Independent assessment of the 2018-19 fish deaths in the lower Darling

Interim report, with provisional findings and recommendations

20 February 2019

Independent panel

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Acknowledgement of the Traditional Owners of the Murray–Darling Basin

The panel acknowledges and pays respect to the Traditional Owners, and their Nations, of the Murray–Darling Basin, who have a deep cultural, social, environmental, spiritual and economic connection to their lands and waters. The panel appreciates the need for recognition of Traditional Owner knowledge and cultural values in natural resource management associated with the Basin.

The panel is thankful for the insights and assistance provided by the Barkandji people to the panel during their preliminary assessment, and acknowledges the Barkandji people's enduring connection to, and care of, the Barka (Darling) River.

The approach of Traditional Owners to caring for the natural landscape, including water, can be expressed in the words of the Northern Basin Aboriginal Nations Board:

…As the First Nations peoples (Traditional Owners) we are the knowledge holders, connected to Country and with the cultural authority to share our knowledge. We offer perspectives to balance and challenge other voices and viewpoints. We aspire to owning and managing water to protect our totemic obligations, to carry out our way of life, and to teach our younger generations to maintain our connections and heritage through our own law and customs. When Country is happy, our spirits are happy.

This report may contain photographs or quotes by Aboriginal people who have passed away.

The use of terms 'Aboriginal' and 'Indigenous' reflects usage in different communities within the Murray–Darling Basin.

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PREAMBLE

Three large-scale fish death events occurred in the Darling River near Menindee between December 2018 and January 2019. The first event occurred on 15 December 2018, affecting a 30 km stretch of river between Weir 32 and the Menindee Main Weir. New South Wales (NSW) Department of Primary Industries Fisheries (NSW DPI Fisheries) staff who inspected the site reported tens of thousands of dead fish, with high numbers of dead fish observed near the Old Menindee Weir and the Menindee Pump Station. The second event occurred on 6-7 January 2019, in the same stretch of river. It was a much larger event, affecting approximately 45 km of the Darling River below the Menindee Main Weir including the Menindee township. NSW DPI Fisheries staff estimated hundreds of thousands of dead fish, with more dead fish downstream toward Weir 32. Local residents reported much larger numbers of dead fish, with estimates ranging between 1 and 3 million. The third event occurred on 28 January 2019, again affecting approximately 30 km of the Darling River between Weir 32 and the Menindee Main Weir. It involved thousands of bony herring along with many golden perch. Together, these events will likely have impacts on fish populations in the local region, and potentially the Darling and lower Darling River for many years.

BACKGROUND TO THIS INDEPENDENT ASSESSMENT

In January 2019, the Minister for Agriculture and Water Resources (the Minister) wrote to the Prime Minister requesting an independent panel be established to assess the fish deaths of 2018-19 in the lower Darling to identify causes, evaluate management responses and provide recommendations.

Professor Rob Vertessy was appointed by the Minister to chair the panel and was requested to select a group of experts to conduct the assessment. Professor Vertessy was chosen based on his expertise in water science and climate change research, and his familiarity with the management of the Murray–Darling Basin via his role as Chair of the Murray–Darling Basin Authority's (MDBA) Advisory Committee on Social, Economic and Environmental Sciences. Professor Vertessy selected five additional panel members based on their areas of expertise and professional standing. Profiles of each of the panel members are provided at Attachment A.

TERMS OF REFERENCE

The Terms of Reference for the Independent Assessment panel are to:

1. Assess the water management, events, and conditions leading up to the 2018-19 fish deaths to identify likely causes.
2. Assess the effectiveness of existing fish management responses to manage fish deaths risks currently being experienced in the lower Darling River.
3. Provide recommendations to the Minister, the MDBA and Murray–Darling Basin Governments on:
    - strategies that could be implemented to prevent similar events in the future, including monitoring activities to provide for early warnings of heightened risk of fish deaths from drought and flood events;
    - strategies to enhance native fish recovery following fish death incidents in the lower Darling River; and
    - priority actions and investments in the lower Darling under Murray–Darling Basin Plan Native Fish Management and Recovery strategy.

CONSULTATION

In conducting this Independent Assessment, the panel is required to:

1. Engage and seek advice from relevant NSW DPI Fisheries scientists, and other experts in relevant fields, including native freshwater fish ecology, water management and water quality.
2. Assess information available and interviews with State and Federal agency staff and local residents including Aboriginal stakeholders.
3. Convene a facilitated workshop involving independent reviewers and a broader group of experts to validate the methods used in, and recommendations from, the independent assessment.

To date, the panel has consulted with officials from Australian Government and Basin state agencies including the Department of Agriculture and Water Resources, the Commonwealth Environmental Water Office (CEWO), the MDBA, the Bureau of Meteorology (BOM), NSW DPI Fisheries, NSW Office of Environment and Heritage (OEH), NSW Department of Industry (DoI), WaterNSW and the Queensland Department of Natural Resources, Mines and Energy (DNRME). Details of consultation to date are at Attachment B.

Members of the panel travelled to Menindee and Pooncarie on 13 and 14 February 2019. This field visit included a tour of the Menindee Lakes and lower Darling River, and meetings with local communities, including Aboriginal stakeholders.

The panel will hold a technical workshop with over 30 subject matter experts to test their provisional findings and recommendations on 27 February 2019.

REPORTING

The Independent Assessment panel is required to:

1. provide a preliminary report and early advice and recommendations to the Minister by 20 February 2019; and
2. provide a report to the Minister, the Chair of the Murray–Darling Basin Authority Board and the Murray–Darling Basin Ministers no later than 31 March 2019.

PANEL APPROACH

The panel's approach to this Independent Assessment involves the following stages:

- Stage 1 – Desktop analysis of relevant reports.
- Stage 2 – Commissioned hydro-climatic analysis by the BOM.
- Stage 3 – Consultation with Australian Government and Basin state technical agencies.
- Stage 4 – Consultation with the community.
- Stage 5 – Preparation of interim findings and recommendations and submission to Minister.
- Stage 6 – Technical workshop to review our interim findings and recommendations.
- Stage 7 – Further consultation as required.
- Stage 8 – Preparation of final report and submission to Minister and others.
- Stage 9 – Share final findings with the community.

The findings and recommendations reported in this interim report are provisional. Additional consultation and research will be undertaken over the next few weeks. The technical workshop at Stage 6 in this assessment will provide critical analysis of the panel's thinking by subject matter experts and valuable guidance on improving the utility of our recommendations.

Related investigations

NSW DPI Fisheries undertook an investigation into the lower Darling fish deaths and released an interim report on 25 January 2019 (NSW DPI Fisheries, 2019). At the request of the leader of the opposition, The Hon. Mr Bill Shorten, the Australian Academy of Science undertook a similar investigation and released their report on 18 February 2019.

Response of Basin governments

Australian Government and Basin state water managers, and environmental water holders met in late January 2019 to look at the immediate risk of further fish deaths and coordinate mitigation strategies. At the meeting, government officials recommended an action plan (MDBA, 2019) to complement initiatives that were underway to manage the fish death events, monitor and mitigate the risk of further events and to support the recovery of native fish populations. Agencies have been progressing some of the recommended actions, including:

- Conducting additional water quality monitoring (mainly dissolved oxygen (DO) and temperature) from February to April 2019 of 17 sites along the lower Darling.
- Trialling (with mixed results) aerators and other technologies to improve water quality in the affected areas.
- Localised fish rescues and translocations to establish 'insurance' populations.
- A large clean-up effort to minimise rotting biomass that might give rise to further oxygen depletion in the weir pools.

The Minister also announced a $5 million Native Fish Management and Recovery Strategy to protect and restore native fish populations in the Murray–Darling Basin over the long-term. Initial work to scope the strategy has commenced and will draw on the findings and recommendations of this independent assessment. The MDBA will convene a workshop to scope and develop the strategy in April 2019.

Current situation

At the time of writing this interim report, the situation in the lower Darling remains critical. Various field activities are contributing to managing the risk of further fish deaths, but more deaths are likely to occur as low inflows and dry conditions continue across the lower Darling catchment for the foreseeable future. Recent water quality monitoring conducted by NSW DPI Fisheries provides evidence of continuing high stratification and low water quality in several areas. Low dissolved oxygen levels and high stratification has been detected in various sampling sites across the lower Darling including Karoola, Moorara and Bono and there is still presence of algae scum on surface in Appin, the Main Weir, Bono, Karoola and Lelma. This additional monitoring is vitally important to informing prioritisation of government responses and understanding the processes giving rise to fish deaths.

DESCRIPTION OF THE SYSTEM

THE DARLING BASIN

The following content draws primarily on Webb McKeown (2008). The Darling Basin covers an area of 699,000 square kilometres (km), and makes up 70% of the total area of the Murray–Darling Basin (Figure 1). Approximately one third is in Queensland and two thirds is in NSW. The Darling Basin covers about half of the total area of NSW, and one tenth the total area of Queensland. The distance from its northern most point to its most southern is approximately 1,100 km, and it is a similar distance from its most eastern to its most western edge.

The main trunk of the river system rises in the Great Dividing Range, close to the border of NSW and Queensland, and travels south-west for 2,700 km before it empties into the Murray at Wentworth. This makes it the longest river in Australia. The Darling Basin is flatter and much less mountainous than the neighbouring Murray Basin. Some 60% of the Darling Basin is less than 300 m above sea level. Nowhere does it rise more than 1,500 m above sea level. Even its eastern Great Dividing Range edge is often less than 1000 m above sea level. Only a few areas along its northern and western edges rise above 500 m. At Wentworth, the Darling is just 50 m above sea level.

The low relief of the Darling Basin means that the river and its major tributaries are very low energy rivers over the majority of their length. Coupled with the very variable rainfall and runoff of the catchments, this has meant that the rivers become a series of branching channels and wetland lakes that distribute their flows across large areas, especially during flood times.

Compared to the rivers in the Murray Basin, flows in the rivers of the Darling Basin are highly variable, with annual discharges showing a greater departure from the average than in the Murray. In the Darling Basin above Menindee, the augmentation of natural river flows by release of water from major dams (river regulation) is restricted to the main tributary channels and a few effluents of the Macintyre, Gwydir, Namoi and Macquarie, and to a short section of the Condamine–Balonne system. No regulated supply is provided to the Barwon or upper Darling.

The ratio of major dam size to total runoff and the proportion of flows regulated by dams in the Darling Basin above Menindee are both much lower than in the Murray system. This means that a relatively high proportion of the flows in the Darling River above Menindee, and even in most of its regulated tributaries, are the direct result of runoff from rainfall and groundwater inflows rather than releases from dams.

In all Darling tributaries with major irrigation industries, large-scale irrigation development has occurred in the lower reaches of the system. This means that average annual flows in all major irrigation valleys, at least as far downstream as their “mid river” maximum flow point, are only 3% to 15% less than under natural conditions. The high value of cotton, abundance of irrigable land and high proportion of natural river flows remaining in rivers, encouraged many farmers to construct large on-farm storages and divert water into them during high flows to augment the supply available from major dams.

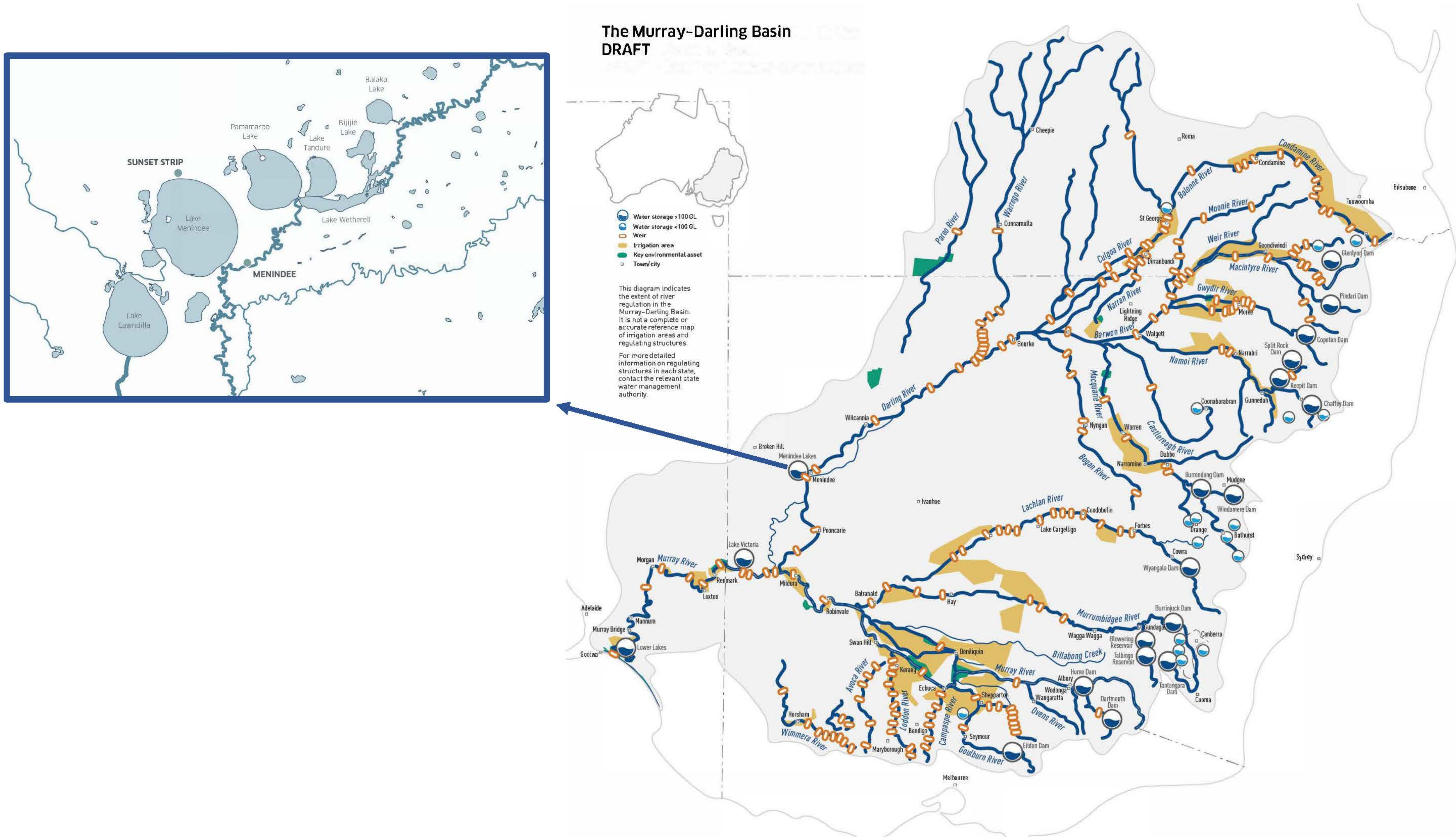


FIGURE 1. THE MURRAY–DARLING BASIN AND THE MENINDEE LAKES

In NSW, management of the Darling Basin has historically focussed on each separate water management area. The rules contained in NSW water sharing plans have primarily focused on within valley needs of environmental values, assets and extractive users. The main exception to this has been the Interim Unregulated Flow Management Plan for the North West (IUFMP) which commenced in October 1992 (Water Resources NSW, 1992). This plan was a response to the major blue-green algae bloom along the entire Barwon–Darling in late 1991. The rules developed for the IUFMP, which required periodic restrictions in supplementary access in the Border Rivers, Namoi, Gwydir, or Macquarie River systems were subsequently incorporated into the statutory water sharing plans for the Border Rivers, Namoi, and Gwydir Valleys. The rules aim to provide flows for riparian needs, algal suppression and fish passage in the Barwon–Darling, but the policy has not been consitenly implemented since its formulation in 1992.

Arrangements for sharing of water in the Barwon–Darling are set out in the state water sharing plan for the Barwon–Darling. This was developed by NSW in 2012, and commenced a month prior to the *Basin Plan 2012* (Cth) (Basin Plan) coming into effect. The draft of the *Barwon–Darling Water Sharing Plan 2012* (NSW) was released for public comment in late 2011. Significant changes occurred between the development and consultation on the draft plan and release of the final plan, including a change to the share components that resulted in fewer C Class (high flow) shares, and an increased number of A Class and B Class (low and medium flow) shares. These changes have been controversial because the net effect was to allow extraction of water more often and at lower flow thresholds.

Going forward, the need to manage the Darling Basin as a connected system in terms of environmental assets and values has been recognised in the Basin Plan, through the purchase of held environmental water by the Australian Government in upstream tributaries for use in the Barwon–Darling, and in the Northern Basin Review Toolkit Measures. New management arrangements being considered for implementation in NSW include:

- arrangements to protect environmental flows (including amendments to tributary and Barwon–Darling Water Sharing Plan access rules);
- event-based mechanisms such as formulation of first flush rules in the Barwon–Darling;
- improvements in the coordination and delivery of environmental water through active management and improved monitoring and compliance; and
- environmental works and measures to promote fish movement and habitat.

While these measures will facilitate connectivity within the Barwon–Darling, further work is required to develop management arrangements that facilitate improved connectivity between the Barwon–Darling river above Menindee Lakes and the downstream lower Darling River.

In Queensland, state water plans have provided for connectivity along tributary systems through achievement of end-of-system flow regimes that achieve specific environmental flow objectives. In the past, these plans tended to not target environmental values in the Barwon–Darling, but rather focus on end-of-system values for the various sub-catchments. For example, the current plan for the Condamine–Balonne has end-of-system values relating to the Narran Lakes complex and the national parks of the Culgoa floodplain. Although it contributes to maintaining or improving the ecological condition of the Darling River upstream of Bourke, it has no recognition of the impact of flows from this system on the Darling below Bourke. Likewise, the Warrego, Paroo, Bulloo and Nebine plans make no comment of flows from this tributary system being required for ecological benefit in the Darling River system. In the new water resource plans required under the Basin Plan, the management and protection of connectivity events originating from Queensland tributaries requires the quantification of any held environmental volumes that enter NSW.

From mid-2019, future water management arrangements across all sub-systems of the Murray–Darling Basin will be specified in water resource plans. These plans are a more comprehensive articulation of how water will be managed within the Sustainable Diversion Limit (SDL) set for each water management area under the Basin

Plan. The NSW and Queensland governments are in the process of developing water resource plans for all water resource plan areas including for the Barwon–Darling and for the Border Rivers-Moonie respectively. Once completed, they will need to submit the plans for accreditation to the Minister. The MDBA advises the Minister whether the water resource plans meet the requirements of the Basin Plan.

The Menindee Lakes

The following draws primarily on the lower Darling Reach Report for the Constraints Management Strategy (MDBA, 2014).

The Menindee Lakes system is comprised of seven natural lakes that have been connected to the lower Darling River through a series of weirs, channels and levees. The primary supply lakes within the storage system are lakes Menindee, Cawndilla, Pamamaroo and Wetherell. Lake Wetherell is an artificial lake formed by raising the river height to 14 m at the Main Weir, which connects several smaller natural lakes. The lakes are listed in the Directory of Important Wetlands in Australia (Department of Environment and Energy, 2010).

The Menindee Lakes are important to local Aboriginal people, with cultural sites dating back over 13,000 years. It is estimated that Aboriginal people have lived in the area for at least 35,000 years. The lakes are an important waterbird habitat, with more than 30 species of waterbirds recorded on the main lakes, including a number of threatened species such as freckled duck and migratory waders. Kinchega National Park near Menindee covers more than 440 km^2 and includes 62 km of Darling River frontage. It is one of only two large conservation areas along the Darling River, and protects substantial areas of river red gums, and rare acacia and bluebush communities.

Before the Menindee Lakes storage scheme was completed in 1968, lakes Menindee and Cawndilla supported expanses of lignum, black box and river red gum. Permanent inundation has reduced the area of native vegetation. Today, many of the lakes are open water with dead trees, surrounded by remnant black box and river red gum woodlands. The Menindee Lakes supply water for irrigation, stock and domestic supply on the lower Darling channel, and for stock and domestic use via a pipeline in the Great Darling Anabranch, as well as supplying the towns of Broken Hill, Menindee and Pooncarie.

Operation of the Menindee Lakes is subject to the longstanding Murray–Darling Basin Agreement (Agreement) between NSW, Victoria, South Australia and the Australian Government. WaterNSW manages the lakes and is responsible for managing the storages during flood. The Agreement allows the MDBA to access water in the lakes to support downstream demand in the River Murray. Under the Agreement, the MDBA can access water in the lakes when they rise above 640 gigalitres (GL), and until the lakes drop below 480 GL. This arrangement is referred to as the '640/480 rule'.

The total storage volume of Menindee Lakes at full supply level is 1,731 GL, with an ability to surcharge the lakes after seasonal inflows to a volume of 2,050 GL. A large share of the water held in both lakes Cawndilla and Menindee is inaccessible below a certain storage volume, a quantity regerred to as 'inactive' or 'dead' storage.

While water conservation and operational efficiency are the main objectives in managing the lakes today, the MDBA also gives consideration to NSW water supply obligations (Broken Hill and lower Darling entitlements), protecting the structural integrity of the lakes, water quality issues and various environmental and cultural heritage features of the lakes.

Weir 32, located downstream of the Menindee Lakes, was constructed in 1960 to provide town water supply for Menindee, and to supply water to Broken Hill via a pipeline. Concerns over the ability for the Darling River to sustain the Broken Hill supply led to the development of a new pipeline project. Under the new scheme, up to 35 ML per day would be delivered to Broken Hill via pipeline from the Murray River at Wentworth, reducing the call on the Menindee Lakes for town water supply.

THE LOWER DARLING RIVER

The following draws primarily on lower Darling Reach Report for the Constraints Management Strategy (MDBA, 2014).

The lower Darling is the section of the Darling River between Menindee Lakes and the confluence of the Darling with the River Murray at Wentworth. Below the Menindee Lakes, the Darling River continues in two channels: the lower Darling main channel and the Great Darling Anabranch. The Great Darling Anabranch is the ancestral channel of the Darling River and features a number of ephemeral lakes that can hold water for prolonged periods following a flood event. It branches off from the main channel about 55 km south of Menindee and joins the Murray downstream of Wentworth.

The lower Darling area is one of the lowest rainfall regions in NSW, with annual average rainfall ranging between 220 and 280 mm (Green et al., 2012). The region has very high evaporation rates, from 2 mm a day in winter to up to 13 mm in summer (Green et al., 2012). Most of the water that flows into the Menindee Lakes comes from tributaries to the Darling that start in southern Queensland and northern NSW. Flood events generally occur as a result of high rainfall in these upper catchments (Lloyd, 1992).

The flow regime in the lower Darling has changed significantly since the completion of the Menindee Lakes storage scheme in 1968, and as a result of abstractions in the Barwon–Darling and its tributaries. It is estimated that the mean annual flow in the Darling River has been reduced by more than 40% as a result of abstractions in the Barwon–Darling (Gippel & Blackham, 2002). The timing of flows has fundamentally changed, with the largest volumes of water now flowing in summer to meet consumptive demand, rather than autumn or spring as was the case prior to development. Winter flows are now less variable, with flows staying in the 200–500 ML/day level some 65% of the time (Thoms et al., 2000). Bankfull flows are less frequent and mid-range peaks have halved. Flows above 15,000 ML/day now occur in only 30% of years, compared to 60% prior to development (Gippel & Blackham, 2002).

The flow regime in the Great Darling Anabranch has also changed significantly since the completion of the Menindee Lakes storage scheme. Prior to development, the Anabranch would have naturally filled during floods. Flows into the upper parts of the Anabranch would have occurred as often as two out of every three years (Thoms et al. 2000) and flows large enough to reach Lake Nearie at the bottom of the system would have occurred a few times per decade (NPWS, 2008). Reductions to flows that inundate the floodplain have affected the health of river red gum trees (Green et al., 1998), and have also potentially reduced the supply of leaf litter and organic matter transported into the main channel ecosystem (Thoms & Sheldon, 1997).

The various hydrologic changes described above have reduced the health of fish populations, with an observed reduction in the number of native species and an increase alien fish species such as European carp (Gilligan, 2009). However, more recently, environmental water management in the region has assisted with recovery of native fish populations and local residents and visitors have observed marked improvements in the lower Darling. Fish movement and migration has been affected by the construction of three small weirs along the main channel (Green et al., 1998). Fishways have now been installed at Burtundy Weir (2007), Weir 32 (2009) and Pooncarie (2013).

COMMUNITY PERSPECTIVES ON THE LOWER DARLING SITUATION

As well as being a significant source of water for local towns and irrigation users, the Menindee Lakes, and the nearby Darling river, are located in an area of environmental, social and cultural significance and provide recreational, tourism and economic opportunities for the towns and surrounding region. When full, the lakes provide a popular area for water sports and other recreational activities. The nearby Darling River is also renowned as a recreational fishing hotspot, with regular captures of large Murray cod being a drawcard for visitors. The Menindee Lakes contain a broad diversity of both terrestrial and aquatic flora and fauna including threatened species and nationally important wetlands.

On 13 and 14 February 2019, the panel visited Menindee to see the location where the fish death events occurred. Whilst in the region, the panel had the opportunity to meet with representatives of the Barkandji people, local residents, and landholders from along the lower Darling.

The panel met with an engaged, well informed, but distressed community. They were grieving for the loss of amenity in their town: access to a clean and reliable water, what this means for their business and the continued viability of their community. It was evident that they were fearful for their future. It was made clear to the panel that the health of the river has a major impact on the physical and mental health of the community and a noticeable bearing on crime.

For the Aboriginal people of the region, the Barkandji, the river is at the heart of their culture and profoundly spiritual. They told the panel of the importance of the River in providing healthy food and medicine, as well as a physical connection to their history and culture:

"The river is our memory – we walk along it and remember our history and our ancestors by looking at the marks and places"

From Badger Bates' submission to the South Australian Royal Commission on the Murray–Darling Basin, provided to the panel Chair at Menindee on 13 February 2019.

The panel heard about the changes Aboriginal people had observed in their lifetimes. In their experience, the river nearly always had flowing water, and that if it stopped there would still be water in the deep waterholes. The colour of the water has changed and they stressed that they never used to have water quality issues like they do now. They are worried that important cultural heritage sites like scar trees won't survive. The species impacted by the fish deaths, such as Murray cod and Bony herring, have specific significance in Aboriginal storytelling, folklore and medicine (Paszkowski, 1969). The Darling is also the lifeblood that sustains important areas such as scar trees that were used for canoes, coolamons, shields and other culturally important sites like boundary trees. Water within the Darling preserves these sites, sustains the fish, and ensures that these cultural links are maintained.

Despite their distress, there was a positive energy among community members who were determined to rebuild. People have contributed their time and resources to protect the remaining fish. Many residents helped to remove dead fish from the river and donated money for fuel to run aerators. They are now looking to governments to follow through on the start the community have made.

The local communities affected by the fish deaths are united in wanting to see the lakes managed more effectively to give their community more certainty and improve river health. They have a lot of energy to help remedy the situation and have researched and developed alternative options for many of the proposals actively being considered by governments. People in the region feel neglected by institutions and governments and are frustrated that their concerns are not being heard or acted upon.

The community were critical of the current operation of the Menindee Lakes, telling the panel that they believed that the operation of the lakes had changed since the Millennium drought, with lake levels being lowered much faster than in the past. They supported the principle of efficient lake operations to minimise system losses, but were sceptical of the reconfiguration projects currently proposed as part of the SDL adjustment process. They suggested releases from the lakes should be more conservative, anticipate dry sequences, and that more should be held in reserve to meet local water needs. They viewed the upper two lakes (Lake Pamamaroo or Lake Wetherell) as integral for drought supply and vital for the survival of the lower Darling environment, businesses and families during dry times.

The community conveyed scepticism and a lack of trust in the information being used to make decisions about river operations and water management. They disputed the evaporation rates used to justify operational decisions to draw on Menindee Lakes for Murray systems operations. They noted that at times, reported flow rates did not align with their own on-ground observations. Some also believe that the lakes have changed in depth over time.

The community expressed frustration at not being adequately engaged in planning and operational decisions that affect their lives. They felt that consultation to date on a range of projects in the region lacked transparency and that governments show little regard for the community voice. Landholders, residents and traditional owners alike are actively seeking opportunities to be genuinely involved in the management and operation of the lakes, as well as water management decisions further upstream.

The panel was impressed that several members of the community had gone to a lot of personal effort to understand the complex operational, environmental and governance context for managing water in the lower Darling and Menindee Lakes. A resounding message was that they were frustrated at a lack of acknowledgement given to the lower Darling system as an important ecological asset, in its own right. Time and again, the panel heard concerns about the growth of diversions in the upper catchments, and now with drought conditions prevailing across the Barwon–Darling and its tributaries, the local community perceive that their water needs have been put last. The community exhorted governments to adopt a truly whole-system approach to water management because they argue that current arrangements still largely focus on individual catchments, excluding the participation of people from connected regions.

It is evident that concerns about the lower Darling fish deaths extend beyond the communities of the lower Darling region. The broader community response to these events demonstrates that there is widespread public concern for the health of the Darling River and the Basin at large. The public discourse frequently calls into question the legitimacy and effectiveness of water management arrangements in the Basin, and highlights the differing expectations that people hold about the purpose and promise of the Basin Plan.

WHAT ARE FISH DEATH EVENTS?

Fish death events are here defined as any sudden and unexpected mass mortality of wild or cultured fish (Lugg, 2000). Fish death events are often very visible events and generate a significant amount of public interest and concern. Fish death events are experienced globally and can range from localised events killing only a small number of fish, to large events killing millions of fish (Hoyer et al., 2009). They can be isolated events, or widespread and transient where the causal factor and number of fish affected is often difficult to determine.

Fish death events can be natural or human-induced (Koutrakis et al., 2016). Natural causes include old age, climatic conditions, hypoxia, starvation and disease outbreaks (Hoyer et al., 2009). Human-induced factors include toxic substances (Koutrakis et al., 2016), water infrastructure management (Brown et al., 2014), or biocontrol measures such as the removal of invasive species (Bonvechio, Allen, Gwinn, & Mitchell, 2011). For over half of the reported fish death events, the causal factors are unable to be determined.

Fish death events have been reported in all Murray–Darling Basin catchments and are unfortunately a regular observation in human-modified landscapes. NSW DPI Fisheries has recorded over 1,600 fish death events since the 1980s. The Victorian government has previously responded to fish deaths in the Goulburn River, Campaspe River, Broken Creek and Ovens River (Ellis and Meredith, 2004). Recent fish deths were also recorded from Bourke (in 2011) and Tilpa (in 2012) (NSW DPI Fisheries, unpublished data). These fish death events affected between tens and thousands of fish and were caused by a range of factors including hypoxia, toxins, flooding and high temperatures.

HYDRO-CLIMATIC CONTEXT

At the commencement of the Independent Assessment, the panel invited the Bureau of Meteorology (BOM) to provide an analysis of recent climate and hydrologic trends in the northern Basin. The foregoing discussion of the hydro-climatic context includes the BOM's analysis.

RECENT CLIMATE CONDITIONS

The fish death events at Menindee were preceded by exceptional climatic conditions (BOM 2017a, 2017b, 2017c, 2018a, 2018c, 2019). The BOM advised that the recent prolonged drought, coupled with extreme temperatures, in the northern Basin is unparalleled in the observed climate record.

In the northern Basin, average maximum temperatures in 2018 were the hottest on record and were 2.28°C above the long-term (1961-1990) average. Average minimum temperatures in 2018 were the 6th hottest on record and were 1.40°C above the long-term average. Average rainfall across the northern Basin in 2018 was 294 mm, which is 57% of the long-term (1961-1990) average, making it the 6th driest year since records began in 1900.

Against this backdrop of hot and dry conditions through 2018, the lower Darling area was subject to extreme heatwaves during the summer when the fish deaths occurred. Most of the Murray–Darling Basin had its hottest December-January period on record (Figure 2). The maximum temperature at Bourke was 40.0°C or more on 21 consecutive days from 9-29 January 2019. This is a new record for NSW, exceeding the 17 days from 6-22 January 1939 at the former Bourke site. The highest temperature recorded at the Menindee Post Office during the current summer was 48.8°C, occurring three days prior to the third fish death event. This is the highest temperature ever recorded at the site. Whilst the absolute extremes recorded in the area are similar to those recorded in January 1939, the recent duration and spatial extent of heatwaves have been more severe than in 1939.

Date	Mean maximum temperature (anomaly)	Men minimum temperature (anomaly)	Rainfall previous year (% average)
Jan 2019	39.7 °C (+6.0 °C)	23.3 °C (+5.4 °C)	133.4 mm (48 %)
Jan 2003	36.0 °C (+2.3 °C)	19.8 °C (+1.9 °C)	129.9 mm (47 %)
Jan 1966	34.2 °C (+0.5 °C)	19.2 °C (+1.3 °C)	172.3 mm (62 %)
Jan 1939	39.3 °C (+5.6 °C)	22.4 °C (+4.5 °C)	145.6 mm (52 %)

TABLE 1. JANUARY MEAN MAXIMUM AND MINIMUM TEMPERATURES, AND RAINFALL FOR THE PREVIOUS YEAR, FOR THE MENINDEE LAKES AREA FOR JANUARY 2019 AND SELECTED PREVIOUS YEARS. NUMBERS IN BRACKETS ARE ANOMALIES RELATIVE TO THE 1961-1990 LONG-TERM MEAN. AREA AVERAGE TEMPERATURES ARE FROM GRIDDED ACORN-SAT V2 TEMPERATURE ANOMALIES RENORMALISED BY AWAP, AND AREA-AVERAGE RAINFALL FROM AWAP GRIDDED RAINFALL ANALYSES.

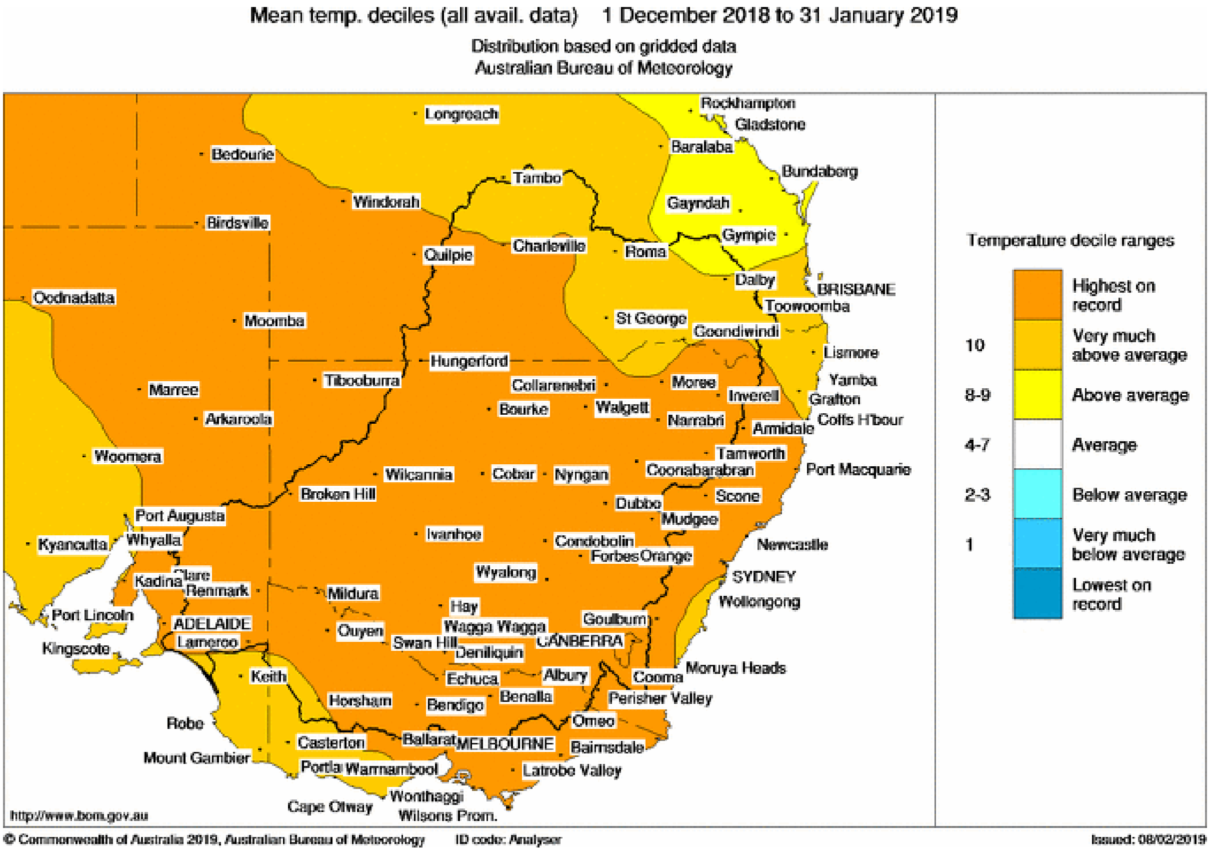


FIGURE 2. MEAN TEMPERATURE DECILES FOR SOUTHEAST AUSTRALIA, DECEMBER 2018 TO JANUARY 2019. THESE ARE CALCULATED AGAINST ALL DECEMBER-JANUARY PERIODS SINCE 1910. THE MURRAY DARLING BASIN IS SHOWN BY THE SOLID LINE.

The year-to-year climate variability in the southern half of Australia, including the Murray–Darling Basin, is occurring against a background drying trend over recent decades (BOM, 2018d). This drying trend is the most sustained large-scale change in rainfall since national records began in 1900 (BOM, 2018d). Of particular note, there has been an ~11% decrease in April to October rainfall in south eastern Australia for the period 1999 to 2018, compared to the 1900 to 1998 period (BOM, 2018d). Rainfall for April to October periods have been below average in southern Australia for 17 of the last 20 years (Figure 3). Such changes have profound hydrological importance for the Murray–Darling Basin as they coincide with what is commonly referred to as 'the filling season'. In general, these changes are making water storages in southern Australia less reliable than they were prior to climate change.

For inland areas of southern Queensland, northern NSW and central and western Victoria, the dry conditions of the last two years followed severe long-term rainfall deficiencies over the period from April 2012 to April 2016 (BOM, 2018c). As such, much of the northern Basin has experienced significantly lower than average rainfall since 2012 (BOM, 2018c), despite a significant but short-lived reprieve in 2016.

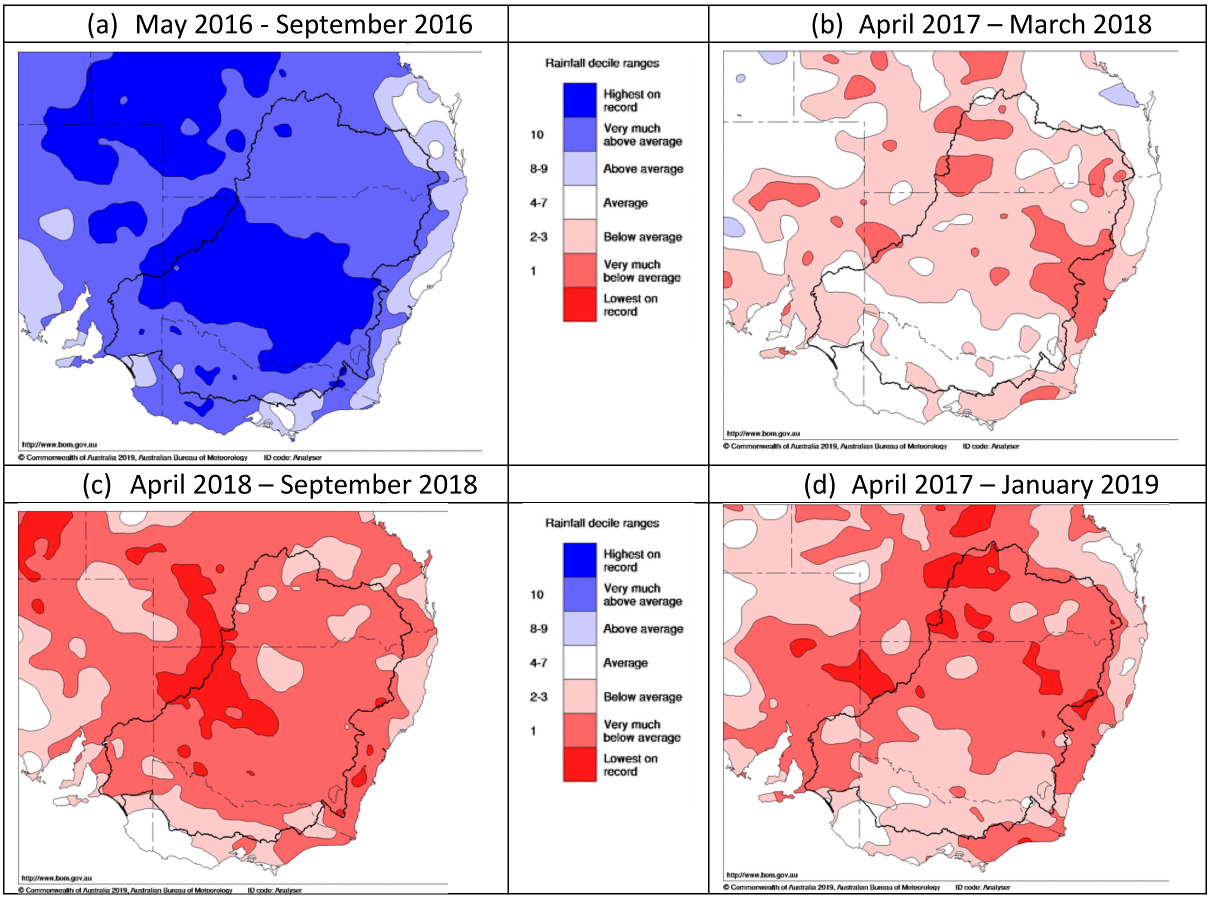


FIGURE 3. RAINFALL DECILES FOR SOUTHEAST AUSTRALIA FOR SELECTED PERIODS. THESE ARE CALCULATED FOR THE GIVEN YEAR AND MONTHS AGAINST ALL SUCH PERIODS SINCE 1900. THE MURRAY–DARLING BASIN IS SHOWN BY THE SOLID LINE.

CLIMATE TRENDS AND PROJECTIONS IN THE NORTHERN BASIN

The BOM has advised that the recent extreme weather events in the northern Basin have been amplified by climate change. In the northern Basin, the annual mean temperature has warmed by about 1.5°C since 1910, which is at least 0.5°C more than the national average. There is a marked tendency across Australia, including the northern Basin, for more extreme and persistent heatwaves (Figure 4). Such changes are increasing the risk of fish deaths.

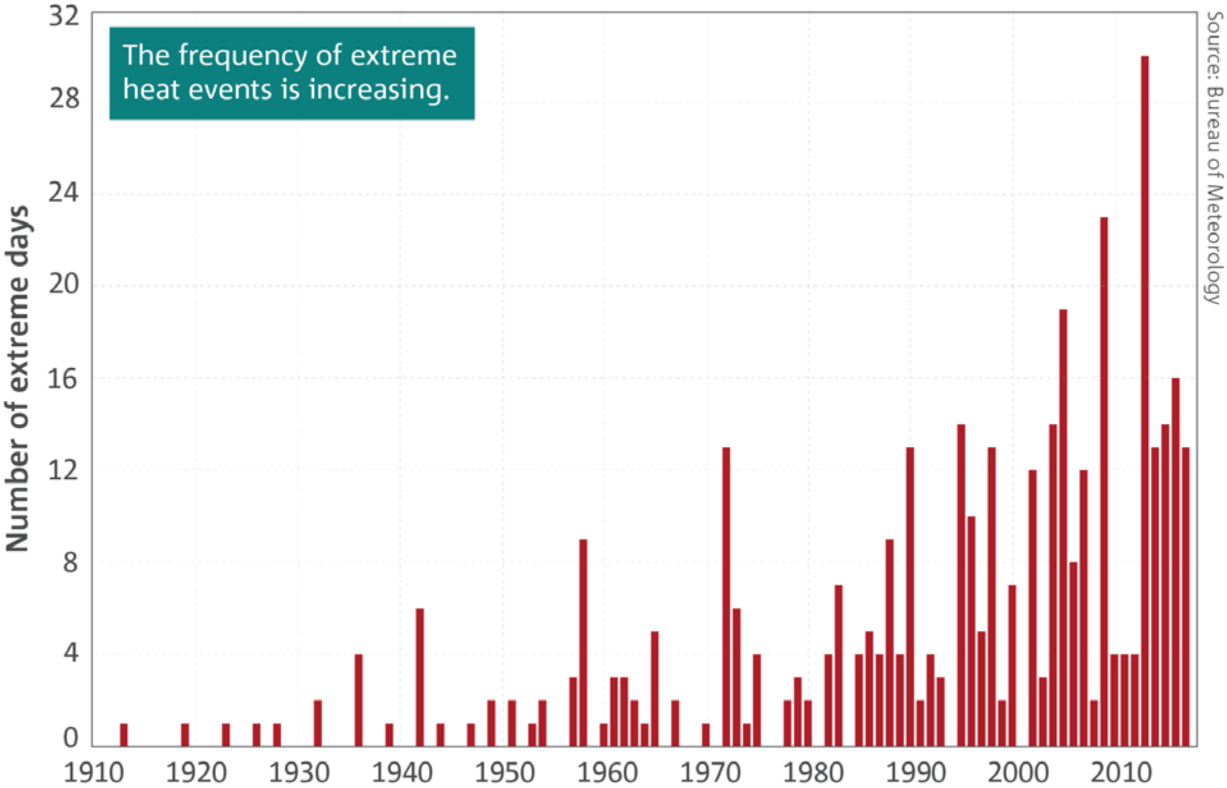


FIGURE 4. NUMBER OF DAYS EACH YEAR WHERE THE AUSTRALIAN AREA-AVERAGED DAILY MEAN TEMPERATURE IS EXTREME. EXTREME DAYS ARE THOSE ABOVE THE 99TH PERCENTILE OF EACH MONTH FROM THE YEARS 1910–2017. THESE EXTREME DAILY EVENTS TYPICALLY OCCUR OVER A LARGE AREA, WITH GENERALLY MORE THAN 40 PER CENT OF AUSTRALIA EXPERIENCING TEMPERATURES IN THE WARMEST 10 PER CENT FOR THAT MONTH. SOURCE: BUREAU OF METEOROLOGY, STATE OF THE CLIMATE 2018.

Two of the *Climate Change in Australia* regions, referred to as the Murray Basin and Central Slopes clusters, correspond respectively to the Murray–Darling southern (including the Menindee Lakes area) and northern Basins (Climate Change in Australia, 2016). For both clusters, there is *very high confidence* of rising temperatures through the 21st century. Under a high emissions scenario, annual mean temperatures by 2090 are projected to increase by 2.7-4.5°C and by 3.0-5.4°C for the Murray Basin and Central Slopes clusters respectively, relative to a baseline period of 1986-2005.

There is no clear signal in the projected changes in total annual rainfall. However, under a high emissions scenario, by 2090 winter rainfall is projected to decline for both clusters. For the Murray Basin cluster, the range is -38% to +4% (*medium confidence*) and for the Central Slopes cluster the range is -39% to +15% (*high confidence*). The range of these estimates underscore the difficulty that water managers face in planning for the impacts of climate change on future water availability. Nevertheless, the potential impacts of these rainfall changes on hydrology are serious, so it is critical that they are taken into consideration in water planning.

CLIMATE-INDUCED CHANGES IN RUNOFF GENERATION

Rainfall declines result in a corresponding decrease in river flows, with implications for water availability for the environment, industries and communities (BOM 2018d, 2019). In the northern Basin, the decreased rainfall over recent years means that conditions are less favourable for saturating the ground and priming it for generating runoff during the following wet season. Such changes in runoff generation have been discussed by Saft et al. (2016) and highlighted in the northern Basin in a recent study by the MDBA (MDBA 2018).

It has been demonstrated that runoff responses to rainfall are significantly reduced during droughts, and that runoff appears to have been affected more severely during the severe Millennium drought when compared to previous, lesser droughts. This was confirmed by MDBA (2018) in their assessment of cumulative flows at North CuerIndi, a largely un-impacted catchment upstream of Keepit Dam (Figure 5). This trend was also observed in the same study for other locations through the northern Basin. Such impacts further compound the effects of drought on water availability and are a cause for concern.

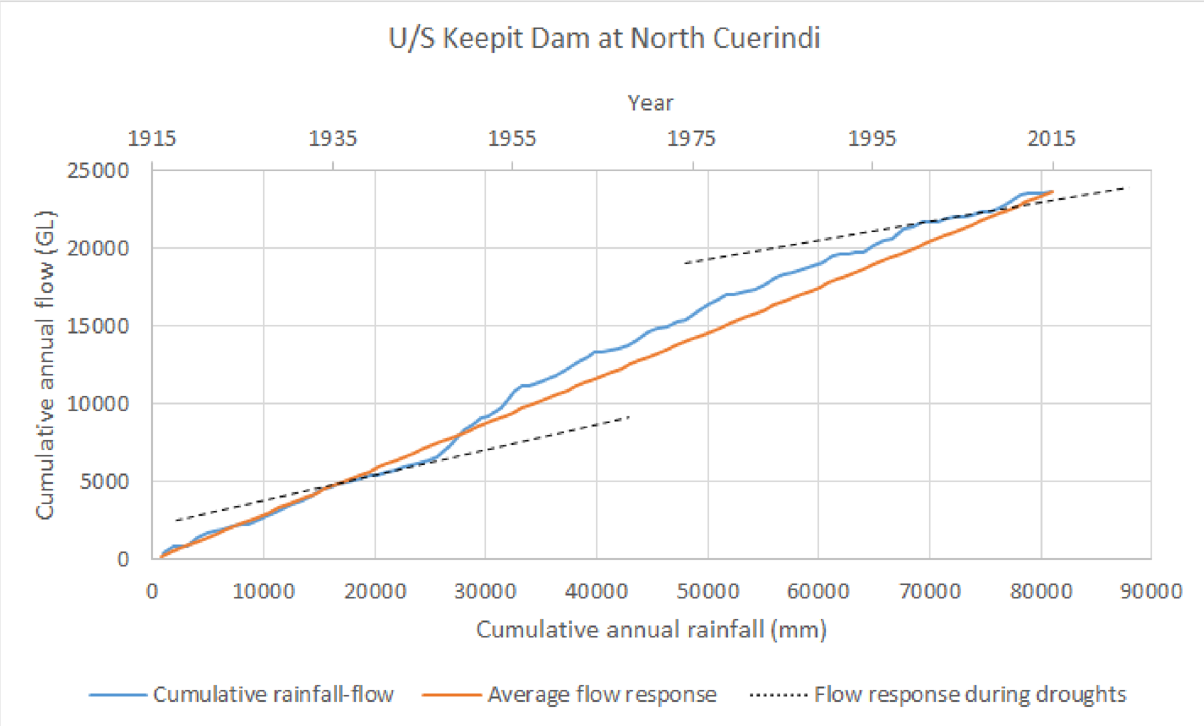


FIGURE 5. CUMULATIVE ANNUAL FLOW (GL) AT NORTH CUERINDI VERSUS CUMULATIVE RAINFALL (MM) (MDBA, 2018).

FLOWS IN THE BARWON–DARLING TRIBUTARIES

Understanding the hydrologic changes occurring in the Menindee Lakes and lower Darling River requires a consideration of flows generated in the upstream tributaries of the Barwon-Darling river.

The recent abnormally dry climate has resulted in extremely low northern Basin mid-system tributary flows and tributary inflows into the Barwon–Darling. Figure 6 highlights the amount of mid-system flow (flow above major extraction points) that becomes end of tributary inflow to the Barwon–Darling.

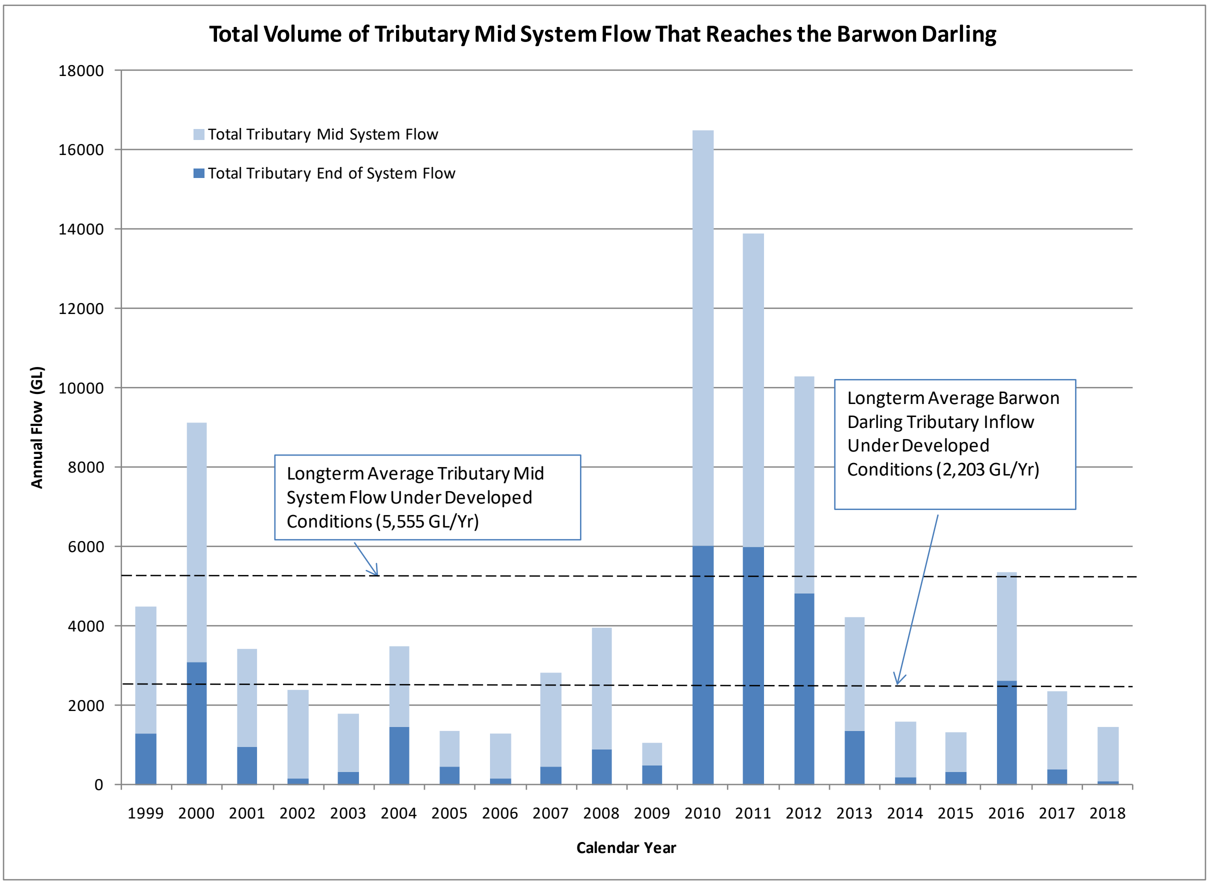


FIGURE 6. AMOUNT OF TOTAL MID SYSTEM FLOWS THAT BECOME TOTAL TRIBUTARY INFLOWS INTO THE BARWON–DARLING.

Table 2 compares historic tributary mid-system flows and end of system inflows into the Barwon–Darling for the past 2 and 20 (in brackets) years.

	Mid River Flow (GL/Yr)	Average Inflow to Barwon–Darling (GL/Yr)	Inflows as a % of Mid System Flow	Inflows as a % of total inflows from Barwon–Darling Tributaries
Border Rivers[#1]	459.8 (637.9)	112.9 (313.0)	25% (49%)	46% (20%)
Gwydir System[#2]	410.1 (501.4)	29.0 (127.6)	7% (25%)	12% (8%)
Namoi	233.4 (421.8)	18.0 (321.6)	8% (76%)	7% (20%)
Macquarie-Bogan[#3]	591.4 (763.7)	31.8 (281.6)	5% (37%)	13% (18%)
Moonie	38.2 (137.5)	31.4 (132.7)	82% (97%)	13% (8%)
Condamine/Balonne[#4]	110.7 (1045.9)	20.4 (342.4)	18% (33%)	8% (22%)
Warrego	48.3 (695.1)	4.5 (70.4)	9% (10%)	2% (4%)
Paroo	24.7 (415.5)	0.0 (0.0)	0% (0%)	0% (0%)
Total Flow (GL/yr)	1916.5 (4618.5)	248.0 (1589.4)	13% (34%)	100%

TABLE 2. HISTORIC ANNUAL AVERAGE LAST TWO YEARS (1 JAN 2017 TO DEC 31ST 2018) COMPARED TO LAST TWENTY YEARS (1 JAN 1999 TO DEC 31ST 2018) SHOWN IN BRACKETS. #1. NO DATA FOR BOOMI AT NEEWORA USED BOOMI AT OFFTAKE #2.NO DATA FOR COLLYMONGLE GAUGE ASSUMED ZERO INFLOW CONTRIBUTION #3.NO DATA FOR COONAMBLE ASSUMED ZERO INFLOW CONTRIBUTION FOR CASTLEREAGH #4.MID RIVER FLOW LIKELY TO BE AN UNDERESTIMATE OF WATER AVAILABILITY DUE TO UPSTREAM EXTRACTIONS.

An assessment of flows over the past 20 years reveals that two-year total mid-system flow volumes have only been lower than the 2017-18 total on three occasions, whilst two-year total Barwon–Darling inflows have been the lowest on record over the past 20 years. The average of the past 20 years tributary mid-system and end of system inflows to the Barwon is less than what would be expected over the longer term. This is illustrated by the comparison with river system modelled inflows from Jan 1900 to Dec 2012 (in brackets) in Table 3.

	Mid River Flow (GL/Yr)	Average Inflow to Barwon–Darling (GL/Yr)	Inflows as a % of Mid System Flow	Inflows as a % of total inflows from Barwon–Darling Tributaries
Border Rivers	637.9 (829.5)	313.0 (539.6)	49% (65%)	20% (24%)
Gwydir System	501.4 (732.9)	127.6 (151.2)	25% (21%)	8% (7%)
Namoi	421.8 (729.6)	321.6 (602.2)	76% (83%)	20% (27%)
Macquarie-Bogan	763.7 (1192.4)	281.6 (498.4)	37% (42%)	18% (23%)
Moonie	137.5 (82.7)	132.7 (84.8)	97% (103%)	8% (4%)
Condamine/Balonne	1045.9 (1035.0)	342.4 (257.9)	33% (25%)	22% (12%)
Warrego	695.1 (480.8)	70.4 (69.4)	10% (14%)	4% (3%)
Paroo	415.5 (467.0)	0 (0)	0% (0%)	0% (0%)
Total Flow (GL/yr)	4618.9 (5550.0)	1589.4 (2203.5)	34% (40%)	100%

TABLE 3. HISTORIC ANNUAL AVERAGE LAST TWENTY YEARS (1 JAN 1999 TO DEC 31ST 2018) COMPARED TO MODELLED LONG-TERM AVERAGE 1900 TO 2012 SHOWN IN BRACKETS.

FLOWS IN THE BARWON–DARLING AND LOWER DARLING RIVERS

Streamflows in the Barwon–Darling over the past two years show similar trends to those of its tributaries, with flows being considerably less than the 20-year average (Table 4). Furthermore, the total two-year flow for 2017-18 is the lowest in the last 20 years at Bourke and Wilcannia.

Barwon–Darling	Average Flow (GL/Yr
Collarenebri	130.6 (607.9)
Brewarrina	97.5 (1008.4)
Bourke	107.3 (1620.3)
Wilcannia	61.4 (1227.4)
Menindee Inflows	67.4 (1227.8)
Weir 32	276.3 (876.1)

TABLE 4. AVERAGE ANNUAL STREAMFLOWS AT VARIOUS POINTS IN THE BARWON–DARLING RIVER FOR THE LAST TWO YEARS (2017-18) AND THE LAST 20 YEARS (1999-20018) (IN BRACKETS).

Flows have been significantly below average in the past two calendar years (Figure 7). In 2018, streamflows were mostly attributable to the release of managed held environmental water from the Gwydir and Border Rivers.

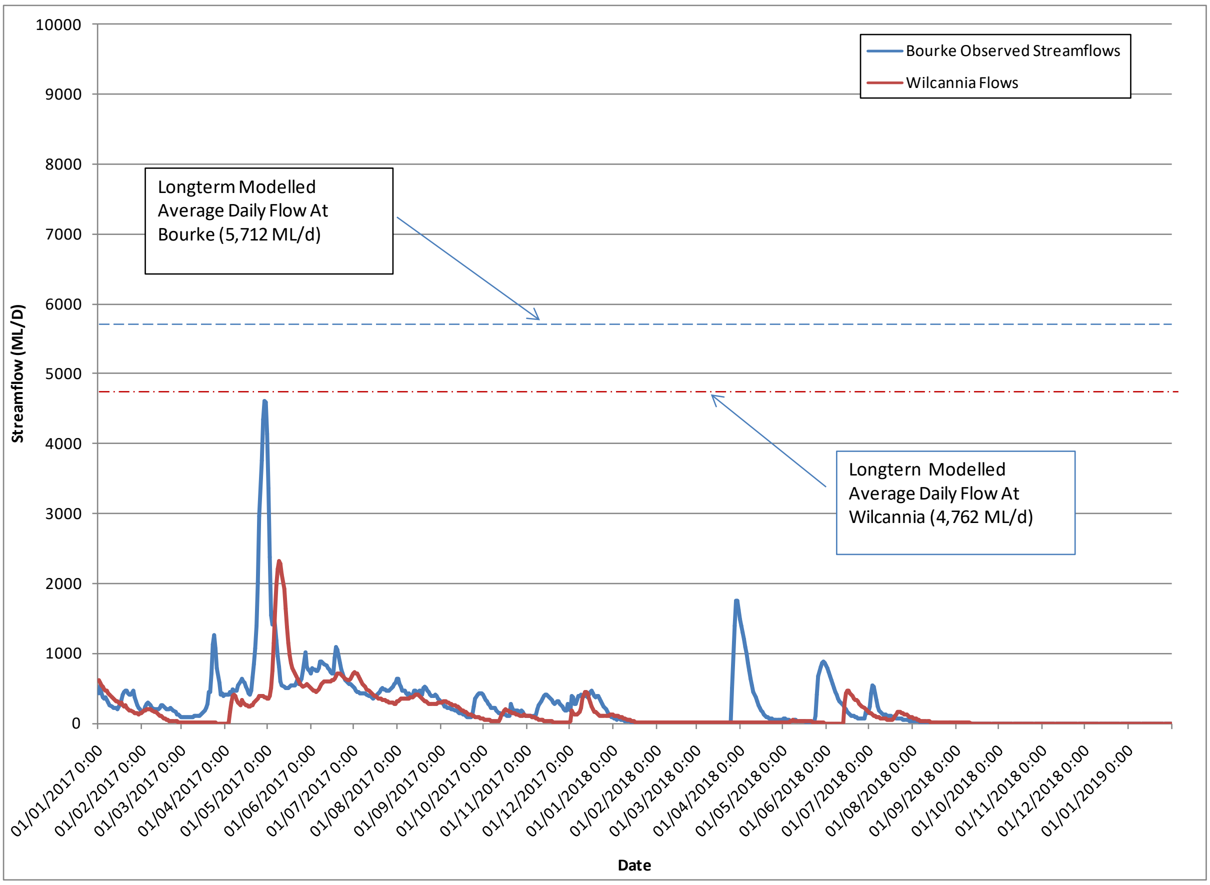


FIGURE 7. DAILY STREAMFLOW AT BOURKE AND WILCANNIA ON THE BARWON–DARLING RIVER.

Relative to flows above the Menindee Lakes, observed flows downstream of the lakes have not been as low relative to the past 20 years, due to re-regulation of water in the storage. The total 2017-18 downstream flow has been lower on nine occasions over the past 20 years (Figure 8). There have been periods of annual flows of similar volumes to those observed over 2017-18, with the 2018 annual flow total at Weir 32 being lower on just 5 occasions over the period 1915-2018.

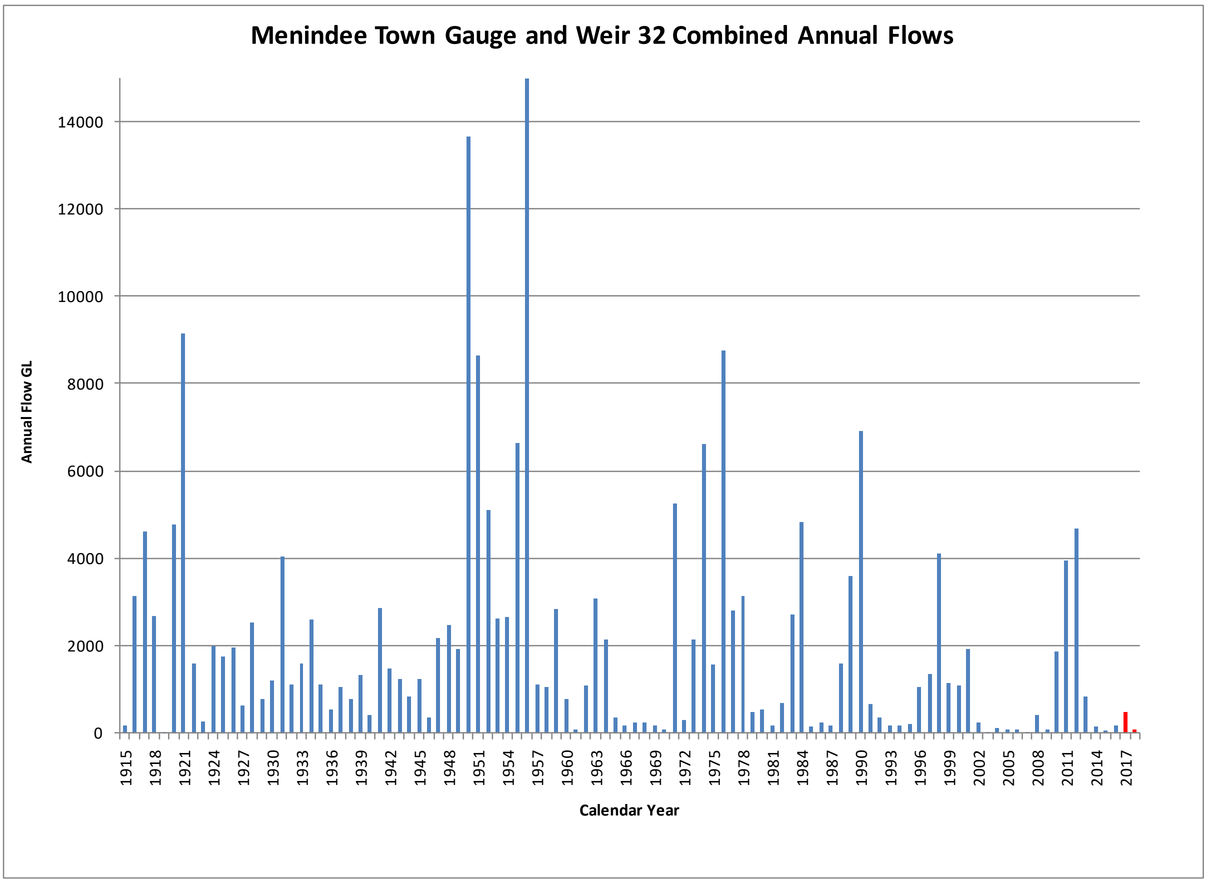


FIGURE 8. ANNUAL FLOWS AT MENINDEE TOWN GAUGE / WEIR 32, 1915-2018. NOTE FLOW IN 1956 (TRUNCATED IN THIS GRAPH) WAS 25,331 GL.

Historic Extractions upstream of Menindee

The influence of upstream extractions on inflows to the Menindee Lakes is an important consideration when assessing the causes of fish death downstream at Weir 32.

An analysis of the proportion of tributary mid-system flows extracted over the past 20 years in the tributaries of the Barwon–Darling is presented in Figure 9. The sum of the three components shown in Figure 9 represents the mid-system flow. The analysis indiactes that the *proportion* of flow extracted is greater in years of low mid-system flows. In these low flow years, a large proportion of mid-system flows is made up of regulated dam releases of water that has been accrued in the storages by water users (including the environment) in preceding wetter years. Extractions during 2017-18 represented the second highest proportion of mid-system flows extracted over the past 20 years in the northern Basin. This is not surprising given that mid-system inflows were some of the lowest over the past 20 years.

Extractions in the Barwon–Darling have been found to represent a small proportion of tributary system inflows, even when inflows are small such as in 2017-18 (Figure 10). The analysis of extractions, mid-system flows, and tributary inflows into the Barwon–Darling suggests that the majority of impacts from extractions on Menindee inflows, and therefore Menindee Lake volumes, are from tributaries above the Barwon–Darling and not the Barwon–Darling itself.

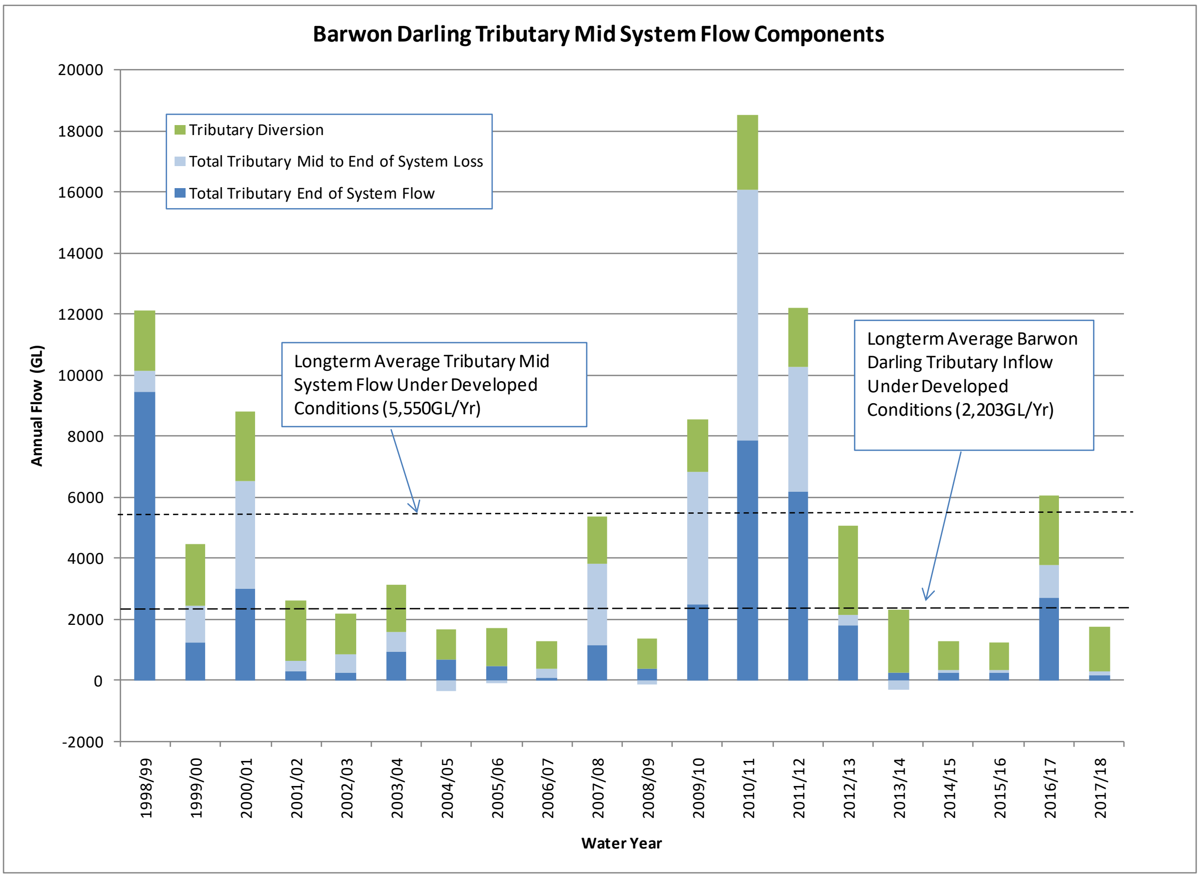


FIGURE 9. AMOUNT OF TOTAL MID-SYSTEM TRIBUTARY FLOW EXTRACTED.

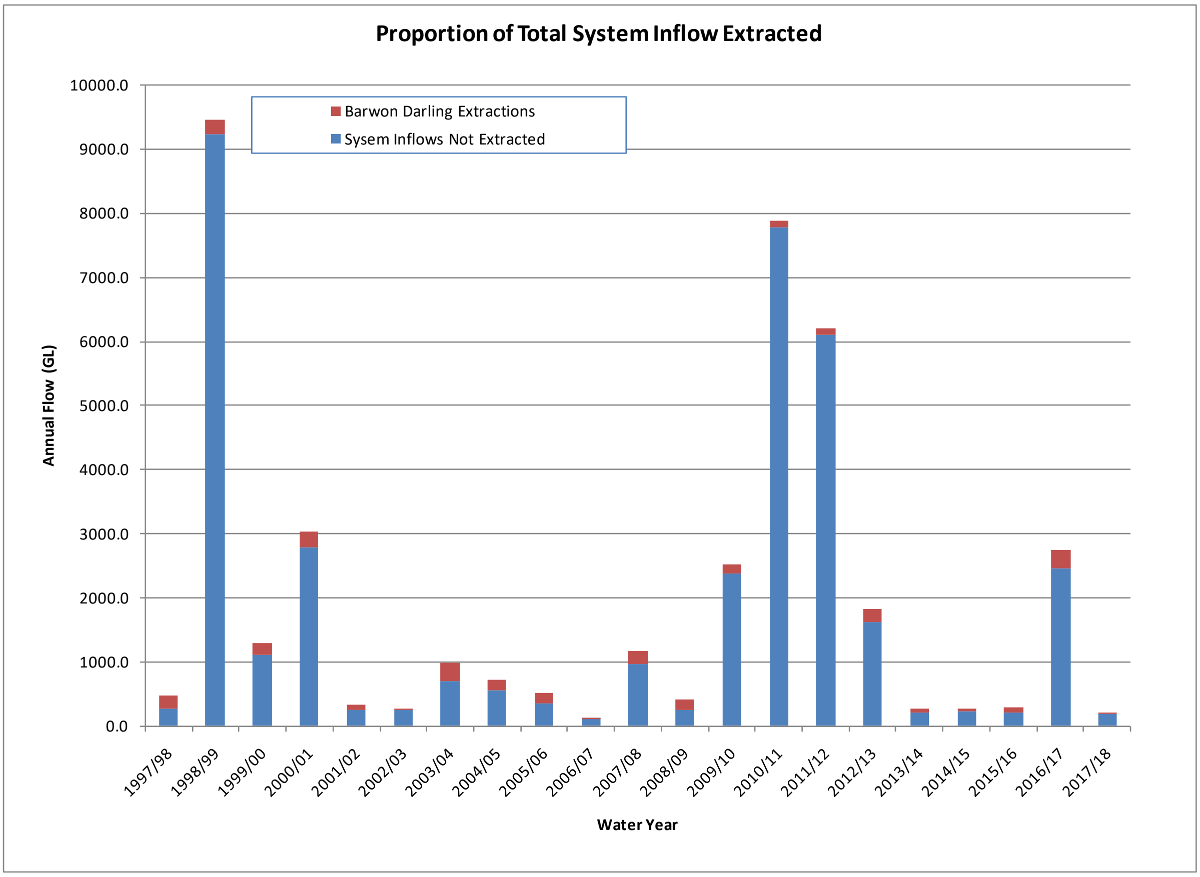


FIGURE 10. AMOUNT TRIBUTARY SYSTEM INFLOW EXTRACTED IN THE BARWON–DARLING RIVER.

An assessment of the impact of upstream extractions on Menindee Lakes inflows over the long-term can be made by comparing pre-development and current development configurations of river system models applied to the period 1895-2009 (Figure 11). As can be seen, in years of low developed inflows (the blue bars) there are significant additional flows that would have occurred under pre-development conditions. The same analysis has also been carried out assuming that upstream tributaries and the Barwon–Darling are at the Sustainable Diversion Limit (Figure 12). Whilst Menindee Sustainable Diversion Limit inflows exceed those under the Baseline Diversion Limit, they are still considerably less than pre-development inflows. It should be noted that river system models generally over-predict low flows, so care must be taken when using them to assess the impacts of diversions in dry years. Consequently, both modelled pre-development and developed inflows into the Menindee Scheme are likely to be overestimated for low flow situations.

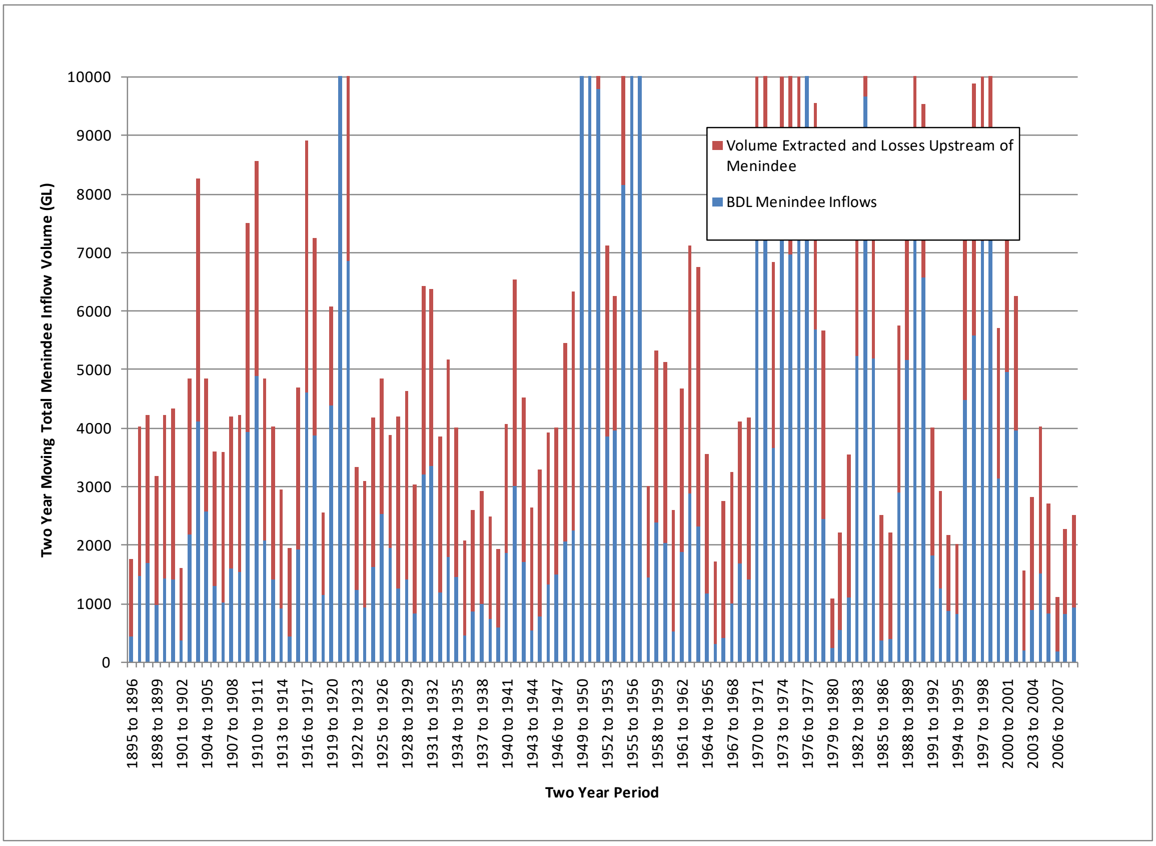


FIGURE 11. PRE-DEVELOPMENT AND BASELINE DIVERSION LIMIT TWO-YEAR TOTAL MODELLED MENINDEE INFLOWS.

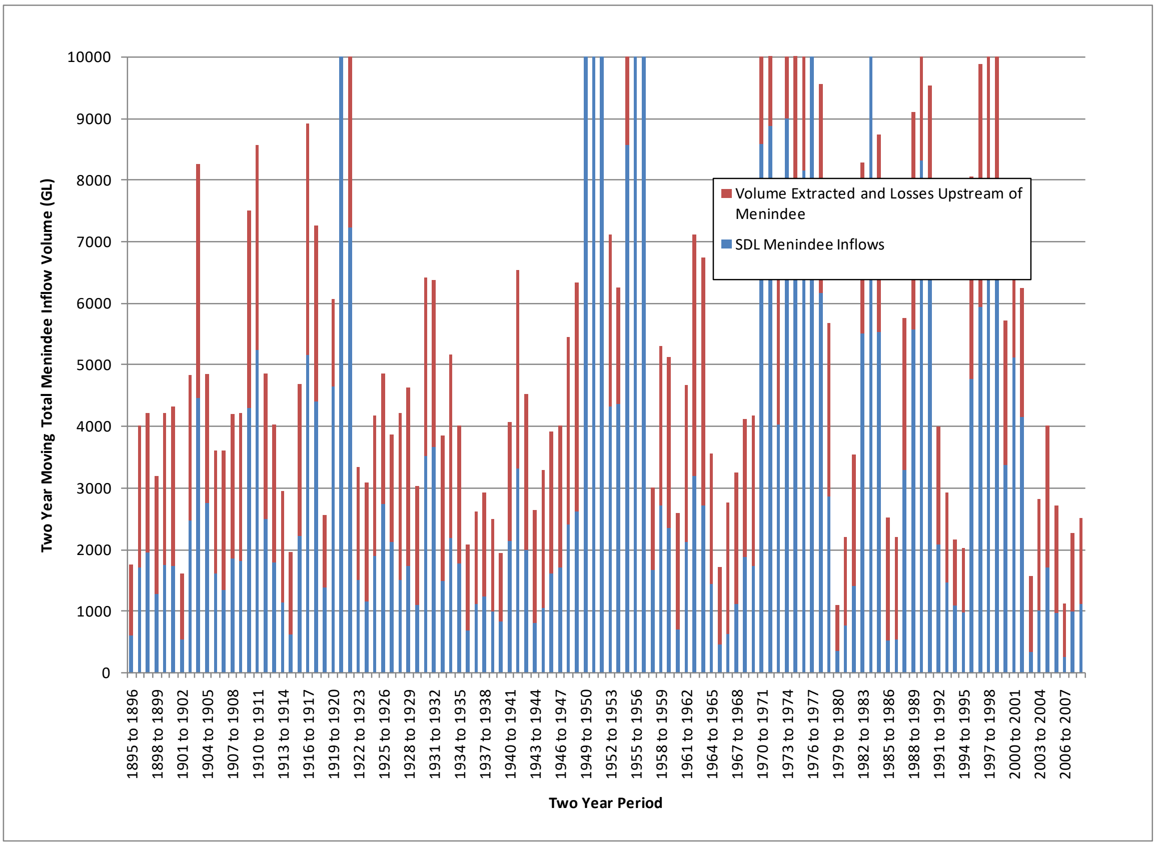


FIGURE 12. PRE-DEVELOPMENT AND SUSTAINABLE DIVERSION LIMIT TWO-YEAR TOTAL MODELLED MENINDEE INFLOWS.

OPERATION OF THE MENINDEE LAKES SINCE JULY 2016

Recent debate over the causes of the fish deaths in the lower Darling has included reference to how the Menindee Lakes were operated by NSW and the MDBA. As noted earlier, control of the lakes is passed between NSW and MDBA according to the '640/480' rule. Below, we examine the timing and amount of releases since mid July 2016, prior to filling to full supply level later that year. A graphical depiction of these releases is provided in Figure 13.

On 28 July 2016, WaterNSW recommenced water releases at Weir 32 with a first pulse of 14.4 GL. From late August to mid-September 2016, a second pulse was released taking the total release to 31.6 GL. From mid-September to the start of December 2016, water was released from Weir 32 at a rate of some 600 ML/day for spawning and recruitment of Murray cod in the lower Darling and return flows to the Murray. The environmental entitlements releases during late 2016 were lower Darling entitlements, delivered to Burtundy.

On the 21 October 2016, the Menindee Lakes reached a level of 640 GL and the water within the storage became part of the shared resource of the River Murray System, with control passed to the MDBA. After the flooding in the Murray (at Wentworth) had peaked in December 2016, environmental releases were increased from the Menindee Lakes to wet in-channel benches along the lower Darling to provide more food and habitat for juvenile fish.

In early January 2017, in consultation with WaterNSW, the MDBA commenced calling on water from the Menindee Lakes to support River Murray system demands. These releases were timed to reach the River Murray as regulated conditions returned and included water to meet additional dilution flow entitlement commitments at the South Australian border. Initially, the release rates were high (peaking at 6,200 ML/day) as water was moved off the Wetherell floodplain, but were steadily reduced to 5,000 ML/day and then to 4,000 ML/day as demands eased along the Murray due to rainfall. By late April 2017, the end of irrigation season had returned the river Murray to low water demands.

From late April 2017 to the end of September 2017, environmental flow releases were continued to promote survival of Murray cod larvae and dispersal of golden perch. In October 2017, water was again released from Weir 32 at a rate of some 1,500 ML/day to assist in meeting demands in the Murray system, with a small portion used to meet local Darling water needs.

In mid-October 2017, with the 480 GL trigger level approaching, and on the advice of the MDBA and WaterNSW, the Joint Governments negotiated a lower rate of call by the MDBA to extend the time above 480 GL and improving the ratio of water held in Wetherell and Pamamaroo (top storages) against that held in Cawndilla and Menindee (bottom storages).

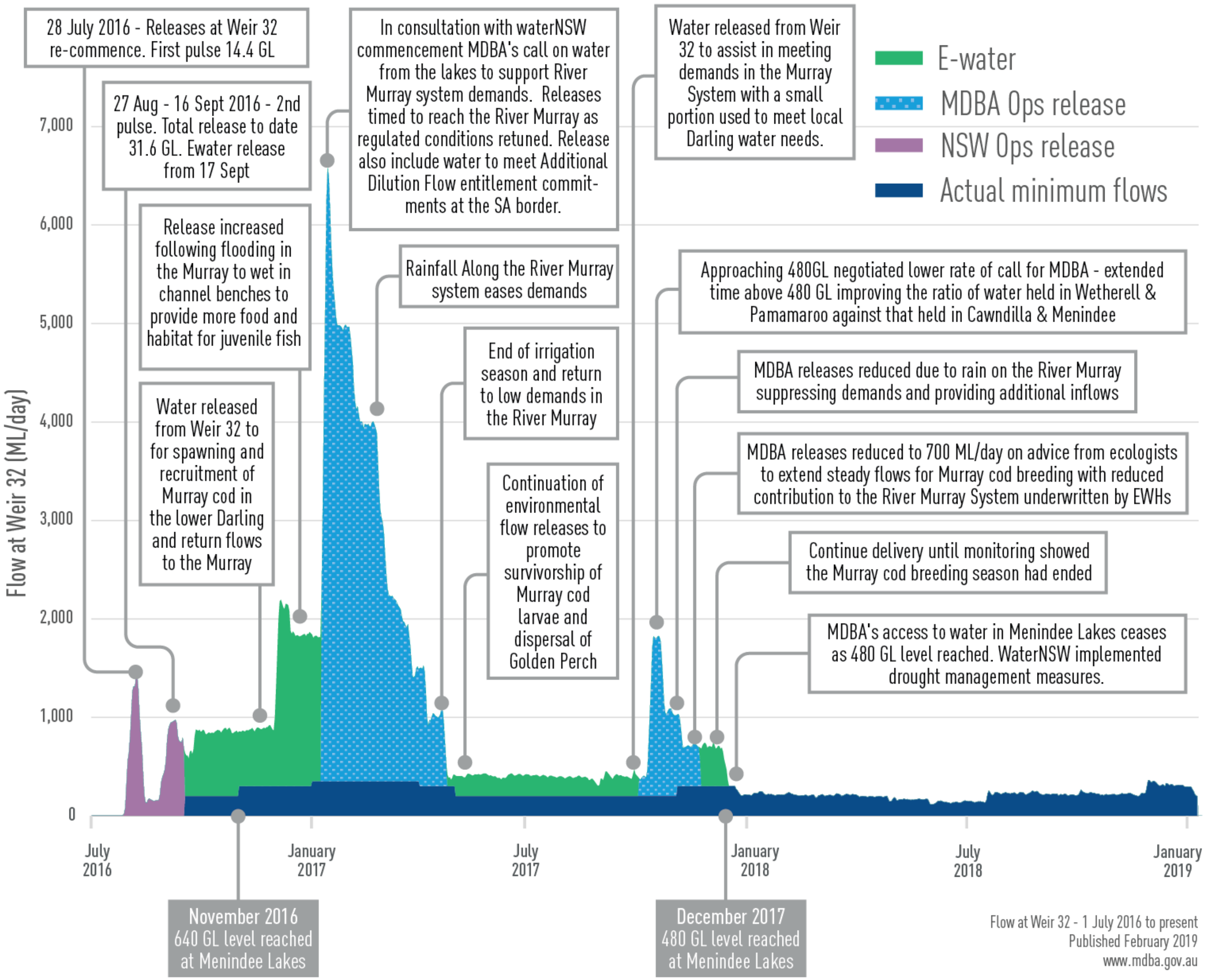


FIGURE 13. FLOW AT WEIR 32 – 1 JULY 2016 TO PRESENT (MDBA, 2019).

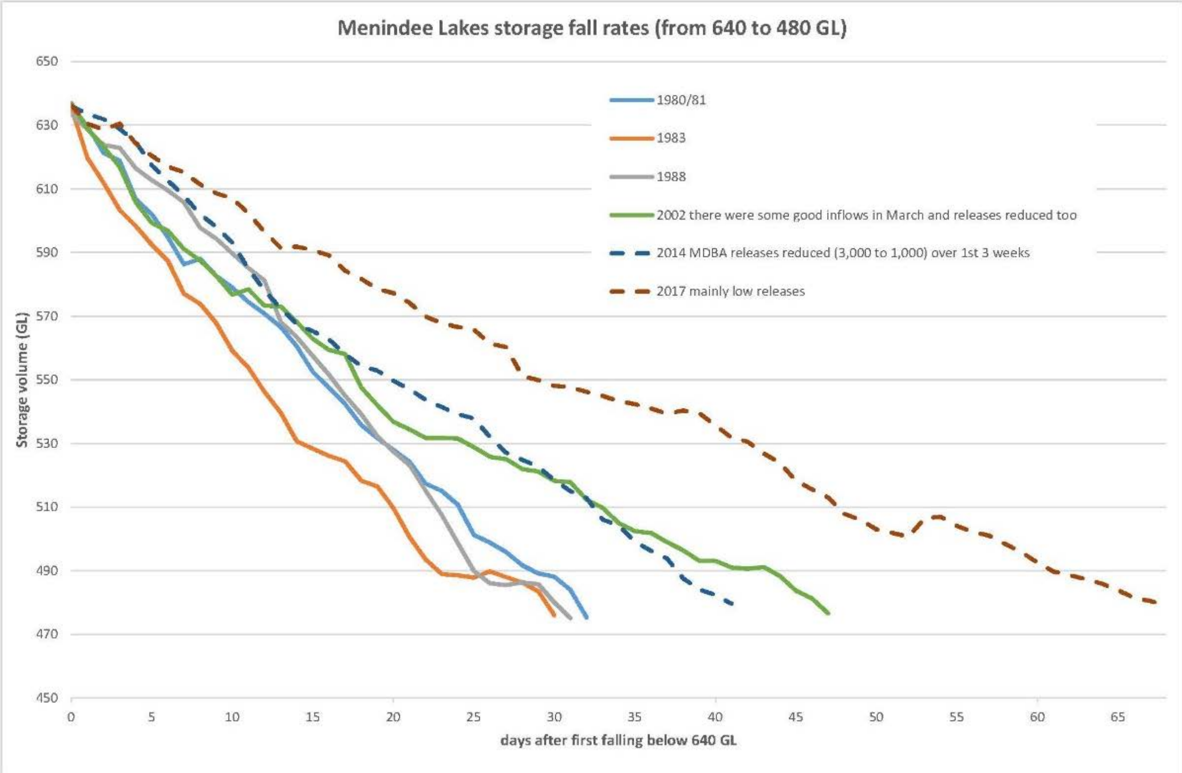


FIGURE 14. MENINDEE LAKES STORAGE FALL RATES FROM 640GL TO 480GL, COMPARED ACROSS VARIOUS YEARS. THIS SHOWS THAT THE MOST RECENT MDBA RELEASES WERE CONSERVATIVE, BEING MORE GRADUAL THAN IN PRIOR YEARS.

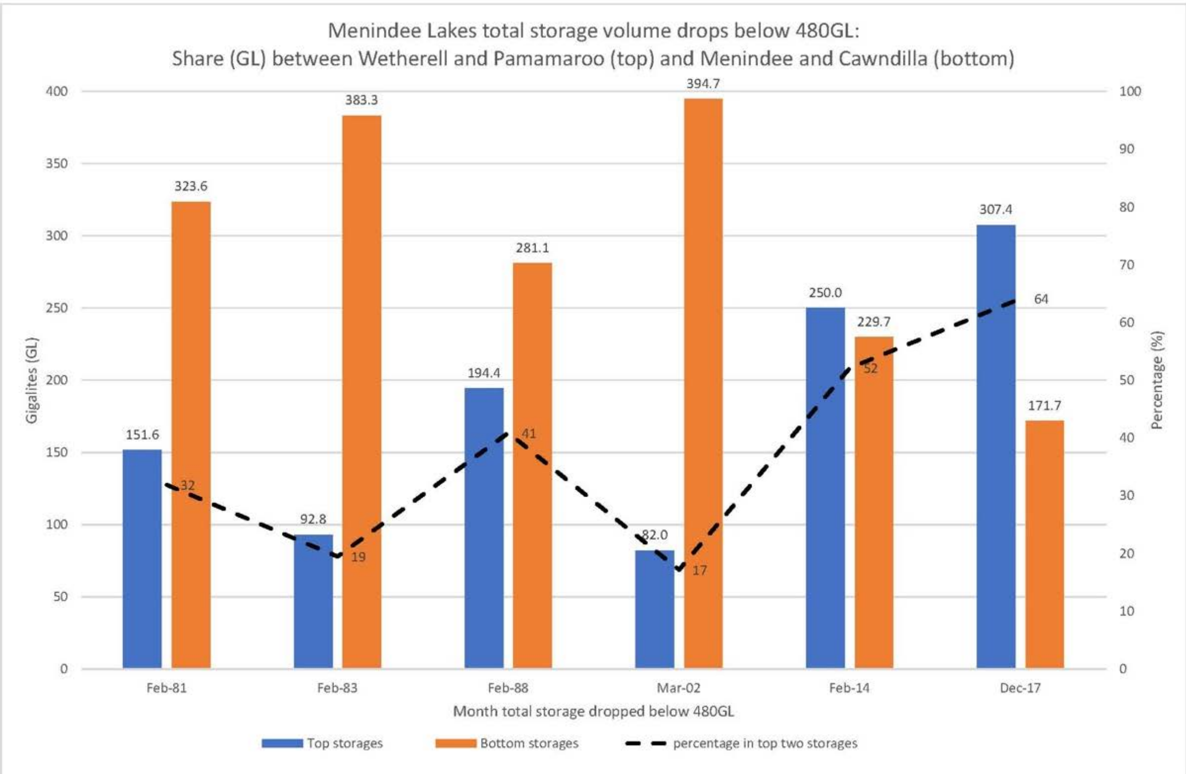


FIGURE 15. COMPARISON OVER VARIOUS YEARS OF THE DISTRIBUTION OF TOTAL WATER STORAGE WITHIN THE MENINDEE LAKES SYSTEM WHEN STORAGE VOLUMES FALL TO 480GL AND ARE HANDED OVER TO NSW CONTROL. THIS SHOWS THAT IN MORE RECENT TIMES THE MDBA HAS SOUGHT TO BIAS STORAGE TO THE UPPER LAKES TO PROVIDE MORE OPTIONS FOR LATER DOWNSTREAM USE.

Figures 14 and 15 show the reduction in the rate of lake water releases in recent years and changes in the proportion of water stored in the top storages against that stored in the bottom storages.

In late October 2017, releases from the lakes reduced due to rain on the River Murray suppressing demands. By early November 2017, MDBA releases had reduced to 700 ML/day on advice from ecologists to extend steady flows for Murray cod breeding, with reduced contribution to the River Murray System underwritten by the CEWH. The MDBA continued delivery until mid-November, when rain along the River Murray again suppressed demands. To maintain flows at 700 ML/day, environmental water was released from Menindee until the 15 December 2017, when Menindee Lakes reached a level of 480 GL and WaterNSW commenced implementation of drought management measures.

During this period, water was also being released by WaterNSW from Cawndilla into the Great Darling Anabranch. Between July 2016 and January 2018, 164 GL was released, of which 100 GL was environmental water intended to achieve fish breeding outcomes in the Darling Anabranch. The remainder of the water released was to meet orders of local entitlement holders.

THE 2018-2019 FISH DEATH EVENTS IN THE LOWER DARLING

The three fish death events in the lower Darling between December 2018 and January 2019 reflect not only the conditions existing at the time of the deaths (proximate causes), but also the antecedent conditions in the Menindee Lakes area leading up to the fish deaths (ultimate causes). To understand the proximate causes, it is useful to break the ultimate causes into two time periods, 2010-2017 and 2017-2018 (Figure 16).

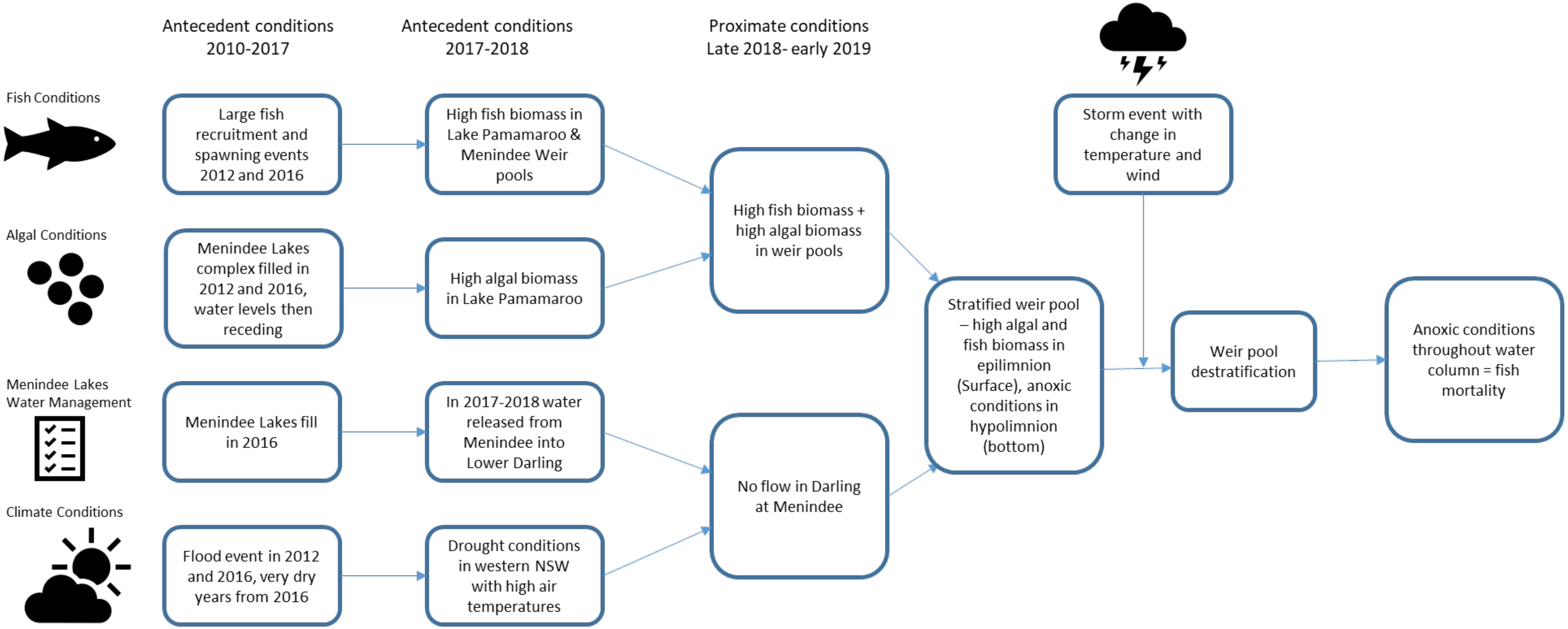


FIGURE 16. SUMMARY OF FACTORS LEADING TO FISH DEATHS IN THE LOWER DARLING.

ANTECEDENT CONDITIONS, 2010-2017

Since the end of the Millennium drought in 2009, there have been two high flow events in the Darling River. The first was a sequence of high flow events spanning 2010-2012, which filled the Menindee Lakes (Figure 17). After a series of low flow years (2013-2015), in 2016 there was another single significant rainfall event that filled the Menindee Lakes. When full, these lakes are significant nursery habitats for native fish. These two relatively recent flow events (2012 and 2016) are known to have facilitated significant fish spawning and recruitment across the upper Barwon–Darling River system. This has led to a significant increase in fish biomass (Figure 18).

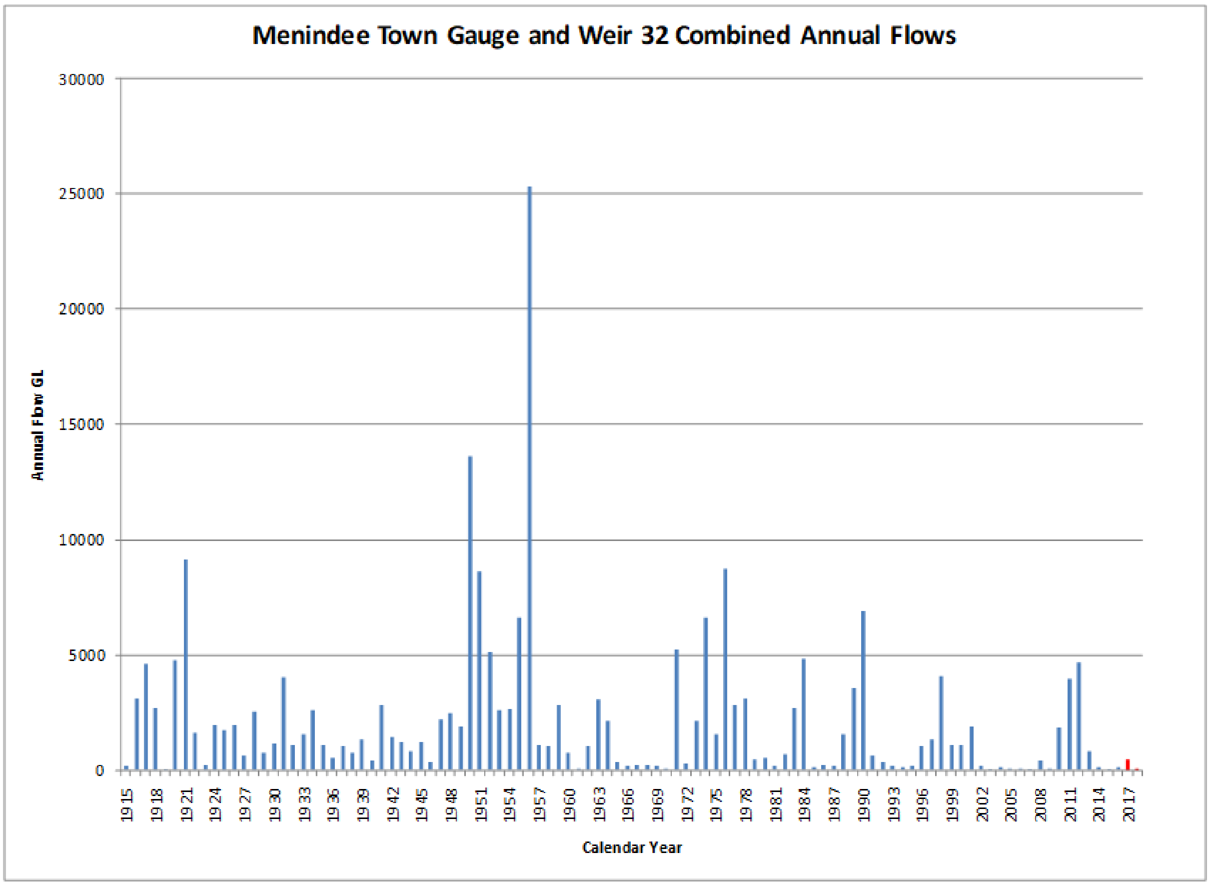
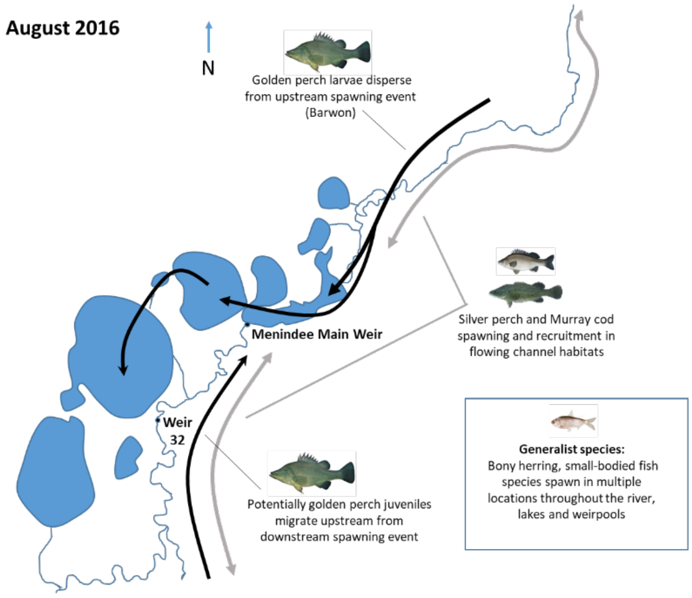
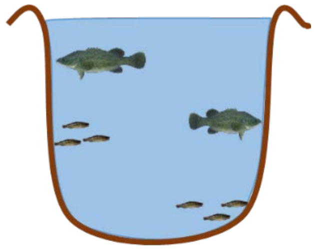


FIGURE 17. DAILY STREAMFLOW AT MENINDEE TOWN GAUGE AND WEIR 32.



(A) During the high flow events fish move throughout the Barwon–Darling River system – both downstream from the northern tributaries and also upstream from the River Murray system.

When full, the Menindee Lakes provides a vast nursery area for fish, increasing recruitment of a range of species.

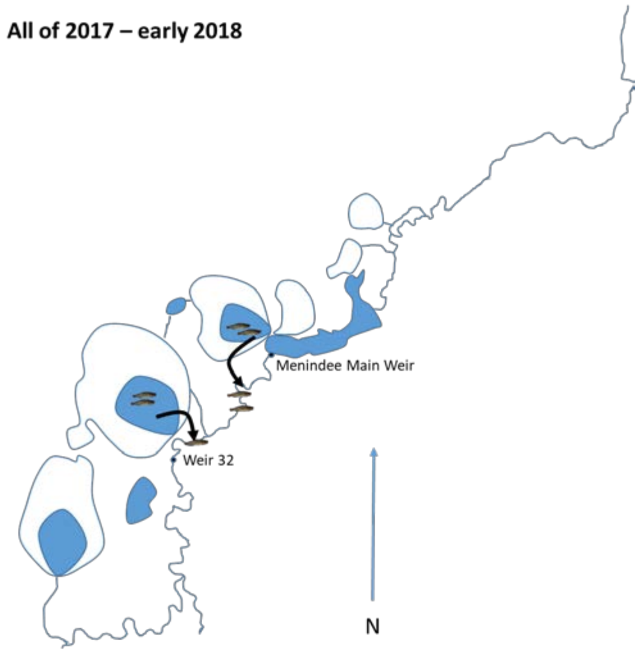


(B) When the river is flowing and pools are connected there is only weak intermittent stratification in the water column. Oxygen levels are distributed evenly and algal biomass is low.

FIGURE 18. CONCEPTUAL MODEL OF EVENTS IN 2016 LEADING UP TO THE 2019 FISH DEATH EVENT; (A) A LANDSCAPE SCALE CONCEPTUAL DIAGRAM OF THE MENINDEE LAKES AND (B) A CONCEPTUAL DIAGRAM OF CONDITIONS WITHIN THE WEIR 32 WEIR-POOL.

Antecedent conditions, 2017-2018

After the 2016 high flow event, there were no further inflows into the Menindee Lakes. As part of the regular management operations for the lakes, water was released down the lower Darling system and into the River Murray. Biota within the lakes (fish, algae and other biota) would have moved with the water from the lakes into the weir pools around Menindee, including the Main Weir and Weir 32 (Figure 19).



(A) After an extended period of no inflows water is diverted from the Menindee Lakes back into the Darling River, for a period water passes over Weir 32. As flows drop water levels drop below the weir pool and fish and algae become 'trapped' in the weir pools

This potentially leads to high biomass of biota in the weir pools, particularly when biomass in the lakes has been high.

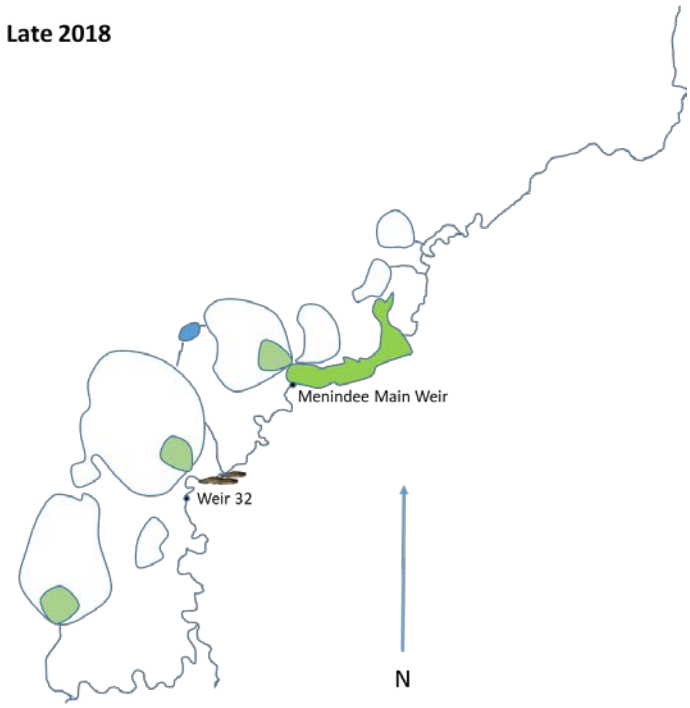
(B) Biomass of fish and algae in the weir pools will be high, as available habitat is restricted and fish are prevented from moving further downstream by the weir structures.

FIGURE 19. CONCEPTUAL MODEL OF EVENTS DURING 2017 LEADING UP TO THE 2019 FISH KILL EVENT; (A) A LANDSCAPE SCALE CONCEPTUAL DIAGRAM OF THE MENINDEE LAKES WITH THE MOVEMENT OF WATER FROM THE LAKES BACK INTO THE WEIR POOLS OF THE DARLING ALONG WITH RESIDENT FISH (B) A CONCEPTUAL DIAGRAM OF CONDITIONS WITHIN THE WEIR 32 WEIR-POOL SHOWING HIGH BIOMASS OF FISH.

PROXIMATE CONDITIONS, LATE 2018–2019

Low flows dominated in the Darling River at Weir 32 from July 2018 onwards. Flows increased from approximately 150 ML/d in July 2018 to between 200 and 250 ML/d from August 2018 to November 2018. At these flows in previous years, persistent thermal stratification has been known to form in mid-October leading to a separation of surface and bottom water layers in the lower Darling River (Mitrovic et al., 2011). WaterNSW algal sampling showed biomass of potentially toxic cyanobacteria to be very low (none detected) between July 2018 and September 2018. Biovolume increased to approximately 0.12 mm^3/L (amber alert level) on the 23rd of October 2018. By the next sampling on the 24th of November 2018, biovolume had increased to over 8 mm^3/L (red alert level), and in some samples was over 60 mm^3/L. The dominant species was *Dolichospermum* previously called *Anabaena sp.* which is a known producer of saxitoxin in Australia, a potent neurotoxin. This is consistent with previous research which has identified that blooms of *Dolichospemum* occur in this weir pool during low flow conditions (<300 ML/d) which allows the formation of persistent thermal stratification (Mitrovic et al., 2011). The persistent thermal stratification gives this species an ecological advantage; the ability to access light through buoyancy regulation (flotation) to the surface (Mitrovic et al., 2001) and this is why scums are sometimes seen.

Persistent thermal stratification also leads to a separation of the surface waters (epilimnion) from the bottom waters (hypolimnion) with a thermocline or area of rapid temperature change between the layers. Based on the flow and algal data available, it would be reasonable to assume that persistent thermal stratification occurred in the weir pool from approximately mid-October 2018 (Figure 20). Persistent thermal stratification without mixing can occur for weeks or even months in rivers like the Darling River (Mitrovic et al. 2003; 2011). Strong winds, lower air temperatures and inflows from rain events or increases in flow can all breakdown persistent thermal stratification.



(A) Low / no flows continue combined with extended hot and dry weather conditions. Algal blooms develop in the remaining water of the Menindee Lakes and also in the water remaining behind weir pools.

Fish biomass remains high in the weir pools and is now combined with high algalbiomass.

(B) Strong stratification develops in the weir pools, with high fish and algal biomass in the epilimnion (surface waters) and likely severely hypoxic or anoxic conditions in the hypolimnion (bottom waters). Although oxygen levels in the surface would have been high during the day, fish would have been stressed by high water temperatures and nightly oxygen depletion.

FIGURE 20. CONCEPTUAL MODEL OF EVENTS DURING LATE 2018 AND EARLY 2019 LEADING UP TO THE 2019 FISH KILL EVENT; (A) A LANDSCAPE SCALE CONCEPTUAL DIAGRAM OF THE MENINDEE LAKES SHOWING ALGAL BLOOMS IN WATER REMAINING IN LAKES AND ALSO IN THE WEIR POOLS OF THE DARLING (B) A CONCEPTUAL DIAGRAM OF CONDITIONS WITHIN THE WEIR 32 WEIR-POOL SHOWING THERMAL STRATIFICATION WITH FISH RESTRICTED TO THE SURFACE WATERS.

PROXIMATE CONDITIONS CAUSING THE FISH DEATH EVENT

Surface waters are oxygenated through contact with the air. When the water column is fully mixed the entire water column is generally well oxygenated. However, when the water column persistently thermally stratifies the surface layer (epilimnion) remains well oxygenated but the bottom layer (hypolimnion) may become reduced in oxygen. This reduction in bottom layer oxygen concentrations occurs as the thermocline (rapid change in temperature between the two layers) separates the two layers and surface water diffusion into the bottom layer is reduced. Respiration of organic matter in the bottom waters and sediment uses up oxygen and levels decrease in the bottom waters. If the water body is quite turbid with low light penetration then there will be little oxygenation through photosynthesis by algae and water plants.

Under persistent thermal stratification in rivers the bottom water oxygen levels drops with time, and within a matter of days to weeks oxygen levels can be very low (<2 mg/L). This has been previously seen in the Darling River. The period of time that persistent thermal stratification occurs will influence the amount of oxygen in bottom waters. The high temperatures in December 2018 and January 2019 may have also led to the development of stronger thermal stratification than seen in previous years. Analysis of data by the BOM for Menindee found maximum temperatures in 2018 were the second hottest on record, the anomaly of +1.77°C is just behind +1.80°C in 2013. Minimum temperatures in 2018 were the 4th hottest on record, 1.18°C above the long-term average. Thermal stratification was also likely stronger due to the high algal biomass colouring the water and increasing absorption of solar energy. The algal bloom may have also resulted in increased biological matter (dead algal cells) dropping into the hypolimnion using up oxygen as they decomposed.

When the water column mixes, such as with a cool change and increased wind speed or with increased river flow, the oxygen concentration equilibrates based on the distribution of oxygen through the water column.

Depth (m)	DO %	DO mg/l
0	115.6	8.89
0.5	114	8.77
1	105	8.14
1.5	59.8	4.74
2	36	2.84
2.5	31.3	2.5
3	7.2	0.55

TABLE 5. TYPICAL OXYGEN PROFILE FOR WEIR 32 UNDER STRATIFIED CONDITIONS (COLLECTED BY WATERNSW).

The algal bloom in the river at the time may have influenced oxygen levels. Algae photosynthesise during the daylight hours and through this process produce oxygen in the water. At night in the dark, algae respire and this process reduces oxygen levels in the water. This leads to a diel (or daily) cycle of increasing and decreasing oxygen levels. This fluctuation can be minor if algal concentrations and photosynthesis/respiration rates are low. However, during blooms this can be very high leading to large fluctuations in oxygen levels. During the day supersaturation can be seen and at night reduced oxygen levels occur. Given the high biomass of algae in the river, it is likely that respiration of algae reduced oxygen levels at night. There is evidence of supersaturation in Weir 32 based on spot dissolved oxygen measurements taken by WaterNSW. Before the algal blooms started to develop, regardless of time of day, the % oxygen saturation readings taken were all between 90% and 111% saturation. After the bloom developed in November 2018, readings were more extreme and were 141% at midday and 257% at 4:30 pm on 20 November 2018. On 18 December 2018, just after the first fish death event, levels were at 200% at 4:00 pm, indicating high algal influence on oxygen concentrations.

Figure 21 shows diel oxygen cycles for a site downstream of Weir 32, Burtundy, which had a dissolved oxygen logger. There were large fluctuations in oxygen levels, but these were unlikely to cause fish deaths at this location, even though levels reduced to less than 50% saturation and less than 5 mg/L.

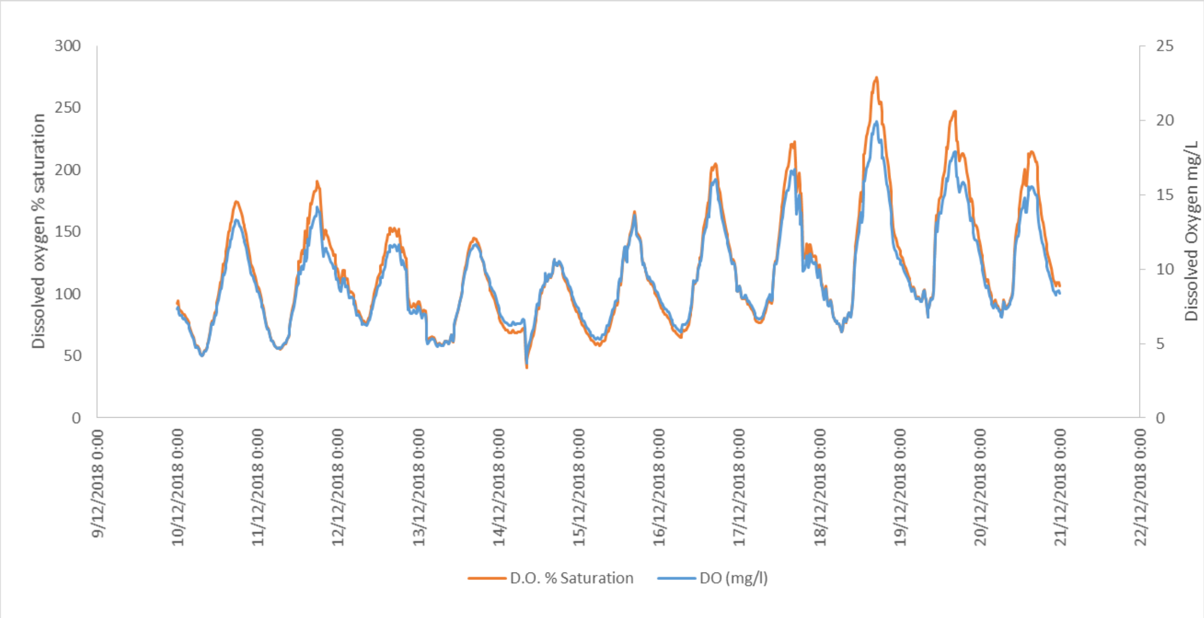


FIGURE 21. CHANGES IN DISSOLVED OXYGEN CONCENTRATIONS AND % SATURATION AT THE DARLING RIVER AT BURTUNDY GAUGING SITE AROUND THE TIME OF THE FIRST FISH DEATH EVENT IN WEIR 32.

A cool change occurred on 13 December with a reduction in air temperature from 39°C on 12 December 2018 to 24°C on 13 December 2018, reaching a minimum of 19°C on 14 December 2018. Water temperature as measured at approximately 60 cm depth decreased from 27.5°C on the 12 December 2018 to 23.1°C on 16 December 2018 (Figure 22). Strong winds (24 km/h) prevailed on 13-14 December 2018, along with rainfall of 5 mm on 14 December 2018 and 14 mm on the 15 December 2018. This weather change likely triggered a mixing event that combined very low oxygen bottom waters with the surface waters where the fish were located. A change in conductivity that may be due to mixing of surface and bottom waters occurred in the early morning of 16 December 2018, the day of the first fish deaths.

The second mortality event (6 January 2019) occurring upstream of Weir 32 coincided with another cool change. In this event, maximum air temperatures fell from 46°C on January 4 2019 to 28.5°C on January 5 2019. The cool change was also associated with strong winds (17, 24 and 17 km/hr on January 3, 5 and 6 2019, respectively) and resulted in a substantial fall in water temperature (from above 30°C on January 4 2019 to 26°C on January 6 2019). The conductivity data shows that another rapid change occurred on the morning of the 6 January 2019, just prior to the second fish death event.

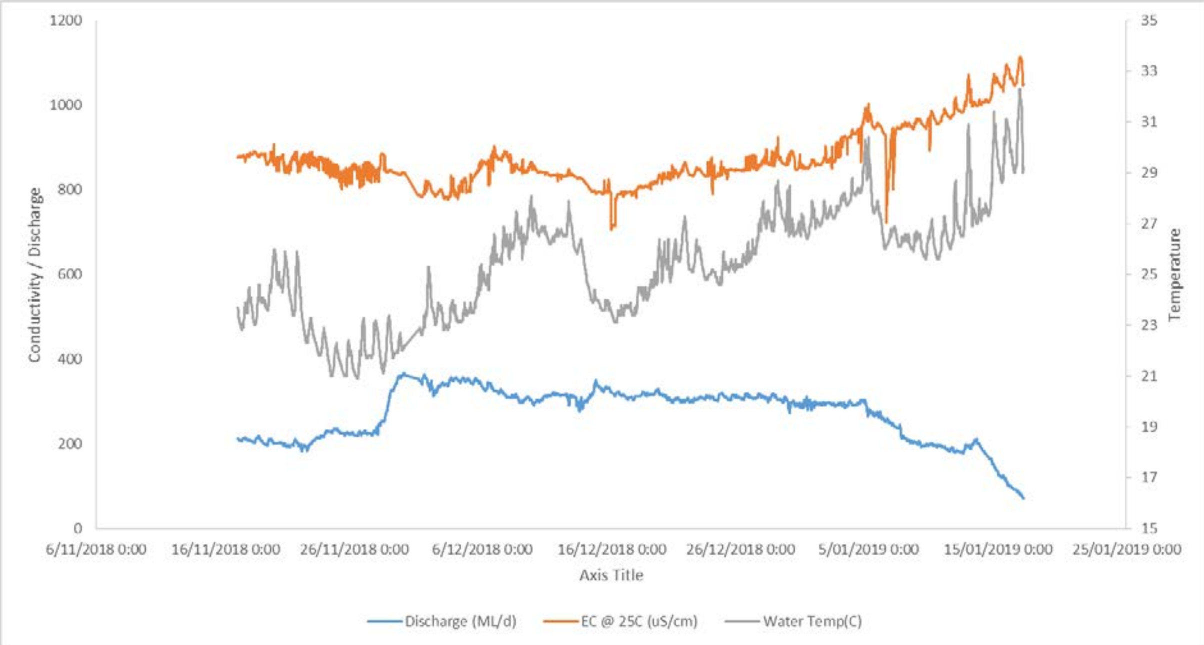
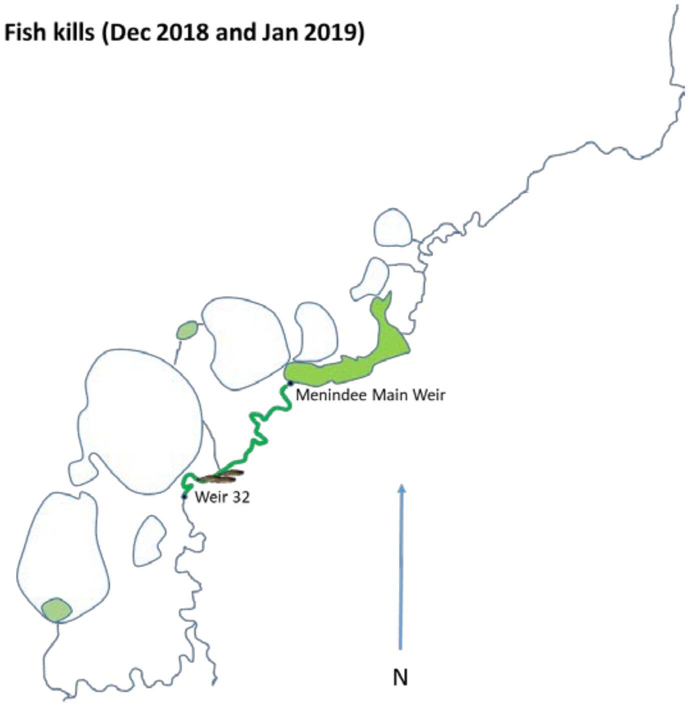


FIGURE 22. CONDUCTIVITY, DISCHARGE AND WATER TEMPERATURE AS MEASURED AT THE WEIR 32 GAUGE.

As noted earlier, when the water column mixes, the oxygen concentration equilibrates based on the distribution of oxygen through the water column.

It is likely that the mixing events in combination with algal respiration caused exceptionally low levels of oxygen to be distributed throughout the water column. Fish were likely already stressed due to the persistently high water temperatures, and the added and likely extended low oxygen event caused the mortality (Figure 23). There is also the possibility of increased organic loading from sediment resuspension by mixing contributed.

Fish deaths of the magnitude seen in the lower Darling at Weir 32 can be influenced by positive feedback. For instance, following the first fish death a significant proportion of dead fish would have sunk to the hypolimnion. This increase in carbon load would have fuelled bacterial production in the hypolimnion and further contributed to persistent hypoxic conditions. Similar situations would have occurred on subsequent fish deaths. With no flows to effectively “flush” the additional carbon from the system, and extreme hot conditions creating conductions suited to bacterial growth, this created a feedback loop which would have contributed to subsequent fish deaths. Under such situations, nitrates would increase and lead to build up of ammonia thus adding an additional stressor to the system.



(A) Low / no flows continue combined with extended hot and dry weather conditions. Algal blooms continue to dominate in the water remaining behind weir pools.

(B) Sudden changes in climate conditions – increased wind, reduced temperatures – cause a rapid destratification of the water column and resulting low oxygen levels throughout the water column. This results in mass fish mortality. Fish deaths occur.

FIGURE 23. CONCEPTUAL MODEL OF EVENTS DURING LATE 2018 AND EARLY 2019 RESULTING IN THE FISH DEATH EVENT; (A) A LANDSCAPE SCALE CONCEPTUAL DIAGRAM OF THE MENINDEE LAKES SHOWING ALGAL BLOOMS IN WATER REMAINING IN LAKES AND ALSO IN THE WEIR POOLS OF THE DARLING (B) A CONCEPTUAL DIAGRAM OF CONDITIONS WITHIN THE WEIR 32 WEIR-POOL AFTER SUDDEN DE-STRATIFICATION LOW OXYGEN DOMINATES THE WATER COLUMN, RESULTING IN MASS FISH DEATHS.

SUMMARY OF PROVISIONAL FINDINGS

Summary of provisional findings by the panel
1. The fish death events in the lower Darling were preceded and affected by exceptional climatic conditions, unparalleled in the observed climate record.
2. The recent extreme weather events in the northern Basin have been amplified by climate change. Future changes in the global climate system are likely to have a profound impact on the hydrology and ecology of the Murray–Darling Basin and exacerbate the risk of fish deaths.
3. Runoff responses to rainfall in the northern Basin appear to have been more severely reduced during recent droughts when compared to previous droughts, compounding the impacts on long-term water availability.
4. Modelled data up to 2009 suggest that pre-development inflow volumes into the Menindee Lakes are of the order of two to three times greater than those under current developed conditions. The comparative effects of drought and development on lake inflows during 2017-18 could not be determined reliably, owing to the unavailability of an updated pre-development model.
5. The relative effects of diversions on flows within the Barwon–Darling tributaries are greatest in dry years.
6. Water extractions from the tributaries of the Barwon–Darling have a much greater impact on Menindee inflows than extractions directly from the Barwon–Darling River.
7. Total tributary mid-system flow volumes (above major extraction points) have only been lower than the 2017-18 total on three occasions over the past 20 years.
8. 2017-18 flows on the Darling River at Bourke and Wilcannia were the lowest observed at those points over the last twenty years.
9. Due to the unfavourable water availability outlook in the northern Basin during 2017-18, the MDBA operated Menindee Lakes relatively conservatively. The rates of MDBA releases of water from the lakes were more gradual than usual, and the pattern of release favoured maintaining storage in the upper lakes rather than the lower lakes.
10. The Menindee Lakes are an ideal nursery habitat for juvenile fish and a refugial habitat for some species of adult fish. High flow events in 2012 and 2016 connected the river system and created good conditions for significant fish spawning and recruitment.

11. Releases from the Menindee lakes throughout 2017-18 were lower than the minimum advised under the water sharing plan, with the intent to prolong stock and domestic requests to meet critical human needs.
12. By the end of 2018, high fish biomass from the spawning events, release of water from the lakes, and the inability of fish to move upstream or downstream due to the restriction of weirs, resulted in the accumulation of large fish populations in the weir pools of the Menindee Main Weir and Weir 32.
13. Hot conditions resulted in significant algal blooms in Lake Pamamaroo, the weir pools of the Menindee Main Weir and Weir 32.
14. Continued hot conditions, combined with low flow, caused the weir pools to stratify. High fish numbers and algal biomass became concentrated in the epilimnion (surface water) and hypoxic or anoxic conditions developed in the hypolimnion (bottom waters).
15. Sudden reductions in air temperature and increased wind associated with storms caused the weir pools to suddenly de-stratify, resulting in low oxygen water throughout the water column and no escape for the fish. This was the primary cause of the fish deaths.
16. Existing responses to aerate water and translocate fish appear to be creating refuge zones and “insurance” populations. Creating pockets of surviving fish will be important for short- and long-term recovery.
17. The current situation in the lower Darling remains critical. The prospect of more fish deaths exists due to persistent stratification in the remaining weir pools. Without significant flushing inflows, further deaths of surviving fish may also be expected in the future.
18. The full extent of the fish deaths on fish populations and the broader ecology of the lower Darling River will not be known until conditions have abated, fish are no longer stressed and targeted research investigations can commence.

PROVISIONAL RECOMMENDATIONS

The following provisional recommendations are grouped under the headings of (1) preventative and restorative measures, (2) management arrangements, and (3) knowledge and monitoring. Our intention is to propose actions that will enhance the ability of state and federal agencies to discharge their responsibilities more effectively within the extant policy settings of the Basin Plan and Murray–Darling Basin Agreement. We have placed a strong emphasis on improving monitoring, data, models, reporting and engagement with science institutions and the community. We note that Basin governments already have some of the proposed actions in train, and where possible we have sought to recognise these within our recommendations. However, it is quite clear that delivering on these actions in a timely fashion will require (1) further investment to accelerate progress and deepen impact, (2) support by governments to take effect and (3) increased community and Aboriginal involvement with implementation.

PREVENTATIVE AND RESTORATIVE MEASURES

1. ***Undertake a risk assessment to identify parts of the Basin most at risk of fish death events. This should inform the development of early warning systems and crisis intervention plans.***

We have found no evidence that a risk assessment was performed at Weir 32, despite a likely blue-green algal event being identified in the WaterNSW Lower Darling Operations Plan over the 15 months prior to the fish death events occurring. The events have illustrated that under very low flows, certain sections of the river may be more at risk of low oxygen conditions than others (notably stratified weir pools with algal blooms occurring). Our investigations to date have revealed little evidence of a systematic assessment of high-risk areas for low oxygen, despite reasonable knowledge about similar high-risk areas for high carbon load blackwater.

A comprehensive risk assessment should be undertaken to determine which areas may be more susceptible to low oxygen levels as result of thermal and oxygen stratification in weir pools and other sections of rivers and lakes. This should be based on depth, channel morphology, algal growth, organic carbon inputs and susceptibility to stratification and mixing. A risk assessment of areas susceptible to blackwater should also be updated to ensure there is comprehensive knowledge of risk areas, and to determine if there is combined potential impact with thermal and oxygen stratification.

2. ***Address gaps in water quality monitoring (dissolved oxygen, temperature, algae) at high risk sites across the Basin. This could include investigating and adopting emerging technologies such as remote sensing, and improving the use of real time data in early warning detection and forecasting.***

Our investigations to date suggest that at the site of the fish death events, no monitoring was being undertaken of key water quality indicators that would have provided early warning of a potential fish death event. Although Weir 32 did not have this information, the downstream site at Burtundy did. This would have helped in determining risks of low surface water dissolved oxygen and the high daily fluctuations caused by algal blooms.

Measures to give early warning of risks should be implemented at the high-risk sites, and as part of broader Basin-wide monitoring. Consideration should be given to increasing installation of real time dissolved oxygen monitoring equipment such as in the current WaterNSW network. These can be added to existing monitoring stations and should include deep located probes to detect stratification, if possible. Unfortunately surface water measurements do not give information on stratification and bottom water dissolved oxygen.

We recommend consideration of the following:

- Surface and bottom water loggers that measure oxygen and temperature in real time at key weir pools or stratification risk sites.
- If oxygen logging equipment is not possible, surface and bottom temperature loggers to indicate when thermal stratification is strong and persisting for longer periods of time.
- Real-time algal monitoring through fluorometry to track algal blooms, noting that this may only work in locations with low turbidity.
- Remote sensing for algal biomass and water temperature measurement.
- Improved monitoring of waterways to include factors such as organic carbon concentrations, algal biomass, thermal and oxygen profiles.
- The broader on-ground water quality monitoring network in the Basin should also be examined to ensure it is covering high risk areas.

We note that the 1992 Interim Unregulated Flow Management Plan for the North-West made statements about the need to set up an algal monitoring framework, fund research into flow forecasting and setting up an Advisory Panel to review the plans performance every 6 months.

Good monitoring and risk assessment are critical ingredients for managing adverse conditions such as stratification and algal blooms, but the challenge remains to deploy field operational procedures to treat them once they arise.

3. Improve opportunities to manage water quality risks in the lower Darling.

Our initial investigations suggest a lack of inflows this summer did not recharge the lakes to a level that would have allowed the recommended releases in the Water Sharing Plan to be followed. If more water had been available in Menindee Lakes, flows at the rate suggested in the Water Sharing Plan may have reduced the risk of stratification and the subsequent algal bloom.

Water management arrangements that increase the water in Menindee Lakes available for release downstream would help reduce the risk of thermal stratification and the potential for future fish death events.

The influence of flow management on thermal stratification should be investigated further, and strategies to reduce persistent thermal stratification should be considered. This could include approaches such as keeping flows above certain thresholds to stop thermal stratification forming during the hotter months, or pulses of higher flows interspersed with lower flows. This may reduce low oxygen levels building up in the bottom layers.

Prior to submitting our final report we will further investigate opportunities for improving flow regimes for preventing stratification at Weir 32 and similar locations on the lower Darling.

We suggest Basin governments build on existing knowledge of water quality, algae and fish deaths available for the Darling to develop better management approaches and manage the system with oxygen and algal bloom issues in mind. For instance, although high algal biomass water in Menindee may not be desired to be released downstream, its ability to mix the water column under critical low oxygen periods may outweigh the negative effect of the algal bloom.

4. Support emerging initiatives within the Basin to remove barriers to fish movement, especially in locations with high stratification potential and locations that act as refuges during low flow events.

Our initial investigations indicate that stratification in artificially-created weir pools that inhibit fish movement was the root cause of the fish deaths.

Removing barriers will reduce the risk of stratification and improve fish mobility and recovery. Globally, there has been a significant push to remove barriers to fish migration, which has led to significant improvements to fish stocks and ecosystem function.

From our consultations to date, we understand that barrier removal is not widely considered as a viable management option. If structures are functionally-redundant, or function could be achieved in another way, removal should be considered.

The panel recommends a review of high-risk structures and encouraging the removal of those with high stratification potential and/or those which block fish passage. The local community should be consulted should such a review be considered.

5. Continue short-term efforts to prevent further fish deaths, through the use of aerators and other technologies as well as fish translocations, noting that these are short term emergency measures and may not prevent additional fish death events if adverse conditions arise again.

Emergency responses are critical to support fish communities during fish death events. Our observations of government and community actions to aerate water indicate that they have had some success in providing localised refuge zones to support surviving fish through these extreme conditions. In addition, temporary translocations to establish 'insurance populations' for reintroduction when conditions become suitable, are proving a viable option for Murray Cod.

It is important to note that the current event is not over. Further fish deaths could be expected this year, and in future years if inflows remain low. The panel recommends actions to aerate pools be maintained until the weir pool stratification and blue-green algal event ends. Translocated fish should not be reintroduced until inflows have returned.

6. At the appropriate time, undertake monitoring of fish populations in the lower Darling to more fully understand the impacts of the recent fish deaths on fish numbers and population structure.

Fish continue to be stressed as the current event persists. Performing invasive research activities whilst fish are under significant physiological stress could contribute to further mortality.

Without the ability to perform research, there is limited ability to report on the number of surviving fish nor the impacts on other aquatic life. The panel recommends that funds be mobilised to commence this research as soon as inflows return and fish are no longer stressed. The results will be important to learn about the extent of the existing event and advise the best mechanisms for ecosystem recovery in the impacted reach.

Furthermore, while fish were the obviously impacted taxa, poor water quality, and hypoxic conditions affect all aquatic life. The second event also impacted yabbies (*Cherax destructor*) and freshwater prawns (*Macrobrachium australiense*) and the extreme low flows and drying sections of channel are impacting the large freshwater river mussel (*Alathyria jacksoni*). Fish will be reliant on these as food sources as populations recover.

7. ***Implement measures to enhance opportunities for recruitment of native fish and facilitate population connectivity.***

Previous research has demonstrated that fish communities within the impacted zone are connected to other regions of the Basin in a variety of ways. For example, in 2016 fish spawned at Bourke moved into Menindee, then entered the Darling main channel and dispersed into the Murray. Likewise, during high flow events fish migrated from the Murray River, through fishways at Burtundy and Pooncarie into Weir 32.

It is also now known that actions taken to facilitate outcomes for fish will benefit other biota (such as freshwater mussels, invertebrates and riparian vegetation). These observations highlight the importance of connectivity throughout the entire Basin. Promoting and enhancing connectivity, along with installing innovative monitoring systems (such as PIT or acoustic tags), will be critical to facilitating and measuring fish recovery.

The panel recommends a long-term commitment to implementing a combination of targeted flow releases, fish passage infrastructure (upstream and downstream), habitat restoration and screening irrigation diversion systems to accelerate fish recovery and build long term resilience.

8. ***Ensure that the Basin Native Fish Management and Recovery Strategy is an authentic collaboration involving government water scientists, academics and consultants, local communities and Aboriginal stakeholders. This should build on efforts such as the Native Fish Strategy and current state programs.***

Fish are highly mobile and move throughout the Basin when the system is connected. The fish community must therefore be managed as a transboundary-shared resource which has significant conservation, recreational and cultural significance. Any emerging management framework must recognise that threats and processes relevant to native fish act on a Basin scale and require a long-term commitment to recover.

Our consultations indicate that since de-funding of the Native Fish Strategy in 2012, Basin states have largely progressed native fish management independently. The panel believes that there is a strong need to integrate and merge efforts into a single, long-term Basin-scale strategy that is appropriately resourced. Aboriginal and community perspectives need to be captured within such a plan.

9. ***Progress implementation of the northern Basin Toolkit Measures, prioritising those that would support native fish population's recovery (e.g. fish passage).***

The evidence we have considered to date strongly suggests that native fish respond significantly to environmental water in the Darling system, and that any mechanism to deliver increased flows to the Menindee Lakes region will be beneficial.

However, simply providing flow is not enough. Fish need to disperse to nursery habitat, have access to food, have sufficient habitat and be protected from harmful processes like passage through undershot weirs and extraction into irrigation systems. These will require "complementary measures" which are implemented alongside watering programs.

The Northern Basin Review identified a number of "Toolkit Measures" including protection of environmental flows, coordinated delivery of environmental water, active management of environmental water entitlements, construction of new fishways and addressing cold water pollution issues through improved dam operations, and a new package of constraints measures in the Gwydir Valley.

The panel strongly recommends a whole-of-system approach to implementing the Toolkit Measures, which will complement environmental watering programs to facilitate fish recovery.

MANAGEMENT ARRANGEMENTS

10. Review and consider changes to Menindee Lakes' operating procedures to provide greater drought resilience in the lower Darling region, encompassing the Menindee Lakes, the lower Darling river and the Anabranch.

The existing arrangements for release of water from the Menindee Lakes were devised in the 1960s (shortly after one of the wettest periods on record) and embedded in the Murray–Darling Basin Agreement. Under the Agreement, the MDBA (on behalf of the joint governments of South Australia, Victoria and NSW) can access water in the lakes when they rise above 640 GL, and until the lakes drop below 480 GL. Once the storage volume within the lakes is less than 480 GL, the water held within the lakes is managed by NSW to meet local demands. This rule was implemented to ensure that local communities had security of supply for up to two years. Given the high evaporative losses Menindee Lakes is now the first storage called on to deliver water into the Western Murray, such that changes to its operation would influence reliability in South Australia, Victoria and NSW.

The panel learned that an initial assessment by the MDBA of the impact of varied water release strategies during the period from January 2017 to January 2019 indicated that a zero-release strategy would have resulted in 414 GL addition volume in the lakes as of January 2019. Minimum releases from Menindee from January 2017 would have resulted in 244 GL additional volume in the Lakes as of January 2019.

The differences in Menindee Lakes' water volumes as of January 2019 for differing release rates would indicate that alternate management would have enabled more effective mitigation of the recent fish death events by increasing releases to breakdown stratification. Whilst maintaining water in storage in the lakes would confer local benefits it would also result in greater water losses and thus have adverse effects in the downstream Murray system.

The panel also learned that the operation of the Broken Hill pipeline is likely to reduce the volumes of reserves needed to be set aside in the Menindee Lakes to meet NSW essential requirements. Interim advice we received suggests by 150GL. This will allow for greater releases when the storage is in NSW control and consequently potentially delay or mitigate the conditions that predicated the recent fish deaths.

The panel recommends that governments work collaboratively to revise and update the operating procedures for the Menindee lakes.

11. Re-evaluate the Menindee Lakes SDL adjustment project to improve environmental outcomes in the lower Darling region and to provide greater water security to the local communities to meet their critical human needs.

The NSW government has identified the opportunity to improve the efficiency and reduce evaporative losses from Menindee Lakes through the SDL adjustment project. Key components of the project are the removal of the requirement to store approximately 200 GL of water in the lakes to cover evaporative losses associated with the supply of water to Broken Hill (6 GL per year), and the alteration of the 640/480 rule to allow for the lakes to remain in MDBA control, on behalf of the Joint Governments, for a longer period of time. The likely outcome of the proposal will be a greater rate of drawdown of the lakes and a reduction in evaporative losses, but also reduced flexibility to manage water quality problems in the lower Darling in times of drought.

NSW submitted its proposal in the form of a Business Case to Basin governments in 2016. In reviewing the Business Case, the MDBA expressed the following concerns:

- The nature of how the water savings from the project will be captured as an enduring change requires agreement.
- Protection of additional inflows from the northern Basin under the Basin Plan needs to be addressed. Further management actions linked to flows at Bourke should also be linked into the new management arrangements.
- Further details on protection of the ecological values of the site is required, in particular golden perch and the lowland Darling River Endangered Ecological Community, listed under the *Fisheries Management Act 1994* (NSW).
- Potential risks and impacts to downstream water users, including reliability of supply, water quality and interactions with planned environmental water (PEW).
- The MDBA anticipates the issues raised here will be included in the confirmation statement and will form part of the forward work plan.

The panel learnt that NSW-led community consultation on the project was substantially delayed, and by then communities were upset about lack of information and transparency surrounding the project, and were extremely concerned about potential negative cultural, social, environmental and water quality outcomes. Efficiency considerations have been a key driver for the project to date, but the community raised that other balancing objectives should be included in the detailed design and implementation of the project. Issues raised by the community that are yet to be satisfactorily addressed in the project include caring for the significant Barkandji cultural heritage, maintaining connectivity of the lakes and meeting downstream environmental needs in the lower Darling and Great Darling Anabranch, maintaining a sufficient drought reserve for the Menindee community and adequately considering water quality. The recent fish deaths have exacerbated community concerns about the project.

The panel notes that the project proposal in its current form may increase cease to flow risks in the lower Darling, but the mechanism provides an opportunity to revisit the configuration and operation of the lakes to improve environmental outcomes into the future.

12. ***Accelerate and deepen efforts to move towards a more dynamic "active event-based management" approach to providing flows through the Darling system. Strategies should be implemented as soon as possible to protect first flushes, protect low flows, shepherd environmental releases, enhance system connectivity, and improve water quality.***

Unlike other rivers across the Basin, the management arrangements in the Barwon–Darling are relatively passive — that is, extraction is governed by long-term rules, not by an actively engaged river operating framework. These long-term rules are embedded within water sharing plans (or equivalent) that stipulate the minimum flow thresholds above which particular licence holders can pump from the river. Historically there have been no provisions to prevent pumping once those minimum thresholds are reached, meaning that environmental flows are not adequately protected. This compromises environmental outcomes achievable through water recovery, particularly in providing downstream connectivity to the Darling system.

There is a recognised need to modify existing arrangements to address these issues, in particular by (i) implementing more dynamic 'active event-based' management of extractions to protect releases of held environmental water, (ii) protecting ecologically important first flushes after prolonged dry spells, and (iii) implementing individual daily extraction limits (IDELs) to ensure that minimum in-channel flows are protected (NSW DPI, 2018).

These actions are currently in various stages of implementation (MDBA, 2018). However, recent events highlight the importance of implementing these reforms as quickly as possible. It is therefore recommended that NSW continues to move towards active event-based management in the Barwon–Darling system as proposed in their 'Better Management of Environmental Water in NSW' report (December 2018).

In the case of Queensland, the interaction between the Border Rivers and the Barwon–Darling should be considered in water resource plans and long-term watering plans. This includes quantifying the volumes of environmental water crossing the border from Queensland to NSW. This would increase transparency and would help the CEWH with their planning, as well as clear the path to move to active management in Queensland.

Achieving full active event-based management in the Barwon–Darling with community support is a long-term endeavour, so it is also recommended that the NSW, Queensland and federal governments work together to address any policy conflicts and resourcing shortfalls required to overcome the active management challenges in this river system.

Active event-based management brings risks and uncertainties. Nonetheless governments should be encouraged to embrace this uncertainty within an adaptive management context as a means to achieving long-term improvements to flow regimes.

13. More sophisticated Basin management approaches will require much better measurement and reporting to increase public confidence in water reform and management arrangements.

Planning and operation of the Basin river systems depends on accurate accounting and reporting on water volumes, including volumes held in storage, flow rates, extractions, and system losses (seepage and evaporation). It is evident to the panel that in many instances there is a heavy reliance on dated or imprecise measurements and estimates, and there is a lack of confidence among some scientists and the community in how many of those estimates are derived. This lack of confidence in the underlying information base weakens confidence in management arrangements and the social license for water reform.

Increasing stakeholder confidence thus requires greater investment in the measurement and reporting on water information, including some forms of consumptive use that remain poorly characterised. For example, the bathymetry of the Menindee Lakes was last quantified in 2004, and is postulated by the local community to have changed over time due to sediment deposition, thereby decreasing storage volumes. Similarly, in the case of Menindee Lakes, losses that include seepage are often described only in terms of evaporative losses, creating considerable confusion. Whether or not such concerns are well founded, there is a significant perception issue to be addressed.

KNOWLEDGE AND MONITORING

14. Significantly increase investment in research and development, co-opting the science community, to address long-standing gaps in hydrological and ecological knowledge.

Australia has amongst the world's most sophisticated water policy settings and water management arrangements, in large part because of a strong culture of investing in research and development. Research undertaken by universities, CSIRO, state agencies and various water-related Cooperative Research Centres (all now lapsed) has had a major impact in providing a strong evidence base and a social license for water reform.

In the fields of catchment and river hydrology and freshwater ecology (seminal to Basin management), Australian researchers made rapid and substantial advances due to Cooperative Research Centre funding made available by the Commonwealth (and supported by States) through the 1990s and until the mid 2000s. This was strongly complemented by investments made by Land and Water Australia through the 1990s and the National Water Commission through the 2000s. By the early 2010s, all of these sources of funding had terminated and today aggregate levels of funding have reduced to early 1980s levels, at a time when water was far less of a public policy challenge than it is today. The knowledge generated and human capacity developed under these programs have been critical in developing and implementing the Basin Plan and various state water planning approaches. It is critical to keep refreshing this base of knowledge and skills if we are to surmount the profound challenge of balancing our highly dynamic water supply and demand.

With regard to fisheries research, the initial ten-year implementation of the Native Fish Strategy advanced knowledge on native fish more rapidly than in any other period. Most scientific understanding of lower Darling fish ecology comes from a variety of disconnected studies conducted over several decades. Learnings have been incremental and are often applied in a 'multiple-lines of evidence' approach to infer the overall ecological function. In determining fish death recovery strategies, it is immediately important to understand how many fish survived the event. Implementing a medium-to-longer term research program, across all fish species and other organisms (such as freshwater mussels and invertebrates), is needed to determine changes over time. This should include structured multi-species community surveys, movement and dispersal studies, spawning site surveys and creel surveys.

Importantly, future ecological research needs to be correlated with hydrology to ensure the links between flow and system productivity are clearly made; this must include and recognise low-flows as a part of the Darling hydrology. However, current knowledge of hydrological connectivity in the northern Basin is sparse and has a high degree of uncertainty. The following recommendations address specific knowledge gaps in hydrology.

15. Improve monitoring of end-of-system tributary flows that contribute to connectivity in the Darling system.

Our investigations to date indicate that, due to the highly distributory nature of many of the tributaries that enter the Barwon–Darling, there are a number of locations where flows into the Barwon–Darling are not currently measured or where existing measurement methods are subject to a high degree of uncertainty.

In order to better support efforts to improve connectivity throughout the Basin, the panel recommends improving information about the relative contributions made by each tributary both on an event basis and over the longer term.

16. Introduce real-time monitoring of diversions in the Barwon–Darling, to ensure protection of managed connectivity events.

In the Barwon–Darling, we have found that even though time event metering exists, the technology has not allowed for a systematic assessment of compliance with licence conditions while a particular flow event is occurring.

Our consultations to date indicate that the NSW Government has recognised the limitations of its metering system and is now addressing this issue through the new Natural Resources Access Regulator (NRAR) and a metering rollout that aims to provide greater certainty and transparency around the protection of environmental water within the Darling system. While we commend the commitment to fund and implement this initiative, we note that past metering programs have fallen short of their planned outcomes. For example, the 1992 Interim Unregulated Flow Management Plan for the North-West states “All Barwon–Darling licences with on-farm irrigation storages will be required to fit approved time/event/flow meters before October 1992. Others with allocations greater than 1,200ML or an authorised area greater than 80 ha will be required to install an approved time/event/flow meter on irrigation pumps before October 1993.” Similarly, federal ambitions announced in 2007 to significantly expand water metering in the Murray–Darling Basin under the National Plan for Water Security ultimately floundered.

The same time event metering should be implemented within the Queensland tributaries. While low to medium flows in these tributaries do not connect with the Barwon–Darling, their management and protection means the end of system wetlands will retain environmental value and health and allow high flows to pass through the tributaries more frequently.

17. Improve the reliability and transparency of the assessment of the hydrologic impacts of floodplain harvesting.

The panel has found that data relating to floodplain harvesting diversions is only in the form of estimates provided from river system models. The effect of floodplain harvesting activities on stream flows within and between systems can only be known with certainty through collection of accurate information on floodplain harvesting volumes.

We understand that NSW and Queensland are working towards tightening controls on floodplain harvesting activities and improving measurement, monitoring and compliance arrangements. Such efforts are underway in NSW as part of their “Draft Floodplain harvesting monitoring and auditing strategy” (NSW, November 2018).

Queensland’s commitment to improve water management, including measurement and monitoring is captured under Queensland’s “Improving Queensland’s rural water management” program. Queensland has also made a series of commitments including measurement of large-volume overland flow in Border Rivers and Moonie Water Plan area by 2020. We recommend that governments do all that is possible to accelerate and deepen these programs and in so doing, redress a serious lack of knowledge and transparency around activities which have a significant bearing on Basin hydrology.

18. Continuously update pre-development model runs developed for the Basin Plan with recent climate information to enable more rapid assessment of the effects of diversions and environmental water releases.

Scientists and catchment stakeholders have expressed significant concerns about the effects of upstream diversions on the health of the Darling River. Under the Basin Plan, governments are committed to reducing diversions over time but there remains significant argument about the pace and proposed magnitude of change. Sadly, much of the argument is poorly informed because of the weak information base available. Our panel sought to quantify the relative effects of drought and diversions on the current water availability crisis in the lower Darling but was stymied by the lack of availability of an up to date pre-development model run for the Barwon-Darling. We recommend that an updated pre-development model run is generated and refreshed on an annual basis.

19. Develop a suitable forecasting tool to support active management of environmental water.

Active management of environmental water will require the development of tools that allow for the forecasting of hydrographs associated with coordinated events in downstream systems. The software is currently available to achieve this, but, we are unaware of any specific project being undertaken to develop and implement an operational forecasting tool that is fit for purpose to aid in planning future coordinated events.

20. Improve analysis of Basin water balances and how they are affected by climate change and climate variability.

There is growing evidence pointing to long-term shifts in the climate of the Basin, based on both instrumental records and climate projections. In particular there is high confidence of increased temperatures, and medium confidence of an increase in the frequency of hot days and duration of warm spells. While there is no clear signal in the projected changes in annual rainfall or in the warm season rainfall, there are projected decreases in winter rainfall for both the northern and southern Basin. There is also medium confidence for both regions that the time spent in drought will increase.

There is also evidence of a recent shift in rainfall-runoff relationships, which results in reduced inflows even under similar mean annual rainfalls. While these recent shifts are not yet fully understood, the evidence points to a likely long-term reduction in catchment runoff and changes to the Basin water balances that must be considered from a water planning perspective.

There has also been a heavy historical reliance in water planning on the specific historical sequence of inflows, yet it is increasingly apparent that this historical sequence is insufficient to support a risk-based approach to drought management. These risk-based approaches would be better served by the development of stochastic inflow sequences that transcend the bounds of the historic record.

NEXT STEPS FOR THE PANEL

This interim report has set out our provisional findings and recommendations, but further work is needed before we can arrive at final conclusions.

A technical workshop is scheduled for 27 February 2019 in Melbourne, to seek comment on our interim report and to invite other expert perspectives. Over 30 subject matter experts are expected to attend this event, drawn from academia, the water industry and Australian Government and state water agencies.

The panel welcomes and will consider comments from any relevant expert or stakeholder. We will also give regard to new sources of information that come to our attention prior to final reporting.

Our final report will be submitted by 31 March 2019. Following submission, we plan to return to the Menindee region to share our final findings and recommendations with the local community.

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ATTACHMENT A: PANEL MEMBER PROFILES

PROFESSOR ROB VERTESSY (CHAIR)

Professor Rob Vertessy has led a distinguished career in water research since graduating with a PhD from the Australian National University in fluvial geomorphology. After leading the Cooperative Research Centre for Catchment Hydrology then CSIRO's Land and Water Division, he joined the Bureau of Meteorology where he served as the Bureau's CEO and represented Australia at the World Meteorological Organization. Professor Vertessy currently conducts research on climate change and water security as an enterprise professor with the University of Melbourne's School of Engineering, and chairs the Australian Academy of Technology and Engineering's water forum. Environmental intelligence is the focus of Professor Vertessy's consulting company, which has taken him to Asia on behalf of the Australian Water Partnership and the Commonwealth Government to share Australia's water reform experience. He chairs a number of state and Commonwealth technical committees concerned with climate and water matters.

DAREN BARMA

Daren Barma is a hydrologist and a river system modeller with extensive experience in water resource management, particularly in the Murray–Darling Basin. He has worked on a large number of technical, policy and planning studies in relation to water resource management across NSW and Queensland. Daren was the external reviewer for river system models as part of the CSIRO Murray– Darling Basin Sustainable Yields Project and reviewed the river system models used in development of the Murray–Darling Basin Plan. Daren Barma is the Director of Barma Water Consulting.

ASSOCIATE PROFESSOR LEE BAUMGARTNER

Dr Lee Baumgartner is an Associate Research Professor in Fisheries and River Management at the Institute for Land, Water and Society at Charles Stuart University. He has over 20 years of research expertise on fish passage, fish migration, flow ecology, invasive species, the impact of human disturbance on aquatic ecosystems and, more recently, the effectiveness of native fish stocking. Dr Baumgartners' work has also focused on developing innovative methods for assessment and applying those information into revised policy and management frameworks; especially the use of 'complementary measures' to recover fish populations. Recently, he has been working in the lower Mekong Basin, specifically understanding mechanisms to help fisheries recover from human disturbance and quantifying the value of fish in a food security context. He presently sits on a range of national and international fisheries advisory boards.

PROFESSOR NICK BOND

Professor Nick Bond is the Director of the Centre for Freshwater Ecosystems at La Trobe University, and has more than 20 years' experience working on the ecology and hydrology of rivers and streams, with a focus on Australia's water-stressed regions. His primary research interest is in modelling the effects of flow variability on stream biota and ecosystem processes, and has been involved in environmental flow research and monitoring in Australia, Asia and South America. Professor Bond holds a PhD from the University of Melbourne, and is an adjunct professor at the Australian Rivers Institute at Griffith University. He has held leadership roles with several Cooperative Research Centres, helping to establish strong links between research and industry, and translating research to guide water management and policy. He currently sits on a number of scientific advisory panels for state and Commonwealth agencies.

Associate Professor Simon Mitrovic

Associate Professor Simon Mitrovic leads the Freshwater and Estuarine Research Group of the School of Life Sciences at the University of Technology Sydney. His focus is applied research on freshwater ecology, harmful algal blooms, environmental flows and plant ecotoxicology. He has worked on the causes and management of freshwater toxic algal blooms in rivers and lakes for over 20 years. Associate Professor Mitrovic has experience in working with government departments to solve environmental issues and one of his areas of expertise is river management. He has worked on developing flow regimes to control algal blooms and improve river health. He has also examined toxin production by blue-green algae and some of their ecosystem implications.

Professor Fran Sheldon

Professor Fran Sheldon is a member of the Australian Rivers Institute at Griffith University. She has more than 25 years of experience in aquatic ecosystem health, arid stream and river ecology, freshwater invertebrate ecology and urban streams. Professor Sheldon has led and participated in number of major national research programs, and has a significant record of published academic work. Her research has informed and influenced management practices across aquatic ecosystems within Australia. Fran Sheldon is currently the Dean of Learning and Teaching at Griffith University.

ATTACHMENT B: CONSULTATIONS UNDERTAKEN TO DATE

Consultations with federal and Basin state government agencies

Location and date	Stakeholders
Canberra 1 February 2019	Joint briefing: ▪ Murray–Darling Basin Authority ▪ Commonwealth Environmental Water Office
Teleconference 7 February 2019	NSW Department of Primary Industries - Fisheries
Teleconference 7 February 2019	Murray–Darling Basin Authority technical staff
Teleconference 11 February 2019	NSW Office of Environment and Heritage
Teleconference 12 February 2019	WaterNSW
Teleconference 12 February 2019	Joint briefing: ▪ Queensland Department of Natural Resources, Mines and Energy ▪ Queensland Department of Science, Information Technology and Innovation
Teleconference 12 February 2019	NSW Department of Industry
Teleconference 15 February 2019	Murray–Darling Basin Authority technical staff
Teleconference 18 February 2019	Joint briefing: ▪ NSW Office of Environment and Heritage ▪ Murray–Darling Basin Authority ▪ Commonwealth Environmental Water Office ▪ NSW Department of Primary Industries - Fisheries

Consultation with local communities, including Aboriginal stakeholders

Location and date	Stakeholders
Menindee 13 February 2019	Representatives from the Barkandji people of far west NSW
Menindee 13 February 2019	Tour of affected areas with locals
Menindee 13 February 2019	Roundtable meeting with community members
Karoola station 14 February 2019	Site visit with locals
Pooncarie 14 February 2019	NSW drought meeting
Pooncarie 14 February 2019	Lower Darling Horticulture Group

The panel will hold a workshop with technical experts and representatives from Australian and State government agencies to test their preliminary findings and recommendations on 27 February 2019 in Melbourne.