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Climate Change Reduces Darling River Water Levels by Decreasing Eastern Australian Rainfall

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Accelerated warming influence on east Australian river levels

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Abstract

Significantly decreased rainfall run-off into the dams that feed the Darling River in eastern Australia during the Millennium (1997–2009) and Tinderbox (2017–2019) Droughts coincided with reduced river levels along the Darling River. The rainfall reduction was due to accelerated global warming since the mid-late 1990s. During this period, unmonitored river water extraction from the streams that feed the Darling River was diverted to crops, on-farm dams, and to storage in the Menindee Lake system. This practice exacerbated the effect of the two droughts because streamflow that reaches the Darling River ceased in several upstream rivers, and in the Darling River. Using Darling River height levels, before and after the mid-late 1990s, it is shown that global warming is the key factor reducing Darling River levels in the last 53 years, even allowing for river water diversion and extraction. Between the periods 1972-1997 and 1998-2024 the Darling River mean heights, in the towns of Bourke, Wilcannia and Menindee, were all found to drop by statistically significant amounts. The catchment area rainfall has found to be decreasing due to global warming induced atmospheric circulation changes. Reducing water extraction either before or after it reaches the Darling River is unlikely to stop the short-medium term decline in Darling River levels.

Introduction

The Darling River runs from the town of Bourke to the Murray River, forming Australia's major river system, referred to as the Murray-Darling Basin (MDB) (Figure 1). The Darling River flows through the northern MDB (NMDB) before joining the Murray River (Figure 1). The indigenous river name was the Baaka, but it was renamed as the Darling River in 1829. It has a long history as a navigable waterway, transporting passengers and goods on shallow, flat-bottom paddle steamers. The Darling River became a major transportation route from the late 19th Century to the early 20th Century, despite the irregularity of its water levels and the frequency of drying up.

When navigable by boat, the Darling-Murray system could be likened to the United States Mississippi-Missouri River system, but on a much smaller scale. Midway along the Darling River, near Wilcannia, fish traps have been identified as being used by indigenous people to the area as a food source, for an estimated

Figure 1. Map of eastern Australia showing the Murray and Darling Rivers and their tributaries in the Murray-Darling Basin (MDB). Northern MDB catchment rainfall sites used in the study (red font): Augathella (A); Cunnamulla (C); Normandy (N); Surat (S); Miles (M); Bellata (BE); Bingara (BI); Curlewis (CU). Darling River level sites using archived monthly river level data (black font): Bourke (B); Wilcannia (W); Weir32 (W32). Other locations marked are states and cities.

Figure 2. Paddle steamers and river boats on the Darling River, near Wilcannia (approximately 1913–1919). State Library of South Australia, B 3456.

30,000 years and the river has been an indigenous water resource for even longer [1]. In recent decades water has been extracted from farther upstream tributaries for agriculture, on-farm dams [2] and downstream to supply Menindee Lakes with water to be pumped about 110 km to the key mining city of Broken Hill with potable water [3]. The Darling River has suffered numerous periods of poor water quality. Notably, the heavy rainfall events of 2010-2011 dramatically improved the streamflow. However, subsequent droughts, expanded irrigation, increased salinity, and pollution from farming pesticides and herbicides, have again decreased water levels and quality. Compounding the droughts, the smaller flows that regularly replenished the system now have mostly ceased, although large floods still occur [3]. In addition, the Lakes were drained in late 2016 and 2017, to provide environmental water downstream, after large NMDB catchment rainfall totals occurred in the spring of 2016. Soon after, the Darling River deteriorated again when southeast Australia experienced the "Tinderbox" drought (2017–2019), which was the driest 3-year period on record for the region [4, 5].

The NMDB dam rainfall that feeds the Darling River has been shown to have decreased significantly in April-May, since the 1990s [6,7], precisely when catchment rainfall is necessary to replenish river heights. This is especially the situation when a dry April-May is followed by low to average Spring (SON)/Summer (DJF) rainfall, which often occurs with no Indian Ocean Dipole (IOD) influence in late winter/spring [8], or a La Niña phase in spring/summer [9]. Without catchment "wetting" during April-May, average to below average Winter (JJA) rain provides little run-off into the tributaries that feed the Darling River. A consequence is a high demand for river water from the farms downstream of the dams during the Winter (June-August) to Spring (September-November) growing season, and the Spring-Summer growing season. In the NMDB, large river levels resulting from floods still occur, but are largely controlled by phases of the IOD and La Niña climate drivers mentioned above that influence rainfall from late Winter to Summer [6,7]. Under that scenario, meteorological drought is a key factor affecting both agricultural drought and hydrological drought. A study using 1980-2018 streamflow data for the Darling River [2] found break-point reductions in streamflow of 38% at 1996 and 37% at 2005. They concluded that there was no single breakpoint. On a longer timescale, accelerated global warming (GW) is accepted as dating from the mid-1990s [10–12]. A recent study of NMDB catchment dam rainfall revealed a statistically significant decrease in mean April-May (late Autumn) rainfall since the 1990s [6].

Experimental procedure

From a GW perspective, the impact of reduced water levels in the Darling River with the decreased dam rainfall and reduced inflows is expected to continue for at least the short-medium term. Therefore, this study investigated Darling River levels before and after the mid-late 1990s, during the accelerated GW period.

The differences in the means and variances of the two periods, 1974–1991 and 1992–2024, were tested for statistical significance using sampling without replacement [13]. Then, for the same two periods we test the differences in means and variances between the two periods of the four seasonal groupings of the Darling River levels at three locations: Bourke, Wilcannia and Weir32, downstream of Menindee Lakes (Figure 1).

Data and methods

Monthly Darling River level data are available covering the 53-year period 1972-2024, for Bourke (site No. 425003), Wilcannia (site No. 425008) and Weir32 (site No. 425012) downstream from Menindee Lakes (see Figure 1). These data are downloaded from the archives at the New South Wales State Department of Primary Industries Water website [14]. Monthly catchment rainfall data from 1910 can be downloaded from the Australian Bureau of Meteorology website [15]. The rainfall sites are shown on Figure 1. The precipitation data were summed over all sites to provide a proxy for the total precipitation falling across the entire NMDB catchment area.

The annual means and variances of the Autumn (MAM), Winter (JJA), Spring (SON) and Summer (DJF) seasonal NMDB dam rainfall totals are calculated for the pre- and post- accelerated GW periods, respectively. Two periods, 1972–1997 and 1998–2024, were chosen to represent the pre- and post-accelerated GW periods, respectively. Then, bootstrap resampling without replacement was applied [13], with 5000 resamples, to the means and variances of the Darling River levels and rainfall time series data. This statistical technique can be applied to test significance between two periods of a non-stationary time series as described in previous studies [e.g., 6]. The technique is applied to test significance between the two periods of non-stationary time series as described in a two-sided permutation test of 5000 re-samples without replacement, to assess the statistical significance of any potential trends [13]. A value of $p \leq 0.1$ (90^{th} percentile) is a significant result, and $p \leq 0.05$ (95^{th} percentile) is highly significant.

Results

Seasonal Darling River Catchment Precipitation

The annual Autumn (MAM), Winter (JJA), Spring (SON) and Summer (DJF) time series of NMDB dam catchment rainfall totals for the 110-year period 1910–2019 are shown in Figures 3(a–d). With most annual seasonal totals falling within the 25th and 75th percentiles, it was found that only the annual MAM catchment rainfall exhibits a decreasing trend from the early 1990s to 2019 whereas JJA, SON and DJF show no clear trends. All MAM precipitation totals are at or below the 80th percentile since the early 1990s, except for 2010. Similarly, extreme totals for JJA, SON and DJF have decreased since the 1990s. For JJA, the extreme total in the 10th decile occurred in 1998, which was during the double La Niña of 1998–2000, while a strongly negative IOD in 2016 was responsible for the total just above the 90th percentile. For SON, the two most extreme totals occurred during 1999 and also 2010, which was in the double La Niña of 2010–2012. Again, for DJF, the decile 10 total occurred in 2010. Therefore, excluding the two positive La Niña phases and the strongly negative IOD phase in 2016, since the

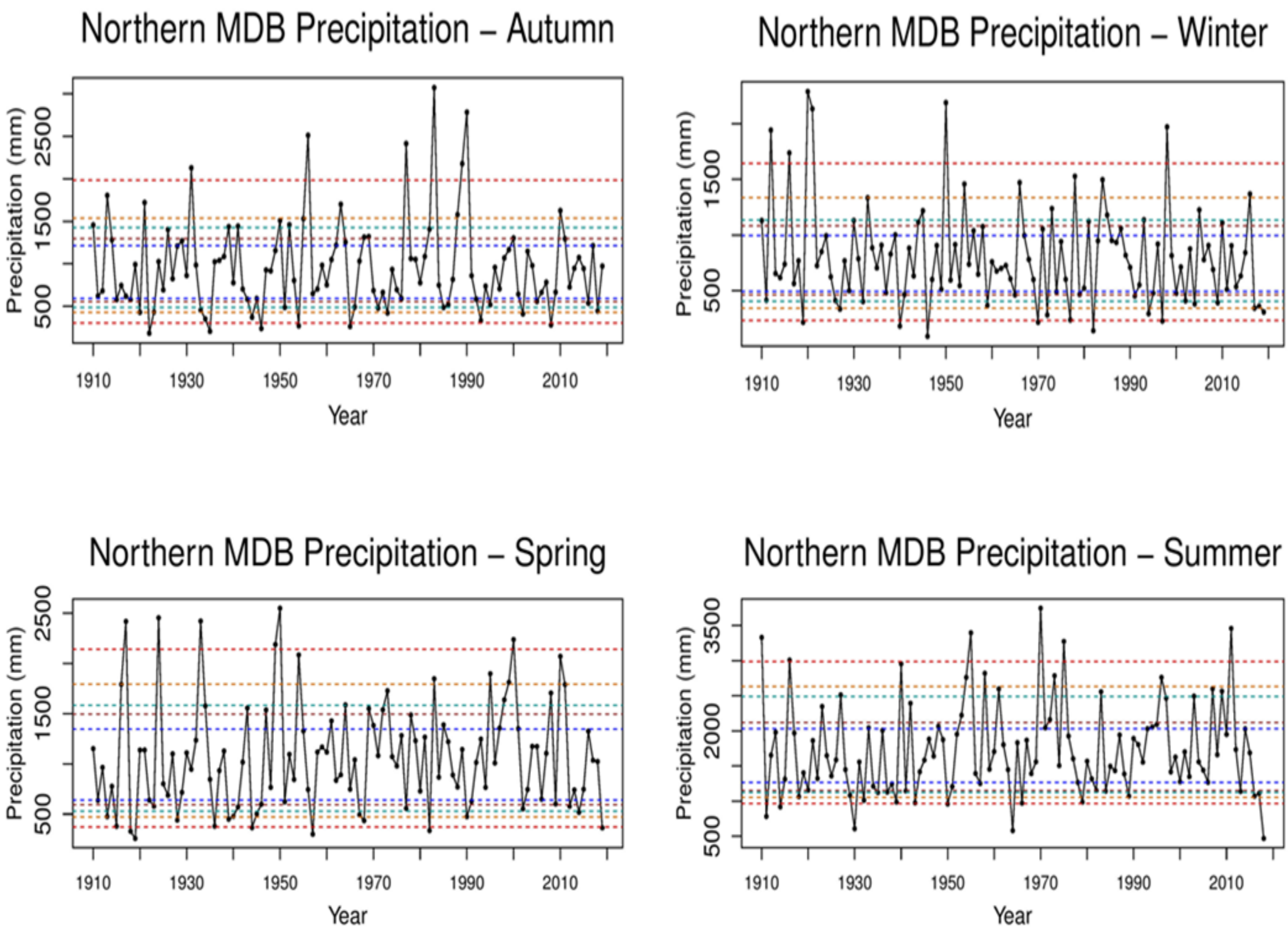

Figure 3. The total precipitation time series for the 8 observing stations in the Darling River catchment for the 1910–2019 period (a–d). The horizontal dashed lines indicate the 5th and 95th percentiles (red); 10th and 90th percentiles (orange); 15th and 85th percentiles (light blue); 20th and 80th percentiles (brown); and 25th and 75th percentiles (dark blue).

Table 1. P-values from permutation testing differences in interval precipitation means and variances from 1965–1991 to 1992–2018 for MAM, JJA, SON and DJF, based on catchment area averages of observing stations in the northeast part of the northern Murray-Darling Basin. Significant values ($p \leq 0.10$) are italicised and highly significant p-values ($p \leq 0.05$) are italicised in bold. Note that the p-value for each variance test is calculated after one sample has had bias correction in the mean. Key point to note is that the significant p-value ($p = 0.079$) for MAM mean precipitation decrease and highly significant p-value ($p = 0.005$) for MAM variance precipitation decrease from 1965-1991 to 1992-2018.

Period	**Precipitation interval p-values**	
	Mean/Variance	**1965–1991 versus 1992–2018**
MAM	Mean Variance	*0.079* ***0.005***
JJA	Mean Variance	0.52 0.956
SON	Mean Variance	0.28 0.25
DJF	Mean Variance	0.859 0.843

1990s, total rainfall is mostly below the 80th percentile for Autumn and 90th percentile for Winter, Spring and Summer,

The p-values for testing the differences in means and variances of total precipitation for the NMDB catchment rainfall between the periods 1965–1991 and 1992–2018 are shown in Table 1.

Darling River Heights

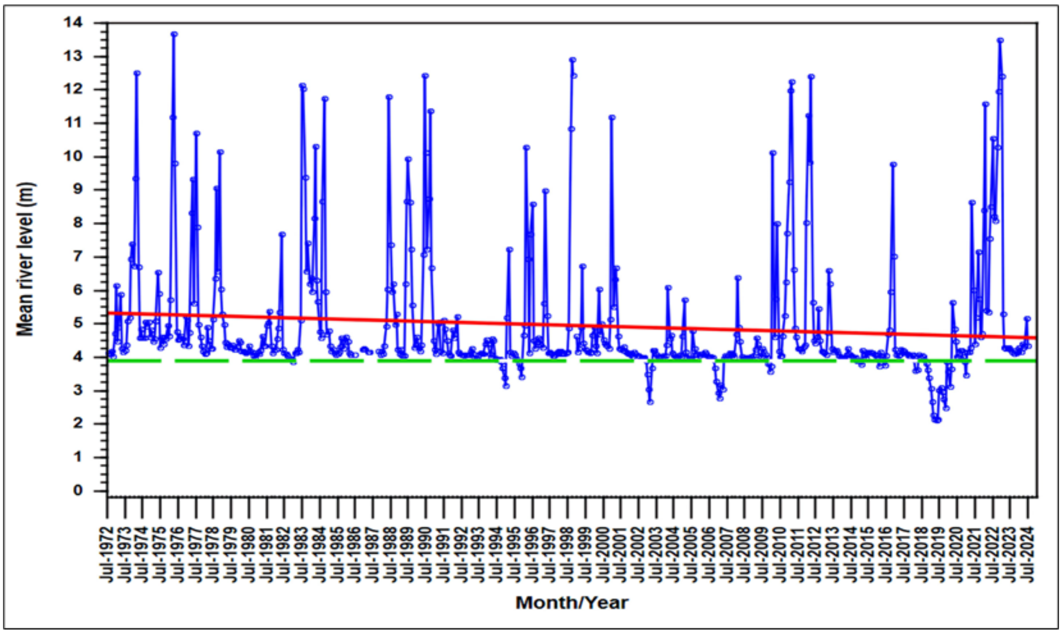

Figure 4a. Average monthly Darling River level at Bourke Town July 1972–July 2024. River ceases to flow at 3.9 m (green dashed line).

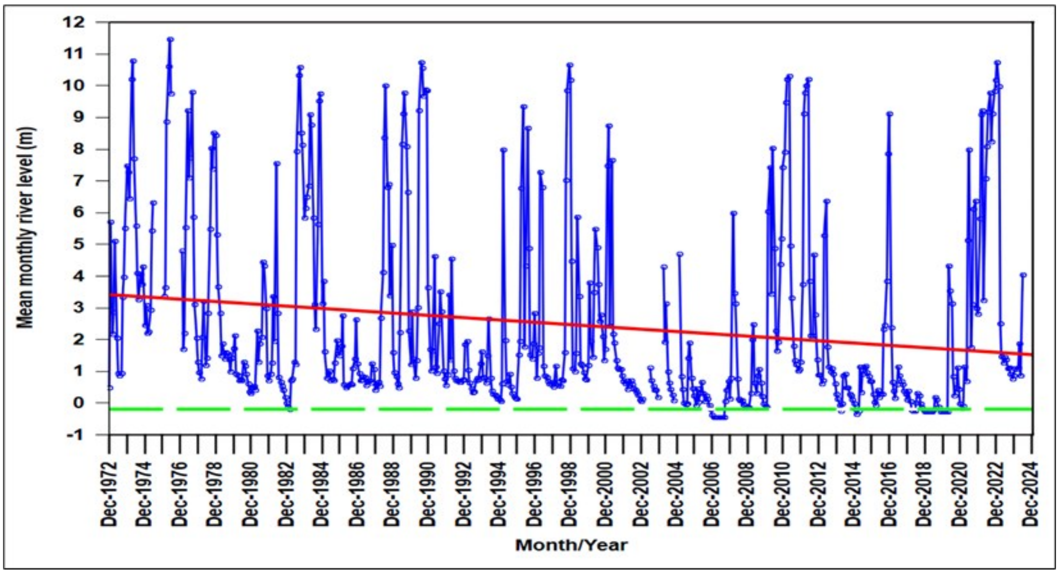

Figure 4b. Average monthly Darling River level at Wilcannia December 1972–July 2024. River ceases to flow at -0.19 m (green dashed line).

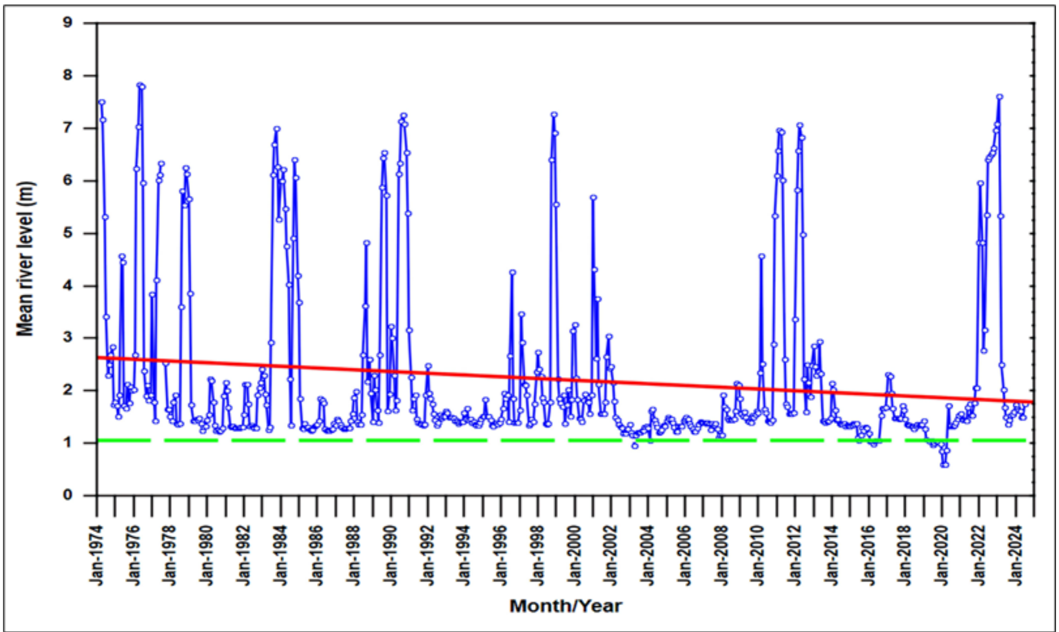

Figure 4c. Average monthly Darling River level at Weir32, downstream from Menindee Lakes, from April 1972–June 2024. River ceases to flow at 1.06 m (green dashed line).

Monthly time series of the river levels at Bourke, Wilcannia and Weir32 (which is downstream of Menindee Lakes) are shown in Figures 4(a-c). At all three locations, periods of both high and low Darling River levels occur before the mid-1990s. After the mid-late 1990s, non-flowing periods occur at Bourke and after 2003 non-flowing periods occur at both Wilcannia and Weir32 locations further downstream. At both Bourke and Wilcannia, the mean monthly Darling River levels above 7 m have decreased by 38%, and 16%, respectively, since 1997, while at Weir32 the decrease above 5 m is 35% since 1997. At these three locations the Darling River has ceased to flow at various times since the 1990s, as indicated in Figures 4(a–c).

Table 2. Mean river gauge heights at three locations along the Darling River showing statistically significant decreases (p-values ≤ 0.10) from 1998.

River gauge location	Darling River mean height (m)		p-value
	1972–1997	1998–2024	
Bourke	5.66	4.23	0.09
Wilcannia	4.04	2.11	0.046
Weir32	2.46	1.31	0.037

The p-values for testing the differences in mean Darling River heights at Bourke, Wilcannia and Weir32 between the periods 1972–1997 and 1998–2024 are shown in Table 2.

Discussion

The significant decrease in Autumn (MAM) precipitation means and variances (Table 1) together with the April to May significant decreases in mean and variance [6] are also consistent across other studies for southeast Australia [7,16]. Average annual inflows to the Murray River in the southern MDB from 1900–1999 have decreased from 9,407 GL per year to 4,820 GL per year (51%) since 2000 [17]. Furthermore, the April to May decrease in the southern MDB [16] has resulted in a river level decrease of 30% for the Murrumbidgee River since the 1990s. More than 90% of water extraction for irrigation occurs downstream of Wagga Wagga [16]. This implies that the primary cause of the 30% decrease in the Murrumbidgee River level in the southern part of the MDB since the 1990s is the decrease in April to May catchment rainfall and, for the NMDB, is likely the main cause of the Darling River level decrease due to its autumn catchment rainfall decrease.

Owing to the Millennium and Tinderbox Droughts since the 1990s, there are periods of very low flow and periods when the Darling River ceases to flow, as shown in Figure 4. In the study by [2], it was concluded that meteorological drought contributed about 1/3 to the decrease in Darling River levels compared to the contributions from water extraction and hydrological drought. However, this estimate underplays the significance of meteorological drought because without it there should far less or no agricultural or hydrological drought. The NMDB dams hold only about 1/5 the capacity of the southern MDB dams. It is correct that those dams with less capacity will reduce water availability even more quickly when water extraction is occurring. Clearly, the smaller the dam capacity the more important is the length and intensity of meteorological drought. Smaller flows that once regularly replenish the Darling River system have mostly ceased because atmospheric circulation changes due to accelerated global warming now predominantly occur irregularly in late Winter/Spring when there is a favourable IOD phase or in Spring/Summer in a moderate or strong La Niña phase [18]. The same seasonal patterns of rainfall have affected both the southern MDB in April to May and the NMDB in MAM. However, with Autumn and Winter rainfall totals in the NMDB catchment representing the drier part of the annual cycle, the NMDB now can fall rapidly into a flash drought [e.g., 18]. In the southern MDB there has been just one year (2010) when Autumn catchment rainfall exceeded the 80th percentile since the 1990s.

Conclusion

The Murray Darling Basin (MDB) is by far Australia's most important agricultural region. It has suffered a statistically significant Autumn or late Autumn rainfall decrease which, in the case of the Darling River in the NMDB has contributed to sustained lower and highly variable river levels. The reduced streamflow can be traced to accelerated GW since the 1990s. The atmospheric circulation changes are known to have generated fewer rain-producing systems since the 1990s that affect inland southeast Australia, including the NMDB catchment dams, during Autumn [18]. The consequences include more intense droughts (Tinderbox Drought) and flash droughts [18], in addition to the historically longer droughts (Millennium Drought) that continue to occur. Shorter, weaker Darling River flows will continue in a future warming climate. In addition, anthropogenically polluted runoff, particularly from floods, will continue unless policy regulations are enhanced and enforced.

Australia's increasingly variable rainfall, streamflow and landscape conditions create water supply challenges. Therefore, Australia has a massive planning challenge to improve water management, provide greater water security and quality, and protect against ecosystem degradation. Managing environmental water, irrigation water for agriculture, and potable water for communities along the river, will be increasingly difficult.

Australia is far from alone in facing water sustainability and management problems. The Colorado River system in the southwestern USA supplies water for farms, irrigation, and communities totalling tens of millions of people in seven states. The region has experienced a drought lasting over 20 years, resulting in record low water availability, thereby generating an immediate need for the various states to reach both water sharing agreements and to address the climate change impacts driving the reduction in water supply. Water scarcity also is affecting China, with southern China's current record longest drought severely restricting water availability both locally and its delivery to the major industrial regions in northern China. In 2023, when China made its 14th five-year plan, for the first time it addressed the need to confront decreasing water security.

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Conflict of Interest

The authors declare no conflicts of interest.

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