

# Exploring post 2011–12 drought in the Murray–Darling Basin

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**Abstract:** Drought, defined as rainfall deficiency, a familiar phenomenon in the Murray–Darling Basin, (the Basin) presents a risk to ecosystems, agriculture, industry and communities. The Millennium Drought from 1998 to 2009, with a peak from 2001 to 2009 (Bureau of Meteorology, 2015), was one of the longest and most severe droughts in the observed recorded history of the Basin. However, the Basin has experienced new intense drought conditions post 2011–12. In this paper, we use various climatic and hydrological variables including rainfall, soil moisture and streamflow to assess the severity of the drought in the Basin. Storage volumes and water market prices provide an indication of the impact of the drought on water availability.

Low rainfalls since 2012–13 led the Basin into drought. The contributing factors are a mixture of consistently rising temperatures and deficits in rainfall resulting in below average streamflows and declining groundwater and storage levels. During the July 2013 to June 2019 period; fifty per cent of the whole Basin experienced either severe or serious rainfall deficiencies. As a consequence, in the last 24-month period, soil moisture deficiencies were more than that during the most deficient 24-month period during the Millennium Drought. During the post 2011–12 period, 90 per cent of the gauges in Namoi, Gwydir and Border Rivers catchments of the northern Basin- recorded very-much-below-average flows.

The impact of drought on water availability is apparent from the total accessible storage volume across the Basin, which has declined to below 40 per cent by the end of 2018–19. In the northern Murray–Darling Basin, storage volume declined to nine per cent, a level as low as observed during the Millennium Drought.

Water market activity in the Basin is greatly influenced by the availability of water. During the low water availability years from 2012–13 to 2018–19 the demand for water rose and the price started to increase. In 2018-19, competition for very limited seasonally allocated water increased markedly, pushing the price up to record levels. Given the drought, prices for high reliability long-term water entitlements also hit unprecedented levels in 2018-19. Consumptive water use in the Basin declined when water availability was low and showed increased dependency on groundwater.

The post 2011–12 drought in the Murray–Darling Basin has in many ways been no less severe than the Millennium Drought; rather it can be considered as being more intense in many parts, especially in the north, even though up to the end of 2018–19 it may not have run its full course.

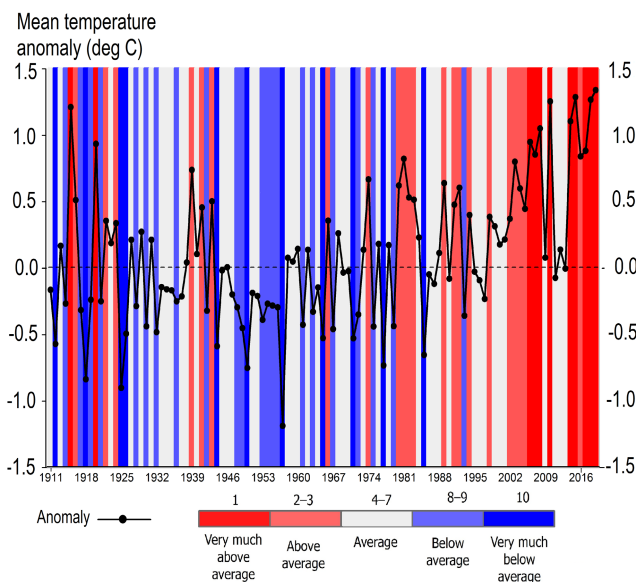
**Keywords:** *Drought, rainfall deficiency, consumptive water use, water trading*

### 1. INTRODUCTION

In the Murray–Darling Basin (the Basin), the largest and most complex river system of Australia, water is a most precious resource for Australia’s food supply and for the survival of the communities and industries in the Basin. The Basin has a highly variable rainfall pattern that is strongly influenced by several climate drivers including the El Niño–Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD). Despite the large natural variability, underlying long-term trends are evident and there has been a shift towards drier conditions across much of the Basin (BoM 2019d). Drought in the Murray–Darling Basin is not an uncommon phenomenon. In the last hundred and fifty years, the Basin has experienced a number of major droughts such as the Federation drought, the World War II drought and the Millennium Drought. In the years post 2011–12, of low rainfalls have resulted in a new drought in the Basin since the Millennium Drought was broken by the floods of 2010. Various climatic and hydrological variables, including rainfall, soil moisture, streamflow and groundwater can be used to assess the severity of drought. Changes in the storage volumes and water market prices provide an indication of the impact of drought on water availability in the Basin. In this paper, we investigate the severity of the post 2011–12 drought by exploring the climatic and hydrological variables between 2012–13 and 2018–19. The impact of this drought on water resources availability and water use are also discussed.

### 2. CLIMATIC VARIABLES

Drought in general refers to an acute water shortage and rainfall is the most suitable climatic variable to assess the incidence of this. Temperature and evaporation can also play a significant role in intensifying the severity of drought by facilitating evaporation.



**Figure 1.** Annual mean temperature deciles and anomalies (calculated from the 1961–1990 average) of the Murray–Darling Basin from July 1911 to June 2019.

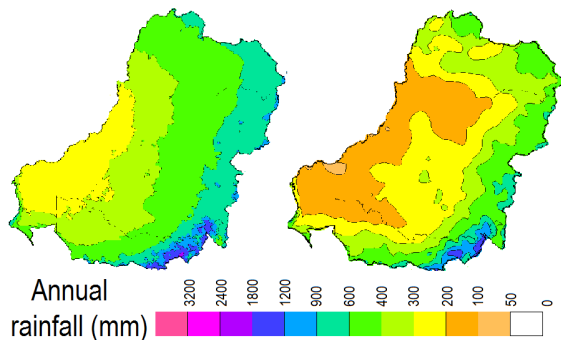
#### 2.1 Temperature

Warm temperatures dominated Australia's climate during 2018–19, especially in the Murray–Darling Basin, which experienced the highest on record mean annual temperature. Droughts are often associated with positive temperature anomalies and temperature anomalies for comparable periods of historical dry years (such as 1972, 1982, and 1994) were around 1 °C above the mean (BoM 2019e). However, this year’s anomaly was 1.33 °C above the average and the upward trend in anomalies indicates the possibility of future warmer dry years. The post 2011–12 drought is characterised by warm conditions in the Pacific and Indian Oceans leading to reduced rainfall over Australia, an increase in temperature and a reduction in wet season rainfall in southern Australia (BoM, 2019d). Very much above–average temperatures have been observed in the Basin since 2013–14 (Figure 1). These continuous warm temperatures have facilitated evaporation in

the Basin and hence the intensity of drought. In 2018–19, the northern part of the Murray–Darling Basin experienced the highest–on–record summer potential evaporation in the previous 30-year period.

#### 2.2 Rainfall

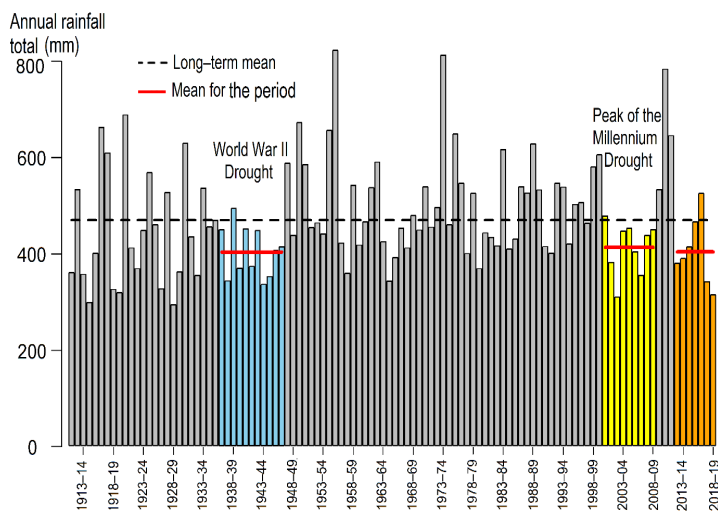
The long-term mean annual rainfall of the Murray–Darling Basin exhibits a strong east–west gradient (Figure 2a) and has a spatial average of 468 mm. In the north, rainfall is summer dominated while winter rainfall dominates in the south. Year to year variation of rainfall is high in the north–west and lower in the south–west (CSIRO 2008). Dry conditions started to develop in many parts of the Basin from 2012–13 and continue to the year 2018–19 (Figure 3), which was especially dry across much of the Basin (Figure 2b). The 2018–19 annual rainfall for the Basin (313 mm) was the fourth lowest on record since 1911–12 and the lowest since the



**Figure 2.** Rainfall in the Murray–Darling Basin (a) Long–term annual mean and (b) 2018–19.

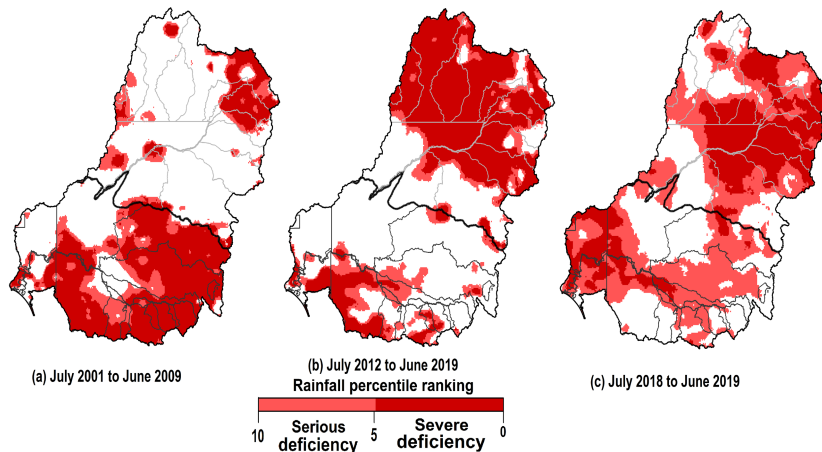
Millennium Drought. The dry period of 2012–13 to 2018–19 was distinct with a low mean rainfall of 403 mm that was close to the mean rainfall (411 mm) during the 2001–2009 peak period of the Millennium Drought (Bureau of Meteorology, 2015).

Drought implies rainfall below a relatively low threshold for a given period. One of the simplest indicators of a drought is rainfall deficiency calculated as the first decile of accumulated rainfall for a given period (Gibbs and Maher, 1967). Rainfall deficiencies are severe when they are in the lowest five per cent and serious when they are in the lowest ten per cent. Figure 4 shows the rainfall deficiencies in the Basin for the peak period of the Millennium Drought, post 2011–12 and during 2017–18.



**Figure 3.** Temporal variability of annual rainfall totals from 1911–12 to 2018–19.

The spatial pattern of the rainfall deficiencies of the post 2011–12 dry period (Figure 4b) is quite different to that during the peak period of the Millennium Drought (Figure 4a). The deficiencies during the Millennium Drought were more prominent in the southern part of the Basin with 45 per cent of the area experiencing rainfall deficiencies (32 per cent severe and 13 per cent serious). Over the 84-month dry period from 2012–13 to 2018–19, severe rainfall deficiencies extended across 37 per cent of the Basin, and an additional 13 per cent of the Basin experienced serious deficiencies. These deficiencies were mostly concentrated in the northern part of the Basin.



**Figure 4.** Rainfall deficiency in the Murray–Darling Basin (a) peak period of the Millennium Drought July 2001 to June 2009, (b) July 2012 to June 2019 and (c) July 2018 to June 2019.

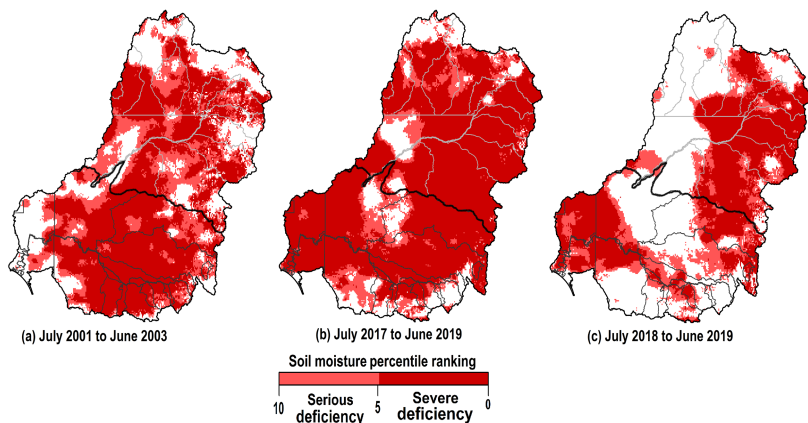
The driest year of the post 2011–12 period was 2018–19, when 65 per cent of the Basin (Figure 4c) suffered from rainfall deficiencies. Most of the catchments in the northern Basin (Boarder River, Namoi, Condamine, Gwydir, Macquarie–Castlereagh) were severely affected. In the southern Basin the Lachlan, Murrumbidgee, South Australian Murray and Mallee–Wimmera were among the most affected catchments.

### 3. WATER RESOURCES

Low rainfall and high temperature for the period 2012–13 to 2018–19 had profound impacts on the water resource in the Basin as indicated by changes in soil moisture, streamflow and groundwater.

### 3.1 Soil moisture

The deficiency in lower soil moisture (estimated using the Australian Landscape Water Balance model AWRA-L daily soil moisture data from 10 to 100 cm of the soil profile) followed the trend of the rainfall but was more intense as soil moisture deficits accumulate over time. Despite the dry conditions that developed in the Basin from 2012–13, the residual effect of the preceding three wet years kept the soil moisture in average conditions until 2015–16. From 2016–17 to 2017–18 soil moisture conditions moved from very much above average to very much below average. These very dry conditions continued into 2018–19. Over the two years of July 2017 to June 2019, soil moisture deficiencies spread across 86 per cent of the Basin (Figure 5b). This is comparable to the worst deficiencies in any two-year period (during July 2001 to June 2003) of the Millennium Drought when the deficiencies spread across 76 per cent of the Basin (Figure 5a).

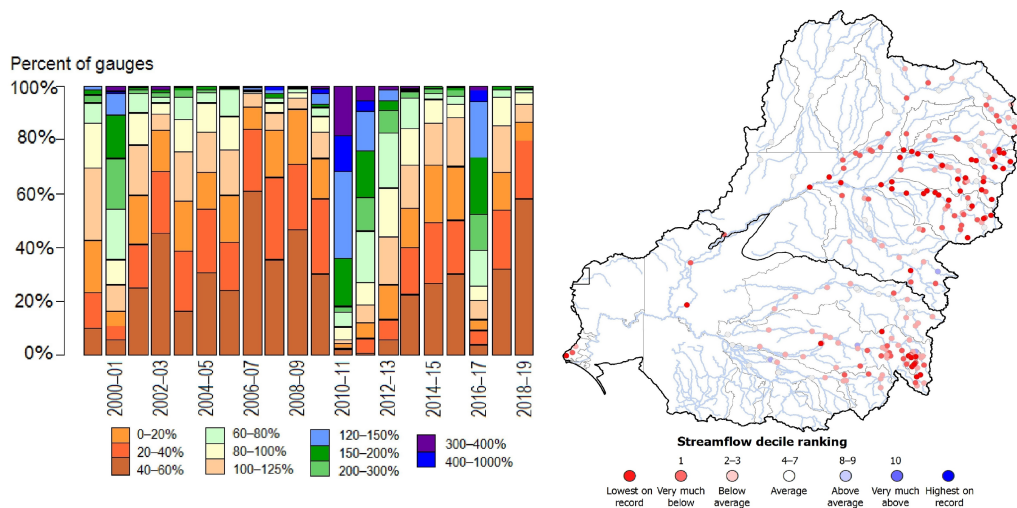


**Figure 5.** Lower soil moisture deficiency map for the Murray–Darling Basin for (a) July 2001 to June 2003, (b) July 2017 to June 2019 and (c) July 2018 to June 2019.

In 2018–19, except the areas in north west and centre of the Basin the rest of the Basin suffered from soil moisture deficiency. Thirty seven per cent of area experienced severe and 31 per cent area serious deficiencies (Figure 5c) that extended over the Border Rivers, Gwydir, Namoi, Macquarie–Castlereagh and Condamine catchments of the northern Basin together with the Lachlan, South Australian Murray and Mallee–Wimmera catchments of the southern Basin. These deficiencies in

soil moisture exerted moisture stress on vegetation and increased the impact on agriculture.

### 3.2 Streamflow



**Figure 6.** (a) Distribution of gauges based on percentage of long-term mean annual streamflow, (b) Streamflow deciles for 2018–19 in the Murray–Darling Basin.

Low rainfall since 2012–13 led to low runoff generation resulting in a pre-dominance of lower-than-average streamflow. The most affected areas recording lower-than-average flows in the northern Basin were Border Rivers, Gwydir, Namoi, Macquarie–Castlereagh catchments - mostly in their headwater areas. The affected areas in the southern Basin were in the Murrumbidgee and Lower Darling catchments. In the Namoi, Gwydir and Border Rivers catchments, 90 per cent of gauges recorded very-much-below-average flows between 2012–13 and 2018–19, while lower-than-average flows were recorded in one-third of the gauges in the



Murrumbidgee catchment. Although below average flows in the post 2011–12 period were widely distributed across the Basin, the majority of them (including lowest on record flows) were in the northern part of the Basin. Since 2012–13, there was a reduction in annual flows at stream gauges in the Basin and a gradual increase in the percentage of gauges observing low flows. The exception was during 2016–17 when increased flows were observed due to above average rainfall. In 2018–19, around sixty per cent of the gauges received less than 20 per cent of the long-term mean flow (Figure 6a) which is comparable to the worst year during the Millennium Drought (2008–09). However, the impacts of the post 2011–12 drought are more severe in some areas than those of the Millennium Drought. During 2018–19 (Figure 6b), 80 per cent of the streamflow gauges in the Murray–Darling Basin recorded lower-than-average streamflow, and over fifteen per cent gauges observed their lowest flow on record.

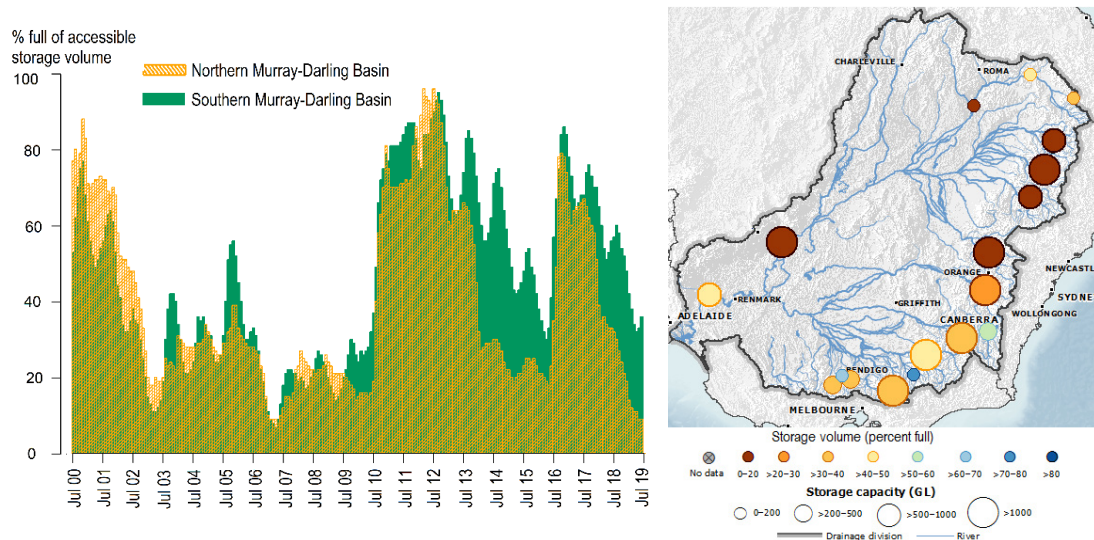
### 3.3 Groundwater

Reduced recharge from rainfall or surface water, and increased groundwater extraction because of drought can affect groundwater levels. Declining groundwater levels have been recorded in many regions of the Murray–Darling Basin due to drought. The annual peak groundwater levels during 2018–19 were below average in 83 per cent of the 632 assessed bores in the Basin. Of these, 20 per cent recorded the lowest on record levels, i.e. lower than those at the end of the Millennium Drought (BoM 2019a). Groundwater level recovery was assessed to understand the impact of the drought on groundwater by creating decile rankings of maximum groundwater levels. Bores in the southeast of the Murray–Darling River Basin, such as Murrumbidgee and Murray–Riverina, tended to be lower overall. In these bores, the maximum recovery level is lower than at any time since 1992. This aligns with long-term rainfall deficiencies and lower-than-average streamflow patterns in these areas; groundwater response to the longer-term drivers (dry conditions before 2018–19); and the influence of increased groundwater extractions. Lower-than-average levels were observed in the bores in the alluvial aquifers of the Darling River Basin, especially in the Macquarie, Namoi, Gwydir and Border catchments. Lowest on record was observed in thirty per cent of these bores (BoM 2019b) which may be due to both increased extraction and reduced recharge over several years.

## 4. WATER AVAILABILITY AND MANAGEMENT

Water availability in the Basin is primarily influenced by the spatial and temporal variability of rainfall and high temperatures facilitating evaporation. Storage conditions and the water market dynamics reflect the impact of drought on water resources management. Abstractions for consumptive water use, especially for agriculture, show the impact of drought on water availability.

### 4.1 Storage

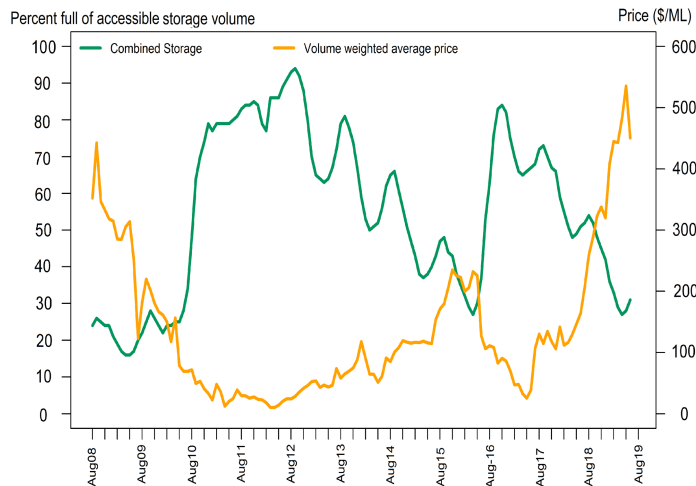


**Figure 7.** (a) Accessible storage volume in northern and southern Murray–Darling Basin, (b) Storage condition by the end of June 2019 (BoM 2019c).

The storage volume in the northern Basin started to decline from January 2014 but recovered after the wet year of 2016–17. Since July 2017, storage volumes have continued to fall and from January 2018, the total storage volume was again reduced to below 40 per cent. Given the distinct spatial characteristics of the recent and the Millennium Drought, there is a marked difference in the total accessible storage volume in northern and

southern Basins. Storage volume in the northern Murray–Darling Basin declined to nine per cent full by the end of 2018–19, as low as the level in May 2007 during the Millennium Drought (Figure 7a). As the post 2011–12 drought is concentrated more in the northern Basin, the total storage volume in the southern Basin has not reached the low level (11 per cent in April 2007) observed during the Millennium Drought. While the total storage capacity in the northern Murray–Darling Basin are smaller than in the south, less water can be stored for consumptive use, and they crucially feed the Darling River system, which has consequently seen record low streamflow in 2018–19. The impact of drought is apparent from the total accessible storage volume in the Basin, which has declined to below 40 per cent by the end of 2018–19 - 18 per cent lower than the previous year. Figure 7b highlights the low storage volumes in June 2019 throughout most of the Murray–Darling Basin, particularly in the northern part of the Basin due to the low rainfall and dry soils prevalent here.

#### 4.2 Water markets



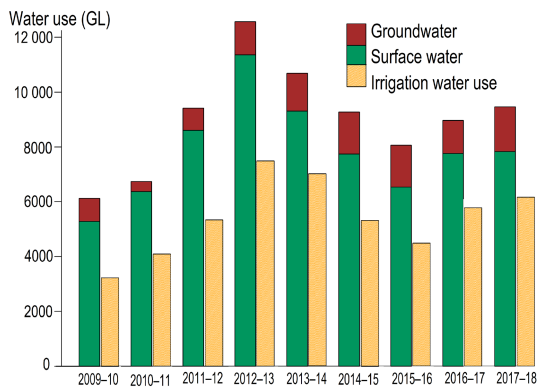
**Figure 8.** Total accessible storage volume and water market price for surface water in the southern Murray–Darling Basin.

Water markets in the Basin are greatly influenced by the changes in availability of water during drought. The demand for water increased during the years 2012–13 to 2018–19 and the price followed the trend of demand. In 2018–19, competition for the very limited seasonally allocated water increased markedly pushing the price up to record levels. Given the drought, prices for high reliability long-term water entitlements also hit unprecedented levels in 2018–19. The most significant increases in prices from 2013–14 to 2017–18 were observed in the Murrumbidgee high and general reliability entitlements, and for New South Wales Murray high-reliability entitlements, which all saw increases of more than 100 per cent in four years.

Very low water availability has been a driving factor for water trading in both the northern and southern Basin in the last two years dry period. At the same time, demand for water for higher value crops such as cotton and horticulture has increased in regions such as the lower Murray in the southern Basin. Allocation prices (for seasonally available water) have hit record highs of around \$600/ML in the southern Basin (up from less \$20/ML in 2016–17). In addition, prices for high reliability long term water entitlements (or licences) in the lower Murray have reached record levels. In the northern Basin, water markets operate as individual isolated markets as each catchment is not hydrologically connected. With very low water availability, prices for entitlements in the Namoi and Gwydir catchments increased from \$500-1000 to \$2000-2500 per mega litre, between 2017–18 and 2018–19, respectively.

#### 4.3 Water availability for consumptive use

Abstraction for consumptive water use in the Basin has roughly followed the pattern of water availability (as represented by the water in storages in Figure 7a). In three years, that followed the break of the Millennium Drought in 2009–10 the consumptive use doubled and gradually declined afterwards due to the drop in the water availability in the Basin. The wet year of 2016–17 saw a rise in consumptive use, which was then constrained by intensification of the drought in the Basin. The biggest proportion of abstraction for consumptive use in the Basin is for irrigation. The contribution of carry-over (the unused allocation from the previous year) uses by irrigators during the post 2011–12 period compensated to a large extent the decline in water availability, and did not allow the water use to fall to the Millennium Drought levels when the carry-over rules were not as widely established (Figure 9). The rise in the water use in this period was driven mostly by irrigation of almond orchards and cotton in the southern Basin. The use of groundwater has gradually increased in the Basin during the drought periods as a supplementary water source (Figure 9). The growth in groundwater use has been observed in less connected systems such as in Lower Murrumbidgee Deep Alluvium (MDBA, 2019).



**Figure 9.** Historical consumptive water use (BoM, 2018) and irrigation water use (ABS, 2019) in the Murray–Darling Basin.

The increase in groundwater use has been influenced by lower surface water availability, changes in land use and policies such as the cap on surface water diversions. Replenishment of groundwater supplies has been affected by reduced rainfall and streamflow in the Basin and increased abstractions. The combined impact of extraction and reduced recharge will be critical in prolonged drought, particularly in shallow aquifers with high connectivity to surface water and relatively smaller volume of water storage capacity.

## 5. DISCUSSION AND CONCLUSION

In this paper, we explored the combined effect of climatic and hydrological parameters on the severity of the post 2011–12 drought in the Murray–Darling Basin. Dry conditions started to develop in 2012–13 and at the end of a seven-year period fifty per cent of the Basin had experienced rainfall deficiencies. The affected areas were mostly in the northern Basin and the Wimmera–Mallee region of the southern Basin. This pattern is different from that during the peak of the Millennium Drought when dry conditions were mostly concentrated in New South Wales and in the Victorian catchments of southern Basin. The rainfall deficit in 2012–13 was exacerbated by the rising temperature which facilitated evaporation and lowered soil moisture. The combination of low rainfall and ongoing dry antecedent conditions resulted in lower than average streamflows in most areas; especially in the headwaters of the northern Basin. In the New South Wales catchments in the eastern part of the southern Basin, very much below average streamflows were prevalent for the whole period. The 2017–18 to 2018–19 soil moisture deficiencies were higher compared to the most deficient two year period during the Millennium Drought. By the end of 2018–19, water availability was at a minimum in the northern water storages, comparable to that during the Millennium Drought. Abstraction for consumptive water use was restricted by the ongoing drought in the Basin and was supplemented to an increased extent by groundwater. Low water availability, although not at the Millennium Drought levels, significantly impacted the water markets, driving the average allocation prices to record high levels. The post 2011–12 drought in the Murray–Darling Basin has in many ways been no less severe than the Millennium Drought; rather it can be considered as being more intense in many parts, especially in the north, even though up to the end of 2018–19 it may not have run its full course.

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