Department of Climate Change, Energy, the Environment and Water

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Baseline climate and hydrological assessment for the NSW Murray and Murrumbidgee regions

Regional Water Strategies Program

May 2024

Acknowledgement of Country

The NSW Government acknowledges First Nations people as the first Australian people and the traditional owners and custodians of the country's lands and water. First Nations people have lived in NSW for over 60,000 years and have formed significant spiritual, cultural, and economic connections with its lands and waters.

Today, they practise the oldest living culture on earth.

The NSW Government acknowledges the First Nations people/Traditional Owners from the NSW Murray and Murrumbidgee regions as having an intrinsic connection with the lands and waters of these areas. The landscape and its waters provide the First Nations people with essential links to their history and help them maintain and practice their traditional culture and lifestyle.

We recognise Traditional Owners as the first managers of Country. Incorporating their culture and knowledge into management of water in the region is a significant step towards closing the gap.

Under this program, we seek to establish meaningful and collaborative relationships with First Nations people. We seek to shift our focus to a Country-centred approach; respecting, recognising and empowering cultural and traditional Aboriginal knowledge in water management processes at a strategic level.

We show our respect for Elders past and present through thoughtful and collaborative approaches to our work, seeking to demonstrate our ongoing commitment to providing places where First Nations people are included socially, culturally, and economically.

As we refine and implement the regional water strategy program, we commit to helping support the health and wellbeing of waterways and Country by valuing, respecting and being guided by First Nations people, who know that if we care for Country, it will care for us.

We acknowledge that further work is required under this regional water strategy program to inform how we care for Country and ensure First Nations people hold a strong voice in shaping the future for all communities.

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Contents

1.Introduction

The NSW Government is investing in regional water strategies for each region across NSW to improve water security and better prepare regions for future droughts.

As part of the development of regional water strategies, we are undertaking cutting-edge scientific modelling to bolster our knowledge and understanding of our water resources and enhance our policies, options and long-term planning, so we can manage our water for the benefit of everyone.

The first sets of documents for the NSW Murray and Murrumbidgee Regional Water Strategies were released in April 2022 for public exhibition. These draft regional water strategies included an overview of regional water resources and the communities and industries reliant on them, as well as a discussion of the strategic challenges and opportunities identified at the time.

As is the case for other regional water strategies, a discussion around how regional water resources across the NSW Murray and Murrumbidgee regions are impacted by a range of climate scenarios is required to progress and finalise these strategies. Baseline hydrological modelling results were not able to be completed in time for the release of the draft strategies due to the size of this task for these regions. Instead, the draft strategies included discussion of climate challenges based on existing hydrological analyses from the NSW Murray and Murrumbidgee regions, and new climate analyses for nearby regions.

The baseline hydrological modelling results for the draft NSW Murray and Murrumbidgee Regional Water Strategies have now been produced. This document presents these results including key implications for regional water resources. Releasing this base set of results is intended to inform public understanding and discussion about the range of potential climate challenges the water resources of the regions may face into the future. Discussion of these challenges has been included in the draft regional water strategy discussion papers for the NSW Murray and Murrumbidgee regions, alongside this report.

The new hydrological modelling data will also be used to analyse certain options identified in the draft regional water strategies to inform community consideration of options and decision-making. The results of those options analyses are expected to be released in 2023, as part of a third set of regional water strategy consultation papers.

The work undertaken here would not be possible without the generous inputs from various agencies across southern NSW and interstate, including:

- Snowy Hydro Limited

- Murray–Darling Basin Authority
- Victorian Department of Environment, Land, Water and Planning
- University of Adelaide and HARC consultants
- ACT Government and Icon Water
- councils and local water utilities throughout the regions.

2. Climate scenarios

Recorded historical hydrological data is used to underpin the periodic reviews of NSW water sharing plans and development of water resource plans, as well as many aspects under the NSW *Water Management Act 2000* including available water determinations and other operational decisions. This will continue to be the case for such purposes.

To improve strategic water planning initiatives, new ground-breaking climate datasets and hydrological modelling, developed for the Regional Water Strategy program, provide a complementary understanding of the climate variability in the NSW Murray and Murrumbidgee regions beyond the recorded historical data.

To support the development of the draft NSW Murray and Murrumbidgee Regional Water Strategies, this document presents climate and baseline hydrological modelling results under three plausible climate scenarios and their respective implications for regional water resources:

- historical climate
- long-term historical climate
- dry future climate.

The historical climate scenario is based on 130+ years of recorded daily rainfall, temperature and evaporation[1] data for 1889–2020. This scenario is useful to understand how climate challenges and proposed regional water strategy options would respond under a repeat of recorded climate conditions.

The long-term historical climate scenario is derived stochastically from historical daily climate data and paleo climatic information. For example:

- 500 years' worth of climatic patterns detected in paleo records such as tree rings, river sediments, cave deposits, ice cores, etc. This data shows us that longer and deeper droughts have occurred prior to observed climate data as well as stronger wet periods, compared with the instrumental record.
- records and scientific understanding about major climate drivers for the southern Murray–Darling Basin, including the Inter-Decadal Pacific Oscillation Index.

[1] Australian and regional high-quality pan evaporation timeseries are available from 1975 for annual, seasonal and monthly evaporation totals, as well as for southern and northern wet season totals. Prior to 1970, Australia's evaporation pan network was too sparse for meaningful analysis. Source: Bureau of Meteorology, About the pan evaporation timeseries graphs, www.bom.gov.au/climate/change/about/evap_timeseries.shtml

This scenario is useful to understand how climate challenges and proposed regional water strategy options would respond under a repeat of the extremes of droughts and wet periods that are possible in the historical record, based on the long-term historical data.

The dry future climate scenario was developed by adjusting the long-term historical climate scenario rainfall, temperature, and evapotranspiration data according to regionally downscaled factors generated from the NSW and Australian Regional Climate Modelling (NARCliM) 1.0 project. The adopted dry future climate scenario is the Special Report Emissions Scenarios (SRES) A2, which represents a high carbon emissions scenario, and thus results in higher projected climate change impacts on the region at 2060-79. This emissions scenario was selected for the regional water strategy program across NSW to understand how a drying climate would impact regional water resources and performance of options identified for regional water strategies. This is not a forecast of how climate change is expected to eventuate but is one of the possible future outcomes that a long-term water strategy needs to be cognisant of.

Combined, these three scenarios provide us with a wide range of plausible climate scenarios, that cover a range of wet and dry sequences.[2]

[2] For further details about the new climate data and modelling, please refer to www.dpie.nsw.gov.au/water/plans-and-programs/regional-water-strategies/climate-data-and-modelling

About the climate change projections

The rainfall and evapotranspiration data that represents the dry future climate scenario used in the regional water strategy modelling was obtained from the CSIRO's Mk 3.0 global climate model and downscaled, under the NARCliM 1.0 project to a level that is useful for regional NSW locations, such as the NSW Murray and Murrumbidgee regions.

An emissions scenario, SRES A2, was selected to understand how proposed options in the draft strategies would respond under the driest of stress-tests in a future where the global response to curbing carbon emissions is slow.

This does not mean that this is the only future climate scenario being considered. As described above, regional water strategies also consider how a future climate may look like under a repeat of the last 130 years or the long-term past where there have been worse droughts and stronger wet periods.

About the SRES A2 scenario

The United Nations' Intergovernmental Panel on Climate Change[3] explains that the SRES A2 scenario describes a very heterogeneous world comprised of self-reliant regions, with well-preserved local identities and a continuously increasing population (15 billion by 2100). Economic development is regionally oriented and per capita economic growth and technological change are more fragmented and slower compared to other emissions scenarios. Potent greenhouse gas such as hydrofluorocarbons and land-use emissions increase rapidly in the second half of the century, and overall emissions in this scenario are the highest of those projected under the other SRES scenarios. This scenario equates to approximately a 2.2 degree increase in average global temperature by 2079 (relative to 1980–1999).[4]

Future climate work for the regional strategies

A pilot study is being progressed by Adelaide University to inform the generation of new climate datasets for the Murrumbidgee and NSW Murray Regional Water Strategies.[5] The aim of this pilot is to determine whether changes in climate in recent decades affect the estimates of present-day climate risk compared with climate risk based on the whole observed historical record. To date, the study has demonstrated that observed rainfall and temperature records in the southern basin experienced statistically significant change over time. Trends of decreasing

[3] UN Environment Program, 2000. IPCC Special Report Emissions Scenarios, Summary for policy makers. www.ipcc.ch/report/emissions-scenarios/

[4] Intergovernmental Panel on Climate Change Fourth Assessment Report. archive.ipcc.ch/publications_and_data/ar4/wg1/en/figure-spm-5.html

[5] Devanand, A., Leonard, M., & Westra, S. 2020, Implications of Non-Stationarity for Stochastic Time Series Generation in the Southern Basins, Pilot Study undertaken by Adelaide University.

autumn and early winter rainfall of 10–20% in southeast Australia since the mid-1990s, and an accompanying decrease in the number of wet days, were at least partly attributable to climate change.

Updating to NARCliM 1.5

The NARCliM project completed NARCliM 1.5 datasets in 2020, delivering updated and expanded projections that use more recent global climate models and two emission scenarios to provide projections out to 2100. These improvements will further advance understanding of plausible future climate conditions and inform future regional water strategies.

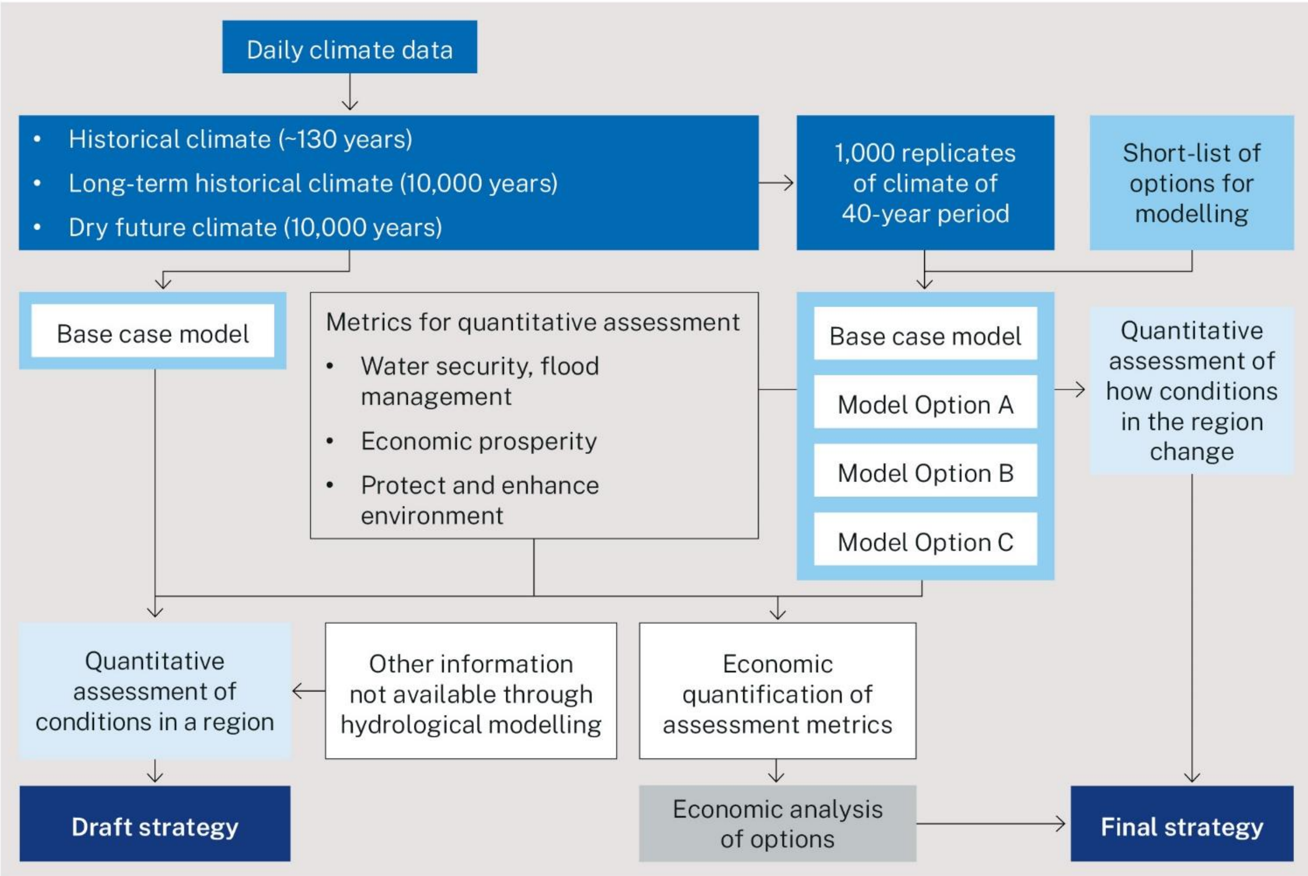
A note of caution

There is always a level of uncertainty with this type of modelling, which needs to be considered as part of any decision-making and planning for water security. In some instances, this may mean managing risks to our water security by being prepared and resilient, rather than relying on firm predictions. As the science develops further, we will be able to reduce or quantify some of these uncertainties.

3. Hydrological model upgrades

The Regional Water Strategies program is supported by a range of river system models that simulate the physical and management processes of river systems over long periods of time. To ensure consistency between the various regional water strategies, a consistent modelling methodology has been applied for climate scenarios, hydrological modelling and options assessment. Figure 1 shows the overall modelling and options assessment methodology.

Figure 1. Regional water strategy modelling and options assessment methodology



Conceptually speaking, the climate data are input into rainfall runoff and snow melt models to provide river system model inflows. The river system models are subsequently run to produce outputs that are used in regional water strategy assessments of water availability, and the analysis of different regional water strategy options.

The regional water strategy model results for this baseline assessment incorporate present day catchment characteristics, infrastructure development, water sharing rules, operations and water use. Given this, the modelled flow outputs under the historical scenario will differ with actual recorded flows and modelling undertaken elsewhere.

The modelling assessments for the NSW Murray region are represented by a suite of models that include the:

- Snowy Hydro Scheme
- Upper Murray above Hume Dam
- regulated Murray River including the Edward/Kolety–Wakool systems
- Goulburn–Campaspe–Coliban–Loddon, Ovens, Kiewa rivers in Victoria
- Eastern Mount Lofty Ranges in South Australia
- Barwon–Darling.[6]

The Murrumbidgee region is represented by a suite of models that include the:

- Snowy Hydro Scheme
- Upper Murrumbidgee upstream of Burrinjuck Dam
- regulated Murrumbidgee River.

The models run on a range of modelling platforms and for different time steps – daily, weekly, and monthly. There are several feedbacks of information between the Snowy, Upper Murrumbidgee, Murrumbidgee, and regulated NSW Murray models. To be able to consider these feedbacks the models typically need to be run through numerous iterations until results converge.

The models are built for the purposes of assessing changes to surface water resources and have not been designed to assess flooding impacts. Past extreme dry and wet (flood) events are accounted for by the variability in the large data sets used. In addition, the models do not currently directly represent groundwater resources, and this will be something explored in the future.

The models have undergone extensive internal quality assurance processes to ensure they are fit for purpose for these regional water strategies.

Specific details relating to the analysis of town water supplies is presented in section 4 below.

A report will be released at a later stage that includes the technical details about the development and implementation of Southern Connected System Integrating modelling undertaken to inform the development of the Murray and Murrumbidgee regional water strategies.

[6] The Barwon–Darling includes contributions from other upstream models.

4. Town water supply shortfalls analysis

To understand high level climate and population growth risks across the Murray and Murrumbidgee regions, assessments have been made of town water demands against available supplies, considering the three climate scenarios – historical climate, long-term historical climate and dry future climate scenarios. For towns that draw water from small, localised town water supply catchments, rainfall-runoff models (with conceptualised town water systems) were run in a single-sequence for the duration of each climate scenario's simulation period (refer to section 2 for details). This covered the towns of Batlow, Bombala and Tumbarumba was based on current population demands as those towns do not have significant projected population growth over the next 40 years.

To assess town water supply shortfalls for Yass, ACT (Queanbeyan), Cooma and towns on the NSW Murrumbidgee and Murray regulated systems based on current and future population demand levels in 2061[7], river system models were setup with current and with future population demand levels, respectively. The models were run using a series of 40-year duration climate data generated for each climate scenario (refer to section 2 for details):

- For the historical scenario – there were 14 of these 40-year runs in each of the two simulations (to examine current population demand levels and future population demand levels in 2061) for towns with significant projected population growth),
- For the long-term historical climate scenario – there were 1,000 of these 40-year runs in each of the two simulations (to examine current population demand levels and future population demand levels in 2061 for towns with significant projected population growth).
- For the dry future climate scenario – there were 1,000 of these 40-year runs in each of the two simulations (to examine current population demand levels and future population demand levels in 2061 for towns with significant projected population growth).

Same initial storage condition was used for all 40-year duration runs. Future population levels are shown in Table 1 below. The increased demands associated with the population projections were

[7] Future population for NSW towns (Table 1) in 2061 and associated demand levels for towns – this uses the 2021-2041 Common Planning Assumption projections, and for 2041-2061 has extrapolated the projected growth rate during 2036-41. Future population of the ACT is based off projections made in July 2017 by the ACT (https://www.data.act.gov.au/People-and-Society/ACT-Population-Projection/nxxv-kkyq) Government and have been combined with Queanbeyan projections. Generally current infrastructure is assumed for all towns, unless stated otherwise.

applied incrementally over the 40-year replicate periods, corresponding to a given year's projected population. These assessments have produced sets of results for town water supply shortfalls.[8]

Table 1. Assumed population projections used in town water supply modelling. Source NSW Common Planning Assumptions 2021. ACT are based of ACT Government projections

Town	Population 2021	Population 2061	2061 population increase
Regulated Murray			
Albury	52,603	102,758	95%
Berrigan Shire	4,499	5,799	29%
Bombala	1,400	no change assumed	0%
Broken Hill	Population not modelled (fixed pattern, limited by pipe capacity)		
Corowa	10,420	11,327	9%
Deniliquin	7,862	7,920	1%
Euston	839	no change assumed	0%
Murray River Council 1	6,558	10,212	56%
Tumbarumba	1,328	no change assumed	0%
Murray River Council 2 (ex. Wakool Shire)	2,358	3,671	56%
Wentworth	4,673	no change assumed	0%
Regulated Murrumbidgee			
Balranald	1,158	no change assumed	0%
Gundagai	2,229	no change assumed	0%
Hay	2,298	no change assumed	0%
Jerilderie	3,895	4,114	6%
Jugiong	17,558	no change assumed	0%
Morundah	12,594	13,688	9%
Tumut	6,086	no change assumed	0%
Unregulated Murrumbidgee			
ACT & Queanbeyan (Combined)	491,502	911,827	85%
Batlow	1,300	no change assumed	0%
Cooma	6,681	no change assumed	0%
Yass	17,442	24,003	38%

Other important notes about this analysis:

- On the regulated river systems, the amount of entitlement available to a town directly affects the prevalence of shortfalls in this analysis. For example, where a town has a water demand that corresponds closely to their amount of water entitlement, then under this analysis they are more likely to record shortfalls due to a growing population causing demand to exceed their full entitlement compared to towns that have demand levels much lower than their entitlement.
- Wagga Wagga, Narrandera and Coleambally were not able to be assessed because a large part of those supplies comes from groundwater. Existing groundwater models were not suitable for simulations. In addition, Griffith and Leeton were also not assessed, as they take

[8] Shortfalls are measured by the number of days where a town's surface water supply is less than its water demand. Here the analysis uses the following percentages 10%, 25%, 50% and 75% as thresholds to show how much demand was not met.

water from within large irrigation schemes, and this would have required extensive data collection and model upgrades to build the irrigation schemes into the model.

- On unregulated river systems, the combination of the amount of entitlement, streamflow volume and capacity of water supply infrastructure (storage capacity) will influence the prevalence of shortfalls in this analysis.
- The demands used in this assessment are unrestricted daily demands, meaning that town water restrictions (that are applied when available supplies reduce to avoid running out of water) were not included.
- The assessment is a high-level comparative analysis, to identify where town water supply shortfall risks could occur across the region, which is complementary to existing work done by councils and local water utilities. The results here are not appropriate for detailed purposes like secure yield analyses or other strategic planning, which is done by local water utilities (councils).[9]
- The analysis provides a relative assessment of water supply shortfall however should not be considered an absolute measure of water security that would consider a range of other factors.
- The purpose of including the results for the ACT is that the NSW town of Queanbeyan is supplied with water from the ACT supply. It is not within the scope of this work to assess the water security needs of the ACT itself. Assessing the water security needs of the ACT is undertaken by the ACT Government according to its own requirements and circumstances, and those differ to those of NSW.
- For towns with projected decreasing population in 2061 the modelling conservatively assumed the same population as the current demand (2021).

Assessing town water security risks

Historically, the department has provided guidance to local water utilities on assessing and adapting to the impact of variable and changing climatic patterns on the secure yield of their town water supplies (TWS) to ensure they have appropriate water supply headworks capacity to ensure levels of service during drought.

'*Secure Yield*' is the water demand that can be expected to be supplied with only moderate restrictions during a significantly more severe drought than has been experienced during

[9] Local water utilities prepare 30-year strategic plans, previously known as integrated water cycle management strategies, to ascertain long-term water infrastructure needs to accommodate population growth in a variable climate. Local water utilities' strategic plans incorporate a secure yield study to identify the capacity and sizing of headworks infrastructure to meet the required levels of service.

observed historical data. The secure yield can be increased by providing larger storages, more water sources, increased transfer capacities or a combination of all three.

The guidelines around the secure yield assessment focuses on using the last 100 or so years of observed historical data and applying a 1-degree warming scenario to understand the volume of storage and water resources needed to allow local water utilities to manage their water supplies though droughts that occur in the forward planning horizon (typically 30 years).

The new data underpinning the regional water strategies include consideration of paleoclimate and climate change impacts in order to develop scenarios of plausible extreme climate events. The regional water strategies have used the scenarios to estimate town water supply shortfalls beyond those that have occurred in the last 100 years and can help understand the level of risk that could be faced by towns in the future over a longer-term planning horizon.

In addition, the methods, models and assumptions for these two types of assessments (town water supply shortfall and secure yield) are different and so produce different results. The town water supply shortfall is used to place an economic value on potential water shortages, whereas the secure yield assessment is used to balance levels of service with the cost of providing the service.

The department will be preparing town water security guidelines on assessing town water security, together with service needs.

5. NSW Murray region results

This section presents the results of the new climate data and hydrological modelling for the NSW Murray region.

5.1 Observed dry and wet periods in the NSW Murray region

The NSW Murray region has experienced extreme droughts over the past 130 years of historical records. The most well-known are the Federation Drought (1895–1902), the World War II Drought (1937–1945) and the Millennium Drought (1997–2009) (Figure 2). A review of the observed historical records indicates that persistent droughts have commonly and increasingly ended with significant rainfall events. For example, significantly above average rainfall in 2010, 2016 and 2020 effectively ended years of below average rainfall.

The most recent drought (2017–2020) includes one of the lowest 24-month rainfall periods across the region and took place against a backdrop of rising temperatures, increasing evaporation and record low rootzone soil moisture (Figure 2). In the 24 months to January 2020, rainfall in the region was 30–40% below average.[10] Later in 2020 and beyond, the region experienced above average rainfall and southern Murray–Darling Basin water storages saw significant increases during 2020 — rising from 37% in March 2020 to 69% at the end of November 2021 and spilling in 2022.[11]

[10] See www.bom.gov.au/climate/drought/ and Bureau of Meteorology 2019, Special Climate Statement 70 update — drought conditions in Australia and impact on water resources in the Murray–Darling Basin.

[11] Bureau of Meteorology 2020, 2020 Annual Climate Statement, www.bom.gov.au/climate/current/annual/aus/2020/

Figure 2 Lowest two-, three- and ten-year average rainfall in the NSW Murray region (1890–2020)

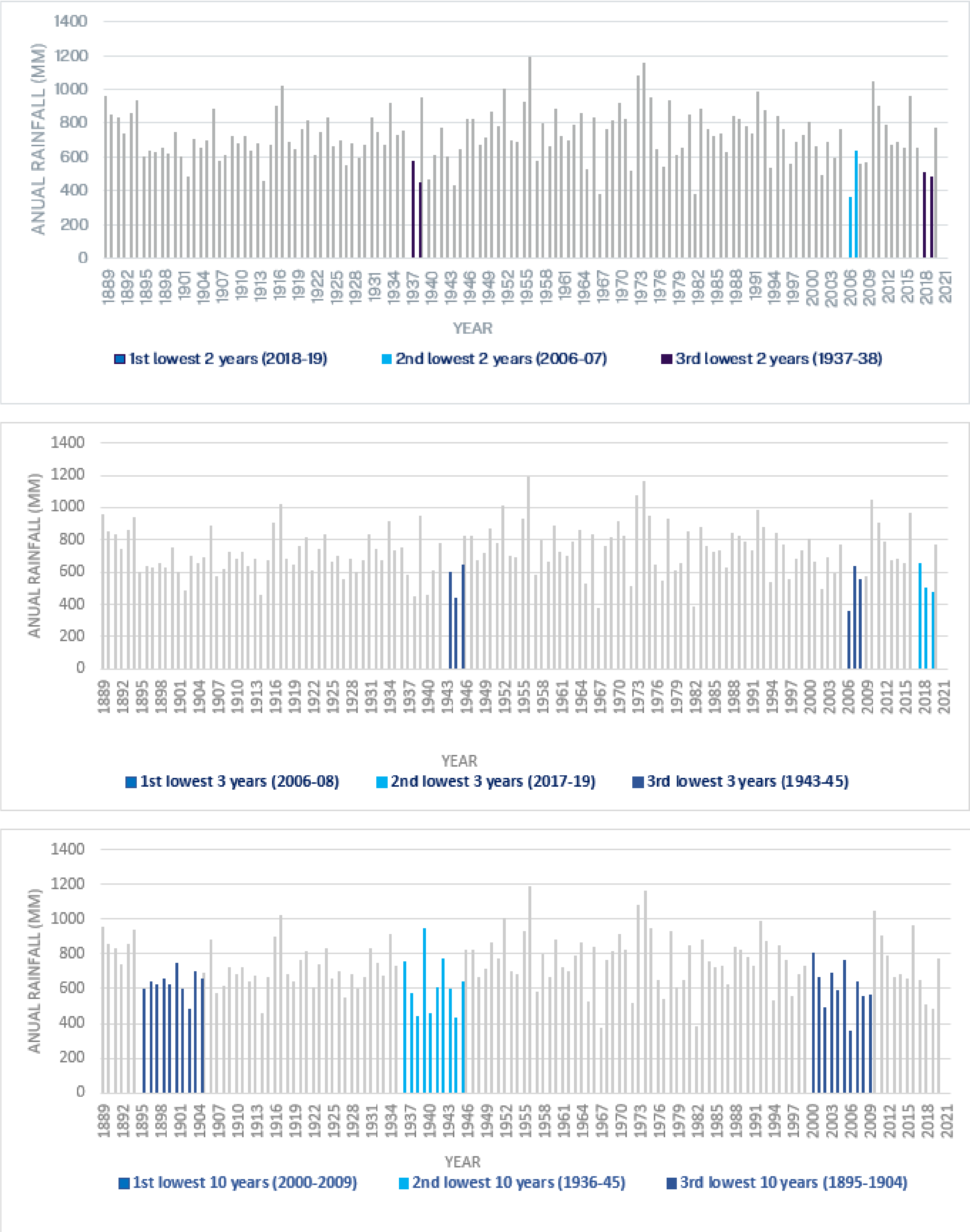


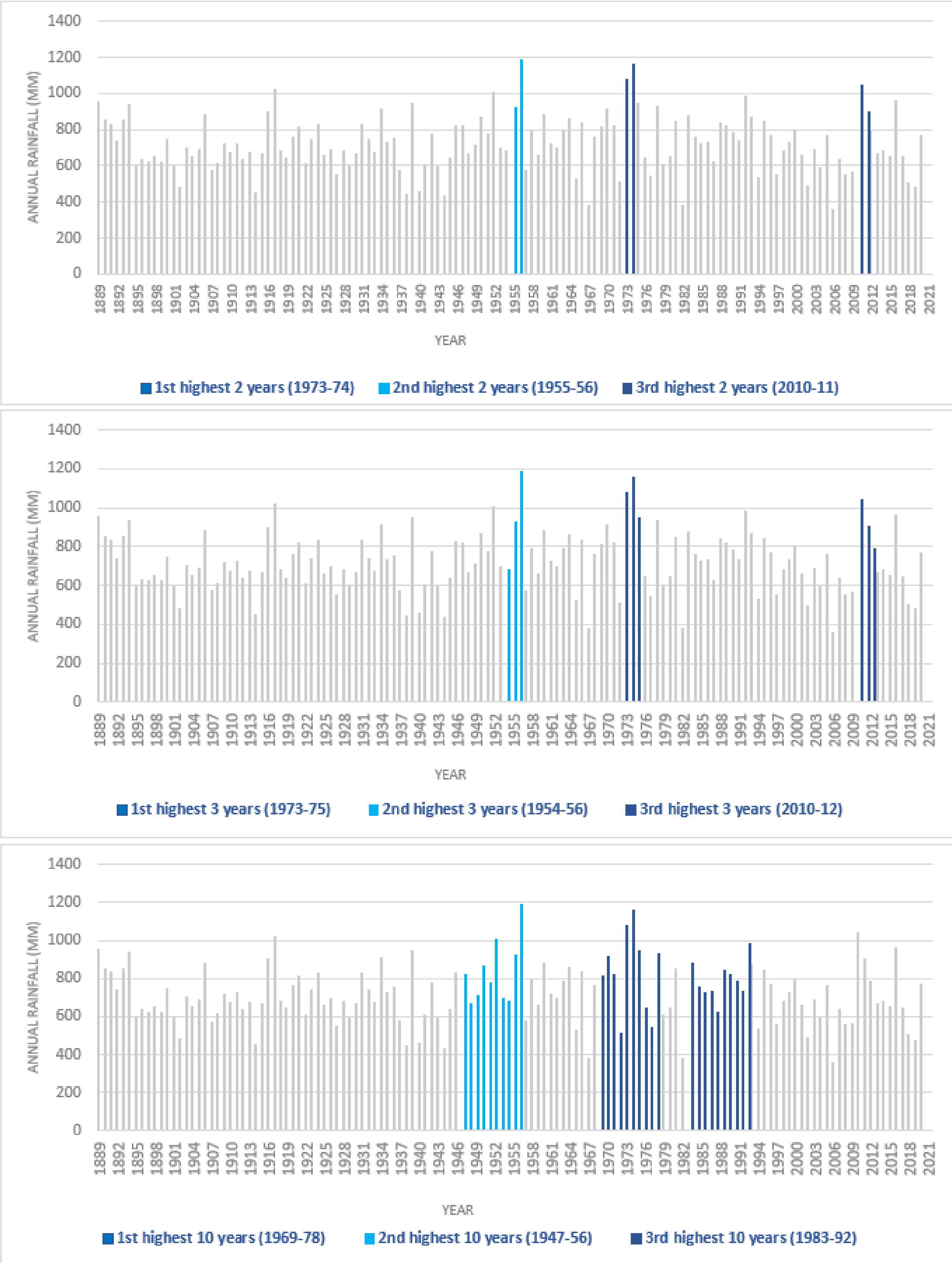
Figure note: The results presented here differ slightly to those presented in the draft NSW Murray Regional Water Strategy. This is due to an update in some of the data sources.

Figure 3 shows that the highest rainfall records for the regulated NSW Murray region primarily occurred from the late 1940s to the early 1990s, a time of significant expansion in irrigated agriculture. However, the wet period of 2010–2012, following the millennium drought, also features prominently in the two- and three-year graphs.

Although 2021–2022 data was not yet available for these graphs, rainfall for the 18 months to October 2022 was recorded to be very much above average across much of the NSW Murray region,[12] following a succession of La Nina events. Submissions received in response to the draft Murray and Murrumbidgee regional water strategies also highlighted that very wet periods, apart from providing necessary water to grow crops, can also cause a range of challenges for irrigated agriculture, including root-rot, waterlogging of soils, loss of livestock, damage to farm infrastructure, and reduced access due to flooding.

[12] Bureau of Meteorology, recent and historical rainfall maps, www.bom.gov.au/climate/maps/rainfall

Figure 3. Highest two-, three- and ten-year average rainfall in the NSW Murray region (1890–2020)



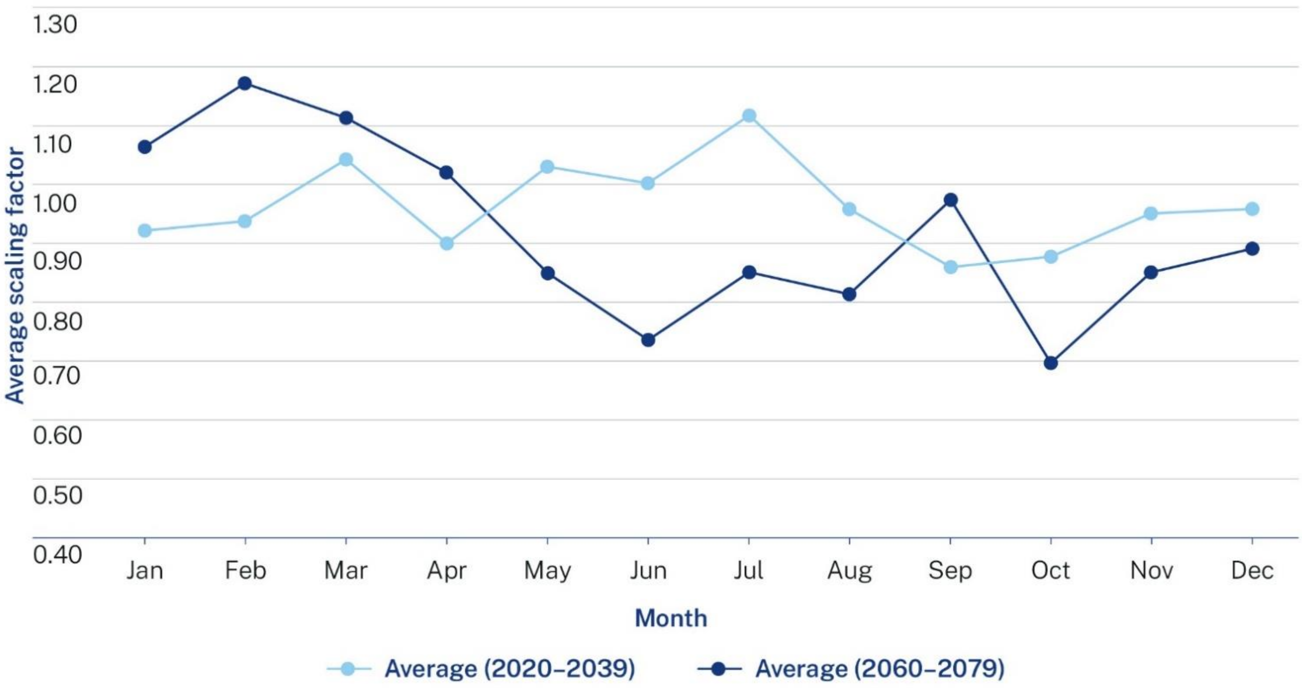
5.2 Precipitation and evapotranspiration under dry future climate scenario for the NSW Murray River

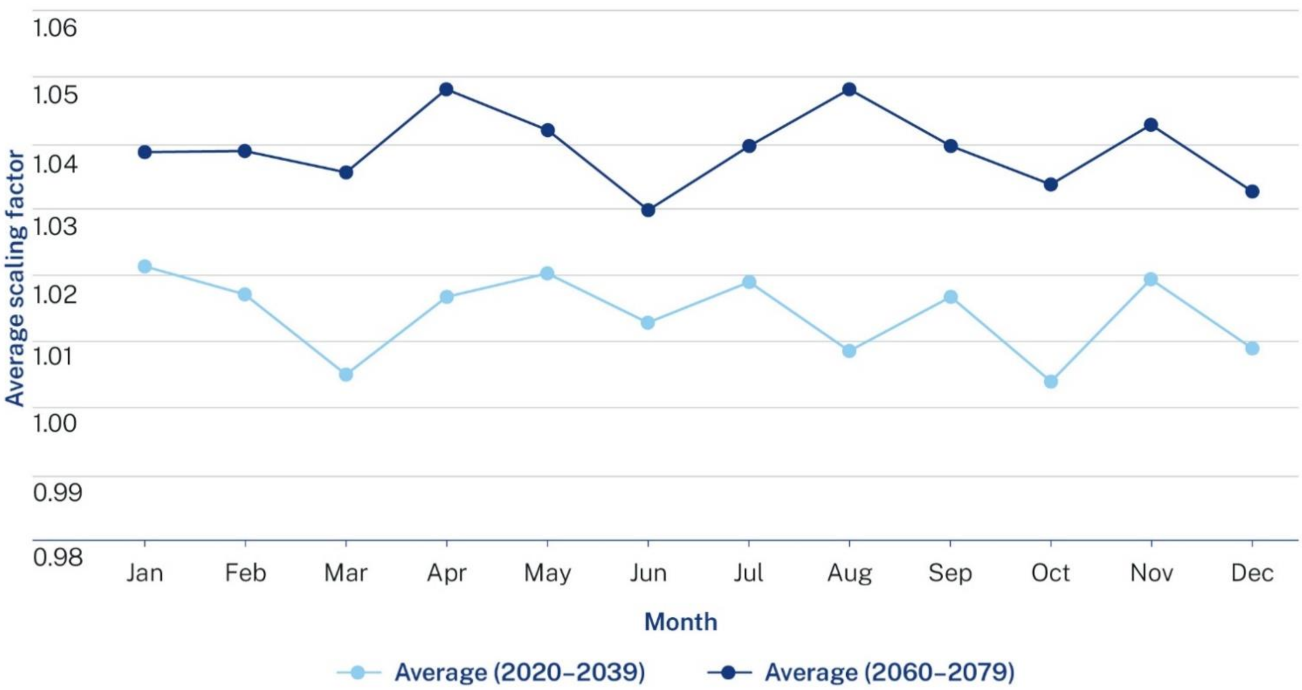
Our climate change scenario suggests that, if the dry future climate scenario eventuates, the NSW Murray region could experience:

- Changing precipitation patterns — average winter rainfall may drop by nearly 20% by 2079. Increases in early autumn rainfall may be offset by equivalent reductions in late autumn. Summer may see increases in precipitation by up to 17% and decreases by up to 30% in spring (Figure 4).
- Higher evapotranspiration — average evapotranspiration could increase by up to 2% by 2039 and up to 5% by 2079, compared to levels between 1990–2009 (Figure 4).

These changes in precipitation and evapotranspiration may affect agricultural operations and crop selection, total dam inflows and the ability to optimally manage environmental releases.

Figure 4. Average monthly changes in rainfall (top) and potential evapotranspiration (bottom) for the NSW Murray region under the dry future climate scenario for 2060–2079 compared to 1990–2009





5.3 Impact of modelled climate scenarios on the NSW share of river flows in the NSW Murray region

As demonstrated by the flow in Tumbarumba Creek, unregulated stream flows in the upper reaches of the NSW Murray River catchment showed a similar response between the historical climate and long-term historical climate scenarios (Figure 5). Average stream flow response was significantly lower in all months of the year under the dry future climate scenario.

Figure 5. Long-term average Tumbarumba Creek flow at Tumbarumba

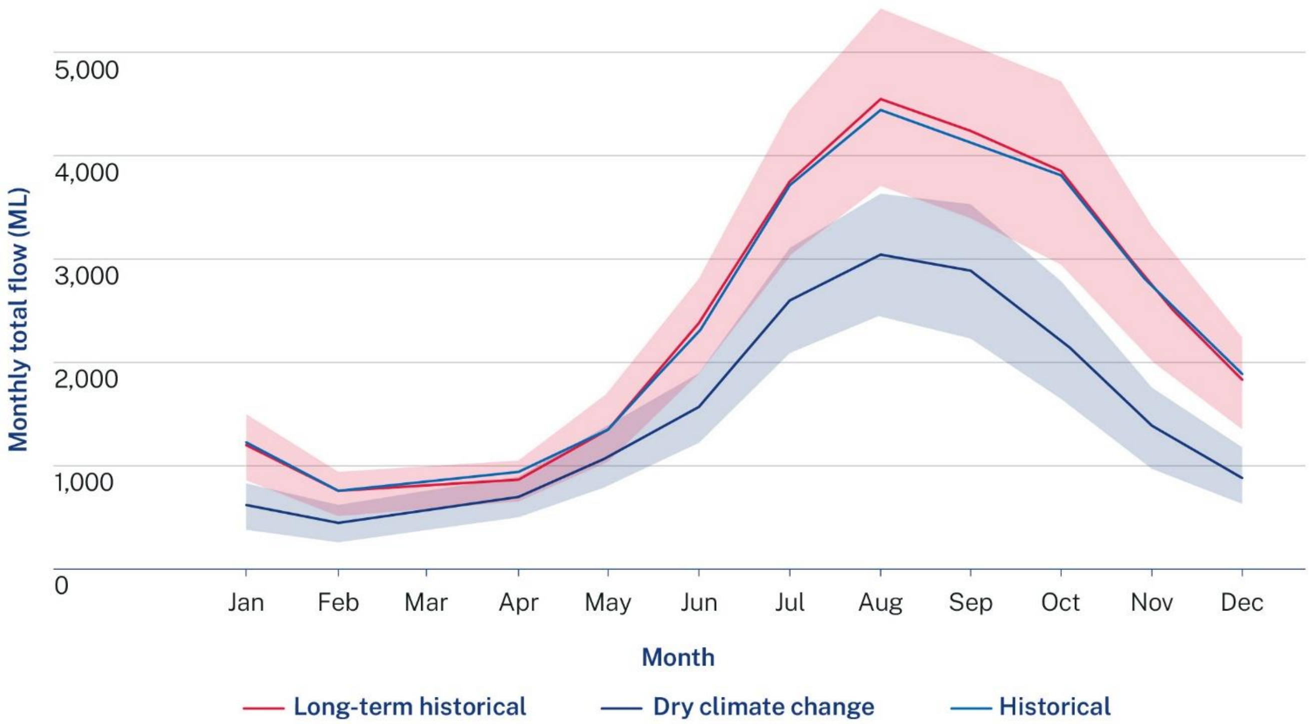


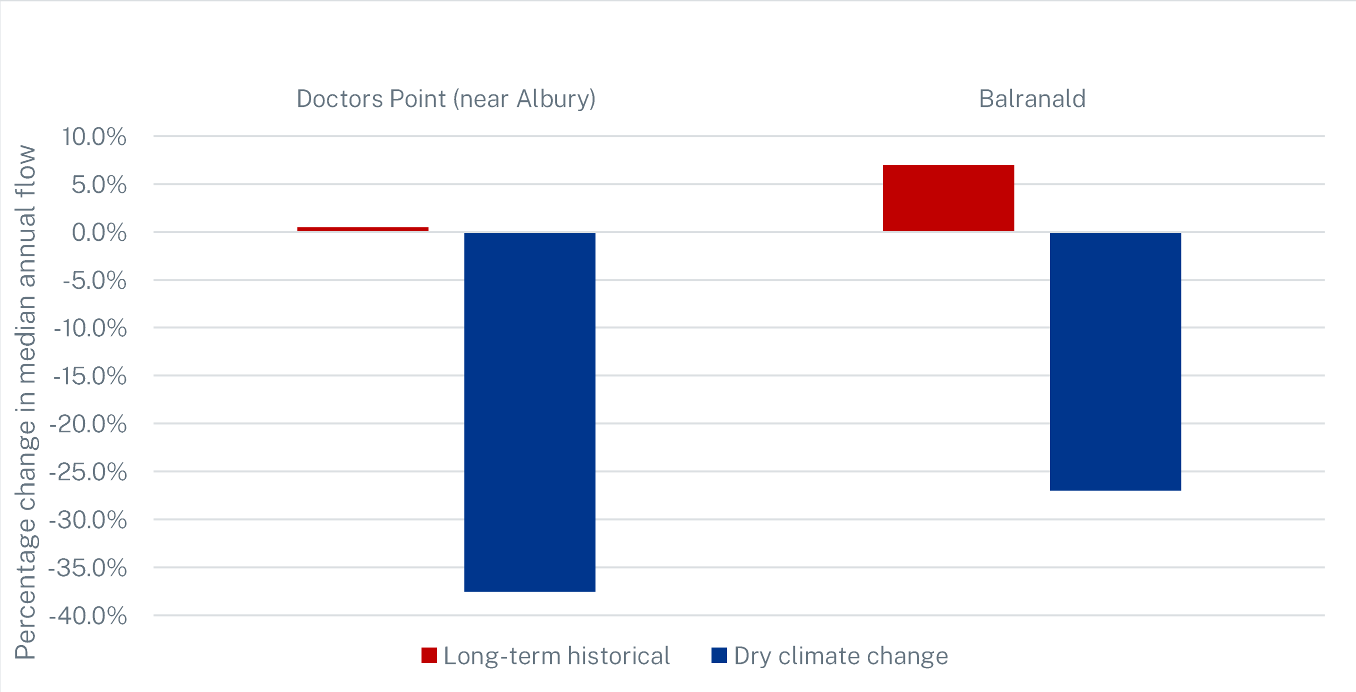
Figure note: red shaded area represents the 95th percentile confidence limit of the long-term historical scenario and the blue shaded area represents the 95th percentile confidence limit of the dry future climate scenario.

Modelling the effects of our chosen climate scenarios along the regulated NSW Murray River indicates the potential for a dry future climate to result in significant changes to river flows by 2060–79, with impacts on riverine, wetland and floodplain ecosystems. Our modelling for the NSW share of the flow shows a 38% decrease from the historical to dry future climate scenarios for median daily flow at Doctors Point near Albury. Similarly, modelling shows a 27% decrease for median daily flows at Balranald on the Murrumbidgee River near its confluence with the Murray River (Figure 6).

A future with reduced flow would constrain efforts to restore the health of the current extent of environmental assets along the NSW Murray River including Koondrook–Perricoota forests, mid-

Murray anabranches and fish populations. Median daily flows under the long-term historical scenario do not increase (0%) for Doctors Point and increases 7% for Balranald (Figure 6) and indicate that if we see a future climate that is like the long-term historical scenario, there would be little change in flow rates. Such similar conditions would not likely present further difficulties for riverine health restoration in the NSW Murray region.

Figure 6. Effect of long-term historical climate and dry climate change scenarios on the NSW share of median daily flows in the NSW Murray River at Doctors Point, and in the Murrumbidgee River at Balranald near the confluence with the Murray River[13]



5.4 Impact of climate scenarios on inflows into the NSW share of the regulated NSW Murray River

Using the regional water strategy climate data, we have modelled inflows into the NSW share of the storages of the regulated NSW Murray River to understand how the different climate scenarios impact the relative behaviour of NSW inflows.

Figure 7 shows how the seasonal NSW inflows respond under the different climate scenarios. The historical and long-term historical scenarios are broadly similar. However, under the dry future climate scenario there is a significant reduction in inflow across much of the year, with the most impact experienced in the winter/spring traditional dam-filling period. The only exception is a small

[13] NSW shares 50% of the flow with Victoria at Doctor's Point and owns 100% of Murrumbidgee outflows (measured at Balranald)

increase in mid-autumn where an increase in Menindee Lakes inflows is shown to occur.[14] By analysing these differences, we can begin conversations with water users about how infrastructure and policy settings can better support water-dependent industries.

Figure 7. Impact of climate scenarios on seasonal inflows into the NSW share of the shared Murray system storages (combined)

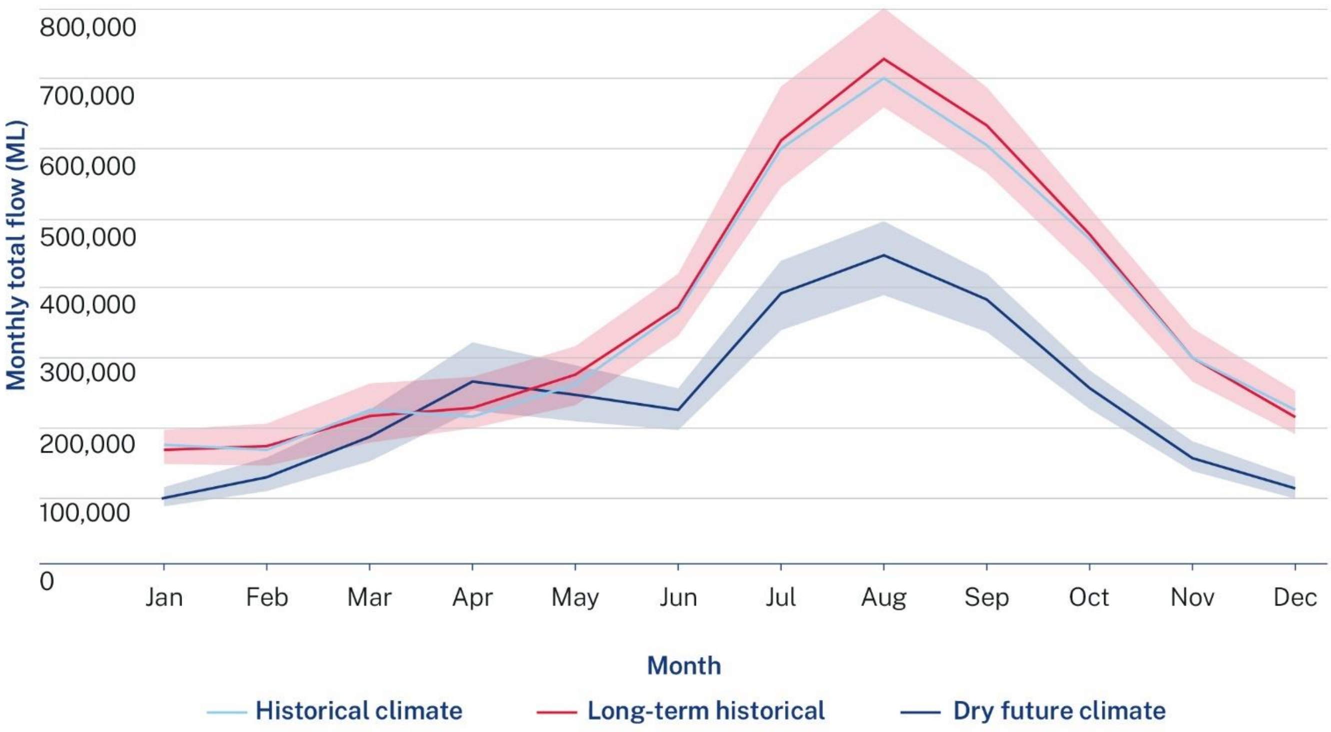


Figure note: red shaded area represents the 95th percentile confidence limit of the long-term historical scenario and the blue shaded area represents the 95th percentile confidence limit of the dry future climate scenario.

Figure 8 shows that droughts in the historical climate scenario are representative of droughts that could be experienced over the long-term historical scenario — a much longer time period, particularly for droughts of 12–18 months duration. At the most extreme scenario, the minimum inflows into the storages over a 3-year period under a dry future climate scenario are close to half of what was experienced in the driest recorded drought.

It is highly uncertain for these scenarios occurring (one event in a 10,000-year dataset). Using a dry future climate scenario may not be the most appropriate upon which to solely base our future water decisions. By analysing these extremes, we can stress test the system and begin a conversation

[14] Refer to Figure 16 in the draft Murray regional water strategy. Available - www.dpie.nsw.gov.au/murray-regional-water-strategy

within the community about how we can plan for accepted levels of risk and extreme droughts, and what we need to do to ensure we can provide water for critical human needs.

Figure 8. 3-year minimum inflow sequences into the NSW share of the shared Murray system storages (combined)

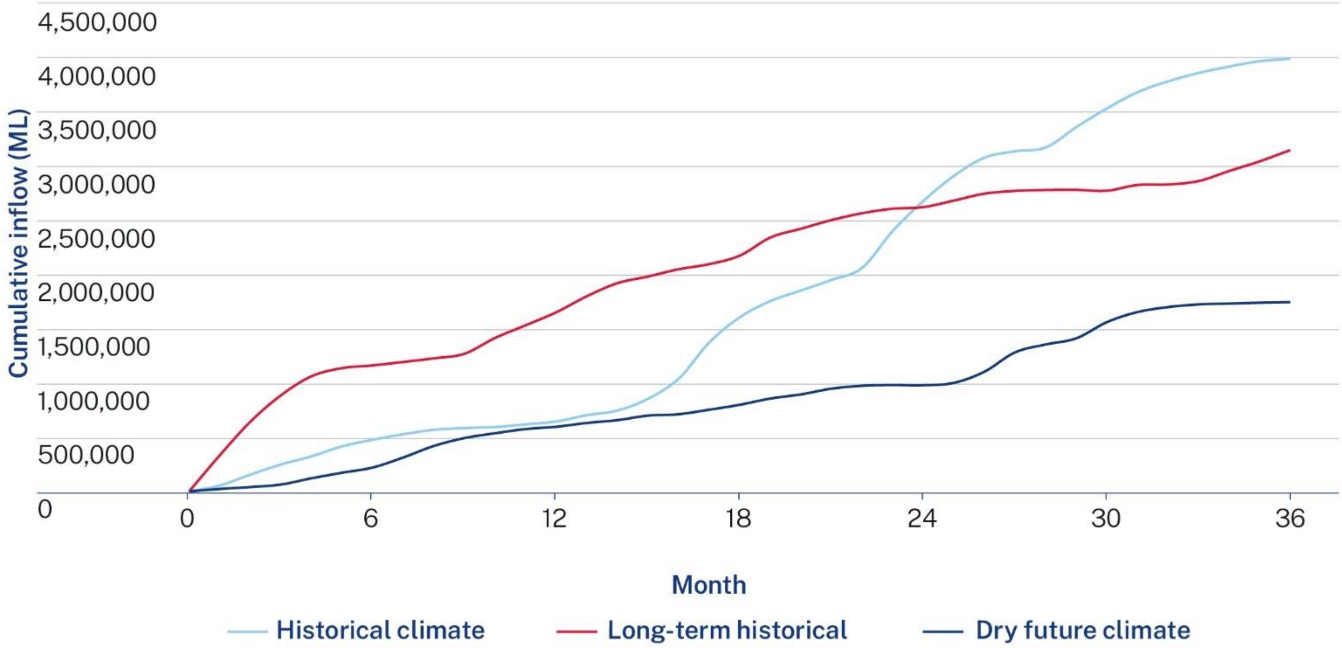


Figure note: These include inflows for Hume and Dartmouth dams, and Lakes Mulwala and Menindee. The Menindee Lakes are situated in the Western Regional Water Strategy area but provide water for lower NSW Murray River water users.

5.5 Impact of climate scenario on available water determinations

The results for available water determinations (Figure 9 and Figure 10) — not including carryover — at the beginning and end of the water year on 1 July and 30 June respectively, show a similar response to inflows into water storages (Figure 8). Under a dry future climate scenario, allocations for general security will open at zero and not reach 100% more frequently than under the historical or long-term historical scenario. At the start of the water year general security allocations:

- would be zero approximately:
  - 30% of the time under the historical and long-term historical scenarios and
  - 80% of the time under the dry climate future scenario
- would be more than 50% approximately:
  - 20% of time under the long-term historical scenario

    - 10% of the time under the historical scenario
    - 5% of the time under the dry climate future

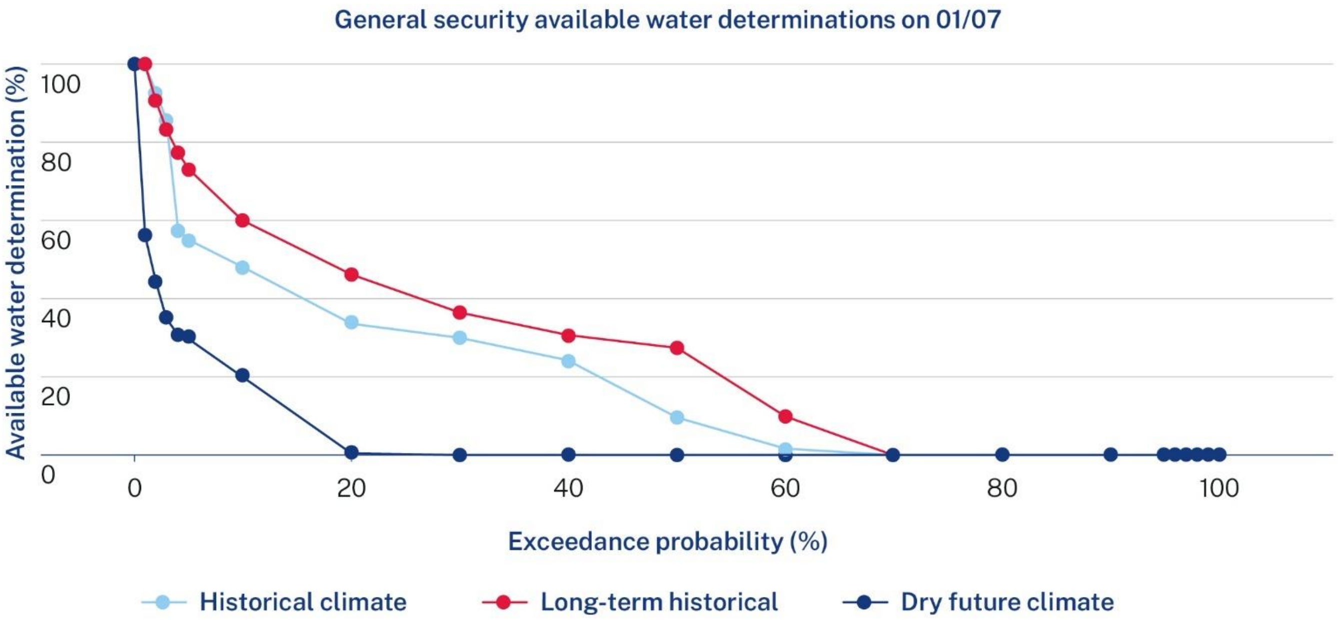
At the end of the water year, general security water allocations would reach 100% (Figure 9) approximately:

- 60% of the time under the historical climate and long-term historical climate scenarios
- 20% of the time under the dry climate future scenario.

These results indicate that a dry future climate scenario would present significant reliability challenges for general security water users.

It should be noted that this new climate data and hydrological modelling is not appropriate for operational decisions made under water sharing plans, such as calculating available water determinations, and it will not be used as such.

Figure 9 Impact of climate scenario on NSW Murray general security available water determinations for 1 July (top) and 30 June (bottom)



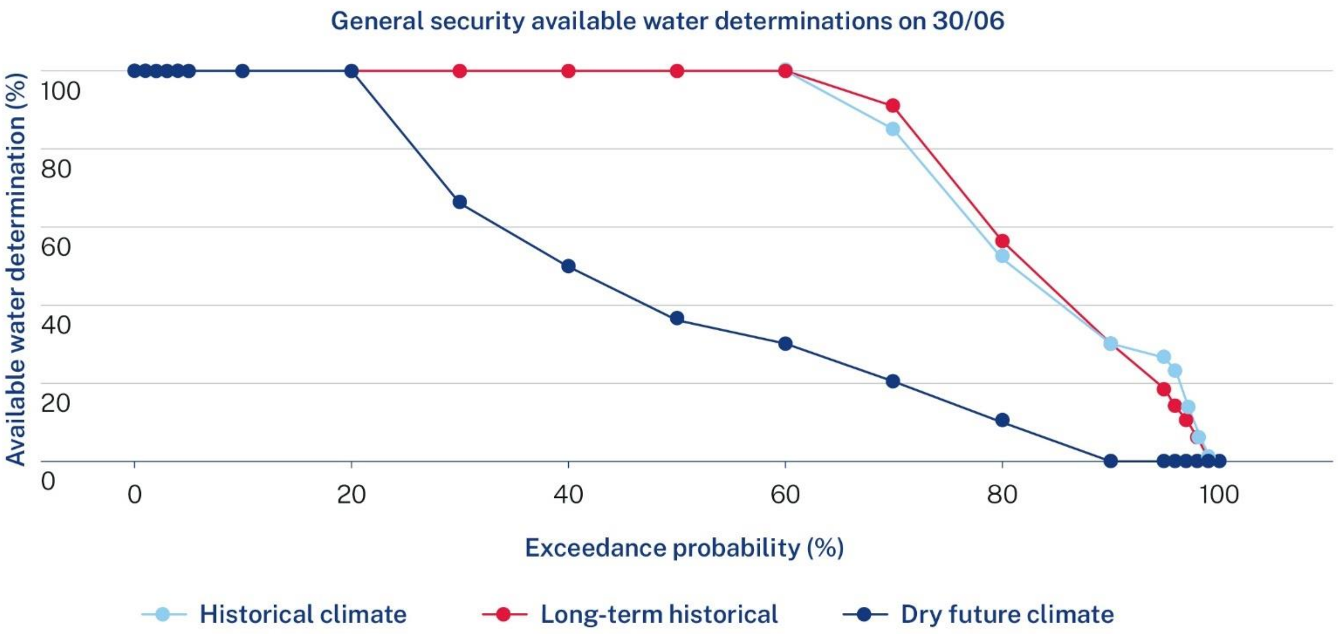


Figure note: These results do not include carryover. To interpret these figures, the higher a point on a line is, the higher the allocation level; whilst the further a point is — on a line — to the right of the graph, the more likely that level of allocation is.

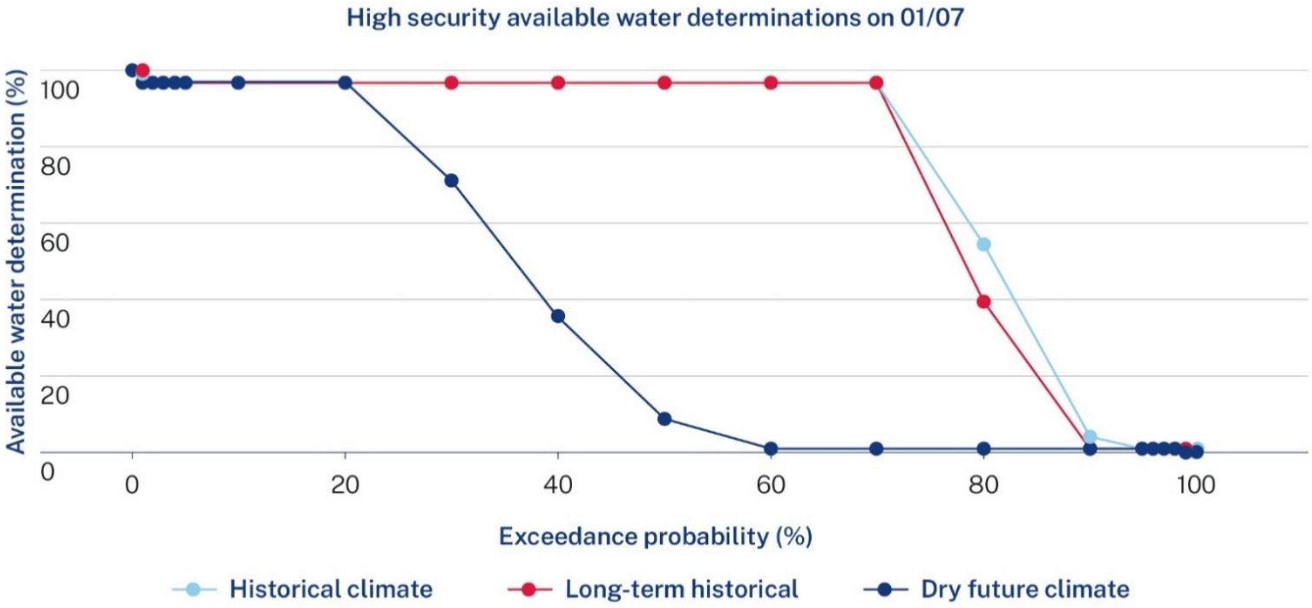
For high security entitlements (Figure 10), start of year allocations

- would exceed 2%:
  - in around 94-95% of the time for either the historical climate or long-term historical climate scenarios, and
  - in 60% of the time under the dry future climate scenario.

- Would exceed 97%:
  - in 70% of the time for either the historical climate or long-term historical climate scenarios
  - in 20% of the time under the dry future climate scenario.

End of year allocations for high security entitlements are similar across all three scenarios, with dry future climate resulting in a small decrease (Figure 10).

Figure 10 Impact of climate scenario on NSW Murray high security available water determinations for 1 July (top) and 30 June (bottom)



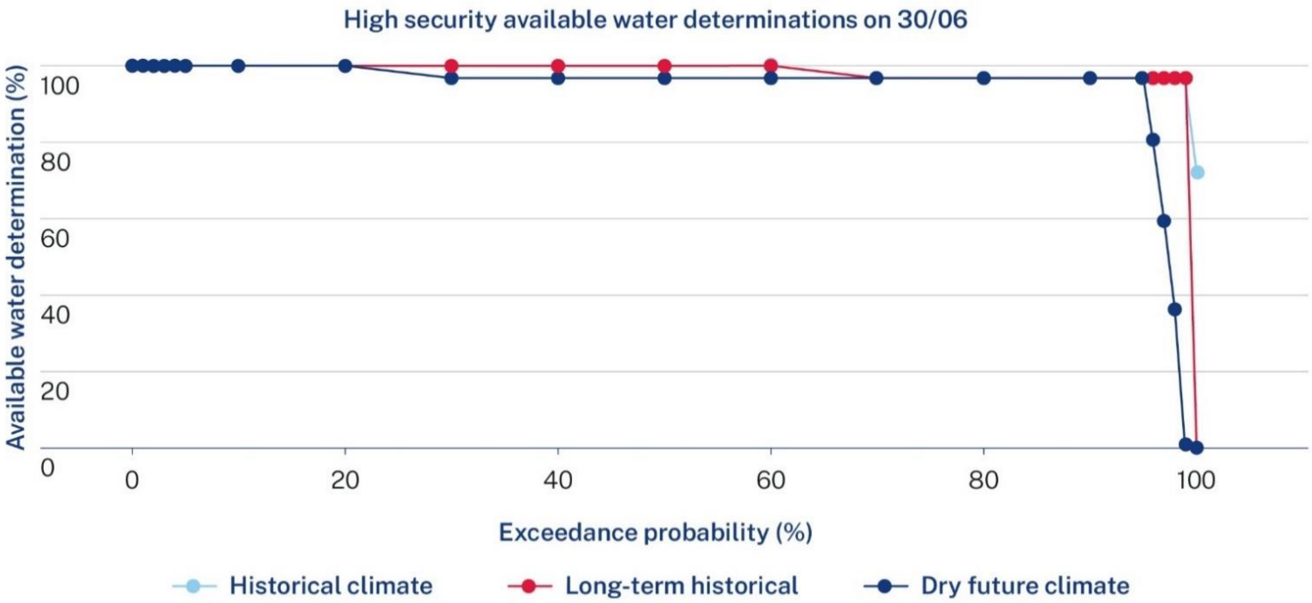


Figure note: These results do not include carryover. Carryover is not a feature for high security licences. To interpret these figures, the higher a point on a line is, the higher the allocation level; whilst the further a point is — on a line — to the right of the graph, the more likely that level of allocation is.

5.6 Impact of modelled climate scenarios on supply shortfalls for town water supplies in the NSW Murray region

This section presents the results of assessments of modelled town water demands against the available supplies, considering the three climate scenarios – historical climate, long-term historical climate and dry future climate scenarios.

Refer to section 4 above for details about the methods and assumptions applied in the analysis.

Results are split into two – the first set (5.6.1) presents the results based off current population demand levels and the second set (5.6.2) presents the results based off future demand levels in 2061.

5.6.1 Town water supply shortfalls based on current demand levels

Table 2 presents the results of an assessment of modelled town water demand (based on current levels of demand)[15] against the available supply. It shows there are significant (greater than 25%)[16] supply shortfalls[17] for Albury, Corowa, Murray River Council and Tumbarumba town water supply demands across all the modelled scenarios, and that these risks increase under the dry future climate scenario.

For example, under the historical scenario for

- Albury there is a 2% likelihood each year of a 23 or more days shortfall event where at least 75% of the unrestricted daily demands cannot be not met.
- Tumbarumba there is a 2% likelihood each year of a 44 or more days shortfall where at least 75% of the unrestricted daily demands cannot be met.

Which under the dry future climate increases to

- 138 or more days shortfall event where at least 75% of the unrestricted daily demands cannot be met for Albury (2% likelihood each year)

[15] This assessment only considered the current levels of town demands. It does not incorporate forecast demand based on future population projections.

[16] A 25% shortfall below unrestricted demands start to have significant implications to water dependant businesses and social amenity as councils start to introduce water restrictions to conserve water for critical human needs.

[17] Shortfalls are measured by the number of days where a town's surface water supply is less than its water demand. Here the analysis uses the following percentages 10%, 25%, 50% and 75% as thresholds to show how much demand was not met.

- 84 or more days shortfall event where at least 75% of the unrestricted daily demands cannot be met for Tumbarumba (2% likelihood each year).

In addition, all towns water supplies show shortfalls of greater than 10% of unrestricted daily demand across all the modelled scenarios, approximately doubling in duration under the dry future climate scenario.

Bombala is also modelled to experience significant shortfalls under the dry future climate scenario.

Although a 10% shortfall could be considered manageable, shortfalls greater than 10% start to have implications on level of service agreements[18] negotiated between councils and their ratepayers.

The next steps will be to work with councils and local water utilities to put these results into local contexts. Consideration of our new climate modelling data and future water availability risk will be important to understand shortfall risks and assess performance of regional water strategy options.

[18] Where affordable, levels of service aim to meet the 5/10/10 secure yield. i.e. restrictions should only be applied for 5 of the time, in a maximum of 10% of year and when applied should not restrict supply by any more than 10%.

Table 2. Modelled town water supply shortfalls for towns along the regulated NSW Murray River and unregulated watercourses – current demands

Town	Annual exceedance probability	Climate Scenario											
		Historical				Long-term historical				Dry future climate			
		Days where at least 10% daily demand not met	Days where at least 25% daily demand not met	Days where at least 50% daily demand not met	Days where at least 75% daily demand not met	Days where at least 10% daily demand not met	Days where at least 25% daily demand not met	Days where at least 50% daily demand not met	Days where at least 75% daily demand not met	Days where at least 10% daily demand not met	Days where at least 25% daily demand not met	Days where at least 50% daily demand not met	Days where at least 75% daily demand not met
Albury	0.10%	Not assessed^				182	140	115	101	366	365	365	342
	0.50%					62	48	31	20	365	333	274	218
	1%	82	76	66	58	31	28	7	0	322	273	219	176
	2%	50	41	31	23	7	0	0	0	253	215	170	138
	10%	0	0	0	0	0	0	0	0	77	60	37	19
Berrigan Shire	0.10%	Not assessed^				31	20	7	6	265	251	192	186
	0.50%					0	0	0	0	144	141	88	83
	1%	0	0	0	0	0	0	0	0	79	77	50	46
	2%	0	0	0	0	0	0	0	0	43	37	19	16
	10%	0	0	0	0	0	0	0	0	0	0	0	0
Bombala	0.10%	Not assessed^				46	46	45	44	177	176	175	174
	0.50%					0	0	0	0	80	80	77	77
	1%	0	0	0	0	0	0	0	0	45	45	45	44
	2%	0	0	0	0	0	0	0	0	8	7	7	7
	10%	0	0	0	0	0	0	0	0	0	0	0	0
Broken Hill #	0.10%	Not assessed^				76	0	0	0	202	0	0	0
	0.50%					42	0	0	0	138	0	0	0
	1%	46	0	0	0	27	0	0	0	111	0	0	0
	2%	37	0	0	0	21	0	0	0	89	0	0	0
	10%	0	0	0	0	0	0	0	0	34	0	0	0
Corowa	0.10%	Not assessed^				186	154	133	117	366	365	365	348
	0.50%					65	50	36	28	365	349	292	230
	1%	108	95	75	68	38	29	10	0	331	290	234	187
	2%	55	48	47	32	16	0	0	0	261	230	182	149
	10%	0	0	0	0	0	0	0	0	87	66	44	28
Deniliquin	0.10%	Not assessed^				94	87	68	48	365	363	327	277
	0.50%					27	22	2	0	288	243	211	176
	1%	29	15	4	0	1	0	0	0	236	195	162	133
	2%	1	0	0	0	0	0	0	0	172	134	108	92
	10%	0	0	0	0	0	0	0	0	29	16	0	0

Town	Annual exceedance probability	Climate Scenario											
		Historical				Long-term historical				Dry future climate			
		Days where at least 10% daily demand not met	Days where at least 25% daily demand not met	Days where at least 50% daily demand not met	Days where at least 75% daily demand not met	Days where at least 10% daily demand not met	Days where at least 25% daily demand not met	Days where at least 50% daily demand not met	Days where at least 75% daily demand not met	Days where at least 10% daily demand not met	Days where at least 25% daily demand not met	Days where at least 50% daily demand not met	Days where at least 75% daily demand not met
Euston	0.10%	Not assessed^				109	101	75	64	365	365	336	296
	0.50%					31	23	3	0	305	247	216	187
	1%	29	15	4	0	7	0	0	0	243	205	172	139
	2%	6	0	0	0	0	0	0	0	185	143	115	97
	10%	0	0	0	0	0	0	0	0	33	18	1	0
Murray River Council 1**	0.10%	Not assessed^				129	118	100	81	365	365	365	330
	0.50%					42	32	22	6	327	321	252	207
	1%	53	52	38	28	24	12	0	0	269	253	203	163
	2%	30	20	6	1	0	0	0	0	215	200	151	122
	10%	0	0	0	0	0	0	0	0	54	45	25	7
Tumbarumba	0.10%	Not assessed^				122	120	119	117	184	181	177	176
	0.50%					95	94	90	88	151	150	148	146
	1%	98	98	96	95	60	59	56	55	122	121	118	116
	2%	49	48	46	44	18	17	15	15	90	89	87	84
	10%	0	0	0	0	0	0	0	0	0	0	0	0
Murray River Council 2**	0.10%	Not assessed^				109	101	81	74	365	365	354	319
	0.50%					33	27	5	0	312	285	237	198
	1%	51	31	13	1	19	1	0	0	247	132	189	152
	2%	20	16	1	0	0	0	0	0	192	171	134	13
	10%	0	0	0	0	0	0	0	0	41	28	9	0
Wentworth	0.10%	Not assessed^				31	31	12	7	265	265	215	193
	0.50%					0	0	0	0	144	144	106	88
	1%	0	0	0	0	0	0	0	0	79	79	58	50
	2%	0	0	0	0	0	0	0	0	43	43	22	19
	10%	0	0	0	0	0	0	0	0	0	0	0	0

*^There are insufficient years within the historical climate scenario simulation period to determine results. #Results for Broken Hill, which sits outside of the NSW Murray regional water strategy area, are relevant to the supply and demand portion that comes from the NSW Murray River only, and the population is not changed for the modelling due to a pipeline constrain that doesn't allow to increase the supply. **Murray River Council 1 includes Moama and Mathoura. Murray River Council 2 includes Barham, Koraleigh, Moulamein, Murray Downs and Tooleybuc. *Tumbarumba results do not factor in the back-up groundwater supply, due to insufficient data regarding the bore reliability.*

5.6.2 Town water supply shortfalls based on future population projections

Table 3 presents the results of an assessment of modelled town water demand (based on projected future levels of demand at 2061) against the available supply. It shows that potential future population increases could increase already significant supply shortfalls[19] for Albury (see 5.6.1) and Murray River Council across all the modelled scenarios, and that these risks increase under the dry future climate scenario.

For example, under the dry future climate scenario with 2061 demand estimates for Albury there is a 2% likelihood each year of a 227 or more days shortfall event where at least 75% of the unrestricted daily demands cannot be not met. This is nearly double the shortfall based on current demands.

In addition, high shortfalls of unrestricted demand to Murray River Council are estimated to occur. For example, there is a 2% likelihood each year of a 100 or more days shortfall event where at least 75% of unrestricted demand under the dry future climate scenario.

The next steps will be to work with councils and local water utilities to put these results into local contexts via the local water utility strategic planning process. Consideration of our new climate modelling data and future water availability risk will be important to understand shortfall risks and assess performance of regional water strategy options.

[19] Shortfalls are measured by the number of days where a town's surface water supply is less than its water demand. Here the analysis uses the following percentages 10%, 25%, 50% and 75% as thresholds to show how much demand was not met.

Table 3. Modelled town water supply shortfalls for towns along the regulated NSW Murray River and unregulated watercourses – 2061 demands

Town	Annual exceedance probability	Climate Scenario											
		Historical				Long-term historical				Dry future climate			
		Days where at least 10% daily demand not met	Days where at least 25% daily demand not met	Days where at least 50% daily demand not met	Days where at least 75% daily demand not met	Days where at least 10% daily demand not met	Days where at least 25% daily demand not met	Days where at least 50% daily demand not met	Days where at least 75% daily demand not met	Days where at least 10% daily demand not met	Days where at least 25% daily demand not met	Days where at least 50% daily demand not met	Days where at least 75% daily demand not met
Albury	0.10%	Not assessed^				366	366	281	189	366	366	366	365
	0.50%					366	366	241	170	366	366	365	344
	1%	366	366	257	177	366	366	232	166	366	366	365	287
	2%	366	366	243	170	366	366	224	162	366	366	340	227
	10%	366	365	203	152	366	365	198	148	366	365	225	163
Berrigan Shire	0.10%	Not assessed^				31	31	10	6	265	265	211	193
	0.50%					0	0	0	0	144	144	96	87
	1%	0	0	0	0	0	0	0	0	79	79	55	49
	2%	0	0	0	0	0	0	0	0	43	43	21	18
	10%	0	0	0	0	0	0	0	0	0	0	0	0
Bombala	0.10%	Not assessed^				46	46	45	44	177	176	175	174
	0.50%					0	0	0	0	80	80	77	77
	1%	0	0	0	0	0	0	0	0	45	45	45	44
	2%	0	0	0	0	0	0	0	0	8	7	7	7
	10%	0	0	0	0	0	0	0	0	0	0	0	0
Broken Hill #	0.10%	Not assessed^				76	0	0	0	202	0	0	0
	0.50%					42	0	0	0	138	0	0	0
	1%	46	0	0	0	27	0	0	0	111	0	0	0
	2%	37	0	0	0	21	0	0	0	89	0	0	0
	10%	0	0	0	0	0	0	0	0	34	0	0	0
Corowa	0.10%	Not assessed^				199	169	140	126	366	366	365	353
	0.50%					90	67	47	35	365	363	304	240
	1%	158	116	88	76	55	36	22	9	348	322	246	196
	2%	120	88	67	54	29	10	0	0	281	248	192	157
	10%	0	0	0	0	0	0	0	0	110	87	59	39
Deniliquin	0.10%	Not assessed^				97	87	69	51	365	363	327	277
	0.50%					28	22	2	0	295	243	213	178
	1%	29	15	4	0	2	0	0	0	239	197	163	134
	2%	1	0	0	0	0	0	0	0	174	135	109	93
	10%	0	0	0	0	0	0	0	0	30	16	0	0

Town	Annual exceedance probability	Climate Scenario: Historical — Days where at least 10% daily demand not met	Historical — Days where at least 25% daily demand not met	Historical — Days where at least 50% daily demand not met	Historical — Days where at least 75% daily demand not met	Long-term historical — Days where at least 10% daily demand not met	Long-term historical — Days where at least 25% daily demand not met	Long-term historical — Days where at least 50% daily demand not met	Long-term historical — Days where at least 75% daily demand not met	Dry future climate — Days where at least 10% daily demand not met	Dry future climate — Days where at least 25% daily demand not met	Dry future climate — Days where at least 50% daily demand not met	Dry future climate — Days where at least 75% daily demand not met
Euston	0.10%	Not assessed^				109	101	75	64	365	365	336	296
	0.50%					31	23	3	0	305	247	216	187
	1%	29	15	4	0	7	0	0	0	243	205	172	138
	2%	6	0	0	0	0	0	0	0	185	143	115	97
	10%	0	0	0	0	0	0	0	0	33	18	1	0
Murray River Council**	0.10%	Not assessed^				366	228	163	135	366	366	365	362
	0.50%					366	186	129	104	366	365	341	258
	1%	366	187	135	106	365	174	122	97	366	359	288	207
	2%	365	181	127	100	365	164	114	91	366	303	219	168
	10%	258	135	93	72	217	127	86	64	365	171	120	95
Tumbarumba	0.10%	Not assessed^				122	120	119	117	184	181	177	176
	0.50%					95	94	90	88	151	150	148	146
	1%	98	98	96	95	60	59	56	55	122	121	118	116
	2%	49	48	46	44	18	17	15	15	90	89	87	84
	10%	0	0	0	0	0	0	0	0	0	0	0	0
Murray River Council 2**	0.10%	Not assessed^				365	192	145	124	366	366	365	358
	0.50%					291	150	110	93	366	365	320	239
	1%	363	162	119	102	238	137	101	85	365	334	257	197
	2%	276	142	107	91	195	123	92	75	365	267	200	159
	10%	113	79	54	40	70	41	22	15	203	135	100	81
Wentworth	0.10%	Not assessed^				31	31	12	7	265	265	215	193
	0.50%					0	0	0	0	144	144	106	88
	1%	0	0	0	0	0	0	0	0	79	79	58	50
	2%	0	0	0	0	0	0	0	0	43	43	22	19
	10%	0	0	0	0	0	0	0	0	0	0	0	0

*^There are insufficient years within the historical climate scenario simulation period to determine results. #Results for Broken Hill, which sits outside of the NSW Murray regional water strategy area, are relevant to the supply and demand portion that comes from the NSW Murray River only, and the population is not changed for the modelling due to a pipeline constrain that doesn't allow to increase the supply. ** Murray River Council 1 includes Moama and Mathoura towns. Murray River Council 2 includes Barham, Koraleigh, Moulamein, Murray Downs and Tooleybuc. *Tumbarumba results do not factor in the back-up groundwater supply, due to insufficient data regarding the bore reliability.*

6. Murrumbidgee region results

This section presents the results of the new climate data and hydrological modelling for the upper and regulated sections of the Murrumbidgee River.

6.1 Upper Murrumbidgee

6.1.1 Observed dry and wet periods in the upper Murrumbidgee region

The most recent drought (2017–2020) includes some of the lowest 24-month and 36-month rainfall periods across the region (Figure 11) and took place against the backdrop of rising temperatures, increasing evaporation and record low root-zone soil moisture. The Federation, Millennium and World War II extended droughts also feature prominently across these low rainfall records.

In terms of the wettest periods across the instrumental records, Figure 12 shows that the highest rainfall records occurred from the late 1940s to the early 1990s. Although 2021–2022 data was not yet available for these graphs, rainfall for the 18 months to June 2022 was recorded to be very much above average across much of the Murrumbidgee region,[20] following a succession of La Nina events.

[20] Bureau of Meteorology, Recent and historical rainfall maps, www.bom.gov.au/climate/maps/rainfall

Figure 11 Lowest two-, three- and ten-year average rainfall in the upper Murrumbidgee region (1890–2020)

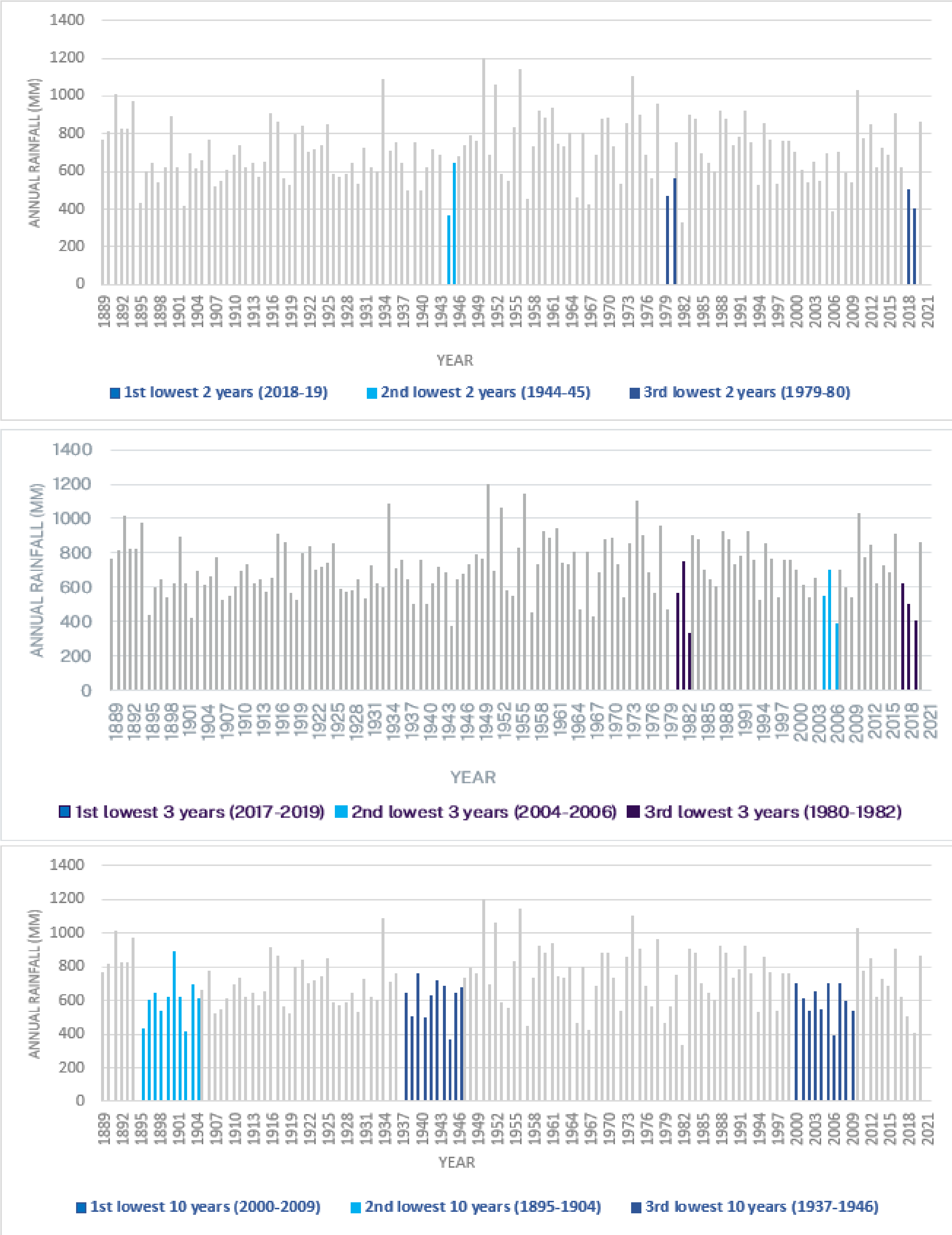
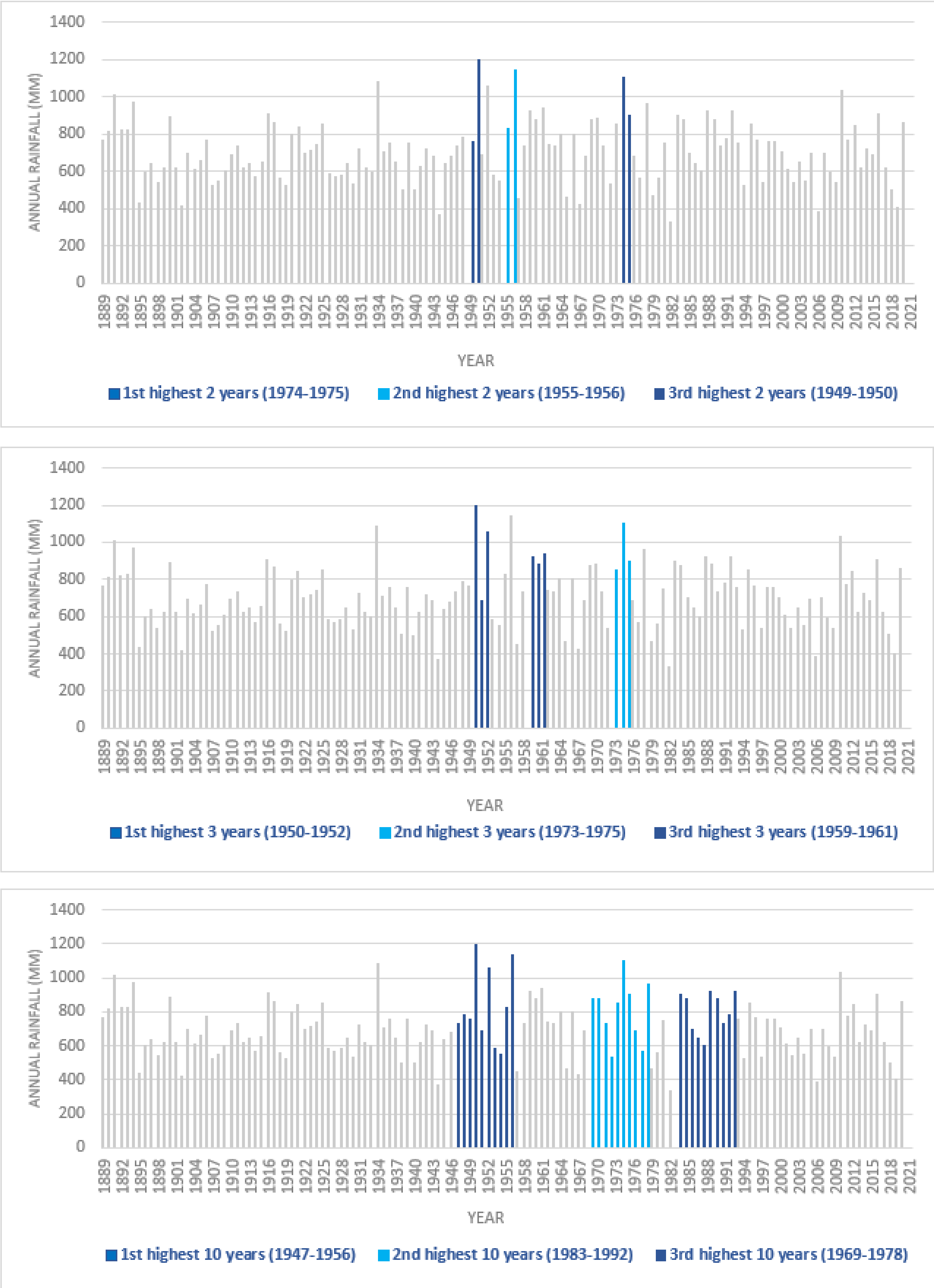


Figure note: The results presented here differ slightly to those presented in the draft Murrumbidgee Regional Water Strategy. This is due to an update in some of the data sources.

Figure 12 Highest two-, three- and ten-year average rainfall in the upper Murrumbidgee region (1890–2020)



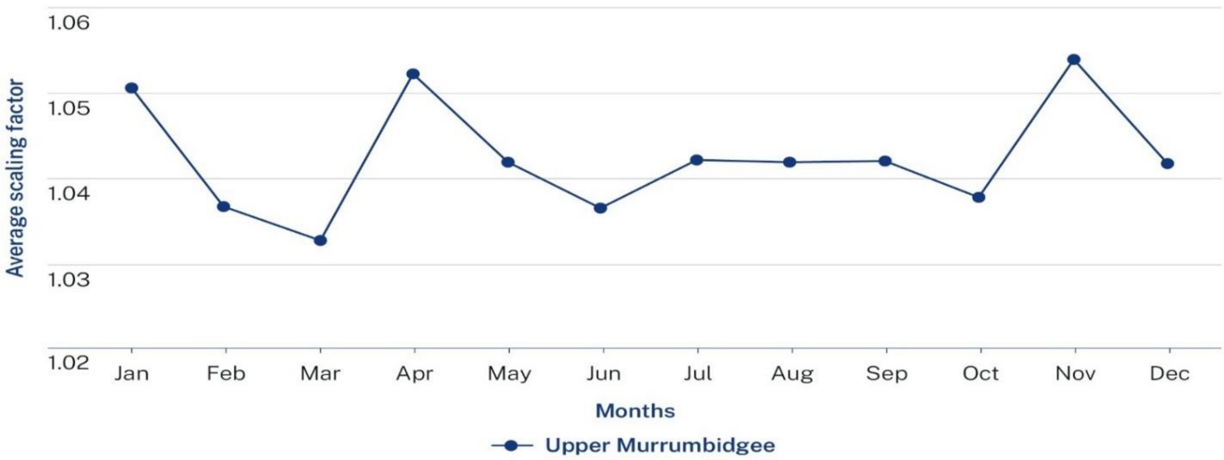
6.1.2 Precipitation and evapotranspiration under dry future climate scenario for the upper Murrumbidgee River

The climate data suggests that, if the worst-case dry future climate scenario eventuates, by 2079, the upper Murrumbidgee could experience (Figure 13):

- reduced precipitation — with decreases in average winter rainfall by 20%. Average autumn rainfall may drop by 11%, with very little reduction in summer and spring rainfall;
- higher evapotranspiration — average evapotranspiration could increase by up around 45%, across the year.

These changes in rainfall and evapotranspiration could impact inflows into the region's major storages and increase the water-related risks to water users and the environment.

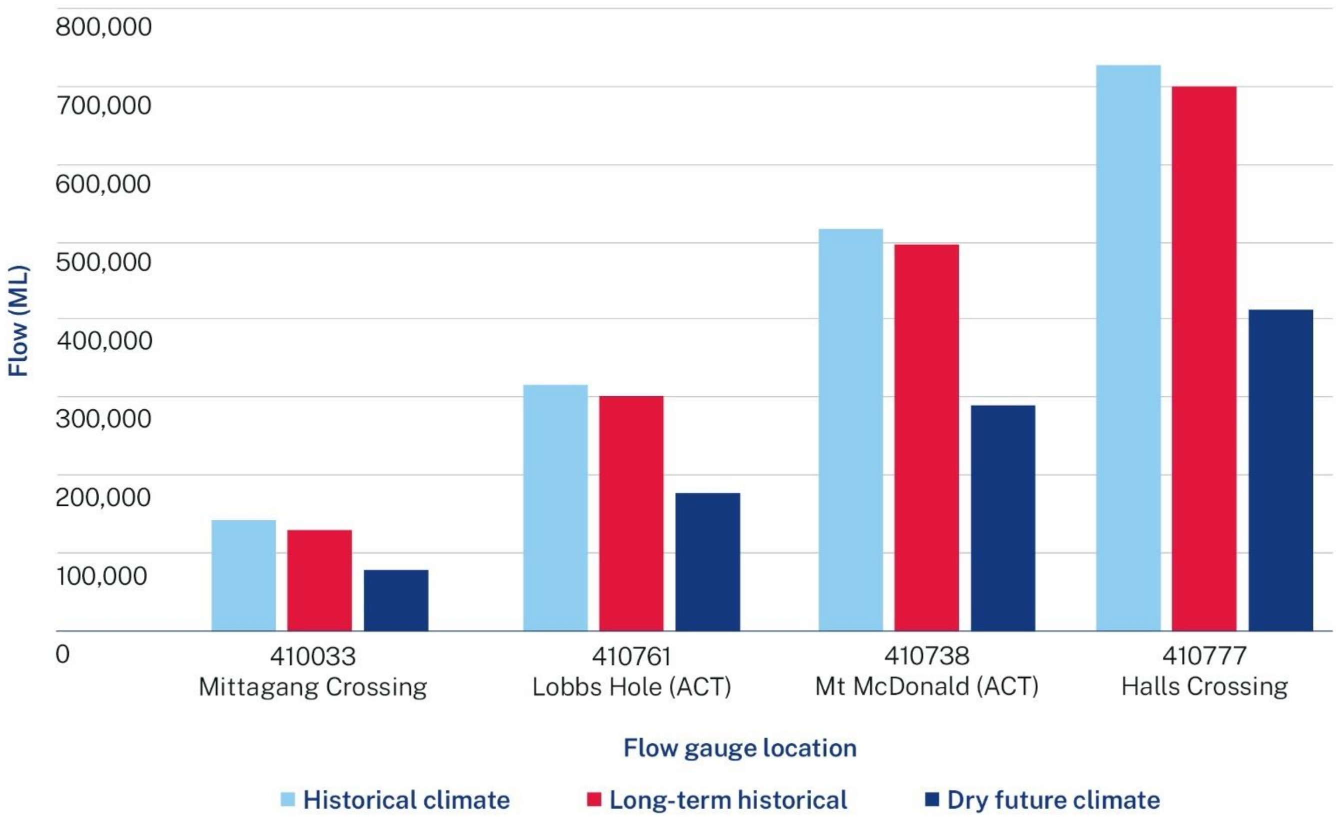
Figure 13. Average monthly changes in rainfall (top) and potential evapotranspiration (bottom) for the upper Murrumbidgee under the dry future climate scenario for 2060–2079 compared to 1990–2009



6.1.3 Impact of modelled climate scenarios on the upper Murrumbidgee River flow regime

The flow regime of the upper Murrumbidgee River responds to the different climate scenarios in a variety of ways. Figure 14 shows how the various modelled climate scenarios impact the mean (average) annual flow at four locations on the upper Murrumbidgee River. Average flows under the dry future climate projection are significantly reduced compared to both the historical climate and long-term historical climate results, which show only minor variation.

Figure 14 Impact of climate scenario on mean (average) annual flow at several locations on the upper Murrumbidgee River from upstream (left) to downstream (right)



As shown in Figure 15, the magnitude of late autumn and winter high flows is dramatically reduced under a dry future climate, despite a small increase in early autumn. If a future climate were to be more consistent with the long-term historical climate, seasonal high flows would be like that experienced in the historical climate scenario.

Figure 15. Impact of climate scenario on seasonal high flows in the Murrumbidgee River at Lobbs Hole

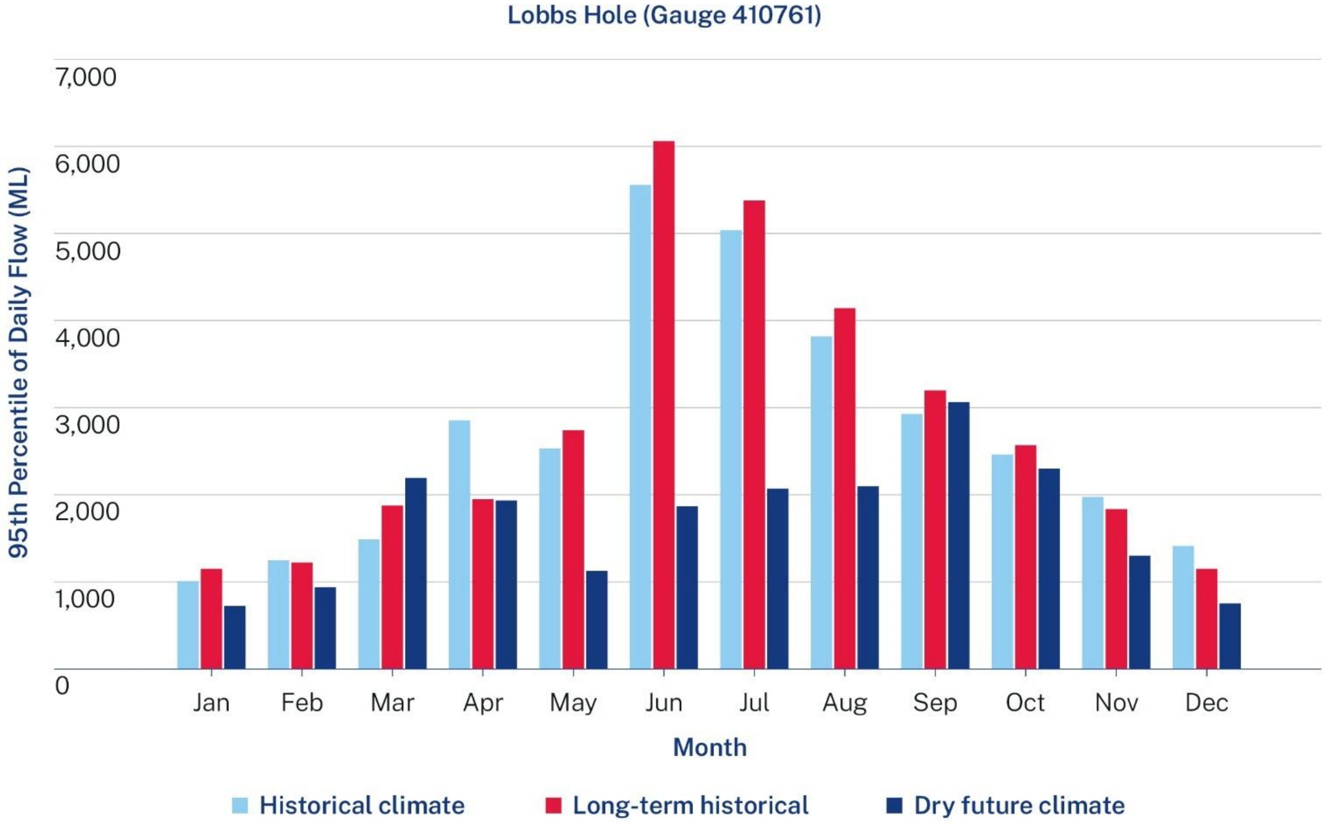
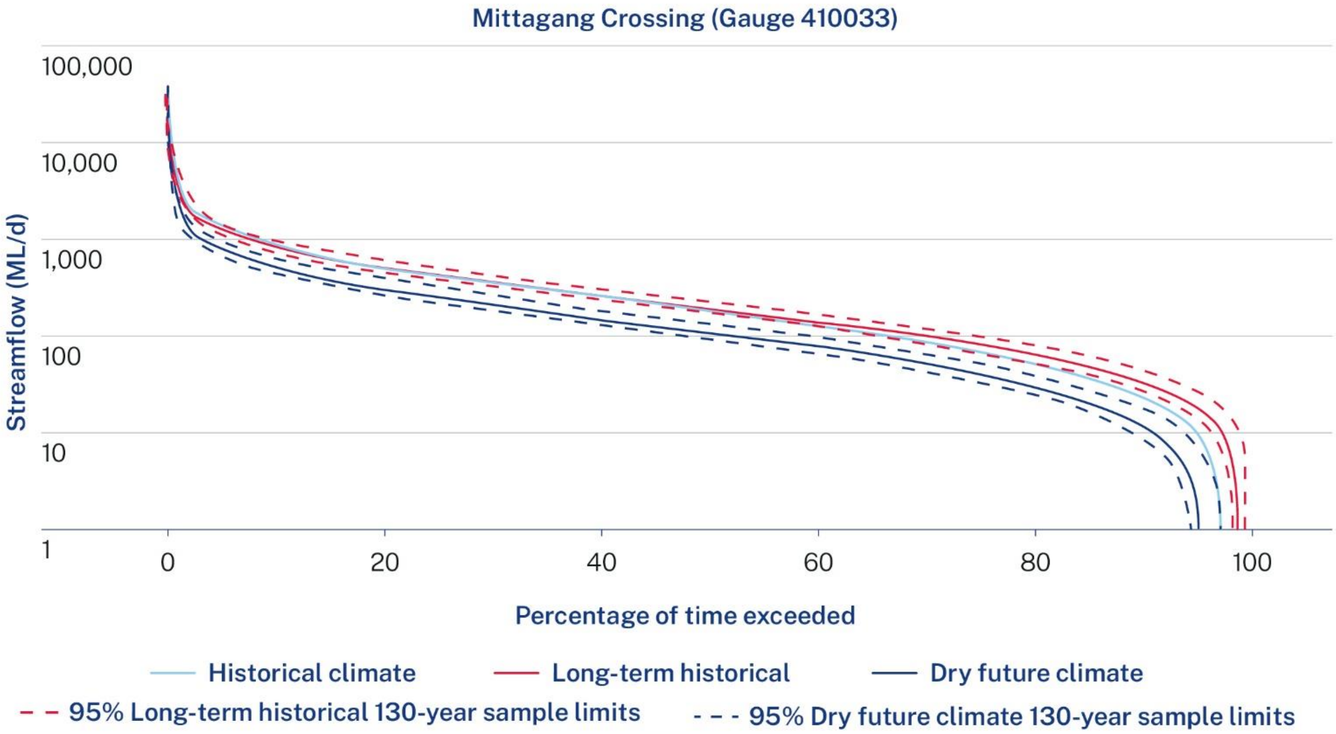


Figure 16 shows that low flows — those that occur 80% of the time, or more — are also impacted under a dry future climate, reducing from around 50 ML/day to 30 ML/day at Mittagang Crossing (near Cooma). If future climate were to be consistent with the long-term historical climate, such flows could increase to 60 ML/day. Similar changes would be expected further downstream at Lobbs Hole, as shown by the graph on the bottom.

Figure 16 Impact of climate scenario on flow duration in the Murrumbidgee River at Mittagang Crossing (top) and Lobbs Hole, ACT (bottom)



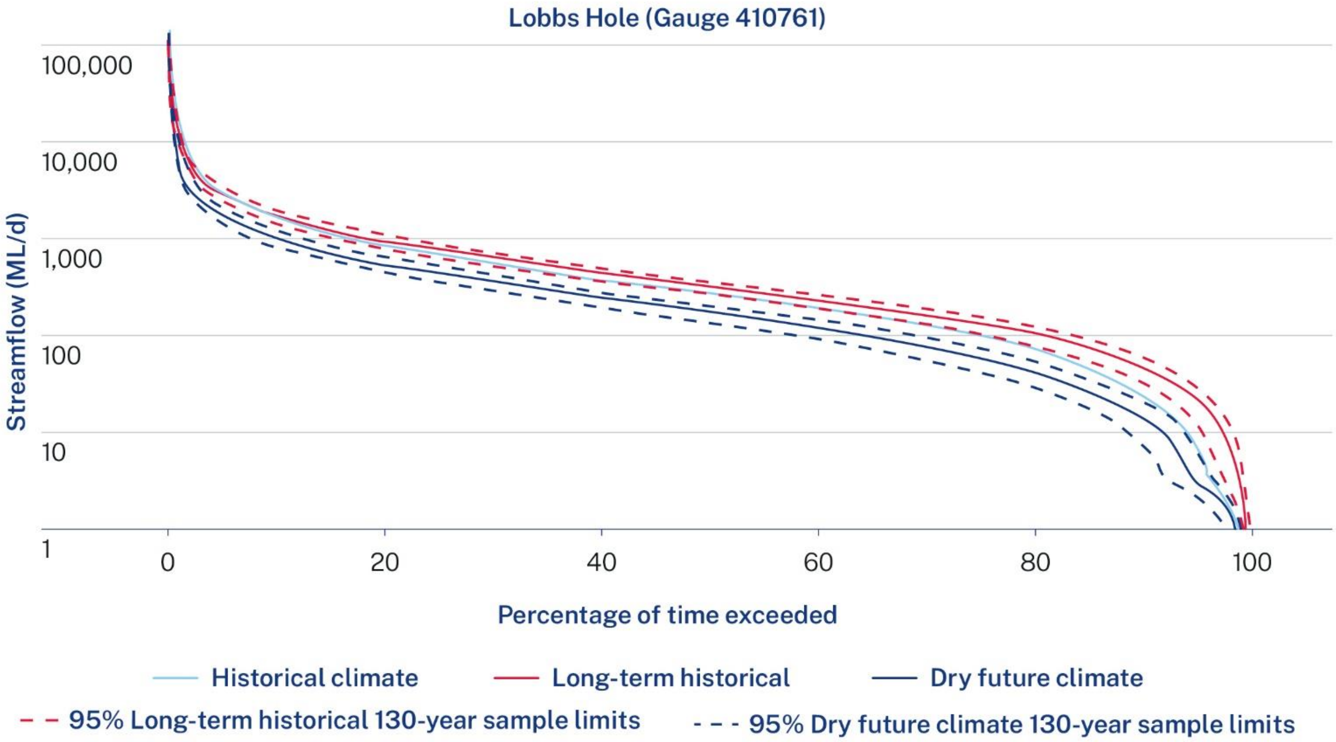
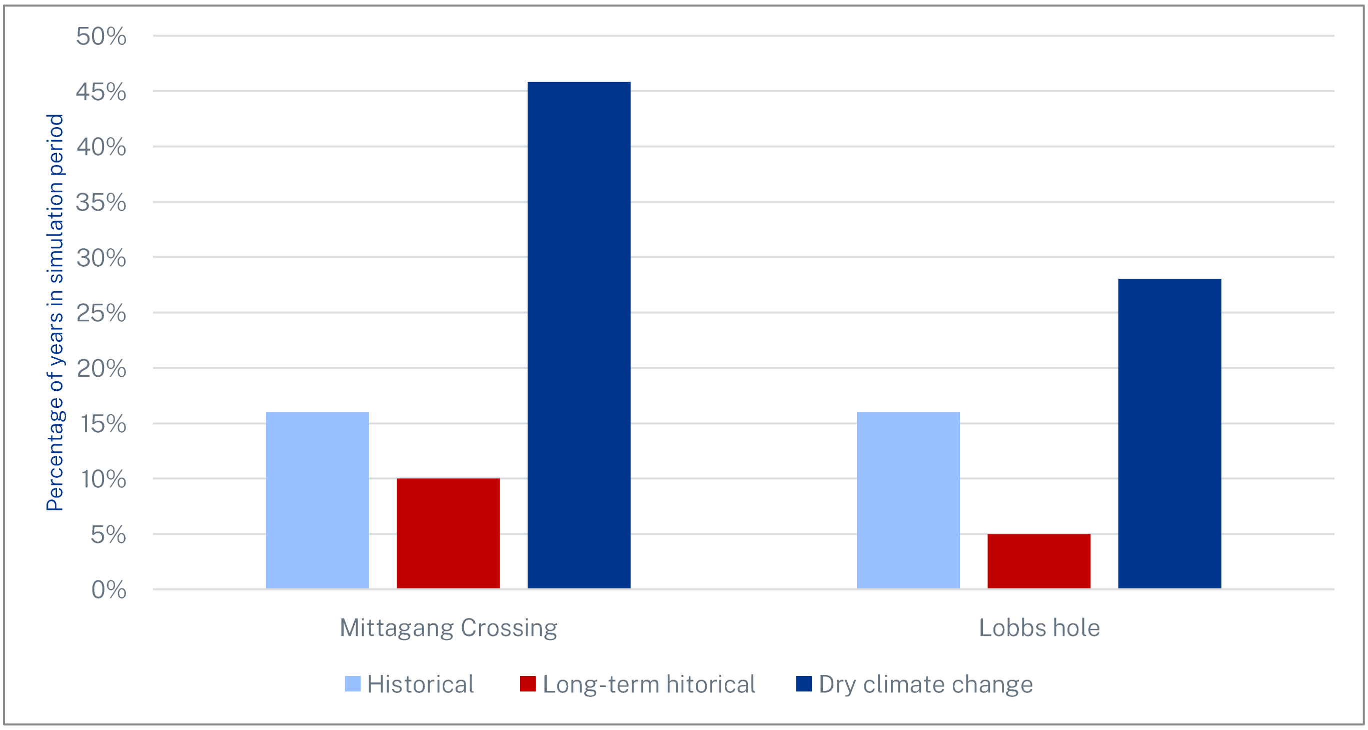


Figure note: The vertical axes are logarithmic, meaning that they increase exponentially and are not linear. This enables the entire flow regime to be included on one graph while showing readable results at the low-flow end of the scale.

Figure 17 presents the results of analysis conducted to understand how cease-to-flow events (defined as a flow of less than 1 ML/day) responded under a dry future climate. For Lobbs Hole, under the historical climate scenario cease-to-flow events occur in 16% of years, 5% of years under the long-term historical climate scenario and that increases to 28% of years under a dry future climate scenario. The average of lengths of CTF events at Lobbs Hole are 7, 4 and 5 days for historical, long-term historical and dry future climate scenarios, respectively. For Mittagang Crossing, which is further upstream, the results are similar under the historical climate scenario, cease to flow events occur in 16% of the years, 10% of the year under the long-term historical climate scenario and 46% of the year under a dry future climate scenario. The average of length of CTF events at Mittagang Crossing are 7, 5 and 6 days for historical, long-term historical and dry future climate scenarios, respectively.

Figure 17. Impact of climate scenario on the occurrence of cease-to-flow events in the Murrumbidgee River at Mittagang Crossing and Lobbs Hole



6.1.4 Impact of modelled climate scenarios on shortfalls for town water supplies from upper Murrumbidgee unregulated watercourses and from ACT storages

This section presents the results of assessments of modelled town water demands in the upper Murrumbidgee against the available supplies, considering the three climate scenarios – historical climate, long-term historical climate and dry future climate scenarios.

Results are split into two – the first set presents the results based on current population demand levels and the second set presents the results based on future demand levels in 2061.

Refer to section 4 for information about the methods and assumptions used in the analysis.

Town water supply shortfalls based on current demand levels

Daily water demands — based on current levels of use (current population) and current infrastructure — for the ACT (Queanbeyan)[21] and the towns of Batlow, Yass and Cooma were assessed against their respective supplies to understand how well supply can meet current levels of demand. The results (Table 4) showed that, under all climate scenarios, there were no shortfalls[22] for most centres. The only exception was Cooma under the dry future climate scenario, which experienced a 49-day shortfall of 10% of the required daily demand at a low probability (0.1% chance of occurring in any given year).

Table 4. Modelled town water supply shortfalls for Cooma, ACT, Batlow and Yass (without future population increase)

Town	Annual Probability	Climate Scenario								
		Historical	Long-term historical				Dry future climate			
		at least 10%, 25%, 50% and 75% daily demands not supplied	at least 10% daily demand not met	at least 25% daily demand not met	at least 50% daily demand not met	at least 75% daily demand not met	at least 10% daily demand not met	at least 25% daily demand not met	at least 50% daily demand not met	at least 75% daily demand not met
ACT	No shortfalls									
Batlow	No shortfalls									
Cooma	0.10%	Not assessed^	11	7	0	0	50	48	40	6
	0.50%		0	0	0	0	30	27	16	0
	1%	0	0	0	0	0	22	19	9	0
	2%	0	0	0	0	0	14	11	3	0
Yass	No shortfalls									

Town water supply shortfalls based on future population projections

Daily water demands — based off future levels of demand and infrastructure — for the ACT (Queanbeyan)[21] and Yass were assessed against their respective supplies to understand how well supply can meet levels of demand associated with projected future population levels. The other towns in the upper Murrumbidgee were not assessed as they did not have significant future population projections.

[21] Note that the results for the ACT considered upgraded water treatment plant capacities that haven't yet been installed.

[22] Shortfalls are measured by the number of days where a town's surface water supply is less than its water demand. Here the analysis uses the following percentages 10%, 25%, 50% and 75% as thresholds to show how much demand was not met.

Table 5 presents the results of an assessment of modelled town water demand (based on projected future levels of demand at 2061) against the available supply. Shortfalls[22] marginally increase in occurrence for the ACT. For example, a very low likelihood (0.1% annual chance of occurring) of a shortfall recorded for the ACT under the dry future climate scenario – a 141-day shortfall event where 25% of the required daily demands were not met. The consequence of these shortfalls for its impact on the ACT and Queanbeyan were not assessed.

The analysis above provides a relative assessment of water supply shortfall however should not be considered an absolute measure of water security that would consider a range of other factors.

Table 5. Modelled town water supply shortfalls for Yass and ACT (with future population projections)

Town	Annual Probability	Climate Scenario								
		Historical	Long-term historical				Dry future climate			
		at least 10%, 25%, 50% and 75% daily demands not supplied	at least 10% daily demand not met	at least 25% daily demand not met	at least 50% daily demand not met	at least 75% daily demand not met	at least 10% daily demand not met	at least 25% daily demand not met	at least 50% daily demand not met	at least 75% daily demand not met
ACT TWS	0.10%	Not assessed^	0	0	0	0	125	116	91	75
	0.50%		0	0	0	0	0	0	0	0
	1%	0	0	0	0	0	0	0	0	0
	2%	0	0	0	0	0	0	0	0	0
Batlow	No shortfalls									
Cooma	0.10%	Not assessed^	11	7	0	0	50	48	40	6
	0.50%		0	0	0	0	30	27	16	0
	1%	0	0	0	0	0	22	19	9	0
	2%	0	0	0	0	0	14	11	3	0
Yass	No shortfalls									

^*There are insufficient years within the historical climate scenario simulation period to determine results.*

Yass did not experience shortfalls in this analysis. However, Yass has experienced some significant supply restrictions in the past, requiring further consideration through the local water utility strategic planning process. A secure yield analysis has been undertaken as part of the Yass Valley Council Integrated Water Cycle Management Strategy and Yass Valley Water Source Strategy. The analysis indicates that the dry-year demand could soon exceed the secure yield of the water supply and be further reduced under a dry future climate scenario.

The next steps will be to work with councils and local water utilities to put these results into local contexts via the local water utility strategic planning process. Consideration of our new climate modelling data and future water availability risk will be important to understand shortfall risks and assess performance of regional water strategy options.

6.2 Regulated Murrumbidgee

6.2.1 Observed dry and wet periods in the regulated Murrumbidgee

The most recent drought (2017–2020) includes some of the lowest 24-month and 36-month rainfall periods across the region (Figure 18) and took place against the backdrop of rising temperatures, increasing evaporation and record low root-zone soil moisture. The Federation, Millennium and World War II extended droughts also feature prominently across these records.

Figure 19 shows that the highest rainfall records for the regulated Murrumbidgee primarily occurred from the late 1940s to the early 1990s, a time of significant expansion in irrigated agriculture. However, the wet period of 2010–2012, following the millennium drought, also features prominently in the two- and three-year graphs.

Although 2021–2022 data was not yet available for these graphs, rainfall for the 18 months to October 2022 was recorded to be very much above average across much of the Murrumbidgee region,[23] following a succession of La Nina events. Submissions received as part of the draft Murrumbidgee Regional Water Strategy also highlighted that very wet periods, apart from providing necessary water to grow crops, can also cause a range of challenges for irrigated agriculture, including root-rot, waterlogging of soils, loss of livestock, damage to farm infrastructure, and reduced access due to flooding.

[23] Bureau of Meteorology, Recent and historical rainfall maps, www.bom.gov.au/climate/maps/rainfall

Figure 18 Lowest two-, three- and ten-year average rainfall in the regulated Murrumbidgee region (1890-2020)

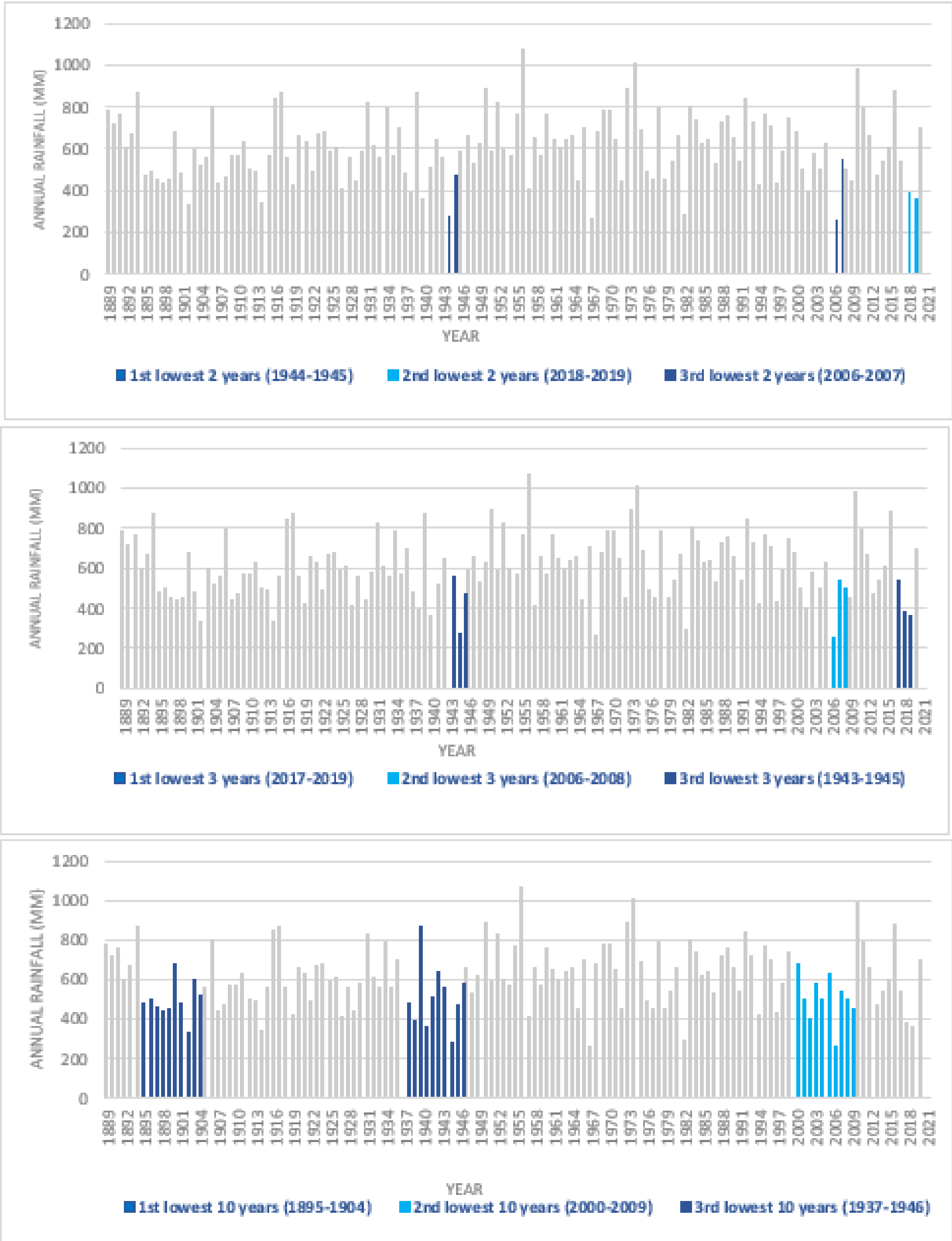
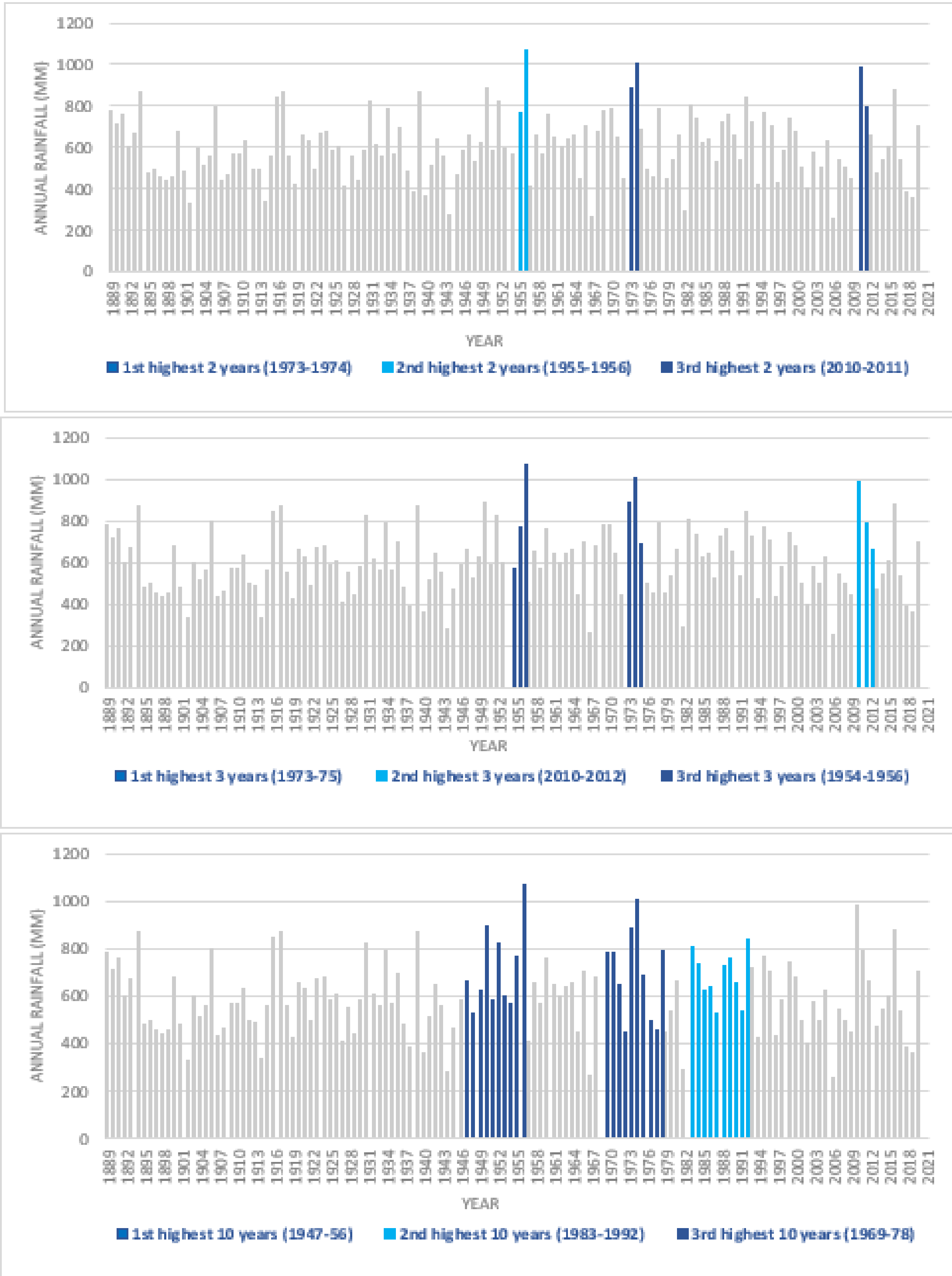


Figure 19 Highest two-, three- and ten-year average rainfall in the regulated Murrumbidgee region (1890–2020)



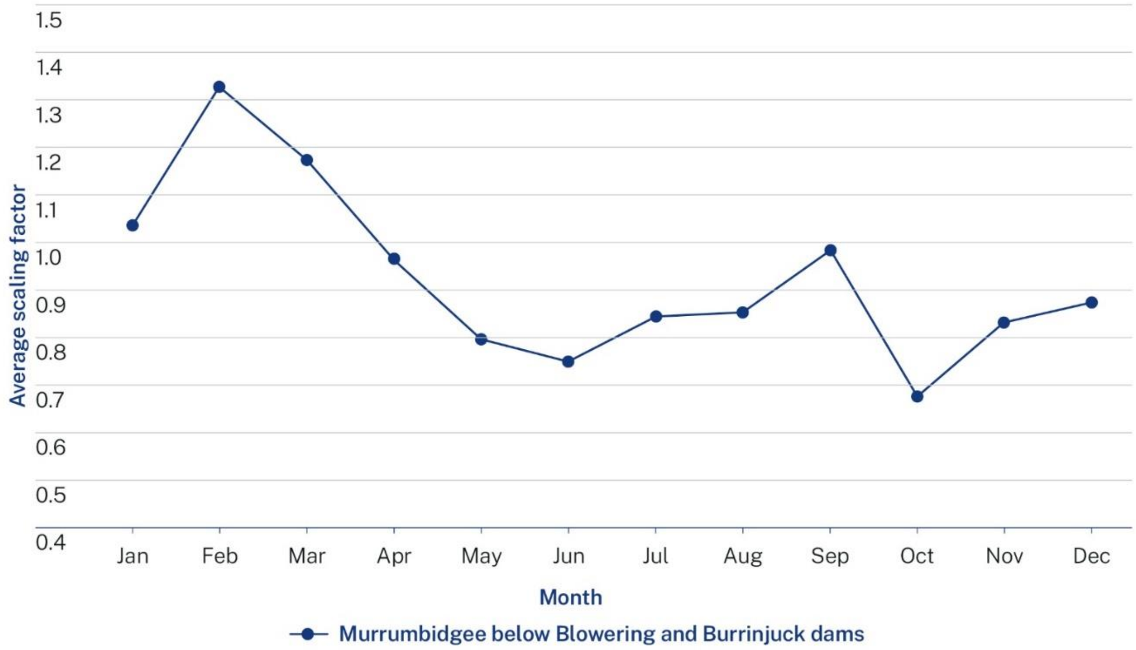
6.2.2 Precipitation and evapotranspiration under a dry future climate in the regulated Murrumbidgee River

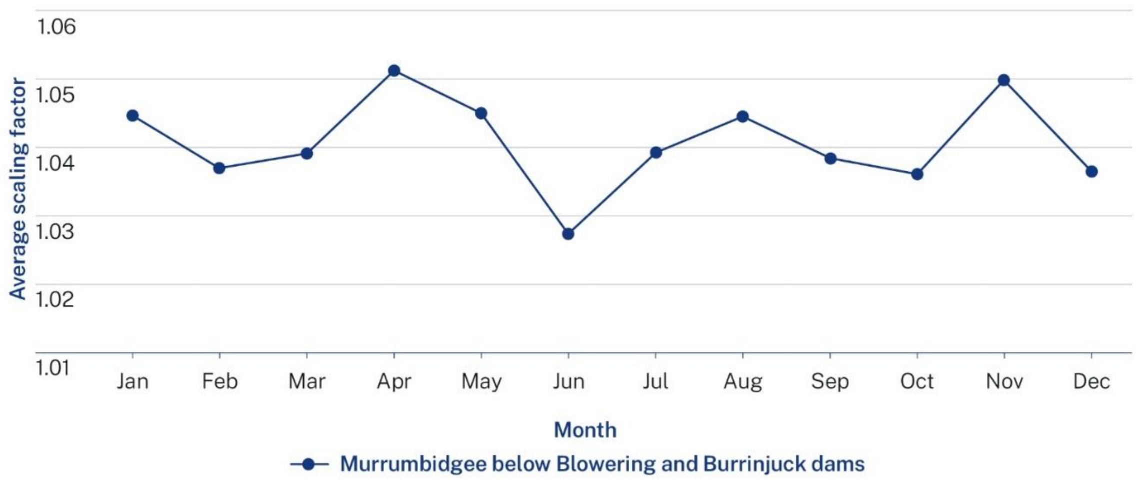
The new climate data suggests that, if the dry future climate scenario eventuates, by 2079 catchments in the regulated river sections of the Murrumbidgee region could experience (Figure 20):

- changing rainfall patterns — with decreases in average winter and spring rainfall by 17-18% and late summer rainfall may increase by over 30%
- higher evapotranspiration — average evapotranspiration could increase by up around 4%, across the year.

These changes in rainfall and evapotranspiration could impact soil moisture in croplands, irrigation, town water and environmental water demands, as well as instream delivery losses.

Figure 20 Average monthly changes in rainfall (top) and potential evapotranspiration (bottom) under the dry future climate scenario for the regulated Murrumbidgee 2060–2079 compared to 1990–2009



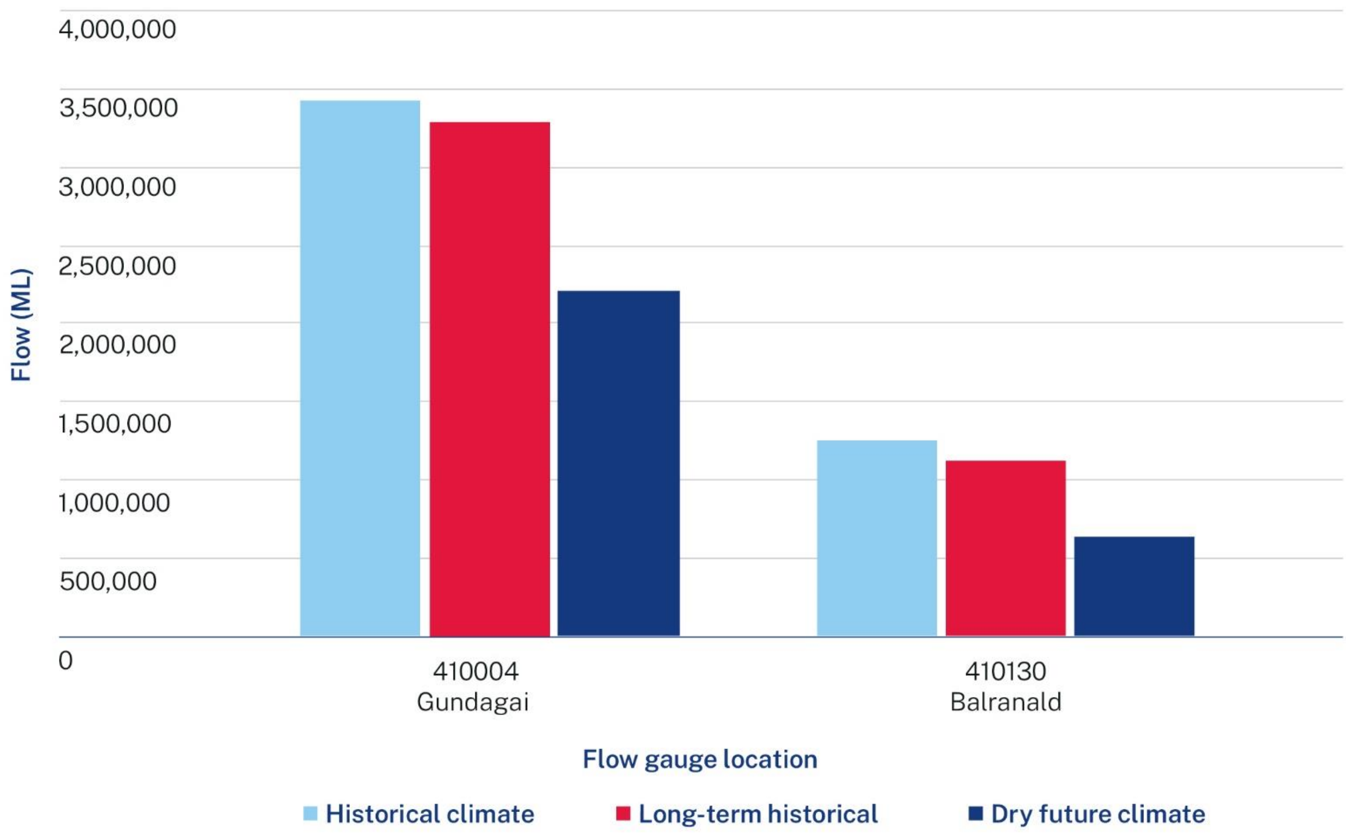


6.2.3 Impact of modelled climate scenarios on the regulated Murrumbidgee River flow regime

The flow regime of the regulated Murrumbidgee River responds to the different climate scenarios in a variety of ways.

Figure 21 shows how the various modelled climate scenarios impact the mean (average) annual flow at Gundagai and Balranald on the regulated section of the Murrumbidgee River. Mean annual flows under the dry future climate projection are significantly reduced compared to both the historical climate and long-term historical climate results. The scale of the reduction between the dry future climate and long-term historical is more significant (44%) at Balranald, which is at the end of the river system, compared with the reduction experienced at Gundagai (33%), which is on the upstream reaches of the regulated system.

Figure 21 Impact of climate scenario on mean (average) annual flow in the Murrumbidgee River at Gundagai and Balranald



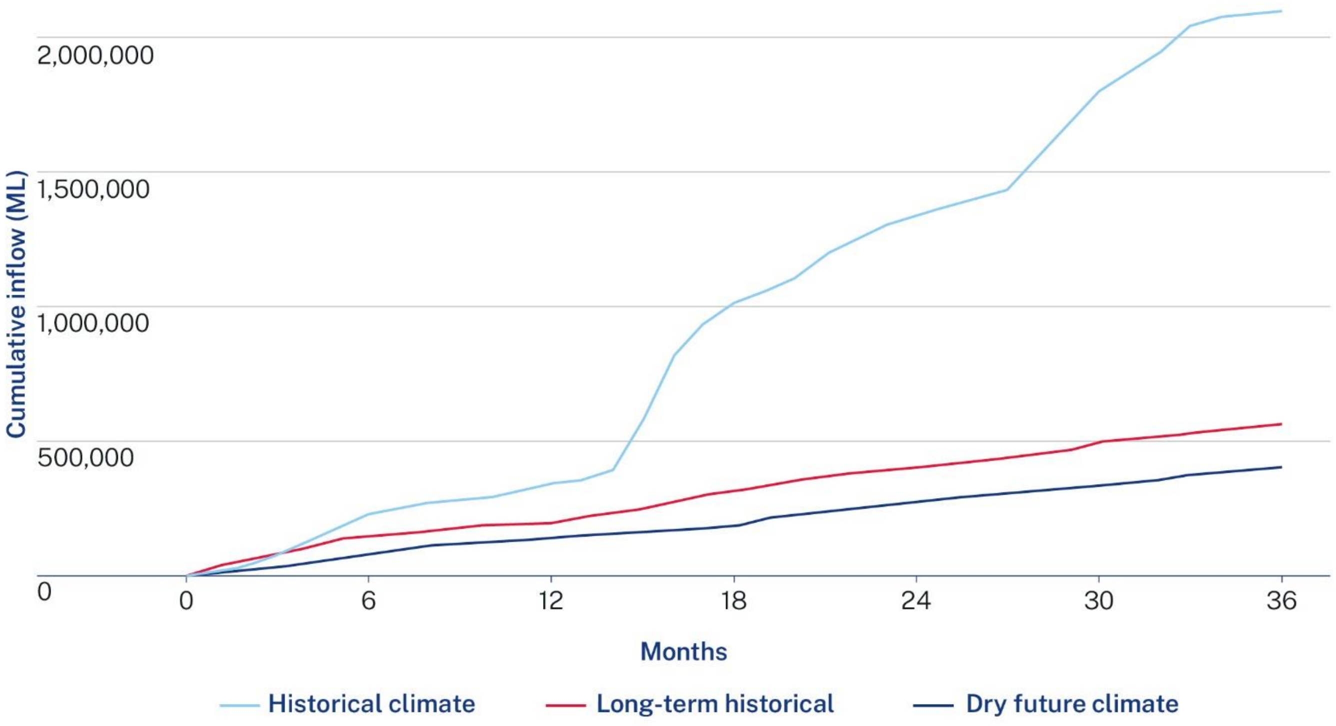
6.2.4 Impact of climate scenarios on storage inflows

Using the regional water strategy climate data, we have modelled inflows into Burrinjuck and Blowering dams to understand how the different climate scenarios impact the relative behaviour of inflows.

Figure 22 shows that the historical climate scenario minimum inflow sequence is much higher than the long-term historical climate scenario, whilst the dry future climate scenario is even lower. Therefore, we could see minimum sequences that are much drier than what we have seen in history.

The probability of these scenarios occurring is very small, one event in a 10,000-year dataset, and they may not eventuate. Using a dry future climate scenario may not be the most appropriate upon which to solely base our future water decisions. However, by analysing these extremes we can stress test the system and begin a conversation with the community about how we can plan for acceptable levels of risk and extreme droughts, and what we need to do to ensure we can provide water for critical human needs.

Figure 22 3-year minimum inflow sequences for combined Burrinjuck and Blowering dams



For seasonal inflows (Figure 23) into both Burrinjuck and Blowering dams, the historical and long-term historical scenario results are broadly similar. However, the dry future climate scenario shows significant reductions in flows for both dams, compared to the other two scenarios. By analysing these differences, we can begin conversations with water users about how infrastructure and policy settings can better support water-dependent industries.

Figure 23. Impact of climate scenarios on seasonal combined inflows into Burrinjuck and Blowering dams

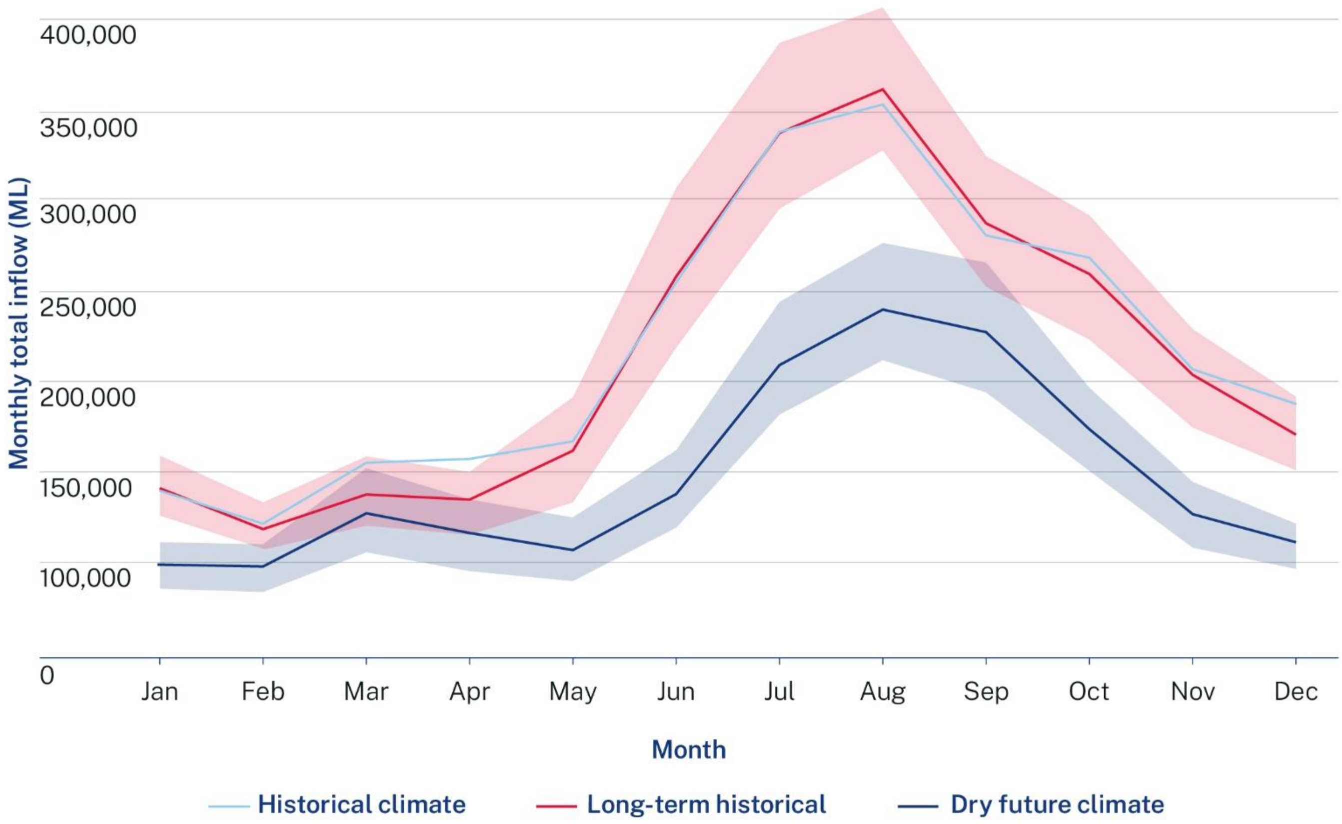


Figure note: red shaded area represents the 95th percentile confidence limit of the long-term historical scenario and the blue shaded area represents the 95th percentile confidence limit of the dry future climate scenario.

6.2.5 Impact of climate scenarios on available water determinations for the regulated Murrumbidgee River

The model results for available water determinations at the beginning and end of the water year (Figure 24 and Figure 25) — not including carryover — for 1 July and 30 June respectively, show a similar response to inflows into water storages and storage levels (Figure 23), shown above.

At the start of the water year general security allocations:

- would be zero approximately:
    - 10% and 5% of the time under the historical and long-term historical scenarios and
    - 20% of the time under the dry climate future scenario.
- would be more than 50% approximately:
    - 15-16% of time under the historical and long-term historical scenarios
    - 3% of the time under the dry climate future.

At the end of the water year, general security water allocations would reach 100% (Figure 24) approximately:

- 40% of the time under the historical climate and long-term historical climate scenarios
- 6% of the time under the dry climate future scenario.

Again, a continuation of previously experienced water availability conditions would see a continuation of historical allocation patterns, whereas a dry future climate would present some significant challenges for consumptive and environmental general security water users.

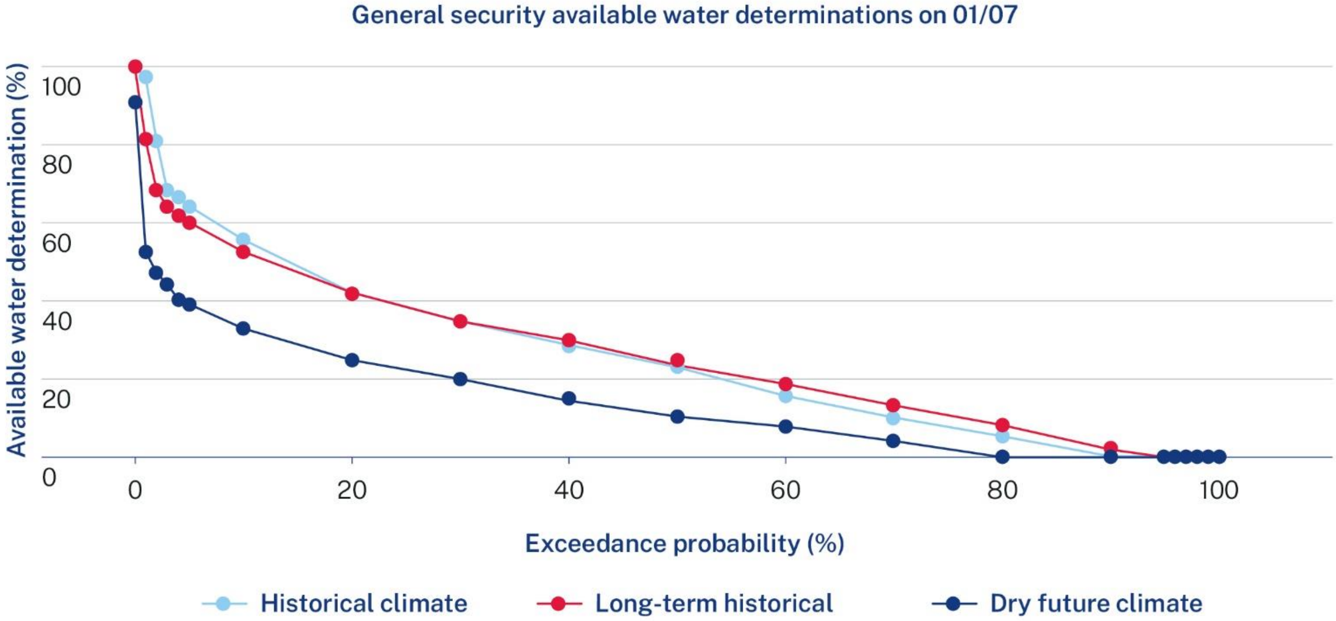
The new climate data and modelling is not appropriate for operational decisions made under water sharing plans, such as calculating available water determinations, and it will not be used as such.

For high security entitlements (Figure 25),

- start of year allocations:
  - would never be zero for either the historical climate or long-term historical climate scenarios, and
  - would be zero in 3% of the time under the dry future climate scenario.
- Would exceed 95%:
  - 80% of the time for the historical climate scenario
  - 95% of the time under the long-term historical climate scenario
  - in 80% of the time under the dry future climate scenario.

End-of-year allocations for high security entitlements are similar across all three scenarios, with dry future climate change resulting in a small decrease (Figure 25).

Figure 24. Impact of climate scenario on Murrumbidgee general security available water determinations for 1 July (top) and 30 June (bottom)



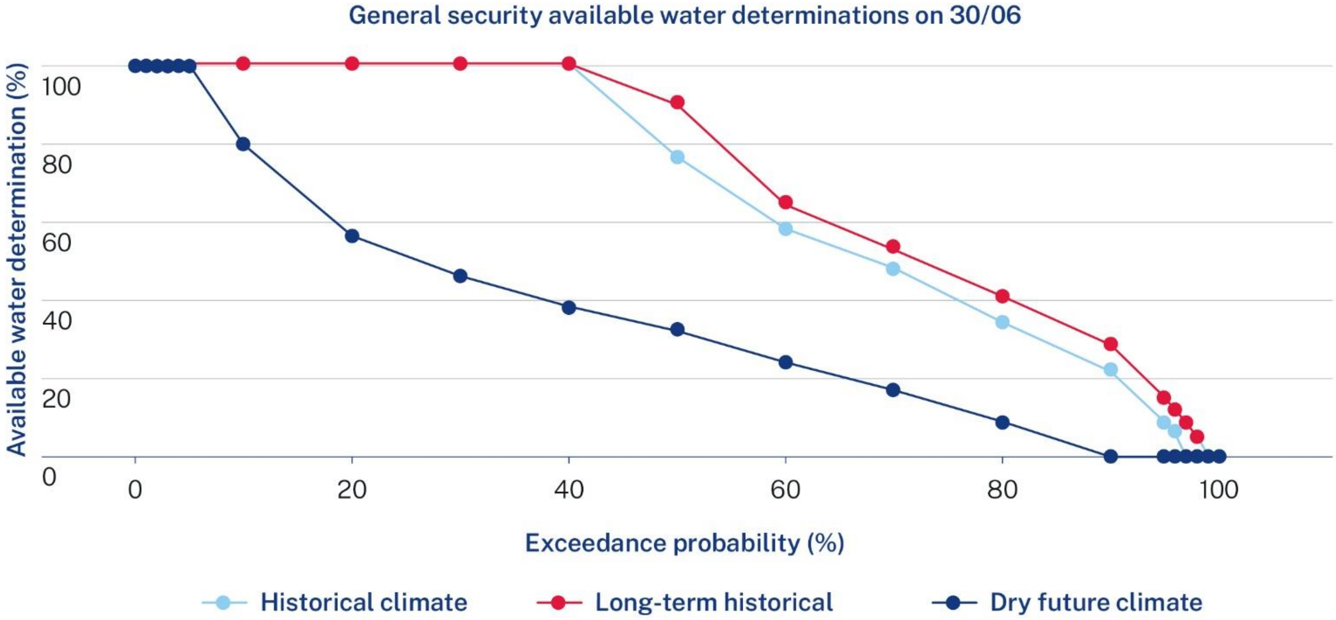
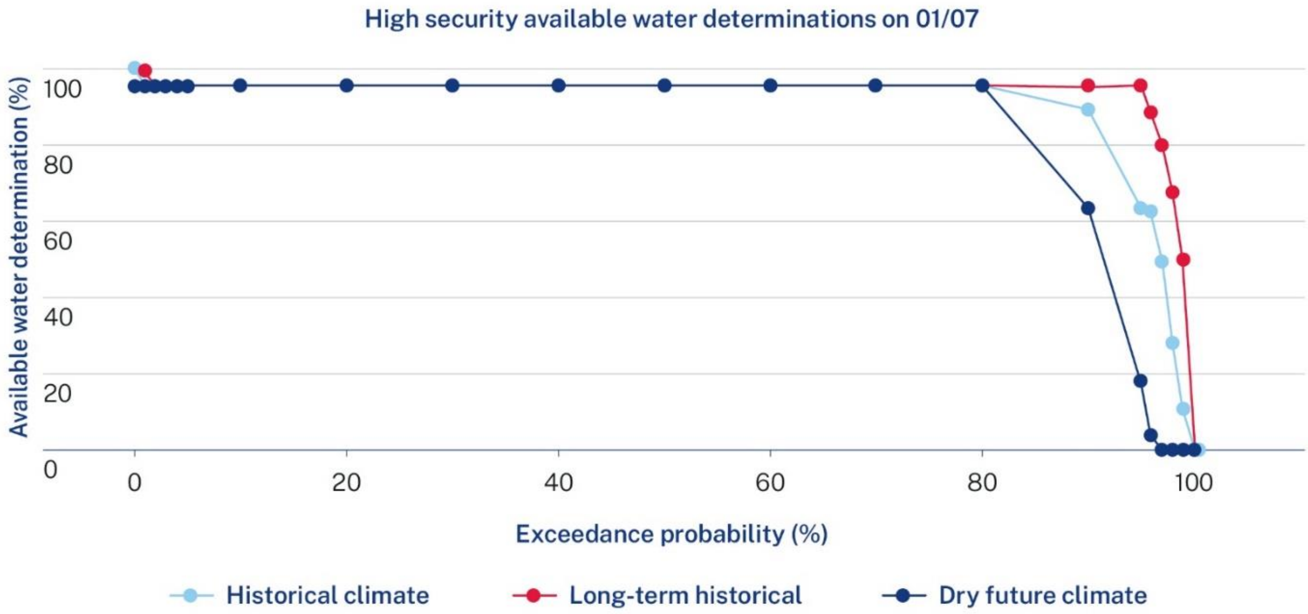


Figure note: These results do not include carryover. To interpret these figures, the higher a point on a line is, the higher the allocation level; whilst the further a point is — on a line — to the right of the graph, the more likely that level of allocation is.

Figure 25 Impact of climate scenario on Murrumbidgee High Security available water determinations for 1 July (top) and 30 June (bottom)



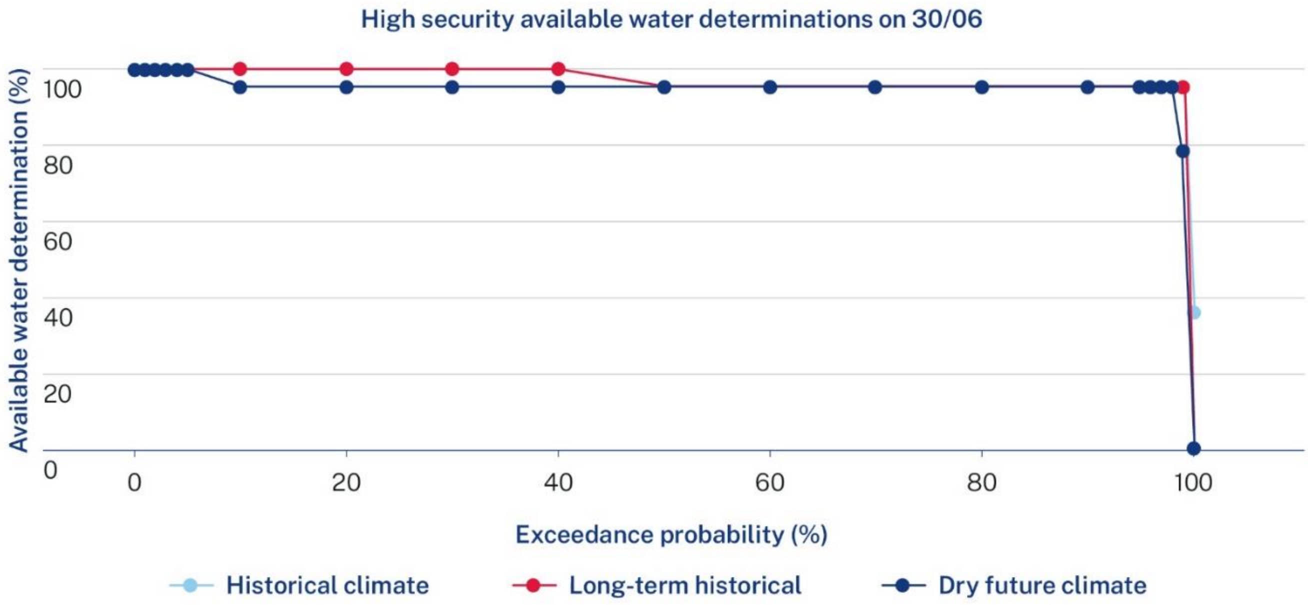


Figure note: These results do not include carryover. Carryover is not a feature for high security licences. To interpret these figures, the higher a point on a line is, the higher the allocation level; whilst the further a point is — on a line — to the right of the graph, the more likely that level of allocation is.

6.2.6 Impact of modelled climate scenarios on supply shortfalls for regulated Murrumbidgee town water supplies

This section presents the results of assessments of modelled town water demands against the available supplies, considering the three climate scenarios – historical climate, long-term historical climate and dry future climate scenarios.

Results are split into two – the first set presents the results based on current population demand levels and the second set presents the results based off future demand levels in 2061.

Refer to section 4 for information about the methods and assumptions used in the analysis.

Town water supply shortfalls based on current demand levels

Table 6 presents the results of an assessment of modelled town water demand (based on current levels of demand)[24] against the available supply from the regulated Murrumbidgee River. It shows that there are no shortfalls[25] under the historical climate scenario. However, the longer droughts present within the long-term historical climate scenario mean that there is the potential for minor shortfalls to Jerilderie, Jugiong and Wanganella.

Furthermore, the reduced water availability under the dry future climate scenario increases the number of towns experiencing shortfall and considerably increases the chances of significant shortfalls each year for Jerilderie, Jugiong and Wanganella. For example, each year for Jerilderie there is a 2% chance that the number of days where at least 10% of the required demand is not met, increases from nothing (historical climate and long-term historical climate scenarios) to 59 days under a dry future climate.

[24] This assessment only considered the current levels of town demands. It does not incorporate forecast demand based on future population projections.

[25] Shortfalls are measured by the number of days where a town's surface water supply is less than its water demand. Here the analysis uses the following percentages 10%, 25%, 50% and 75% as thresholds to show how much demand was not met.

Table 6. Modelled town water supply shortfalls for the regulated Murrumbidgee River towns – current demands

Town	Annual exceedance probability	Historical: Days where at least 10%, 25%, 50% and 75% daily demands not supplied	Long-term historical: Days where at least 10% daily demand not met	Long-term historical: Days where at least 25% daily demand not met	Long-term historical: Days where at least 50% daily demand not met	Long-term historical: Days where at least 75% daily demand not met	Dry future climate: Days where at least 10% daily demand not met	Dry future climate: Days where at least 25% daily demand not met	Dry future climate: Days where at least 50% daily demand not met	Dry future climate: Days where at least 75% daily demand not met
Balranald	0.10%	Not assessed^	0	0	0	0	92	70	30	30
	0.50%		0	0	0	0	2	0	0	0
	1%	0	0	0	0	0	0	0	0	0
	2%	0	0	0	0	0	0	0	0	0
Gundagai	No shortfalls									
Hay	0.10%	Not assessed^	0	0	0	0	30	30	4	0
	0.50%		0	0	0	0	0	0	0	0
	1%	0	0	0	0	0	0	0	0	0
	2%	0	0	0	0	0	0	0	0	0
Jerilderie	0.10%	Not assessed^	62	39	17	0	221	185	120	60
	0.50%		0	0	0	0	116	100	41	26
	1%	0	0	0	0	0	55	30	7	0
	2%	0	0	0	0	0	0	0	0	0
Jugiong*	0.10%	Not assessed^	11	0	0	0	248	198	0	0
	0.50%		0	0	0	0	144	31	0	0
	1%	0	0	0	0	0	68	0	0	0
	2%	0	0	0	0	0	0	0	0	0
Morundah	No shortfalls									
Tumut	0.10%	Not assessed^	0	0	0	0	63	31	30	25
	0.50%		0	0	0	0	0	0	0	0
	1%	0	0	0	0	0	0	0	0	0
	2%	0	0	0	0	0	0	0	0	0

*Table note: The town of Wagga Wagga is not included here due to the very high level of town water supply from groundwater sources — with groundwater not being modelled under this regional water strategy. *Jugiong is the offtake point for Goldenfields water supply network to Cootamundra, Young, Harden, Wallendbeen and a range of individual customers. ^There are insufficient years within the historical climate scenario simulation period to determine results.*

Town water supply shortfalls based on future population projections

Table 7 presents the results of an assessment of modelled town water demand (based on projected future levels of demand at 2061) against the available supply. Given the NSW Common Planning Assumptions 2021 predict low or zero population growth in many towns in the region (Table 1), therefore is no significant change to shortfalls.

Table 7. Modelled town water supply shortfalls for the regulated Murrumbidgee River towns – 2061 demands

Town	Annual exceedance probability	Climate Scenario								
		Historical	Long-term historical				Dry future climate			
		Days where at least 10%, 25%, 50% and 75% daily demands not supplied	Days where at least 10% daily demand not met	Days where at least 25% daily demand not met	Days where at least 50% daily demand not met	Days where at least 75% daily demand not met	Days where at least 10% daily demand not met	Days where at least 25% daily demand not met	Days where at least 50% daily demand not met	Days where at least 75% daily demand not met
Balranald	0.10%	Not assessed^	0	0	0	0	92	70	30	30
	0.50%		0	0	0	0	2	0	0	0
	1%	0	0	0	0	0	0	0	0	0
	2%	0	0	0	0	0	0	0	0	0
Gundagai	No shortfalls									
Hay	0.10%	Not assessed^	0	0	0	0	30	30	4	0
	0.50%		0	0	0	0	0	0	0	0
	1%	0	0	0	0	0	0	0	0	0
	2%	0	0	0	0	0	0	0	0	0
Jerilderie	0.10%	Not assessed^	67	42	11	0	277	227	127	70
	0.50%		0	0	0	0	186	143	71	30
	1%	0	0	0	0	0	108	92	40	30
	2%	0	0	0	0	0	54	30	7	0
Jugiong	0.10%	Not assessed^	0	0	0	0	226	168	87	44
	0.50%		0	0	0	0	114	61	30	20
	1%	0	0	0	0	0	50	30	0	0
	2%	0	0	0	0	0	0	0	0	0
Morundah	No shortfalls									
Tumut	0.10%	Not assessed^	0	0	0	0	63	31	30	25
	0.50%		0	0	0	0	0	0	0	0
	1%	0	0	0	0	0	0	0	0	0
	2%	0	0	0	0	0	0	0	0	0

*Table note: The town of Wagga Wagga is not included here due to the very high level of town water supply from groundwater sources — with groundwater not being modelled under this regional water strategy. *Jugiong is the offtake point for Goldenfields water supply network to Cootamundra, Young, Harden, Wallendbeen and a range of individual customers. ^There are insufficient years within the historical climate scenario simulation period to determine results.*

The next steps will be to work with councils and local water utilities to put these results into local contexts via the local water utility strategic planning process. Consideration of our new climate modelling data and future water availability risk will be important to understand shortfall risks and assess performance of regional water strategy options.

7. Future work

In the southern Basin, we have already seen changes in water availability over the past 20 years. Trends of decreasing autumn and early winter rainfall of 10–20%, decreasing numbers of wet days in southeast Australia since the mid-1990s, and temperature increases in this region, especially post 1960, were at least partly attributable to climate change. More work is being done by Adelaide University to incorporate this non-stationarity in new climate datasets for the second iterations of the Murrumbidgee and NSW Murray Regional Water Strategies to help us more accurately assess current and future drought risk.

The NARCliM Project is expected to complete the NARCliM 2.0 datasets in 2024, delivering updated and expanded projections that use more recent global climate models and three emission scenarios to provide projections out to 2100. These improvements will further advance our understanding of plausible future climate conditions and inform future regional water strategies.

In addition, the models do not currently directly represent groundwater resources. This will be explored in the future.

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