cooler night-time temperatures. Rising temperature trends mean that droughts now sit on a substantially warmer base period and both maximum and minimum daily temperatures are hotter than average.

Record high temperatures add to water demand, increase the stress on natural and human systems (as evapotranspiration from natural and cropped vegetation), thus reducing soil moisture, runoff and storage inflows, increasing evaporation of storages and increasing bushfire risk.

Long-term trends

Temperatures have risen across Australia and the Basin since the start of national records in 1910, and especially since 1950. Averaged across the Basin as a whole (Figure 4), there has been a rise of around 1.4 °C in mean temperature during this time, at an average rate of 0.13 °C per decade. 2019 was the warmest year on record, with every year since 2013 in the top ten warmest. This rise in average temperature has been observed across all seasons for both daytime and night-time temperatures. Both the Northern and Southern Basins have experienced warming during the period from 1910 to 2019 with the northwest (between 0.15 and 0.20 °C per decade) warming at a greater rate than the southwest (between 0.05 and 0.10 °C per decade).

Associated with this rise in temperatures there has been a marked increase in the incidence of extreme daily heat events (Figure 5). Record-warm monthly and seasonal temperatures have been observed in recent years and are made significantly more likely by climate change.

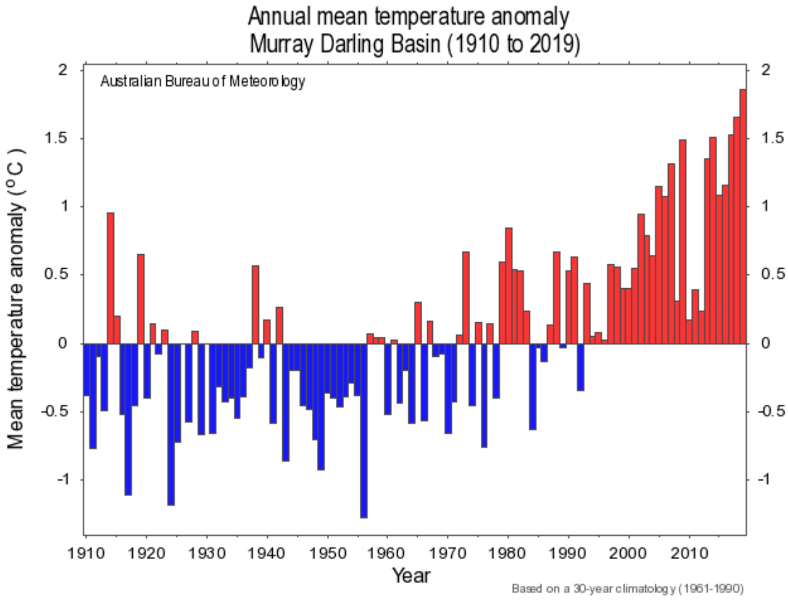
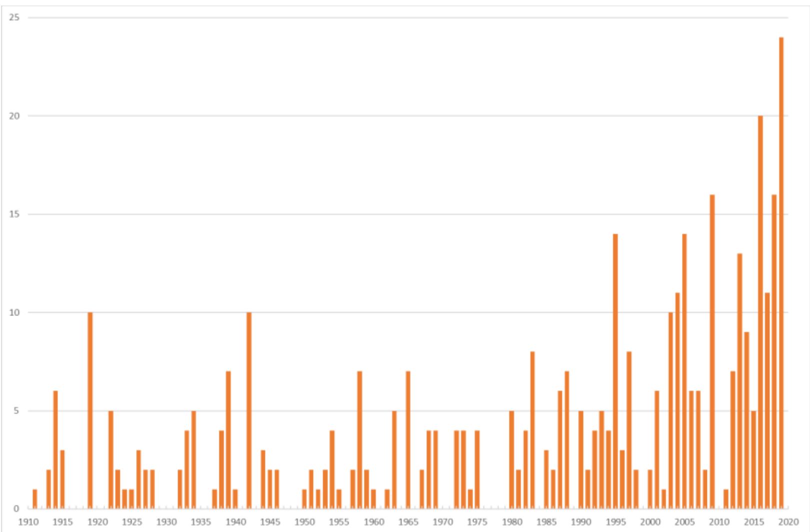


Figure 4 Anomaly of annual mean temperature across the Basin. Based on a 30-year climatology (1961-1990).

Figure 5 Number of days each year where the Murray-Darling Basin-averaged daily mean temperature is extreme. Extreme days are those above the 99th percentile of each month from the years 1910–2019. These extreme daily events typically occur over a large area.



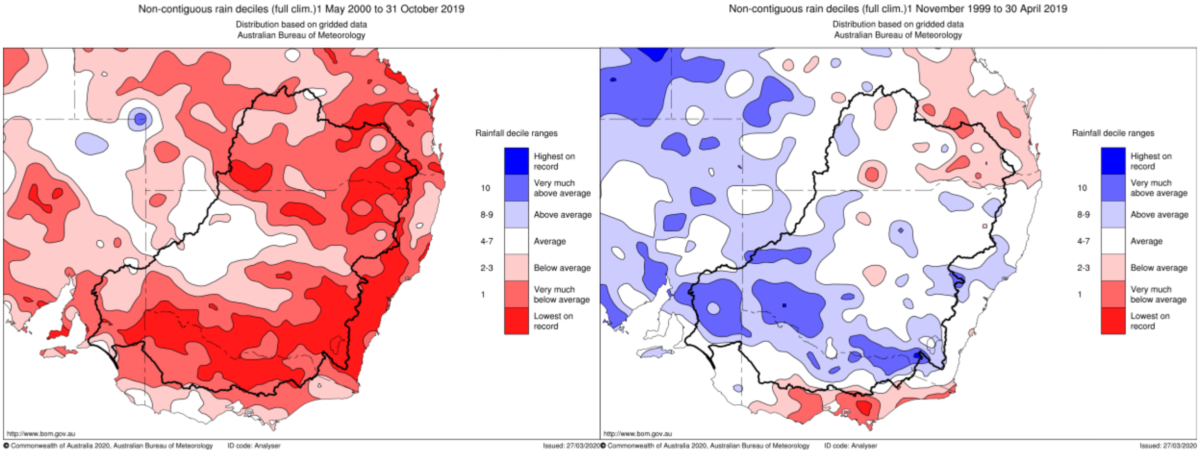


Figure 6 (LEFT) May to October and (RIGHT) November to April rainfall deciles for the last 20 years (2000–2019). A decile map shows where rainfall is above average, average or below average for the recent period, in comparison with the entire rainfall record from 1900.

Recent decades have seen unusually low rainfall affect most of the normally wetter parts of the Basin (Figure 6 and Figure 7), particularly during the cool season (May to October). The low rainfall is part of a long-term decline in cool-season rainfall which is affecting southwest and southeast Australia. For the Basin this means rainfall has declined in the south and on the western slopes of the Great Dividing Range.

The May to October cool season is a hydrologically and agriculturally important time of the year with rainfall during the cooler months important for recharging water systems and for agriculture. This decrease is linked with a trend towards higher mean sea level pressure in the region and a shift in large-scale weather patterns—more high-pressure systems and fewer lows. This increase in mean sea level pressure across southern latitudes is a known response to global warming. For example, a reduction in the number of cold fronts impacting the southwest of Australia has been observed[1], along with a decrease in the incidence and intensity of weather systems known as cut-off lows in the southeast regions of Australia. The last 20 years have also seen very much below average rainfall across northern parts of the Basin (Figure 6 and Figure 7), though with the high variability of rainfall in the area, a statistically significant trend is difficult to determine and it is possible that these change are still dominated by natural variability.

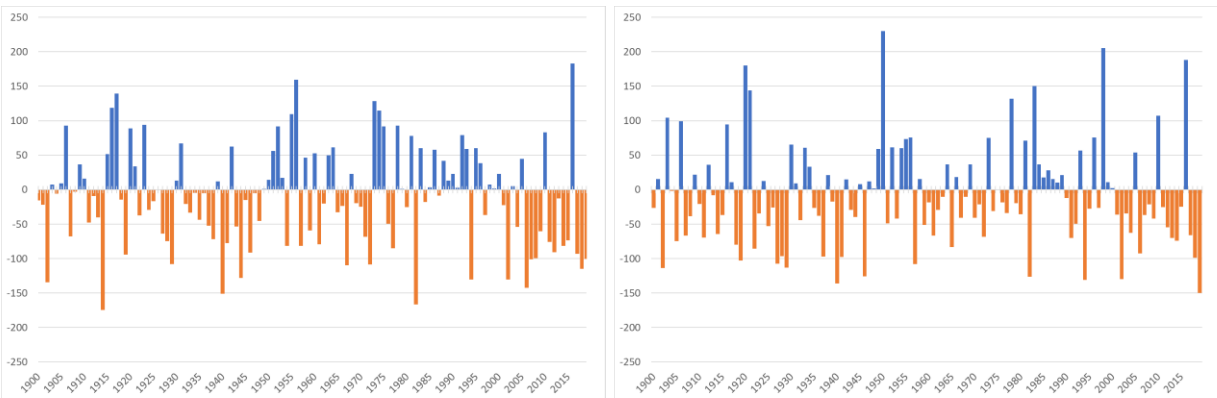


Figure 7 May to October rainfall anomalies 1900–2019 for (LEFT) Southern half of the Basin; (RIGHT) Northern half of the Basin Anomalies are averaged with respect to 1961-1990. Yellow bars indicate years with below average rainfall totals and blue bars indicate years with above average rainfall totals.

[1] Dowdy, A.J., Pepler, A., Di Luca, A. et al. Review of Australian east coast low pressure systems and associated extremes. Clim Dyn 53, 4887–4910 (2019). https://doi.org/10.1007/s00382-019-04836-8

Changes in hydrology

The Basin has become drier in the hydrologically and agriculturally important May to October period over the period of record, especially in the Basin. An analysis of the long-term climatology for rainfall, runoff and soil moisture reveals the highly variable nature of rainfall and hydrology (runoff and soil-moisture) within the Basin. Historical drought periods in the Basin such as the World War II Drought (1937 – 1945) and the Millennium Drought (1997 – 2009) are characterised by prolonged sequences of dry years. In the context of the Basin the sequencing of dry years which are in the lowest percentiles for rainfall, soil moisture and runoff can occur consecutively, or be interspersed with moderate or even wet years. Wet years can still occur, even during episodic dry spells such as periods of drought. Similarly, wet periods have also occurred, for example during the mid-1970s. Since the mid-1970s both the Northern and Southern Basins have experienced more dry years than wet years. Typically, multiple wet years are required to return the Basin from a period of drought.

Trends in rainfall are reflected in both runoff and soil moisture profiles. As a result of the decreases in rainfall since the early 2000's including the significant reduction in Winter rainfall, decreases to runoff are also observed. During the Millennium drought, runoff was particularly low over the period 2001 to 2010 in the Basin, but in the Northern Basin there has also been a severe reduction over the last three years. There is also evidence[2] that there has been a step change in rainfall – runoff response for some parts of the Basin since the Millennium Drought. Since the drought, the runoff response to a give sequence of rainfall events is changing. This is the subject of active research, with the hypothesis that many catchments have not fully recovered to pre-Millennium Drought conditions. Similarly, both the Northern and Southern Basins have experienced a noticeable drop in root zone soil moisture levels during and since the Millennium Drought. This is a response to both decreases in rainfall and increases in temperature driving increases in potential evapotranspiration. A recent assessment[3] of dry conditions across the Basin noted that persistent cloud-free conditions, which means an increase in solar radiation at the surface, may also have contributed to enhanced evapotranspiration.

[2] Saft, M., M. C. Peel, A. W. Western, and L. Zhang (2016), Predicting shifts in rainfall-runoff partitioning during multiyear drought: Roles of dry period and catchment characteristics, Water Resour. Res., 52, 9290–9305, doi:10.1002/2016WR019525.
[3] Special Climate Statement 70—Drought conditions in Australia and impact on water resources in the Murray–Darling Basin. http://www.bom.gov.au/climate/current/statements/scs70.pdf

Changes in streamflow

Declines in streamflow have been observed across the Northern and Southern Basins over the last 50 years with well above half (55%) of streamflow records show a declining trend since the 1970s. These trends in declining streamflow within the Basin are the strongest observed anywhere in Australia[4]. Episodic dry periods such as the Millennium Drought are clearly observable as streamflow reductions during the 1990s; reductions in many parts of the basin were larger than expected with some catchments not recovering (Figure 8).

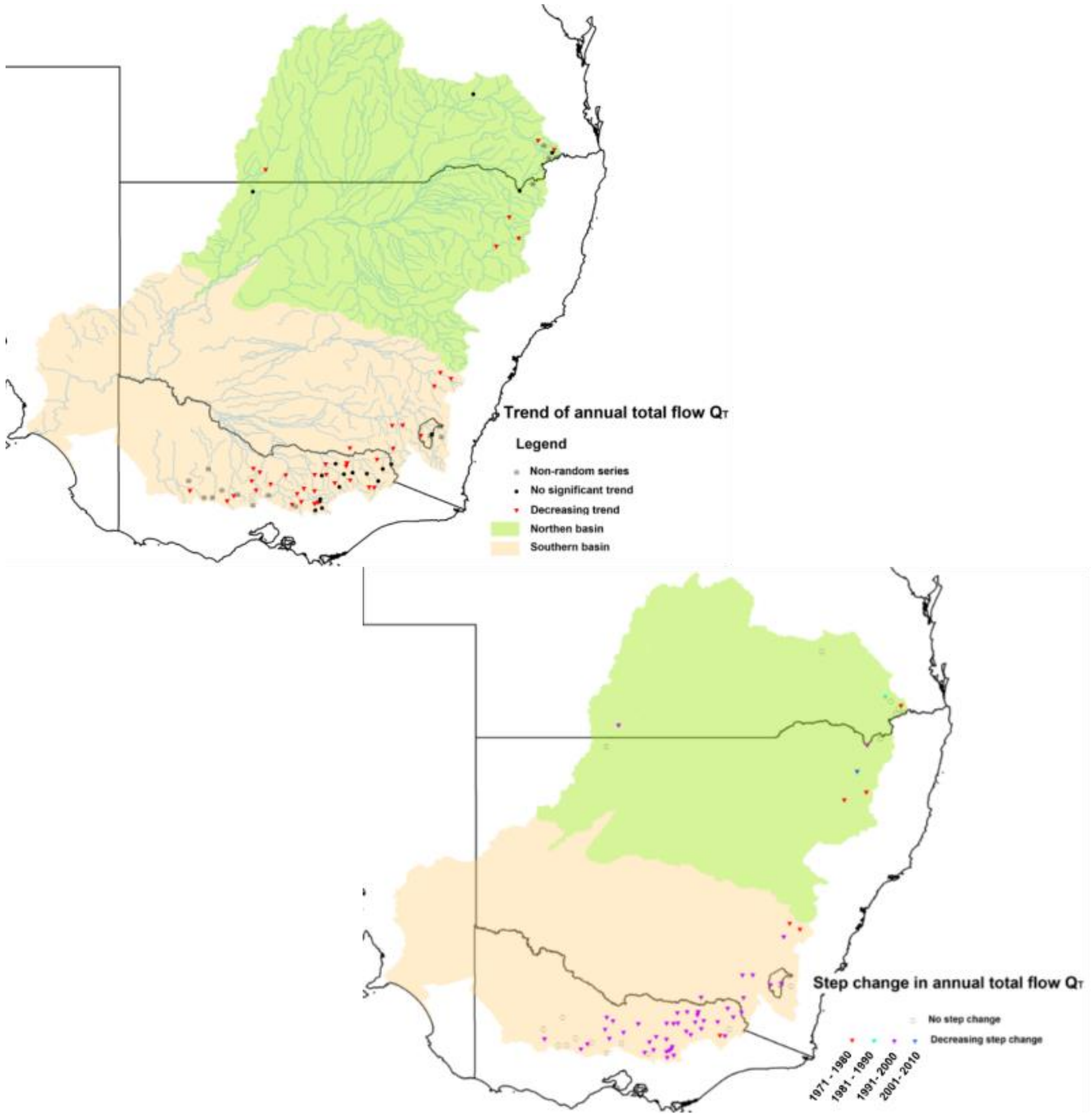
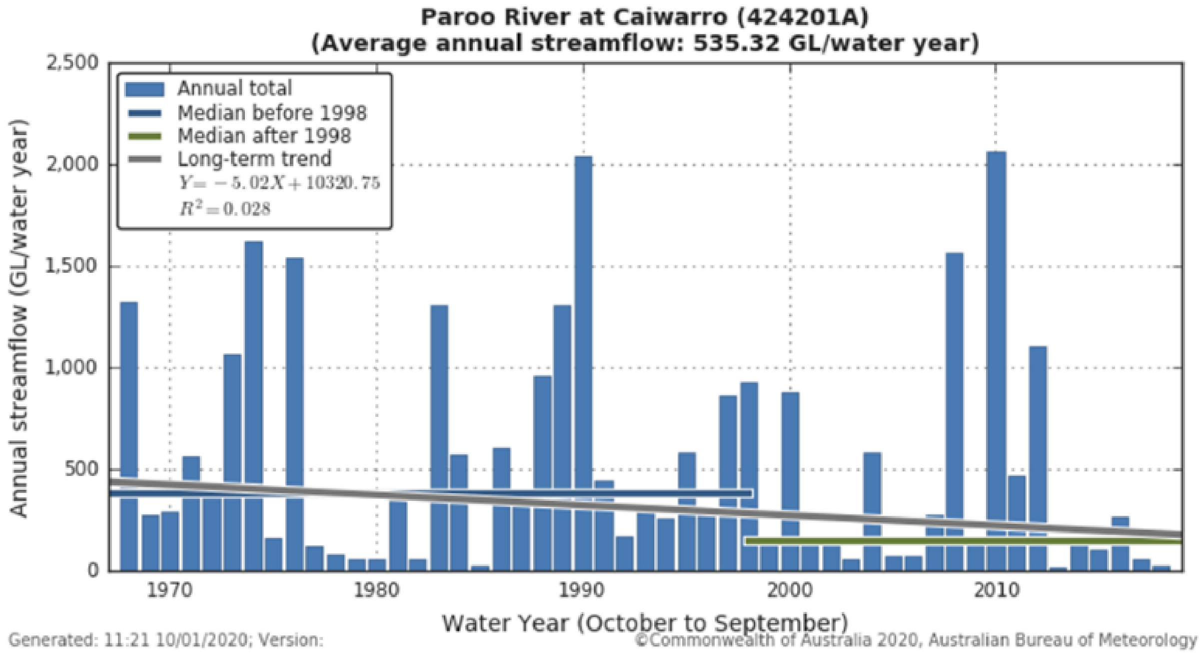


Figure 8 (UPPER) Decreasing trends in annual total streamflow (QT) have been experienced across the Northern and Southern Basins at the majority of 75 Hydrologic Reference Stations (HRS). The HRS represent total catchment flow. They are situated at catchment outlets around the edge of the Basin. Here the direction of the trend is shown for stations with significant trend. Although trends in QT vary across different hydroclimatic regions of the basin, the stations showing decreasing trends (55% of stations) are in both Northern and Southern Basins. (LOWER) Step changes in streamflow have been identified across the Basin, where colours indicate the year of change appearing in each decade and downward arrows represent decreased median values after the year of change. Stations within the Basin exhibited the major feature of a step change in the 1990s which can be seen by the purple downward arrows. Several stations in the Northern Basin show changes in the 1970s.

[4] Zhang, X., Amirthanathan, G., Bari, M., Laugesen, R., Shin, D., Kent, D., MacDonald, A., Turner, M. and Tuteja, N. (2016). How streamflow has changed across Australia since the 1950s: evidence from the network of hydrologic reference stations. *Hydrology and Earth System Sciences*, 20(9), pp.3947-3965.



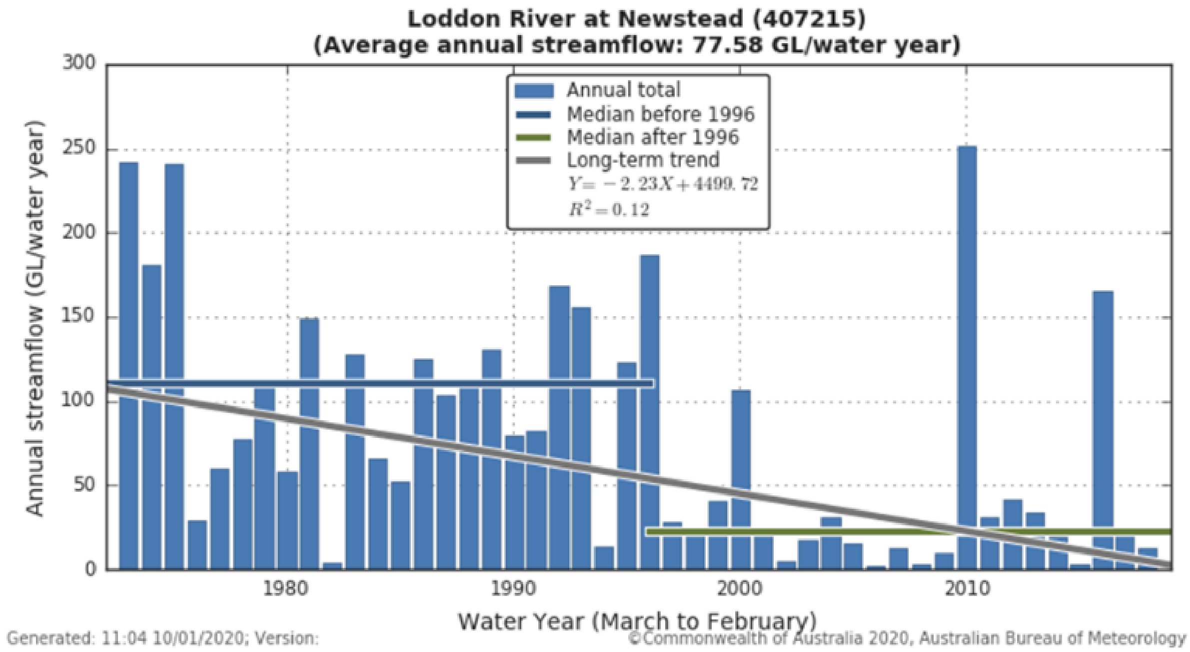


Figure 9 Trend slope and year of step change for streamflow for selected Hydrological Reference Stations (HRS) in the Northern Basin (UPPER) 424201A and in the Southern Basin (LOWER) 407215 for whole duration of record. Note that the year of step change is different for each station. The trend over the duration of each HRS record is shown by the grey line. The mean annual streamflow before the step change is shown by the blue line, the mean annual streamflow after the step change is shown by the green line. The decline in annual streamflow has been more pronounced in the Basin. The impact on streamflow step change in regime identified.

The magnitude of the step change in streamflow across the Northern and Southern Basins varies considerably (Figure 9). Notably, the change in streamflow regime during the period spanning the 1970s to present could be an indication of changes to catchment behaviour, in addition to the response to declining rainfall.

As well as decreasing trends in mean annual conditions, there are decreasing trends across the basin in the extreme flows and flows above the 90th percentile (Figure 10). Trends in streamflow decline are most evident during the winter half of the year, across the Basin. Virtually no spatially consistent trends, either increasing or decreasing, were identified in low flow events (Q10) or during the autumn (MAM) season across the Basin.

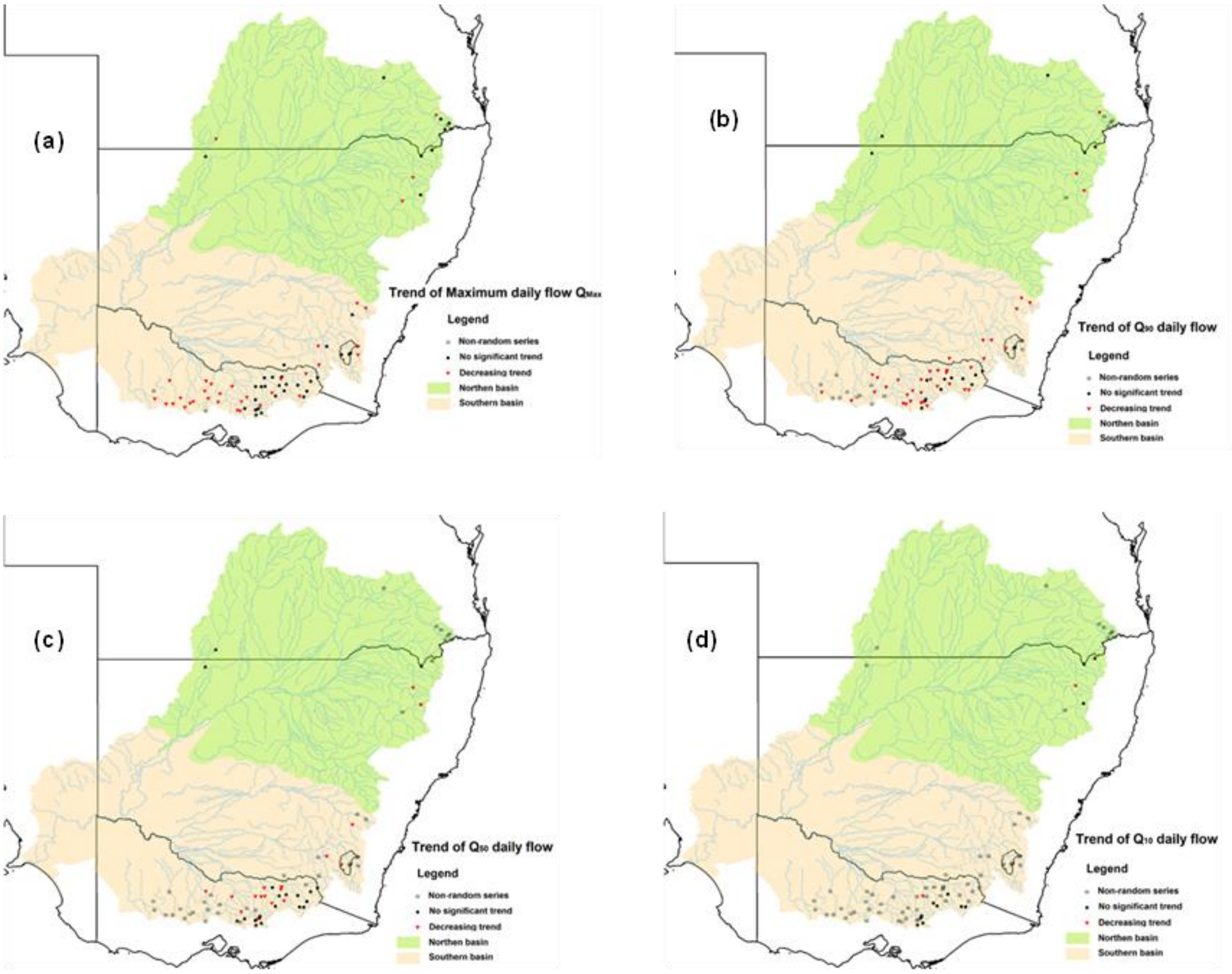


Figure 10 Maps showing trends of daily flow in various magnitude categories (a) maximum daily flow QMax; (b) Q90 daily flow; (c) Q50 daily flow; (d) Q10 daily flow at 10% significant level (p <0.1). Sites where a significant decreasing trend in streamflow was detected are coloured in red and are most prevalent for high flow characteristics. Sites for which no significant trend was detected (black), or for which trend analysis was not possible (grey) are more prevalent for lower flow characteristics.

Groundwater

Groundwater peak recovery indicates the relationship between natural recharge and/or pressure recovery and demands on the groundwater sources. Alluvial aquifer systems in the Basin are being impacted by low rainfall and stream recharge, and by increased pumping for consumptive use, especially given the scarcity of surface water supplies since the onset of the current drought. Thus, less water is getting into aquifers and aquifer systems are under further stress due to increased extractions. This in turn is also affecting base flow to rivers provided by groundwater in highly connected alluvial systems due to groundwater levels declining below stream levels.

To illustrate this complex system, an example for a section of the Namoi river is shown in Figure 11. This shows a change in groundwater surface water connectivity for a section of the Namoi river gauge since early 2000 from medium to high gaining stream[5] to a mainly losing stream. Note that this example is demonstrative of highly connected alluvial systems where groundwater use from pumping has increased through time and may not be representative of all groundwater systems across the Basin.

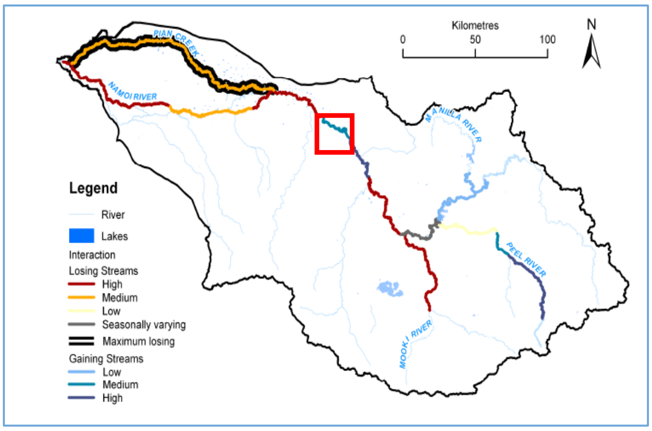
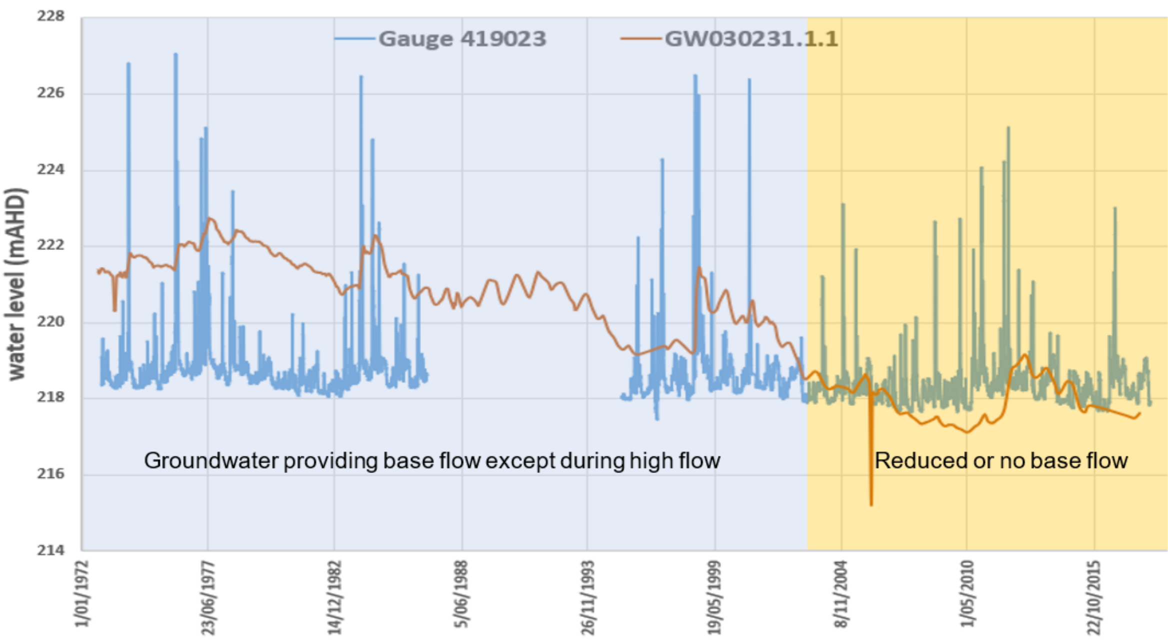


Figure 11 Changed relationship between groundwater and surface water levels (mAHD), since early 2000, near the Namoi River gauge 419023 which was previously classified through the Sustainable Yields Project (CSIRO, 2008) as medium to high gaining stream.



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[5] CSIRO (2008) Murray-Darling Basin Sustainable Yields – Regional Reports. Available from http://www.csiro.au/en/Research/LWF/Areas/Water-resources/Assessing-water resources/Sustainableyields/MurrayDarlingBasin

An analysis of groundwater recovery peaks for 2018-19 in the Basin shows that most groundwater levels across major productive aquifers in the Basin are at historically low levels (Figure 12). The 20-year trend (1999-2019) in groundwater level recovery peaks shows that many bores in the highly productive, alluvial resources are declining, such as the Namoi, Lachlan and Murrumbidgee alluvium (Figure 13). Meanwhile bores associated with saline groundwater resources or less productive aquifers, where water quality limits groundwater use, are essentially stable over the same period. The few bores with very much above average levels and rising trends may reflect longer-term effects such land clearing, irrigation or bore capping in the underlying Great Artesian Basin.

Further understanding is needed to separate the direct effect of climate change and variability from secondary effects, such as increased pumping. An improved assessment of changed conditions in surface water groundwater connectivity due to declining groundwater levels and its effects on streamflow is also needed.

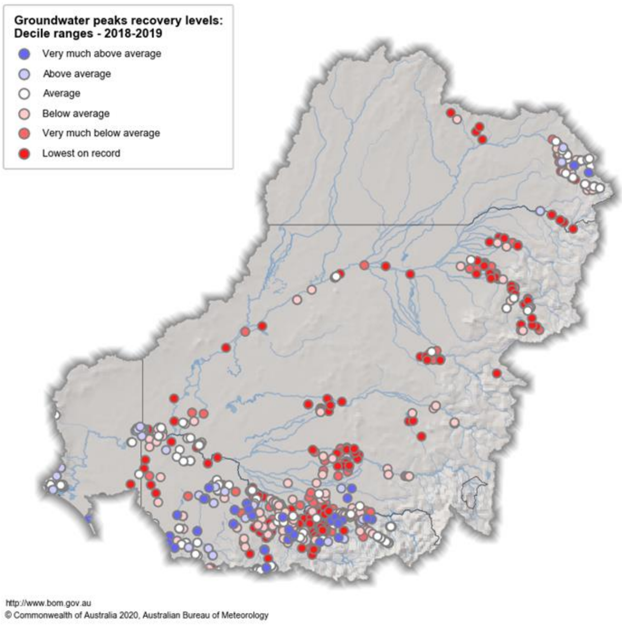

Figure 12 Ranking of annual 2018-19 groundwater level peak recovery against to historical peaks from 1997.

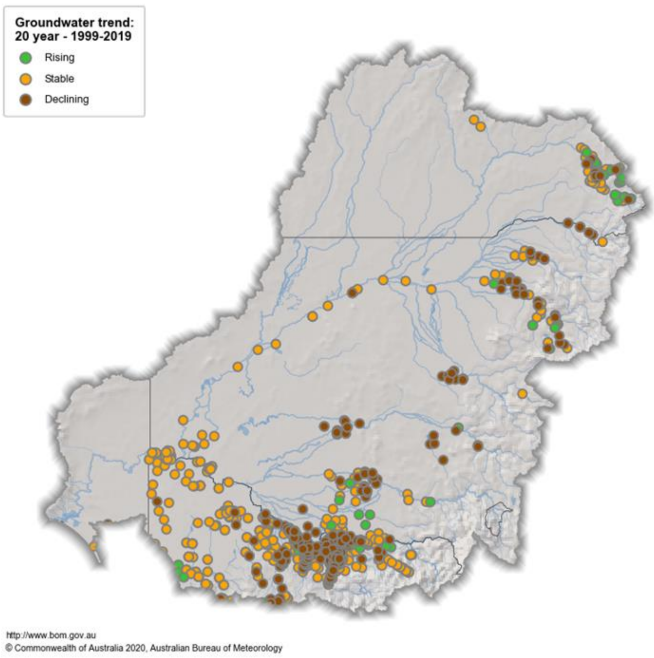

Figure 13 20-year trend (1999-2019) of annual groundwater level peak recovery.

Water Quality

The impacts on various aspects of water quality under a changing climate has been recognised as a challenge for the Basin and its management. Drier conditions and increasing temperatures, as well as changes to flows, are already showing observable impacts on water quality particularly during periods of low flows.

Impacts include increased salinity levels due to less water being available to dilute salts. In recent decades increased frequency of blue-green-algae blooms in the Murray River have been observed, with five major blooms occurring in the last 13 years. The consequences of these events are demonstrated by one of the largest fish-kills ever recorded due low dissolved oxygen and the die-off of algae in the Darling River downstream of Menindee in January 2019. Projected rising temperatures and more frequent heatwaves mean that higher riverine plant, benthic and aquatic compositions will struggle to stay viable at different life cycle stages which has flow on impacts on the health and diversity of many fish species.

Recent years, including the 2019/2020 bushfire season, have also seen hypoxic blackwater events along some river sections in the Basin, associated with the large build-up of organic material from several consecutive dry years and subsequent flooding, with excessive carbon loading. The following low flows and the recent increased high temperatures accelerate organic decay and deoxygenation potentially leading to fish kills.

Further research is needed to improve understanding on how changing flow regimes and changes in ambient conditions trigger issues for a multitude of water quality problems. This includes exploration of how emerging in-situ and remote sensing can be used to identify those trigger values early, in support of early management strategies.

Future state of the Basin

The future state of the Murray-Darling Basin is highly dependent upon the nature and magnitude of climate change impacts. Modelling of future climates over the past several years can provide indications of plausible changes to conditions across the Basin:

- The Basin area has warmed by around a degree since 1910 and will continue to warm (by 0.6–1.5 ºC in 2030 relative to 1995, and by 0.9–2.5 ºC in 2050 without mitigation[6]), with more hot days and fewer cold days.
- Continuation of current observed long-term trends towards drying (reduction in cool season rainfall), which is most pronounced in the Basin during the winter months is predicted (*high confidence*). Year to year variability of rainfall is still expected to be large which means that there will still be wet and dry years (*high confidence*).
- Due to large variability in the response of large-scale climate drivers which produce rainfall over the Basin to a warming climate, both drier and wetter futures are possible. Model results[7] indicate that by 2050 in a very dry future climate scenario the reduction in annual rainfall could be more than or close to 15% of present amounts. In a wetter future scenario annual rainfall could have increased from present amounts by up to 10%.
- Increases in maximum and minimum temperature throughout the year are expected to increase potential evapotranspiration. In regions where significant reduction in rainfall is projected, this will increase the gap between supply and demand, as well as reduce soil moisture. Daily minimum temperatures (overnight lows) are also expected to increase.
- As a result of the decreases in rainfall and increases in temperature, potential evapotranspiration will increase, soil moisture will decrease, and runoff and streamflow will significantly decrease.
- While these projected states are for long-term trends, natural variability in the basin will remain high with extreme wet periods also possible. The decline in the long-term averages will also mean that there will be longer and more severe droughts in the future.

[6] Review of Water Reform in the Murray-Darling Basin Appendix 4. Climate change in the Murray-Darling Basin. Whetton, P. (2017). https://wentworthgroup.org/wp-content/uploads/2017/11/Appendix-4-Climate-change-in-the-Murray-Darling-Basin.pdf

[7] Climate Change in Australia. CSIRO and BOM (2015). Summary Data Explorer: https://www.climatechangeinaustralia.gov.au/static/ccia/2.1.6/NRM/summary-data/csv/projected_change_pr_MB_NRM_OnAv1134.csv; https://www.climatechangeinaustralia.gov.au/static/ccia/2.1.6/NRM/summary-data/csv/projected_change_pr_CS_NRM_OnAv1134.csv