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

Final Report

29 March 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.

Letter of Transmittal

29 March 2019

The Hon David Littleproud MP, Minister for Agriculture and Water Resources
Members of the Murray–Darling Basin Ministerial Council
Ms Joanna Hewitt, acting Chair, Murray–Darling Basin Authority Board

Dear Ministers and Chair

Independent Assessment of the 2018-2019 Fish Deaths in the lower Darling

We, the independent panel appointed by The Hon David Littleproud MP, Minister for Agriculture and Water Resources to undertake the *Independent Assessment of the 2018-19 Fish Deaths in the lower Darling*, are pleased to submit our Final Report.

We approached our task by gathering, analysing and reporting on available evidence and we exposed both our preliminary and final findings to review by subject matter experts. In undertaking our assessment we consulted widely, engaging with the Traditional Owners of the Darling (the Barkandji), other Indigenous groups, representatives of the lower Darling community, irrigator groups, environmental groups, relevant government agencies, academics and consultants.

It was impossible to consult with stakeholders on the fish death events without the conversation turning to the broader issue of Basin water reform. We heard a wide range of views, concerns and experiences, but a common aspiration to improve the environmental health of the northern Basin and the lower Darling, in particular. It is evident that Basin stakeholders hold widely differing opinions on the direction, pace and benefits of water reform. For those feeling disadvantaged or frustrated by the reforms, the fish deaths were emblematic of fundamental flaws in water management in the Basin. Others remain positive that the macro-settings of reform are sound, but that continuing adjustment is necessary. This polarisation is problematic because it threatens to derail reform.

We are cognisant and respectful of the significant, positive efforts made by Basin governments and communities in developing and implementing the Basin Plan. We appreciate that water reform, particularly in the Basin where water access is so strongly contested, is extremely challenging, but know that good progress is being made to improve water security for water users and the environment. We also understand that many of the significant reforms agreed to are still being implemented and that environmental outcomes take time to manifest. We strongly support the Basin Plan and the institutions involved in implementing it. However, mounting negative sentiment across the community demands that more be done.

The severe and prolonged drought conditions in the northern Basin, and climate change are revealing that the northern Basin faces even greater pressures than understood when the current Basin Plan was agreed. Recent media controversies, hardships wrought on certain Barwon–Darling communities by water scarcity, and the community and environmental shock of the lower Darling fish deaths have eroded public confidence in the Basin water reform process. We stress that we do not support calls to pause the Basin Plan and re-prosecute the Basin reform process. We support continuation of the Basin Plan, its adaptive management ethos, and the intent to undertake a comprehensive review of it in 2026. But we also believe that the reform effort must be re-energised and accelerated.

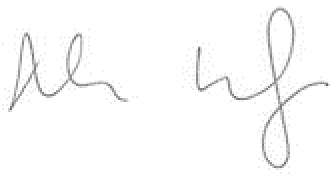
There is a high chance that severe fish death events, such as those recently experienced in the lower Darling, will reoccur in the future, unless significant interventions are made. Fortunately, several options exist to mitigate this risk and these are articulated in our report. Responding to the lower Darling fish deaths in a prompt and substantial manner provides governments an opportunity to redress some of the broader concerns around the management of the Basin. To do so, Basin governments must increase their political, bureaucratic and budgetary support for high value reforms and programs, particularly in the northern Basin. We have provided you with a suite of practical recommendations that, if adopted, can yield improved outcomes for the Basin and consequently improve community trust in the reform process.

In closing, we wish to express our thanks to the many federal and state government agency personnel that supported our assessment. We are particularly grateful to the officers of the Murray–Darling Basin Authority, who provided exemplary secretariat services to our panel. Should you desire it, we are available to brief you on our assessment individually, or collectively at the Murray–Darling Basin Ministerial Council.

Our final task will be to return to the lower Darling region in the next few weeks to share our findings and recommendations with the community and Traditional Owners, and to express our gratitude for their contributions to our assessment and their ongoing stewardship of the lower Darling River.

Yours sincerely

Professor Rob Vertessy (Chair)



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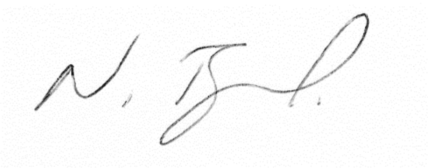
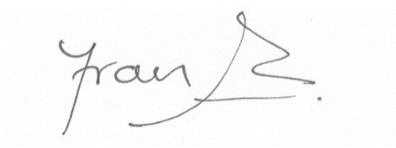


Professor Fran Sheldon



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1 Executive Summary

Three significant fish death events occurred in the Darling River near Menindee between December 2018 and January 2019. The three events took place within two adjacent weir pools in a 30 km reach of river between Texas Downs Station and Weir 32 (DPI NSW Fisheries, 2019). The main native fish species involved included Murray Cod, Silver Perch, Golden Perch, Bony Herring, with mortality estimates in the range of hundreds of thousands to over a million fish. Though post-event fish population sampling is yet to be conducted, we expect that these mortalities will impact populations in the lower Darling River, and perhaps beyond, for many years. These events constitute a serious ecological shock to the lower Darling and reverse positive ecological outcomes that had accrued from environmental watering programs.

We have determined that fish deaths events were primarily caused by local hydrological and climatic conditions (Figure 1-1). The extreme hot and dry climate during 2018, extending into 2019, shaped the conditions that saw a large fish biomass, which had flourished since favourable spawning conditions in 2016, isolated in the weir pools around Menindee, with no means of escaping upstream or downstream. Those adverse climate conditions also shaped the subsequent algal bloom development and the strong and persistent thermal stratification of the weir pools, which created hypoxic conditions in the bottom waters of the pools. All that was needed for this to have a fatal impact on the fish was a trigger for the weir pool waters to become destratified and deprive the fish of oxygen. That trigger duly arrived with a series of sudden cool changes in the weather, with temperature drops and wind action initiating the turnover of the weir pool waters. This sudden depletion of oxygen, combined with the already high water and air temperatures, would have offered the large biomass of stressed fish no means of escape. For each fish death event, the weir pool in which the fish were trapped was bordered downstream by an impenetrable barrier (a weir) and upstream by a dry channel. Ultimately, it was the rapid transition from very favourable conditions to very adverse ones that resulted in such high numbers of fish deaths.

We have also determined that the fish death events were shaped by a broader climatic, hydrologic and basin management context that placed the lower Darling River at risk of such fish deaths. The preceding six years (since 2012) had seen two high flow events that had delivered water into Menindee Lakes (2012 and 2016) and offered opportunities for substantial fish breeding and recruitment. Fish populations were further enhanced by the judicious use of environmental water. The end result was a considerable biomass of fish within the Menindee Lakes, post 2016. Outside of these high flow events there were minimal flows in the Darling River below Bourke. This period was preceded by the Millennium drought (2000-2010), during which time flows across the entire northern Murray–Darling Basin were reduced. All of the hydroclimatic evidence available indicates that the years since 2000 have been some of the driest on record, in terms of inflows into major upstream storages, combined with an increased number of extreme heat days, which would have had a major impact on water quality in remnant pools.

Soon after the events, Basin government officials met and developed an action plan to respond to the crisis. Immediate actions underway include additional water quality monitoring in the lower Darling, the use of aerators and targeted fish relocations. These immediate actions are welcomed, however, the current situation remains critical – without significant inflows, further deaths of surviving fish may be expected. We consider that priorities and actions in the short-term should focus on anticipating a repeat of 'worst-case scenario' outcomes with responses focussed at the site scale. In addition, the Minister for Agriculture and Water Resources announced a Native Fish Management and Recovery Strategy to help manage and recover fish populations across the Basin. We consider that this provides a good opportunity to enhance native fish management and support native fish population recovery and should be developed and implemented through a genuine collaboration between governments, communities, and Traditional Owners. The strategy needs to build on existing and lapsed native fish programs across the Basin.

Through our investigations, it became evident to us that, over the long-term, the extant water access arrangements in the northern Basin, as well as limitations in the river models used to plan water sharing, place the lower Darling River at a higher risk of conditions that can lead to fish deaths during droughts than has previously been anticipated. Given that we are witnessing an increasing frequency of low inflow sequences in the northern Basin, this presents a serious problem for safeguarding fish populations, and populations of other resident biota, during drought in the lower Darling. We have identified that changes to Barwon–Darling water access arrangements made by NSW just prior to the commencement of the Basin Plan in 2012 have enhanced the ability of irrigators to access water during low flow periods and during the first flow event immediately after a cease-to-flow period. Further, it appears that the river models used to develop water sharing arrangements have a tendency to overestimate streamflows during dry sequences, and hence underestimate the impacts of extractions during dry times.

Prudent flow management during dry sequences is crucial for maintaining connectivity along the channel, refreshing the water quality of reaches and pools, reducing the weir pool stratification and providing refuge for fish populations and other biota. So, whilst we would not assert that excessive water extractions caused the lower Darling fish deaths in 2018-19 *per se*, it is clear that historic patterns of extractions in the northern Basin over the last two decades (and particularly since 2012) have reduced the resilience of riverine ecosystems in the lower Darling. Maintaining the present pattern of water extractions into the future will further weaken the resilience of the riverine ecosystem and make it more vulnerable to fish death events. As such, water access and water sharing arrangements in the Barwon–Darling should be reviewed and modified.

There are a number of initiatives in different stages of development or implementation which can be shaped or accelerated to mitigate the risk of future large-scale fish deaths in the lower Darling. For example, as part of the Northern Basin Review, the Murray–Darling Basin Authority (MDBA) recommended a set of Toolkit measures designed to accompany and bolster the outcomes being achieved through water recovery. These measures included enhanced arrangements to protect and coordinate environmental water in the northern Basin. We consider that governments should urgently progress the implementation of these measures, especially those that support native fish population recovery and connectivity.

The need to improve water management across the northern Basin, especially in the unregulated parts, has been strengthened through a series of studies over the past two years, including the Ken Matthew's (NSW DOI 2017) review into water management and compliance. Of particular importance is the NSW proposal to shift its unregulated water sources to an active event-based management regime, in which water access is announced, monitored and reported in an open and transparent way. This change would allow environmental water to be protected from extraction on an event-by-event basis, and would provide greater certainty for consumptive users. NSW has also proposed that the first flow through the Barwon–Darling after an extended dry period should pass through the system without extraction.

These measures are under consideration by governments and the community, but they have not yet been adopted. A number of other complementary measures are under consideration by Basin governments, including the construction of a series of passing structures at weirs to enhance fish mobility, both upstream and downstream during low flow periods. It is vital that the momentum behind these measures is maintained to enhance the connectivity of the river system from northern to southern basins.

Similarly, the Menindee Lakes Water Savings Project (NSW DOI 2018) provides an opportunity to deliver multiple benefits to the river system, including an improved connection between the northern and southern Basins. The project is at the concept stage with a completion date in 2024, and is the subject of an extensive engagement process with stakeholders and the community. The final configuration of the project is still being determined. It is recommended that governments design and implement a project for which water efficiency is only one of multiple considerations. Water management should also aim to enhance the lived experience of the local community with the river. Governments are encouraged to seize the opportunity to strive for a holistic mix of social, cultural, environmental and economic outcomes for the Menindee Lakes and lower Darling regions, even if this reduces overall system efficiency.

Beyond the Toolkit and Sustainable Diversion Limit (SDL) adjustment measures, governments are encouraged to explore other changes to the rules and water sharing arrangements across the northern Basin to better enhance overall river outcomes. As a matter of urgency, we recommend that Basin governments and stakeholders confer on how to adjust water access rules in the Water Resource Plans under development to enhance hydrologic connectivity in the Darling River during drought sequences. Most importantly, this must be done in close consultation with the community and with regard to Traditional Owner values and outcomes, including cultural ties to flow. This could include an agreement on procedures to significantly reduce the rate of water extractions in the northern Basin as streamflows decline.

We believe that such adjustments can be accomplished within the agreed SDL settings, though recommend that a thorough reconsideration of the SDLs in the northern Basin be undertaken in time for the 2026 Basin Plan review. This examination should consider the emerging impacts of climate change, especially in light of the inflows experienced over the last twenty years, but should also consider the ecological needs of the lower Darling as part of the evidence base for northern Basin SDLs.

Our key findings and recommendations are summarised below and expanded in section 7 of this report. We strongly support continuation of the Basin Plan, but we also believe that the reform effort must be re-energised and

accelerated. We present practical recommendations addressed to Basin policy makers and Basin managers separately, that, if adopted, would enhance the ability of State and Australian government agencies to discharge their responsibilities more effectively within the policy settings of the Basin Plan and Murray–Darling Basin Agreement. We believe that these recommendations would also yield valuable outcomes for the Basin and consequently improve community trust in the reform process.

1.1 Findings

1.1.1 Findings relating to the fish deaths

Finding 1: The Menindee Lakes are an ideal nursery habitat for some juvenile fish and a refugial habitat for some species of adult fish. High flow events in 2012 and 2016, combined with the use of Commonwealth environmental water, connected the river system and created good conditions for significant fish spawning, recruitment, growth and dispersal into the Menindee lakes.

Finding 2: By the end of 2018, high fish biomass from the recruitment events, releases of water from the lakes by NSW, and the inability of fish to move upstream or downstream due to the restriction of weirs, resulted in the aggregation of fish populations in the weir pools of the Menindee Main Weir and Weir 32.

Finding 3: Hot conditions and low flows resulted in significant algal blooms in Lake Pamamaroo, the weir pools of the Menindee Main Weir and Weir 32.

Finding 4: The combination of hot conditions, low flows and significant algal blooms, caused the weir pools to stratify. High fish numbers and algal biomass became concentrated in the surface waters of the weir pools and hypoxic conditions developed in the bottom waters.

Finding 5: Sudden reductions in air temperature and increased wind associated with storms caused the weir pools to suddenly de-stratify, resulting in low oxygen throughout the water column and no escape for the fish. This was the primary cause of the fish deaths.

Finding 6: The fish deaths primarily involved Murray Cod, Silver Perch, Golden Perch and Bony Herring. Significant numbers of carp were also reported to have died. Estimates of the number of mortalities range from hundreds of thousands to over a million fish.

Finding 7: Follow-up fisheries surveys using underwater acoustic cameras, conducted immediately after the events, identified that many fish survived the event. The remaining fish populations and their health, will be crucial for subsequent recovery.

1.1.2 Findings relating to climatic condition influencing factors

Finding 8: The fish death events in the lower Darling were preceded and affected by exceptional climatic conditions, unparalleled in the observed climate record.

Finding 9: The recent extreme hot-dry weather events in the northern Basin have been amplified by climate change. Future changes in the global climate system are likely to have an even more profound impact on the hydrology and ecology of the Murray–Darling Basin and increase the risk of fish deaths in the future.

Finding 10: 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 of drought on downstream long-term water availability.

1.1.3 Findings relating to system hydrology and water management influencing factors

Finding 11: Modelled flow data up to 2009 indicate 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 effect of upstream development on lake inflows during 2017-18 could not be determined, owing to the unavailability of an updated pre-development model and insufficient metering of extractions.

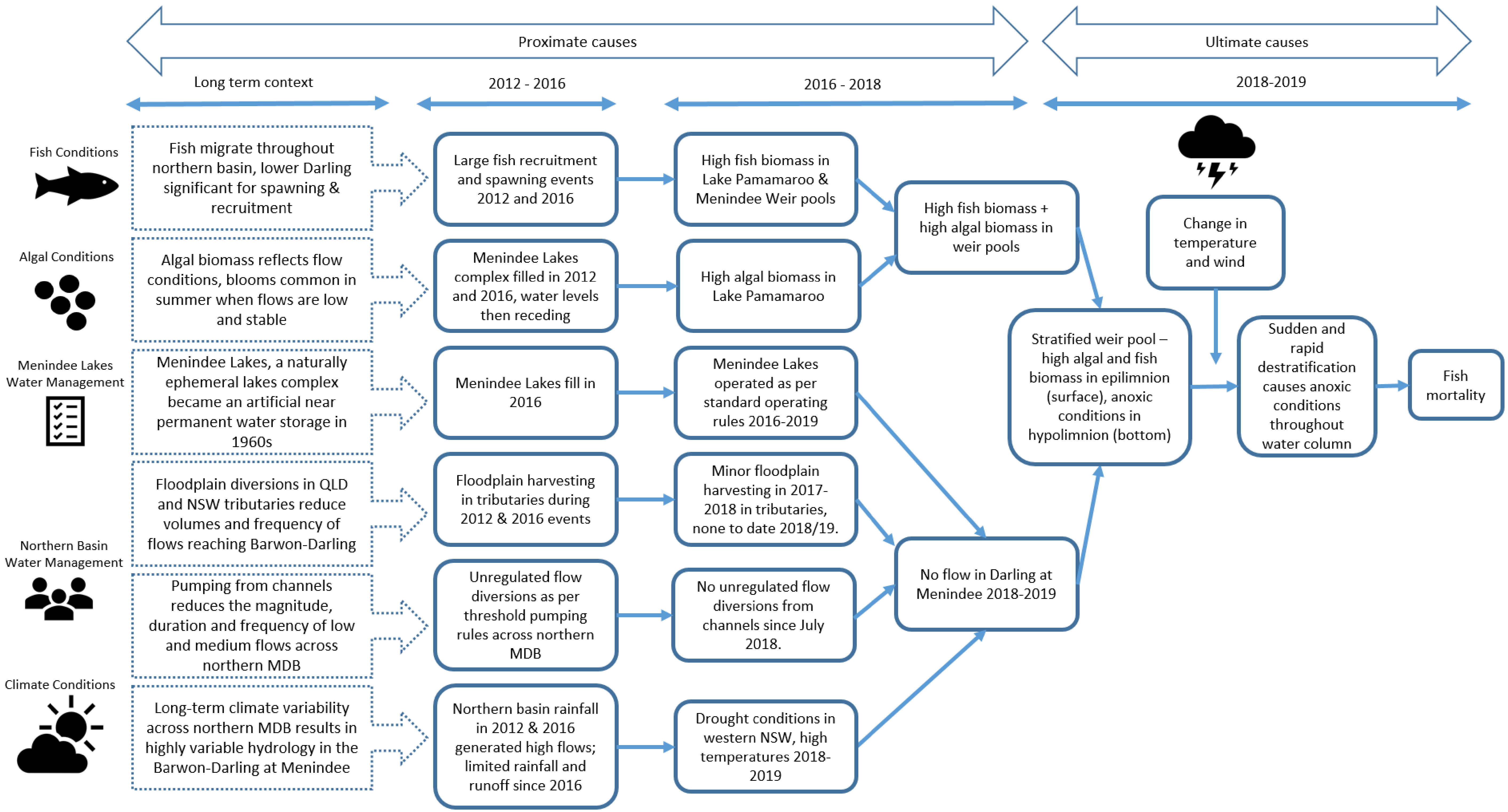


Figure 1-1: Summary diagram of the multiple causes of the 2018-19 fish death events in the lower Darling.

Finding 12: The relative effects of diversions within the Barwon–Darling tributaries upon inflows to the Barwon–Darling are greatest in dry years.

Finding 13: 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. However, when flows in the system are low, the capacity for extractions directly from the Barwon–Darling using A Class licences is a serious threat to the connectivity of the river between Bourke and Menindee.

Finding 14: 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 twenty years.

Finding 15: Flows in the Darling River at Bourke and Wilcannia during 2017-18 were the lowest observed at those points over the last twenty years.

Finding 16: In recent times, one of the main impacts on the frequency, magnitude and duration of low flows in the Barwon–Darling River, which have high ecological importance, is the change in the behaviour and use of A Class diversion licences. Relaxing constraints on water access and providing more flexible "carry-forward" arrangements under A Class licenses in the 2012 Barwon–Darling Water Sharing Plan has led to significant increases in the extraction of water during low flow periods.

1.1.4 Findings relating to lake operations influencing factors

Finding 17: Contrary to public perception, 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.

Finding 18: Releases from the Menindee lakes throughout 2017-18 were lower than the minimum advised under the current lower Darling Water Sharing Plan, with the intent to prolong flows to meet stock and domestic and critical human needs requests.

1.1.5 Findings relating to fish mobility influencing factors

Finding 19: Weir 32 and Menindee Main Weir are partial barriers to dispersal (despite the presence of fishways which largely pass fish upstream); therefore, as flows were reduced, fish became trapped within the reach. This confinement likely exacerbated the scale of the fish deaths.

1.1.6 Findings relating to emergency responses and fish recovery

Finding 20: The 2012 national listing of Murray Cod as a vulnerable species was partly based on impacts of previous fish deaths. Actions to address fish death events are already developed and presented in the “National Recovery Plan for Murray Cod”. The plan provides explicit recommendations on priority actions and investments needed to prevent fish deaths into the future.

Finding 21: Combined community and government actions to respond to the fish death events successfully created refuge zones that protected remaining fish. Fish that were also rescued (Murray Cod, Silver Perch and Golden Perch) were translocated to create “insurance” populations, they have recovered quickly and are in good health.

Finding 22: Responding agencies have been inundated with offers from private industry relating to technology which could improve conditions in weir pools. The various technology solutions are being evaluated.

Finding 23: The prospect of more fish deaths exists due to low oxygen levels in the remaining weir pools. Without significant flushing inflows, further deaths of surviving fish may be expected in the future.

Finding 24: The full extent of the fish deaths on fish populations and the broader ecology of the lower Darling River will not be known until the current adverse conditions have abated, fish are no longer stressed and targeted research investigations can commence.

1.2 Recommendations

1.2.1 Recommendations for Basin policy makers

Recommendation 1: NSW should modify water access arrangements under the Barwon–Darling Water Sharing Plan to protect low flows.

Recommendation 2: In preparing future Water Resource Plans for catchments in the northern Basin, QLD and NSW should ensure that they give greater attention to the need to maintain hydrologic connectivity in the Barwon–Darling River.

Recommendation 3: Basin governments should review and consider changes to the 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.

Recommendation 4: NSW and the Australian government should re-evaluate the Menindee Lakes Water Saving Project to place a greater emphasis on improving water security and environmental outcomes in the lower Darling. Should the revised project contribute less to the agreed Sustainable Diversion Limits, the NSW government would need to commit to addressing the shortfall.

Recommendation 5: NSW and the Australian government should finalise arrangements to support structural adjustment of lower Darling farm enterprises with permanent/perennial crops that depend on high reliability water entitlements, including appropriately targeted strategic water acquisition and compensation for the reconfiguration of farm businesses.

Recommendation 6: NSW and QLD should adopt an active event-based management approach to providing flows through the Barwon–Darling system. Flow management 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.

Recommendation 7: NSW should initiate a program to remove barriers to fish movement and enhance mobility through improved passage at existing weirs and regulators.

Recommendation 8: NSW, QLD and the MDBA should publish their joint plans for implementation of the northern Basin Toolkit Measures, and set an aggressive timeline for delivery. Immediate priority should be given to those measures that support native fish population recovery and connectivity.

Recommendation 9: Basin governments should initiate a joint program to significantly accelerate river model development to evaluate different Basin policy options.

Recommendation 10: Commonwealth and State governments should significantly increase investment in research and development, co-opting the science community, to address long-standing gaps in our knowledge of riverine hydrology and ecology. A priority focus of those new arrangements should be applied research that serves the information needs associated with Basin Plan implementation.

1.2.2 Recommendations for Basin managers, to be implemented within one year

Recommendation 11: NSW should continue emergency responses such as the use of aerators and fish translocations, noting that these are short-term emergency measures and may not prevent additional fish death events if adverse conditions persist or re-occur.

Recommendation 12: Once the adverse environmental conditions have abated, NSW should undertake monitoring of fish populations in the lower Darling to more fully understand the impacts of the recent fish death events on fish numbers and remaining fish population status.

Recommendation 13: NSW and MDBA should jointly undertake a risk assessment to identify parts of the Darling Basin that are most at risk of future fish death events. This information should be used to inform the development of future early warning systems and emergency response plans.

Recommendation 14: NSW should review and refine the flow requirements to control stratification in weir pools deemed to be at high risk of fish deaths.

Recommendation 15: NSW and QLD should establish an agreed protocol to protect first flushes.

Recommendation 16: Basin governments should ensure that the Basin Native Fish Management and Recovery Strategy is adequately resourced and involves authentic collaboration with government water scientists, academics and consultants, local communities and Aboriginal stakeholders. This strategy should build on efforts such as the lapsed Native Fish Strategy and current State programs.

Recommendation 17: The Commonwealth Environmental Water Holder, the MDBA, the Victorian Environmental Water Holder and the NSW Department of Environmental and Heritage should cooperatively undertake a risk assessment to determine how best to manage environmental water during prolonged dry spells, taking into account uncertainty in future inflows.

Recommendation 18: The MDBA's recently announced Climate Change Research Program should be adequately resourced and supported by relevant specialist science agencies and universities. A much better understanding of how climate change threatens Basin water availability and aquatic ecosystems must be obtained ahead of the 2026 Basin Plan review.

1.2.3 Recommendations for Basin managers, to be implemented within two years

Recommendation 19: NSW and QLD should introduce more accurate continuous and real-time monitoring of diversions in the Barwon–Darling, to ensure protection of managed connectivity events. Compliance around all metering requirements and overland flow extractions should be strengthened expeditiously.

Recommendation 20: NSW and QLD should improve the reliability and transparency of the assessment of the hydrologic impacts of floodplain harvesting.

Recommendation 21: The MDBA should 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.

Recommendation 22: Commonwealth and State environmental water managers should cooperate to develop a suitable forecasting tool to support active management of environmental water.

Recommendation 23: NSW should initiate a project to establish a "demonstration reach" in the lower Darling, where multiple threats to fisheries recovery are mitigated to create beneficial conditions for long-term fish recovery. This demonstration reach should be a key feature of the Native Fish Management and Recovery Strategy and should heavily involve the local community, including Aboriginal stakeholders.

Recommendation 24: Basin governments should ensure that the Native Fish Management and Recovery Strategy includes the appropriate elements of the Murray Cod National Recovery Plan pertaining to fish kills.

1.2.4 Recommendations for Basin managers, to be implemented within three years

Recommendation 25: Basin States should upgrade their Strategic Water Information Monitoring Plans to reflect the enhanced hydrologic monitoring requirements associated with the Basin Plan and the recently agreed Murray–Darling Basin Compliance Compact, and agree to commit the necessary resources to enable these plans to be fully implemented.

Recommendation 26: NSW should redress gaps in water quality monitoring (dissolved oxygen, temperature, algae) at high risk sites in the Barwon–Darling. This could include investigating and adopting emerging technologies such as remote sensing, and improving the use of real-time data to support early warning and forecasting.

Recommendation 27: NSW and QLD should improve monitoring of end-of-system tributary flows that contribute to hydrologic connectivity in the Darling system, and make that data readily available.

2 Background

2.1 Preamble

Three significant 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 15 km stretch of river upstream of Menindee town weir 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 Menindee Pump Station. The second event occurred on 6-7 January 2019, in the same stretch of river, and was a much larger event, affecting approximately 45 km of the Darling River below the Menindee Main Weir including the Menindee Township down to Weir 32. 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 over a 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, and 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.

2.2 Background to this Independent Assessment

In January 2019, the Australian Government 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 selected five additional panel members based on their areas of expertise and professional standing. The panel members were all senior, respected water professionals, with significant knowledge of the Murray–Darling Basin and specialist skills in hydrology, fluvial geomorphology, freshwater ecology, fish biology and algal ecology. Panel member profiles are provided at Attachment A.

2.3 Terms of Reference

The Terms of Reference for this Independent Assessment are provided at Attachment B. In brief, the panel was asked 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.

In conducting this Independent Assessment, the panel was 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.

2.4 Consultations

The panel 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 Murray–Darling Basin Authority (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). 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 the Barkandji people, the Traditional Owners of the Darling River, or Barka. Subsequent consultation with these groups was undertaken following the release of our Interim Report. A listing of the consultations we undertook during our assessment is provided at Attachment C.

On 21 February 2019, the panel submitted to the Minister for Agriculture and Water Resources an Interim Report with provisional findings and recommendations and this was released publicly. On 27 February 2019, the panel held a technical workshop with over 30 subject matter experts to comment on our provisional findings and recommendations. Participants in that workshop are listed at Attachment D. The panel also considered a number of written submissions that were received following the release of our Interim Report (Attachment E). On 25 March 2019, our draft Final Report was peer reviewed by four technical experts and two water policy experts (Attachment F). The extensive feedback we have received via stakeholder consultation and specialist reviews since the submission of our Interim Report has shaped our final findings and recommendations.

2.5 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 (Australian Academy of Science, 2019). During our assessment, Water NSW has been performing ongoing monitoring and investigations of blue green algae and water quality in the affected reaches of the lower Darling. Our own assessment has significantly benefited from the work undertaken by these groups.

2.6 Current situation

At the time of submitting this Final Report, the situation in the lower Darling remains critical, with little chance of relief in sight. The northern Basin water storages currently sit at 11% of capacity and the Menindee Lakes are close to empty, with only 22GL remaining in storage. Weir pools and block banks providing refuge for remaining fish continue to shrink under the drought conditions and further fish deaths involving hundreds of fish have been reported by local landholders in recent days. Recent water quality monitoring being conducted by NSW DPI Fisheries and Water NSW 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 emergency responses and better understanding the processes giving rise to fish deaths.

Continuing emergency responses, such as weir pool aeration and fish translocations, are certainly helping, but more deaths are likely to occur as low inflows and dry conditions continue across the lower Darling catchment for the foreseeable future. The probabilistic climate outlook issued by the Bureau of Meteorology favours the continuation of drier than normal conditions for the next three months. The Bureau also advises a greater than 70% chance that an El Niño will form in the Pacific Ocean imminently and that a positive Indian Ocean Dipole is likely to form later in the year. These climate drivers are both harbingers of dry conditions in south-eastern Australia.

3 Description of the system, including water management arrangements

3.1 The Darling Basin

The following content draws primarily on Webb McKeown (2008). The Darling Basin, covers an area of 699,000 square kilometres, and makes up 70% of the total area of the Murray–Darling Basin (Figure 3-3). Approximately one third is in Queensland and two thirds is in NSW. The 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, the Barwon–Darling River system is characterised by a highly variable flow regime, in which prolonged periods of low-flow are periodically interrupted by high flow events that connect the entire river system (Figure 3-1). Historically, despite protracted low-flows, periods without flow were relatively uncommon. However, the frequency of cease-to-flow periods has increased since the early 2000's and the Millennium drought (Figure 3-2), particularly at Wilcannia, midway down the system. Flows immediately downstream of Menindee (Weir 32) have historically been buffered from cease-to-flow periods, with almost continuous flows being delivered from Menindee storages. Further downstream at the Burtundy Gauge (approximately 80 river km downstream), cease-to-flow periods once again occur within the flow series. As well as increases in the frequency of cease-to-flow events, there is a more general reduction in flows evident in the periods 2000-2012 and 2012-2018, relative to 1980-1999. These flow reductions reflect the combined effects of consumptive water use and reductions in catchment inflows during recent droughts. As discussed elsewhere in this report, more precise attribution of the effects of water use on streamflow measured at individual gauges is made difficult by incomplete water accounting and a lack of up-to-date models.

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. The augmentation of natural river flows in the northern Basin 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.

In all Darling tributaries with major irrigation industries, large-scale irrigation development is located in the lower reaches of the valleys. Average annual flows in all major irrigation valleys at their "mid-river" maximum flow point, are only about 3-15% less presently than under pre-development conditions. However, the impact of irrigation development is much higher at the end-of-valleys, prior to entering the Barwon–Darling River. The high value of cotton, abundance of irrigable land and high proportion of natural river flows remaining in rivers below the "mid-river" point, 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. This practice is more prevalent in the lower reaches of the tributaries.

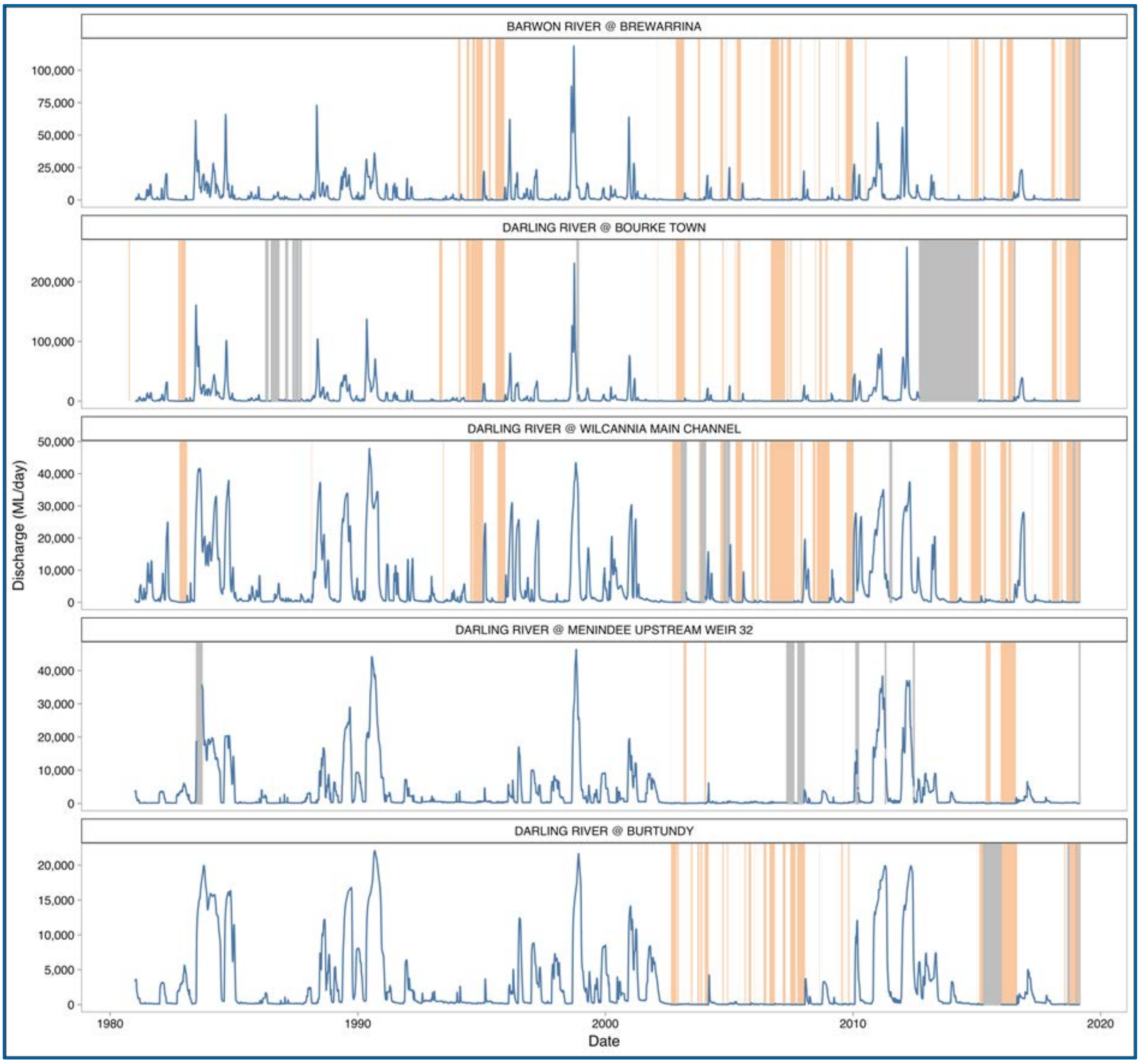


Figure 3-1: Hydrologic time-series for streamflow gauges in the Barwon–Darling system from 1980-2019. Periods of cease-to-flow are identified with orange lines, and missing data with grey bars. (Bureau of Meteorology, Water Data Online).

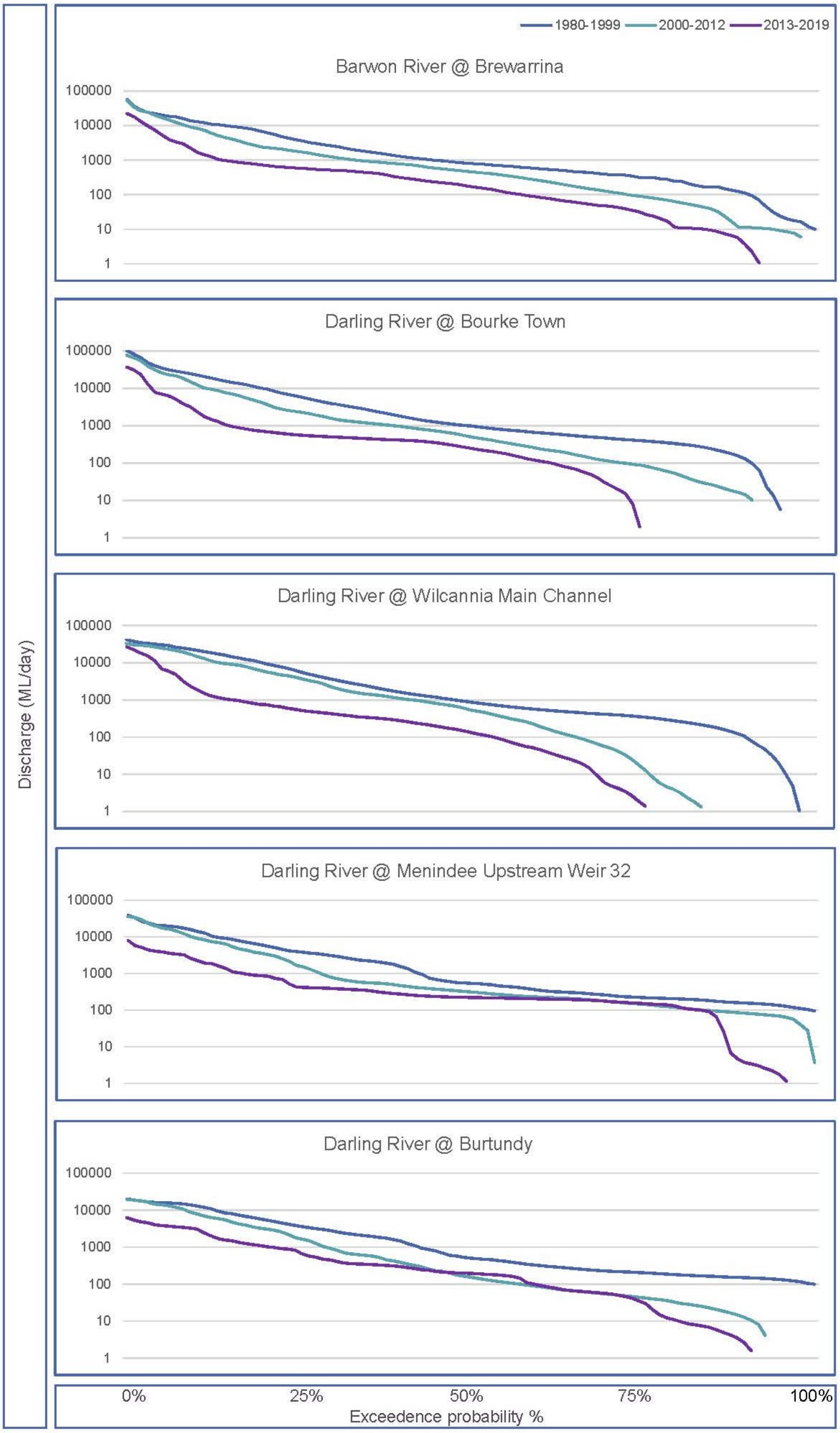


Figure 3-2: Flow duration curves compiled for streamflow gauges in the Barwon–Darling system from 1980-2019. Data are plotted separately for three periods (1980-1999, 2000-2012 and 2013-2019). (Bureau of Meteorology, Water Data Online).

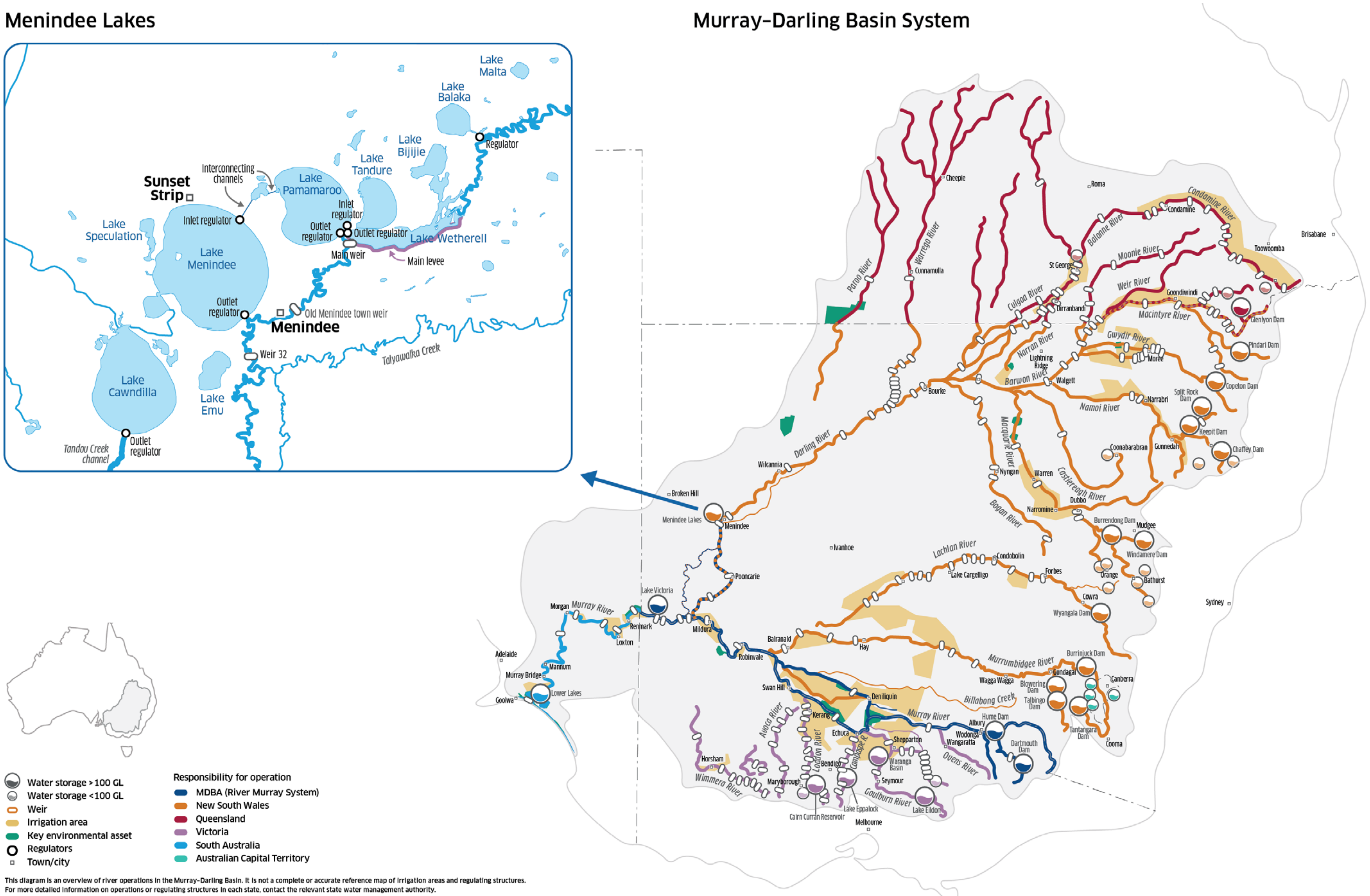


Figure 3-3: The Murray–Darling Basin and the Menindee Lakes.

3.2 State water management arrangements

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. We note that the policy remains interim and has not been implemented consistently over the last 27 years.

Arrangements for sharing of water in the Barwon–Darling are set out in the state Water Sharing Plan (WSP) for the Barwon–Darling. Within the WSP, extraction of unregulated flows is granted under water access licence arrangements. These licenses are classified into several classes (A, B and C), each of which specifies the minimum flow (at a specified gauge) above which water can be extracted by each licence class, with A Class licences being the lowest. The current Barwon–Darling WSP was developed by NSW in 2012, and commenced a month prior to the *Basin Plan 2012* (Cth) (Basin Plan) coming into effect. Table 3-1 outlines the commence to pump rules for different licence classes in the Bourke to Louth Management zone, and provides an ecological context to the different levels of flow being accessed by each licence class.

Flow class	Flow (ML/day)	Ecological relevance (flows are ML/day at Bourke Town gauge)
No Flow Class	0ML/day at Bourke Town gauge or 0ML/day at Louth gauge	
Low Flow Class	1. More than 0ML/day at Bourke Town gauge and more than 0ML/day at Louth gauge, and 2. Less than or equal to 350ML/day at Bourke Town gauge or less than or equal to 26ML/day at Louth gauge	Flow below 390ML/day at Bourke are termed "Riparian Flows" they are the minimum flows required for reaches to remain connected (Interim Northwest Unregulated Flow Plan, 1992)
A Class	1. More than 350ML/day at Bourke Town gauge and more than 260ML/day at Louth gauge, and 2. Less than or equal to 1,250ML/day at Bourke Town gauge or 1,130ML/day at Louth gauge	Small flow pulses – (~500ML/day), critical discharge required to suppress persistent stratification and algal growth in the Barwon–Darling River (from Mitrovic et al. 2010). Flows that enhance spawning in low-flow spawning specialist fish, such as olive perchlet (endangered) and other small bodied fish (see Humphries and Walker 2013)
B Class	1. More than 1,250ML/day at Bourke Town gauge and more than 1,130ML/day at Louth gauge, and 2. Less than or equal to 11,150ML/day at Louth gauge	Moderate in-channel flow pulses (~2000ML/day) and large in-channel flow pulses (~9,000ML/day) important for within-channel connectivity, fish and invertebrate dispersal, nutrient transfer and water quality mediation.
C Class	1. More than 1,250ML/day at Bourke Town gauge and 2. more than 11,150ML/day at Louth gauge	

Table 3-1: Flow class pumping rules in the Bourke to Louth Management Zone. The flow reference points are Darling River at Bourke Town gauge (425003) and Darling River at Louth gauge (425004) (from Carlile, 2017) and the ecological relevance of each flow band (Sheldon, 2017).

The 2012 WSP provided a number of provisions relative to previous water sharing arrangements. First, it allows for users to adjust their licenses through concessional conversions so that active users can re-instate their history of use to that which existed prior to the issuing of Cap license shares to all users. Each licence eligible for a

concessional conversion is subject to a concessional conversion limit, which is equal to the benchmarked history of extraction in a particular licence class (1995–2005). Conversions occur within the existing pool of Cap shares available and do not result in new shares being created. This was done to ensure that growth in usage above Cap levels cannot occur. The plan also removed a previous restriction on A Class licences that limited the maximum pump intake size to 150 mm, and provided opportunity for extraction of up to 300% of access entitlements.

Concessional conversions, removal of the A Class pump intake size restriction, and the relaxed carryover restrictions have been controversial because the net effect has been to allow extraction of water more often and at lower flow thresholds (Figure 3-4). Modelling by DOI Water found that increasing the rate of pumping for A Class users did not alter diversions by any material amount for small-scale water users, and increased diversions by 66ML/Yr for all A Class users.

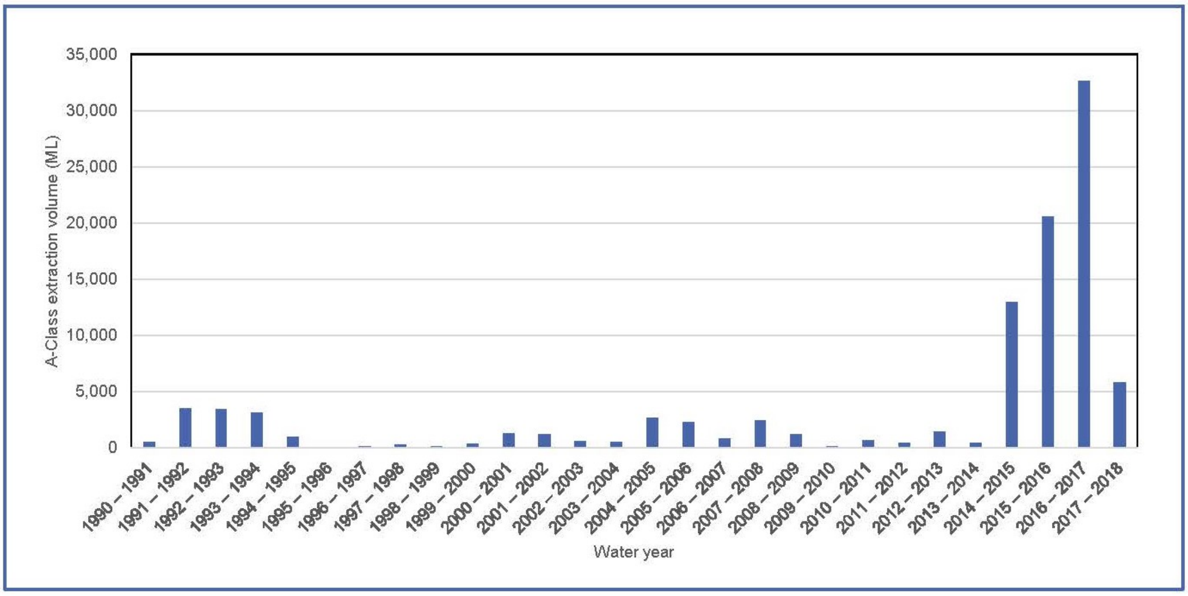


Figure 3-4: Annual volumes of A Class license water extractions in the Barwon–Darling over the last 28 years (MDBA, using data from NSW DPI and NSW Water Register).

There were no material changes to B and C Class take. The analysis also concluded that the increased rate of A Class take allows extraction earlier in the year, and in the right circumstances, can cause the tops and early parts of small flow events to be removed in the base flow and small fresh flow classes. In summary, the analysis indicated that the small volume of A Class shares limits the scale of changes to events and thus flow volumes that can occur. In addition, event reductions early in the season were often offset by gains in later flow events. Whilst the model analysis is likely to correctly predict the long-term impacts, it does not reflect the recent behavioural changes associated with users having greater access to A Class. Recorded usage data prior and after 2012 suggests an increase extraction after 2012, and that under the right climatic circumstances, large amounts of accrued carry over opportunity will result in runs of years where extractions are large followed by longer periods where no A Class extraction occurs. A true indication of the impact of A Class extractions on the low flow regime of the Barwon–Darling can only be gained once the river system model has been updated to reflect contemporary water user behaviour.

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 Commonwealth 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 New South Wales 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 with the Barwon–Darling, further work is required to develop management arrangements that facilitate improved connectivity between the Barwon–Darling above Menindee Lakes with the downstream lower Darling River.

In Queensland, state Water Plans (previously known as Water Resource Plans) have provided for connectivity along tributary systems through achieving end-of-system flow regimes that meet specific environmental flow objectives. Historically, both Water Plan and Resource Operation Plan development have not targeted environmental values in the Barwon–Darling, but have rather focussed on end-of-system values for the various sub-catchments. For example, the current Condamine–Balonne Water Plan has end-of-system values relating to the Narran Lakes complex and the national parks of the Culgoa floodplain and also to contribute to maintaining or improving the ecological condition of the Darling River upstream of Bourke. However, there is no recognition of the impact of flows from this system on the Darling River below Bourke. Likewise, plans for the Warrego, Paroo, Bulloo and Nebine make no comment on flows from this tributary system being required for ecological benefit in the Darling River system, the Border Rivers plan provides no spatial boundaries to ecological outcomes and could be seen as linking through to the Barwon–Darling system. In the future, under the Basin Plan water resource plans, management and protection of connectivity events originating from Queensland tributaries will require the quantification of any held environmental volumes that enter NSW.

From mid-2019, future water management arrangements across 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. NSW and Queensland 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, and when completed will need to submit those plans for accreditation to the Australian Government Minister of Agriculture and Water Resources. The MDBA advises the Minister whether the water resource plans meet the requirements of the Basin Plan.

3.3 The Menindee Lakes

The following draws primarily on the lower Darling Reach Report for the Constraints Management Strategy (MDBA, 2015).

The Menindee Lakes system is comprised of seven natural lakes that have been artificially 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 (Figure 3-3). 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 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 and 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, acting as an agent of the States, to access water in the lakes to support downstream demand in the Murray River. Under the Agreement, the MDBA can access water in the lakes when they rise above 640 gigalitres (GL), and until the lakes drop below 480GL — known as the '640/480 rule'.

The total storage volume of Menindee Lakes at full supply level is 1,731GL, with an ability to surcharge the lakes after seasonal inflows to a volume of 2,050GL. 125GL of the water held in lakes is inaccessible below a certain storage volume, referred to as dead storage. Being shallow relative to their surface area, the Menindee Lakes experience large losses from evaporation, especially when full. Potential evaporation in the area is approximately 2.5 m/year, translating to volume losses of 426GL/year on average, but as much as 980GL/year when the system is full. As a consequence, the lakes operating procedures place a strong emphasis on minimising evaporation by making releases ahead of releases from storages in the Murray system, which have much lower rates of evaporation (for instance, net evaporative losses are near zero in the case of Dartmouth Dam).

Operation of the Menindee Lakes scheme mainly consists of movement of water between the interconnected lakes, and supply of water to meet downstream demands whilst minimising evaporative losses. The current preferred lake filling strategy is to:

1. Fill Lake Wetherell to 59.8 m AHD.
2. Fill Lake Pamamaroo to full supply level (60.45 m) (filling Lakes Pamamaroo and Wetherell simultaneously above 59.8 m).
3. Fill Lake Menindee/Cawndilla to full supply level (59.84 m).
4. Fill Lake Wetherell to full supply level (61.67 m).
5. Surcharge Lake Pamamaroo (61.5 m) and Lake Wetherell (62.3 m), and then Lakes Menindee and Cawndilla (60.45 m).

In most instances, the procedures for releasing water from the lakes are generally the reverse of this, with all immediate consumptive demands being firstly met from Lake Menindee and Lake Cawndilla and Lake Wetherell above 59.8 m. While water conservation and operational efficiency are the main objectives, the MDBA and NSW also give consideration to NSW water supply obligations (Broken Hill and lower Darling entitlements), protecting the structural integrity of the lakes, managing water quality issues and the 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 also, to supply water to Broken Hill via a pipeline. Recent concerns over the ability of the Darling River to sustain the Broken Hill water supply led to the development of a new pipeline scheme capable of delivering up to 35ML per day to Broken Hill from the Murray River at Wentworth. The panel has been advised that the new pipeline is now operational and, when in full service from mid-2019, will significantly reduce the call of water on the Menindee Lakes.

3.4 The lower Darling River

The following draws primarily on the lower Darling Reach Report for the Constraints Management Strategy (MDBA, 2015).

The lower Darling is the section of the Darling River between Menindee Lakes and the confluence of the Darling with the Murray River 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 River downstream of Wentworth.

The lower Darling is one of the lowest rainfall regions in NSW with annual average rainfall between 220 and 280 mm across the catchment (Green et al., 2012). The region has very high evaporation rates, from 2 mm a day in winter to up to 20 mm per day in summer (Green et al., 2012). Most of the water that flows into 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, as a result of abstractions in the Barwon–Darling and its tributaries and more recently also reflecting natural droughts. As far back as 2002 it was estimated that the mean annual flow in the Darling River had been reduced by more than 40% as a result of upstream abstractions (Gippel and Blackham, 2002). The timing of flows had fundamentally changed, with the largest volumes of water in the tributaries flowing in summer to meet consumptive demand, rather than autumn or spring as was the case prior to development. Winter flows were now less variable, with flows staying in the 200–500ML/day 65% of the time (Thoms et al., 2000). Bankfull flows were deemed to be less frequent and mid-range peaks were halved. Flows above 15,000ML/day occurred in only 30% of years, compared to 60% before regulation (Gippel and 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 and Sheldon, 1997).

Hydrologic changes have reduced the health of fish populations, with an observed reduction in the number of native species and an increase in abundance of alien fish species such as carp (*Cyprinus carpio*) (Gilligan, 2009). However, more recently, locals have observed marked improvements in recreational native fish populations in the lower Darling. Fish movement and migration has also 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).

3.5 Broad scale ecological impacts of climate, hydrology and management on the Barwon–Darling River

Below, we provide a summary of why flows are important to rivers and how reductions in low and medium flows can have adverse ecological outcomes.

3.5.1 The importance of flows

Flow pulses have an over-riding influence on both physical structure and ecological responses of all rivers and streams (Poff and Ward 1989; Bunn and Arthington, 2002). Flow pulses, of varying magnitudes, are important for maintaining ecological processes such as nutrient cycling, breeding and spawning responses, and dispersal (Leigh et al. 2010). They are also important for connectivity along river channels (Poff et al. 1997). For every flow pulse, regardless of magnitude, the preceding 'flow history', or antecedent conditions, is also important. As is the timing, which can be essential to trigger seasonal responses like reproduction or dispersal. Flow pulses occurring after extended periods of no flow will elicit a different biotic response to those occurring after a series of similar pulses (Leigh et al. 2010) (Figure 3-5).

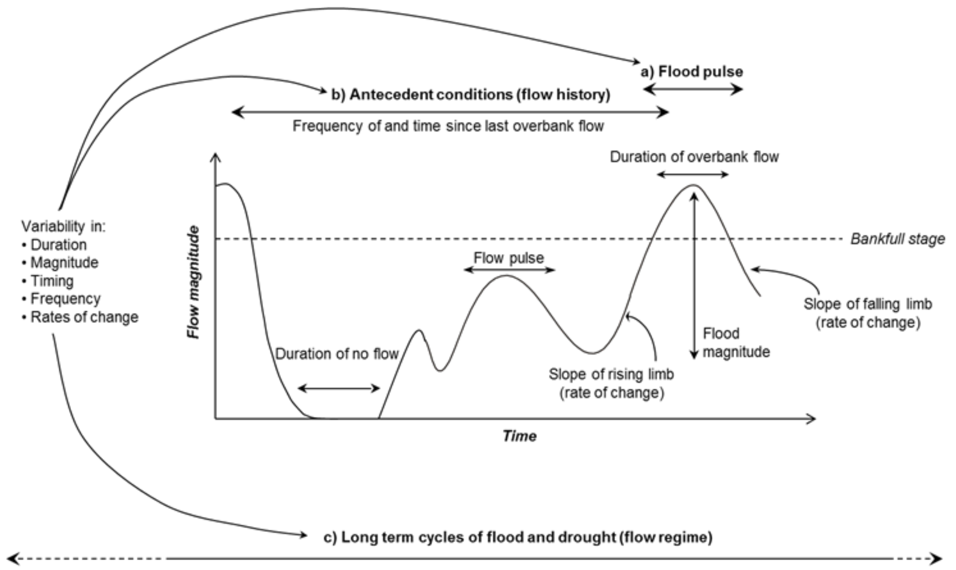


Figure 3-5: Various features of the (a) flood pulse, (b) flow history and (c) flow regime that have ecological significance. (Leigh et al. (2010), modified from Walker et al. (1995)).

All types of flow in rivers are ecologically important. The least frequent large flow pulses and overbank floods (>10-year return interval) (Figure 3-6) are important for reconnecting the river with its floodplain – which is important for sediment and nutrient transfer. Overbank flows provide water to floodplain wetlands and waterbodies, soil moisture to floodplain vegetation - which can act as a germination and recruitment trigger, and opportunities for landscape scale dispersal of aquatic biota. Inundated floodplain habitats are often focal breeding sites for waterbirds and other terrestrial animals. Less-frequent moderate flow pulses, or in-channel flow pulses (eg. 2-5 year interval) (Figure 3-6) are important for reconnecting river reaches and moderating water quality in previously disconnected reaches or weir pools, providing opportunities for spawning and recruitment of fish. The increased turbidity and water movement associated with in-channel flows can reduce the concentrations of nuisance algae (green and cyanobacteria) in the water column. These in-channel pulses are also important for increasing habitat availability – also required for spawning and recruitment of fish and invertebrates when they occur at the right time of year. NSW DPI (2015) showed the increase in availability of snag habitat and in-channel bench surfaces associated with in-channel flow pulses of different magnitudes. The relatively frequent small flow pulses (e.g. 1-year return) (Figure 3-6) are important for maintaining connectivity along river channels and refreshing aspects of water quality in pools and isolated reaches (Poff et al. 1997). These events are often overlooked as being important in river systems, however, they play a vital part in the overall hydrological variability of the river. Low flows control the extent of physical aquatic habitat and thereby influence the composition and diversity of biota, trophic structure, and carrying capacity. They mediate changes in habitat conditions, which in turn, drive patterns in the distribution and recruitment of biota, they affect the sources and exchange of energy in riverine ecosystems, thereby affecting

ecosystem production and biotic composition, and restrict connectivity and diversity of habitat, increases the importance of refugia, and drives multiscale patterns in biotic diversity (Rolls et al. 2010).

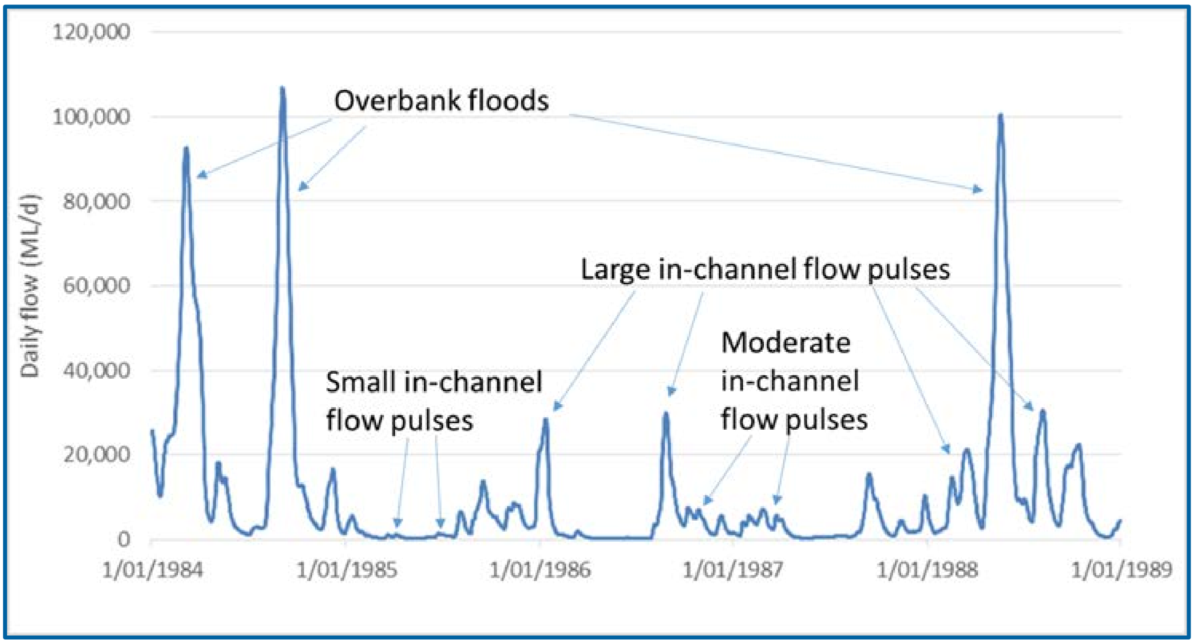


Figure 3-6: Daily flows (ML/day) for the Darling River at Bourke over a five-year period between 1984 and 1989 modelled without development conditions, highlighting ecologically relevant flows (MDBA, 2016).

3.5.2 The significance of increasing the frequency and duration of no-flow periods

In dryland rivers, such as the Barwon–Darling, where there can be extended periods of no, or very little, flow, refugial reaches are vital aquatic habitat for the survival of both aquatic and terrestrial fauna (Sheldon et al. 2010). During periods of extended low flow, water quality in any remaining aquatic habitat can be a significant issue for resident biota. Given the hydrological variability of the Barwon–Darling and associated tributaries and the variable lengths of time between large flow pulses and floods (even under natural flow conditions), these remnant aquatic pools and reaches within the river channel network are critical for the maintenance of healthy populations of many aquatic organisms (Sheldon et al. 2012). Extended periods of no flow are therefore detrimental to the long term viability of native fish and invertebrate populations through (i) the impacts of declining water quality which can directly cause mortality to adults, juveniles or eggs, (ii) reduced availability of habitat for spawning and recruitment and, (iii) in many cases, the absence of triggers for spawning and recruitment. While the impacts of low flows on fish have been well documented, relatively little is known about their impacts on invertebrates and especially the larger invertebrates such as the iconic river mussels. We do know, however, that river mussels are susceptible to anoxia and poor water quality (Sheldon and Walker 1989), so any declines in water quality from extended periods of no flow that resulted in low oxygen levels for extended durations along the bed of the river could have extremely negative consequences for the viability of freshwater mussel populations. Extended periods without flow also increase the extent of habitat fragmentation and population isolation, isolated populations of organisms are more vulnerable to disturbance events which can cause localised extinctions. Extended low flow periods in the Darling River also run significant risk of drying. Presently, the majority of the river between Bourke and Menindee is characterised by a dry river bed. The only remnant water is located in weir pools and much of that is poor quality.

3.5.3 A landscape perspective of flow in the Barwon–Darling River

While it is tempting to think of flow in the Barwon–Darling in isolation of its tributaries, the tributaries play a very important role in providing in-channel flows along the Barwon–Darling between Bourke and Menindee. Flow variability in the Barwon–Darling is complicated and needs to be considered at a landscape scale. While small in-channel flow pulses are often delivered to the Barwon–Darling reach by flows from tributaries with direct connections to the channel (no terminal wetlands), the capacity for low flows to build to larger flow events depends on landscape scale hydrological factors. Leigh et al (2010) showed how the floodplain wetlands at the terminus of

some of the tributary rivers to the Barwon–Darling were important components of the hydrological landscape. Prior to any water abstraction or diversion, these wetlands would have acted as ‘sponges’ or ‘buckets’ absorbing smaller pulses along the tributary rivers and then ‘spilling’ into the main channel of the Barwon–Darling when full. Water abstraction and diversion for irrigation has changed the way in which most of these terminal wetlands function hydrologically at the landscape scale, with only the western Paroo and Warrego floodplains remaining relatively hydrologically intact. Fewer flow pulses make their way through the eastern and northern wetlands and into the main channel of the Barwon–Darling, which impacts on the overall flow variability of the Barwon–Darling system.

4 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.

4.1 Panel visit to Menindee

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 encountered an engaged, well-informed, but distressed community. They were grieving about the absence of reliable access to clean water and 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 (the *Barka*) is at the heart of their culture and profoundly spiritual. Barkandji country extends from the Murray River in the south to southern Queensland in the north and much of the largely arid area of western NSW (Hartwig et al. 2018). The *Barka* is home to *Ngatji*, the rainbow serpent), who created the lands and rivers, and it is the Barkandji who are responsible for *Ngatji's* health and wellbeing (Hartwig et al. 2018). At the community meeting in Menindee, the Traditional Owners of the river told the panel of the importance of the Barka 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 the river during 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 will not survive the changing water regimes. 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, underpins cultural practices and ensures that highly valued relationships with the river 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 they've 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, especially the role that floodplain harvesting may be playing, 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.

4.2 Broader Indigenous context

In 2015, the native title rights and interests of the Barkandji to a portion of the lands and waters originally claimed in 1997 were recognised by Australian law. Since that time, the Barkandji have been understandably extremely passionate advocates for action to rectify the noticeable decline in water availability and quality in the Barka (Hartwig, et al. 2018).

The native title rights of Barkandji Traditional Owners include to take and use water for domestic, social and cultural purposes. Activities such as ceremonies, the preparation of food or bush medicines, the manufacture of artefacts, and the teaching of traditional laws and customs as well as practices such as fishing are now protected by the Native Title Act (1993). Native title rights to take and use water do not allow commercial water use, nor confer exclusive ownership of water.

Since the Native Title Act was passed, national water policy (the NWI) has set a standard for improving Indigenous engagement in water planning and access to water, requiring that State governments:

- include Indigenous representation in water planning, wherever possible;
- incorporate Indigenous social, spiritual and customary objectives and strategies for achieving these objectives, wherever they can be developed;
- take account of the possible existence of native title rights to water in the catchment or aquifer area;
- potentially allocate water to native title holders; and
- account for any water allocated to native title holders for traditional cultural purposes (Hartwig et al. 2018).

Research from this region has identified a gap in how native title decisions are reflected in water plans and the ways in which Aboriginal people are involved in water management (Hartwig et al. 2018). Unfortunately, the

relevant Water Sharing Plans have not allocated water to the Barkandji, despite the native title determination (Hartwig et al. 2018). While there are requirements under the Basin Plan for water managers to consult with Indigenous communities when they prepare water resource plans (they must describe Indigenous water uses, and have regard to Indigenous objectives for water), there are no mandatory requirements for stronger participation in water management.

With the current lack of water remaining in the entire Darling below Bourke, the Barkandji have suffered significant cultural loss which adds to the longer history of environmental degradation and their exclusion from state systems of water management.

5 Terms of reference 1 – Likely causes of the fish deaths

We have identified the likely causes of the 2018-19 fish deaths by examining the water management decisions and environmental conditions associated with the events. We have examined the conditions at the time of the fish deaths (2018-2019), as well as the antecedent conditions in the years immediately prior to the fish deaths (2010-2017). We have also considered the longer term hydrologic, climatic and river management context that has influenced these events (Figure 5-1).

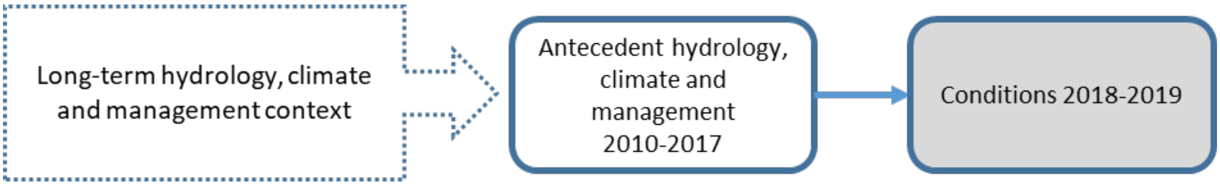


Figure 5-1: Time periods important for understanding the conditions contributing to the fish deaths.

5.1 About fish death events

Fish death events may be defined as any sudden and unexpected mass mortality of wild or cultured fish (Lugg, 2000). They are often very visible events and generate a significant amount of public interest and concern, 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). Events can be isolated, or widespread and transient where the causal factor and number of fish affected is often difficult to determine.

The causes 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, and Mitchell, 2011). For over half of the reported fish death events, the causal factors are unable to be determined thus future events are often difficult to predict.

Significant recent global events include an event in Lake Madeline, Texas, USA where an algae bloom and hypoxia induced the death of over 10,000 Gulf menhaden (*Brevoortia patronus*). Upwelling of hypoxic water was the primary cause of more than 14 mortality events involving over 200,000 fish (Marti-Cardona, Steissberg, Schladow, and Hook, 2008). Extreme changes in weather conditions have caused fish death events mainly due to cold temperatures. Marsh et al. (1999) described a massive fish death event involving more than 1,000 million tilefish (*Lopholatilus chamaeleonticeps*) and deep-sea robin (*Peristedion miniatum*). Wells, Wells, and Gray (1961) also recorded more than 2 billion dead Round herring (*Etrumeus sadina*) and Chub mackerel (*Pneumatophorus colias*) in response to a decline in water temperature at Pamlico Sound, USA. Human development of aquatic systems has increased the global trend of fish deaths (Fey et al., 2015). Scientific efforts to report and understand fish deaths has, in recent times, been extensive (La and Cooke, 2011). But, as river development and irrigation modernisation programs accelerate, fish deaths will become more common.

Fish death events are not unusual and events requiring emergency responses have occurred in New South Wales (NSW) intermittently over the past 100 years. Changes in river hydrology, disease outbreaks, and structural works programs have required various agencies to adaptively-manage situations where fish have become stressed. Actions to rectify these situations usually occur after the event has occurred and only recently has management sought to introduce protocols to deal with some emergency responses in a co-ordinated manner. Since the mid-1980's, approximately 20-50 fish death incidents have been reported to the NSW government on an annual basis (Lugg, 2006). The frequency of these events, and the high public profile, often require some type of management response to ascertain the cause and extent of individual incidences. Unfortunately, for over half of the reported fish deaths, the causal factors are unable to be determined.

Fish deaths are reported in all basin states and are unfortunately a regular observation in modified landscapes. Fisheries NSW have recorded over 1,600 incidents since the 1980's (Lugg, 2006). Fish death events, of various sizes, have previously been reported across NSW, including in the lower Darling River, with a significant fish death event occurring in 2004 (Ellis and Meredith, 2004). Figure 5-2 provides a summary of fish death events in the NSW section of the Murray–Darling Basin, indicating the large number of events that have occurred, as well as their

scale (AAS, 2019). As can be seen, the recent events in the lower Darling are amongst the most serious experienced on record, but not unprecedented. In other parts of the Basin, the Victorian government has previously responded to deaths in the Goulburn River, Campaspe River, Broken Creek and Ovens River (Ellis and Meredith, 2004). More recently, on the Darling River deaths were recorded from Bourke (in 2011) and Tilpa (in 2012) (Fisheries NSW, unpublished data). These events affected between tens and thousands of fish and were caused by a range of factors including hypoxia, toxins, flooding and high temperatures.

To cope with the increasing number of fish death reports, NSW DPI have implemented a reporting system, commissioned a hotline, and established a state-wide database to provide a central registry for all information collected on specific events. NSW DPI Fisheries Compliance Officers were also made available to collect information on events to present to the relevant authorities. The establishment of this system has enabled swift management responses to events that have already taken place, but those responses have limited impact. For instance, in February 2004, an extensive Murray Cod mortality event occurred on the lower Darling River between Menindee and Pooncarie. Mortality occurred for over 160 river km. Anecdotal accounts of dead fish ranged from 2 to 30 carcasses per kilometre, resulting in an estimated 3,000 Murray Cod deaths overall. Investigations into the cause of this fish death event did not take place until reports had been received and assessed by the relevant government authorities (Ellis and Meredith, 2004). Little could be done to reverse the situation because, as with most fish deaths, the causal factors were only determined well after the event.

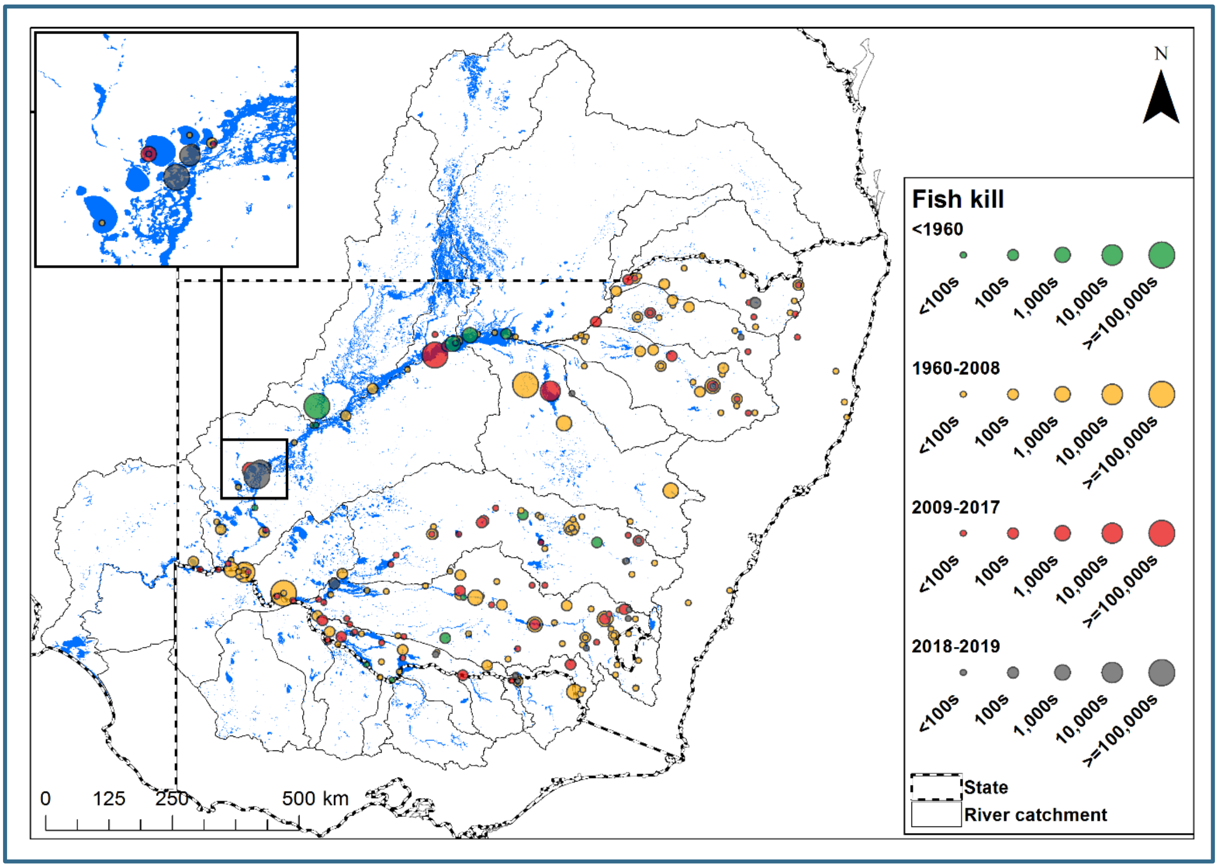


Figure 5-2: Fish deaths recorded for the NSW part of the Murray–Darling Basin over time and in each river, from various causes, sorted by periods including before water resource development (1960), 1960–2008 (main period of water resource development) and 2009–2017 (water recovery period). (Australian Academy of Science, 2019).

5.2 The sequence of events that caused the fish deaths

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, but also the antecedent conditions in the Menindee Lakes leading up to the fish deaths, particularly the period 2010-2017 (Figure 5-3).

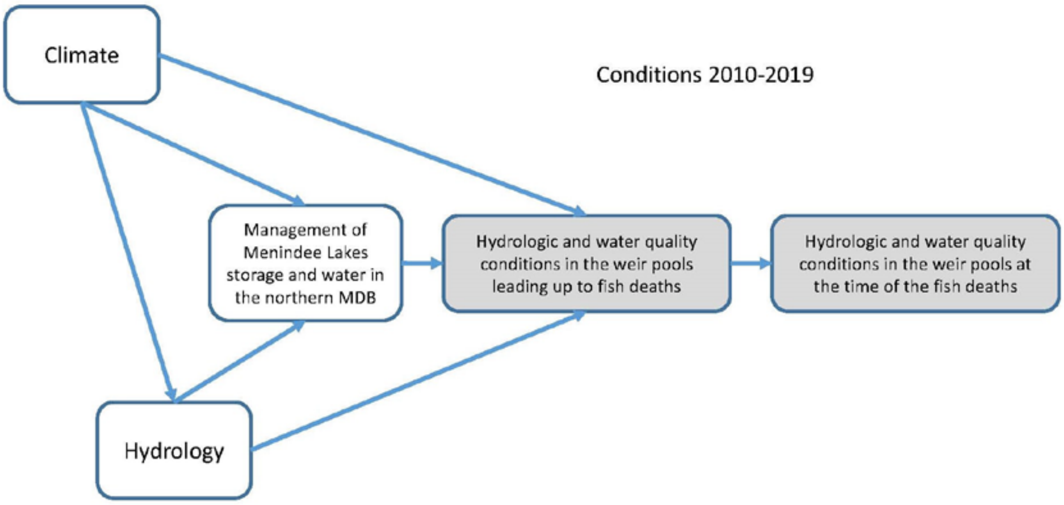


Figure 5-3: Summary of factors leading to fish deaths in the lower Darling; proximate causes are highlighted in the shaded boxes. Ultimate influencing factors are summarised in the open boxes.

5.2.1 Conditions during 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 5-4).

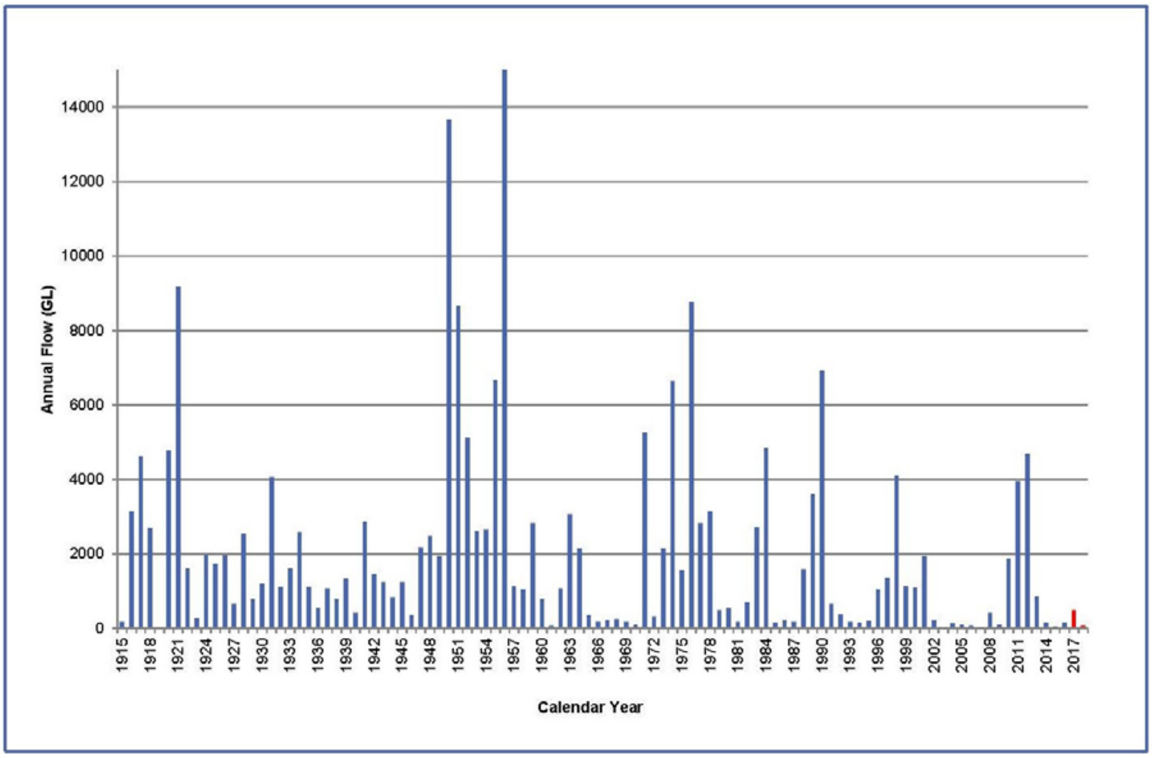
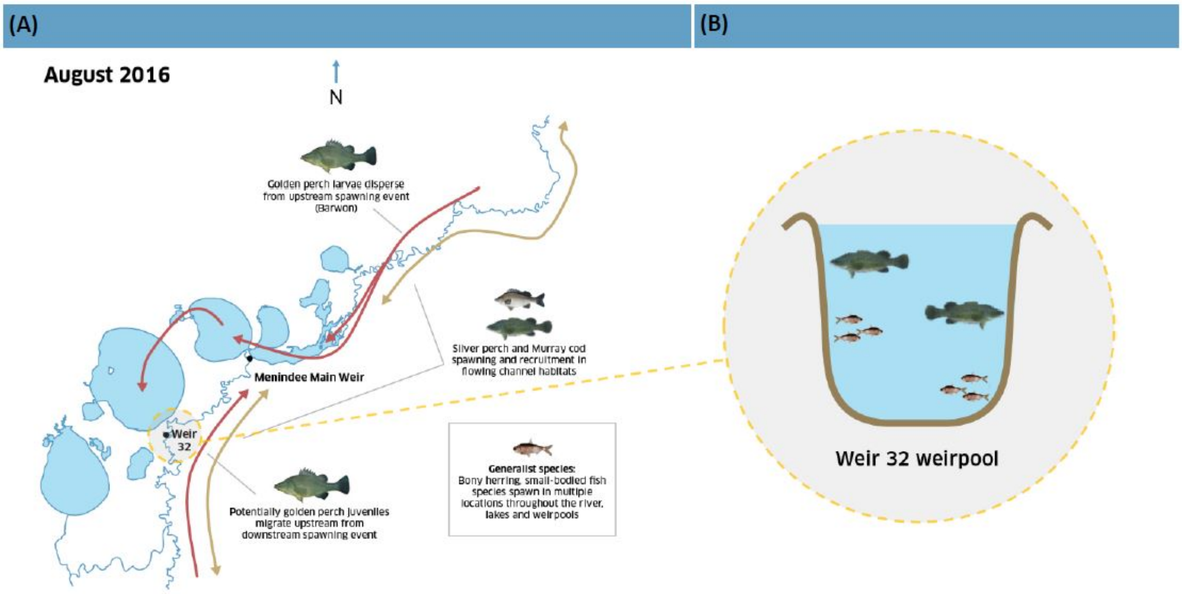


Figure 5-4: Long-term sequence of annual streamflow at Menindee town gauge and Weir 32 (combined). The red bars indicate flows since Menindee Lakes last filled. (Data sourced from WaterNSW)

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 some 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 5-5).



(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.

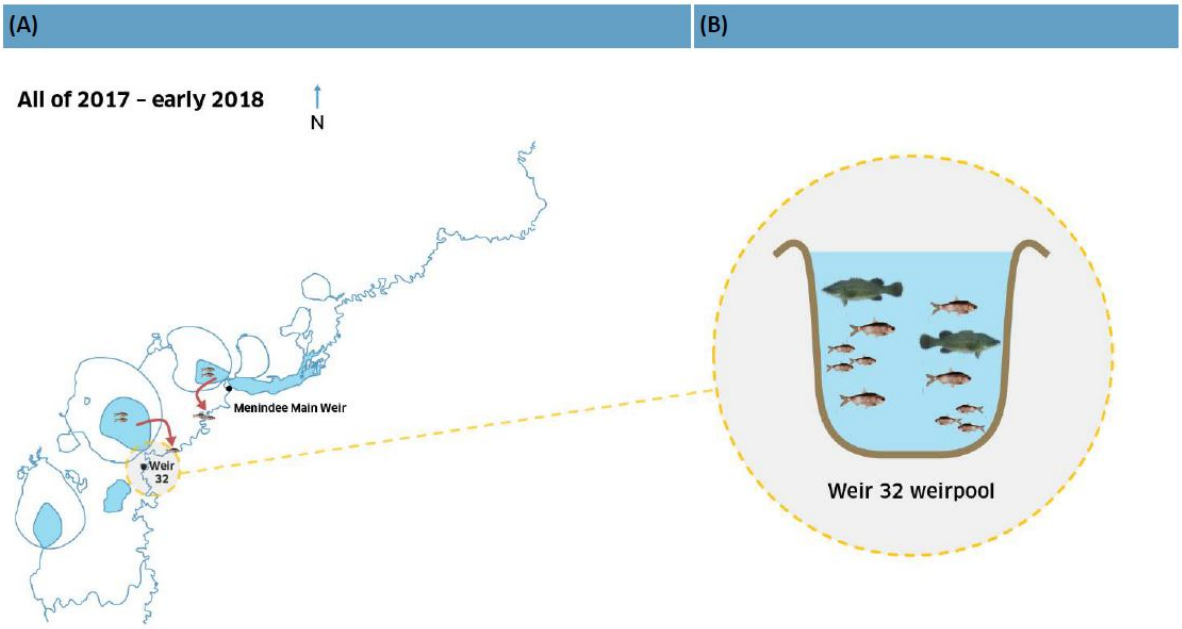
When full, the Menindee Lakes provides a vast nursery area for fish, increasing recruitment of a range of species.

(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 5-5: Conceptual model of the situation in 2016 leading up to the 2018-19 fish death events; (a) a landscape scale conceptual diagram of the Menindee Lakes and (b) a conceptual diagram of conditions within the Weir 32 weir-pool.

5.2.2 Conditions during 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 Murray River. 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 5-6).



(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.

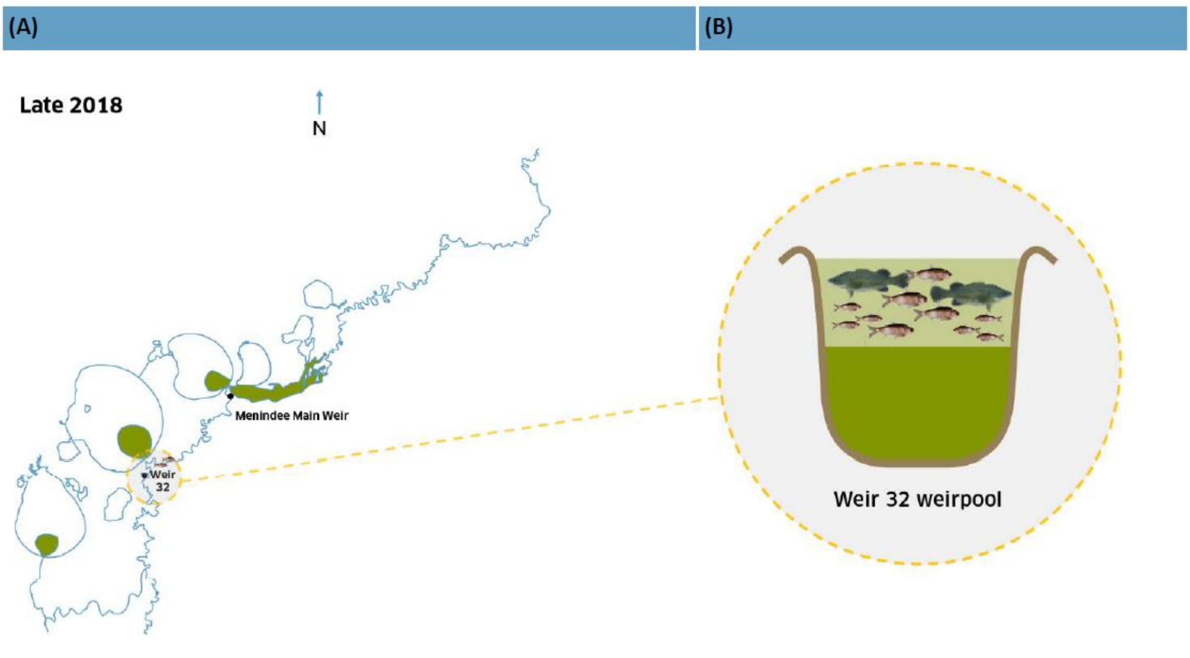
(B) Biomass of fish and algae in the weir pools will be high, as available habitat is restricted and fish are prevented from moving further downstream by the weir structures.

Figure 5-6: Conceptual model of the situation during 2017 leading up to the 2018-19 fish death events; (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.

5.2.3 Conditions during late 2018 and early 2019

Low flows dominated in the Darling River at Weir 32 from July 2018 onwards. Flows increased from approximately 150ML/d in July 2018 to between 200 and 250ML/d from August 2018 to November 2018. At these flow levels in previous years, persistent thermal stratification has been known to form from 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 23 October 2018. By the next sampling on 24 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 circinale,* previously called *Anabaena circinalis,* which is a known producer of saxitoxin, a potent neurotoxin. This is consistent with previous research which has identified that blooms of *Dolichospermum* spp. occur in this weir pool during low flow conditions (<300ML/d) which allows the formation of persistent thermal stratification during the warmer parts of the year, such as the beginning of October to the end of March (Mitrovic et al., 2011). This persistent thermal stratification gives this species an ecological advantage; the ability to use buoyancy to move towards the surface under reduced mixing conditions (Mitrovic et al., 2001) and this is why algal 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 5-7). 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 5-7: Conceptual model of the situation during late 2018 and early 2019 leading up to the 2018-19 fish death events; (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.

On 4 December *Dolichospermum* spp. counts had decreased in the water column. This was after a brief period of increased flows of 300-350ML/d between 29 November 2018 and 7 December 2018. Algal samples collected on 12 December, just prior to the fish death event, showed a mixed community with *Dolichospermum* sp. again increasing to 20,000 cells/mL but other cyanobacteria having similar or higher biomass. Total algal biovolume was very high at 27.3 mm^3/L and of this 14.5 mm^3/L was cyanobacterial with 9.5 mm^3/L potentially toxic species. This was the third highest total algal biovolume recorded between July 2018 and February 2019. These conditions occurred just prior to a cool change in the weather, which started on 13 December 2018 and likely triggered the fish death event upstream of the Menindee Town Weir. River flows after the first fish death event and through January were between approximately 50 and 300ML/d and algal biomass was high with with toxic cyanobacterial biovolume between 3 and 10 mm^3/L and total algal biovolume between 9 and 27 mm^3/L.

5.2.4 Conditions causing the fish death events

Surface waters are oxygenated through contact with the air and, during the day, through the photosynthesis of resident algae and aquatic plants. 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 (zone of rapid change in temperature between the two layers) separates the two layers and surface water diffusion into the bottom layer is reduced. This can be seen in Figure 5-8, where the surface waters (>1m depth) are saturated with oxygen (>100%), there is then a rapid decline in oxygen concentration across the thermocline (1-1.5 m depth) then the bottom waters (<1.5 m depth) have below 50% saturation of oxygen, with very low levels near the bottom of the river.

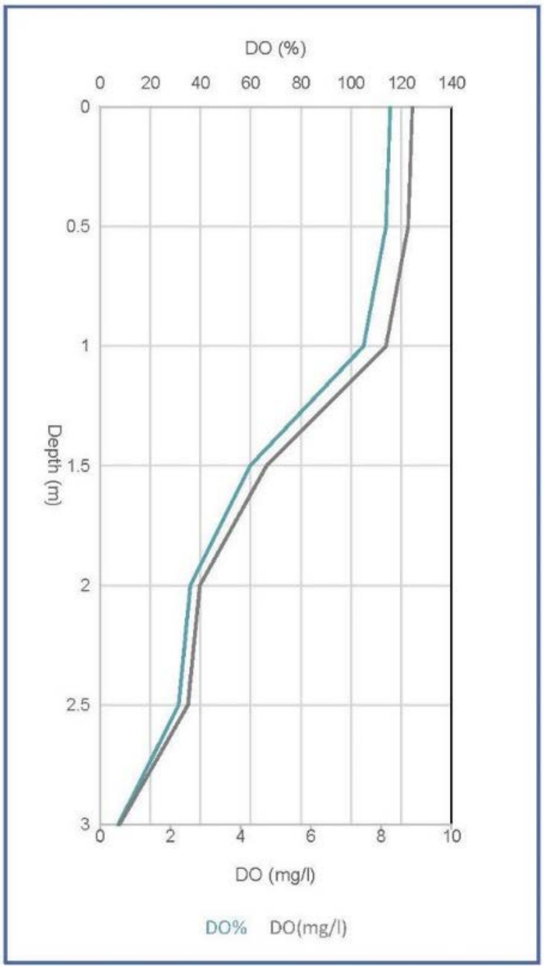


Figure 5-8: Typical oxygen profile for Weir 32 under stratified conditions (Data sourced from WaterNSW).

While stratification persists the two layers effectively operate independently; especially when there is no mixing flow through the weir pool. Respiration of organic matter in the bottom waters is exacerbated by high water

temperatures, as organic matter loads on the bottom of rivers are usually high, this creates a high biological oxygen demand, which uses up any remaining oxygen in the water column and can persist even when there is no measureable oxygen in the water column.

Under persistent thermal stratification in rivers the bottom water oxygen level drops with time, and within a matter of days to weeks oxygen levels can become very low (<2 mg/L) and decline to critical levels. This has been observed previously in the lower Darling River (Meredith and Ellis, 2004). Figure 5-9 shows a typical surface oxygen profile for the lower Darling River. The period of time that persistent thermal stratification occurs will influence the amount of oxygen in bottom waters.

The extreme high temperatures in December 2018 and January 2019 may have led to the development of stronger thermal stratification than in previous years. Analysis of data by the BoM for the lower Darling region found maximum temperatures in 2018 were the second hottest on record, with the anomaly of +1.77ºC being just behind the record +1.80ºC anomaly observed in 2013. Minimum temperatures in 2018 were the 4th hottest on record and 1.18ºC above the long-term average. Thermal stratification was also likely stronger due to the high algal biomass and increasing absorption of solar energy. The algal bloom may have also resulted in increased biological matter (dead algal cells) dropping into the hypolimnion and using up oxygen as they decomposed.

The algal bloom in the river at the time may have also influenced oxygen levels. Algae photosynthesise during the daylight hours and through this process produce oxygen in the water. As photosynthesis does not occur at night to counteract respiratory losses of oxygen, reduced oxygen levels are seen in the water column at night. 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 algal blooms diurnal variations can be very high, leading to large fluctuations in oxygen levels. The fluctuations as well as the low levels at night can cause physiological stress to all resident biota, including fish; for example a logger placed at the Burtundy gauging station downstream of Menindee clearly shows these strong diurnal fluctuations in oxygen during December 2018 (Figure 5-9).

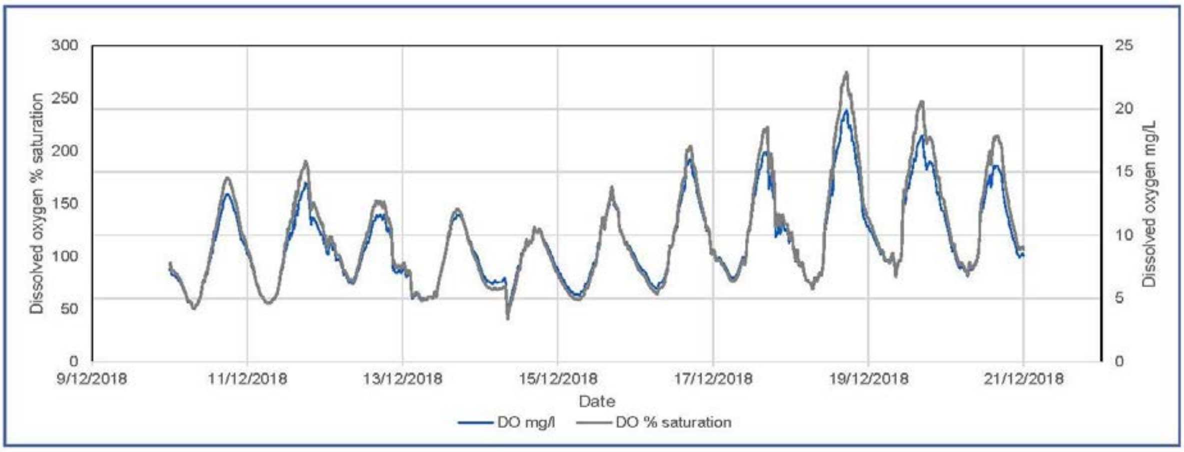


Figure 5-9: Changes in dissolved oxygen concentrations and percentage saturation in surface waters in the Darling River at Burtundy gauging site around the time of the first fish death event in Weir 32. This is a surface water plot only and therefore does not provide information on stratification (Data sourced from WaterNSW realtime data).

The factor that ultimately gave rise to the fatal deoxygenation events that killed the fish was the turnover of the water column. This mixed the deep hypoxic waters with the shallow oxygenated layers where the large biomass of stressed fish was concentrated. The trigger for this was a series of cool weather changes, which can be seen to coincide with the timing of all three fish death events (Figure 5-10). These events effectively mixed the hypoxic bottom water with the surface water, within which the fish were taking refuge.

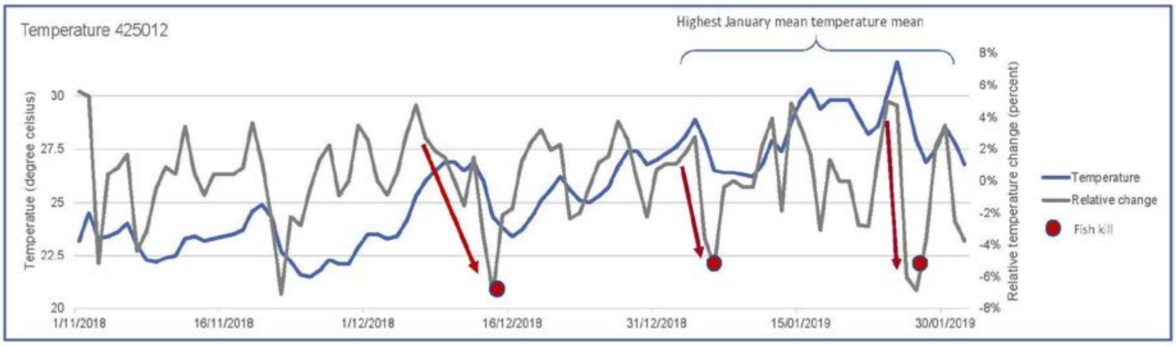


Figure 5-10: Changes in mean daily water temperature recorded at the Darling River U/S Weir 32 gauging station (station number 425012) over the period November 2018 to February 2019. Red dots indicate timing of fish death events, which coincide with sharp drops in mean water temperature as shown by relative change per day (Bureau of Meteorology).

A cool change occurred on 13 December 2018. The daily maximum air temperature at Menindee Post Office was 39.0ºC on 12 December, 24.5ºC on 13 December and 19.3ºC on 14 December. Water temperature, as measured at approximately 60 cm depth, decreased from 27.5ºC on 12 December 2018 to 23.1ºC on 16 December 2018 (Figure 5-11). Increased winds and rain accompanied the cool change. The Broken Hill Airport Automatic Weather Station (AWS), located about 100km WNW of Menindee, recorded a maximum gust of 43 km/h on 13 December. Menindee Post Office recorded 5.2 mm and 13.8 mm respectively in the 24 hour periods to 9am on 14 and 15 December. This weather change likely triggered a mixing event that mixed bottom waters, with very low oxygen, with the surface waters where the fish were located. A change in conductivity likely associated with mixing of surface and bottom waters of different conductivity occurred in the early morning of 16 December 2018, the day of the first fish deaths (Figure 5-11). The first fish death event occurred upstream of the old town weir at Menindee.

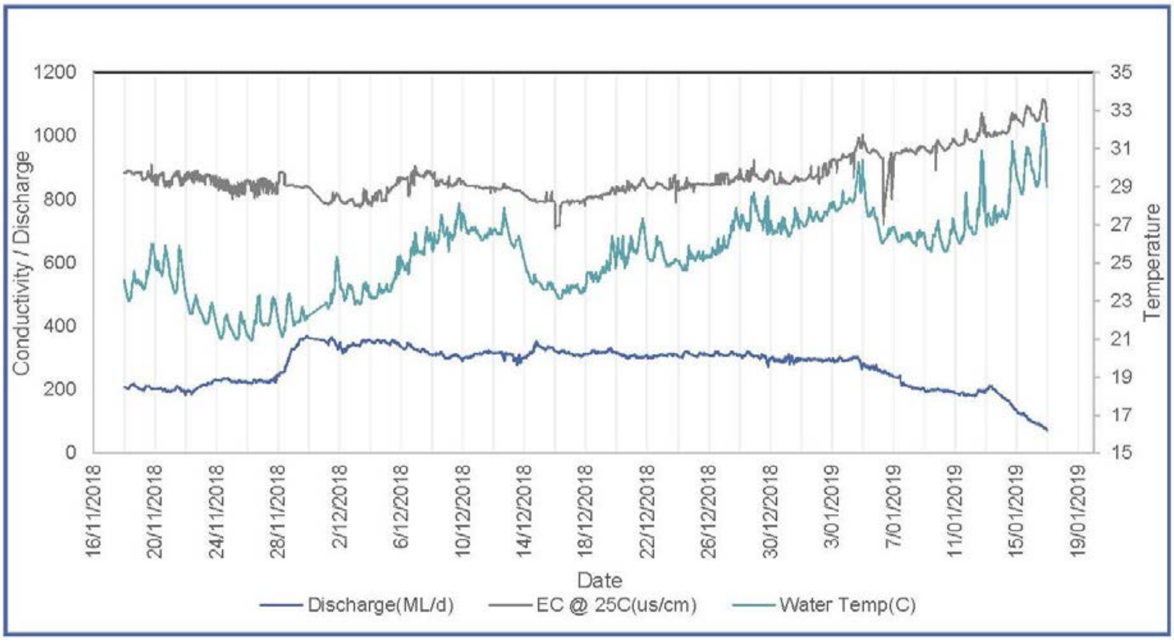


Figure 5-11: Conductivity, river discharge and water temperature as measured at the Weir 32 gauge (Data sourced from WaterNSW real time data).

The second fish death event occurred upstream of Weir 32 and coincided with another cool change on 6 January 2019. In this event, Menindee Post Office maximum air temperatures fell from 46.2ºC on 4 January 2019 to 28.5ºC on 5 January 2019. The cool change was also associated with increased winds, with a maximum gust at Broken Hill Airport AWS of 32 km/h on 5 January 2019. These events resulted in a substantial fall in water temperature (from above 30ºC on 4 January 2019 to 26ºC on 6 January 2019). The available conductivity data shows that

another mixing event from a rapid temperature change occurred on the morning of the 6 January 2019, just prior to the second fish death event (Figure 5-11).

It is likely that the mixing events in combination with algal respiration caused exceptionally low levels of oxygen 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 5-12). There is also the possibility of increased organic loading from sediment resuspension by mixing contributing to the oxygen reductions in the water column.

Fish deaths of the magnitude seen recently in the lower Darling at Weir 32 are likely influenced by positive feedbacks. Following the first fish death event, a significant proportion of dead fish would have sunk to the bottom. This increase in carbon load would have fuelled bacterial production in the bottom waters and further contributed to persistent hypoxic conditions. Given these organic loads in the bottom waters, and the consequent high biological oxygen demand, there would have also been considerable facultative anaerobic bacterial respiration occurring (the sulphur smell reported by the community at the time of the fish deaths suggests this). As soon as the water column mixed, this bacterial community would have rapidly switched to aerobic respiration and consumed any remaining oxygen. Similar situations would have occurred with the subsequent fish death events. With no flows to flush the additional carbon from the system, and extreme high temperatures likely promoting continual bacterial growth and increasing respiration, a positive feedback loop would have contributed to subsequent fish deaths. The nutrients released from decaying fish would have also supported algal blooms.

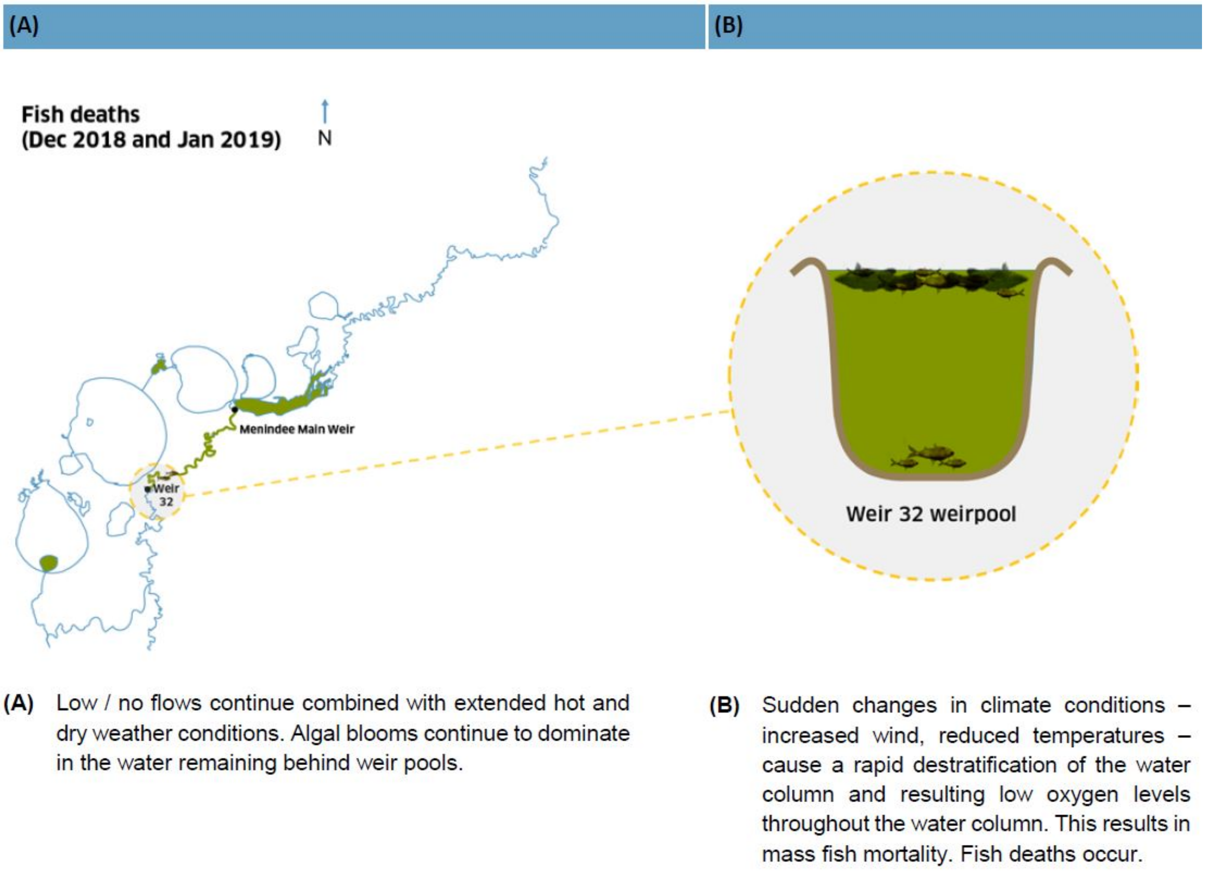


Figure 5-12: Conceptual model of the situation during late 2018 and early 2019 resulting in the fish death events; (a) a landscape scale conceptual diagram of the Menindee Lakes showing algal blooms in water remaining in lakes and also in the weir pools of the Darling (b) a conceptual diagram of conditions within the Weir 32 weir-pool after sudden de-stratification low oxygen dominates the water column, resulting in mass fish deaths.

5.2.5 Findings relating to the fish deaths

Finding 1: The Menindee Lakes are an ideal nursery habitat for some juvenile fish and a refugial habitat for some species of adult fish. High flow events in 2012 and 2016, combined with the use of Commonwealth environmental water, connected the river system and created good conditions for significant fish spawning, recruitment, growth and dispersal into the Menindee lakes.

Finding 2: By the end of 2018, high fish biomass from the recruitment events, releases of water from the lakes by NSW, and the inability of fish to move upstream or downstream due to the restriction of weirs, resulted in the aggregation of fish populations in the weir pools of the Menindee Main Weir and Weir 32.

Finding 3: Hot conditions and low flows resulted in significant algal blooms in Lake Pamamaroo, the weir pools of the Menindee Main Weir and Weir 32.

Finding 4: The combination of hot conditions, low flows and significant algal blooms, caused the weir pools to stratify. High fish numbers and algal biomass became concentrated in the surface waters of the weir pools and hypoxic conditions developed in the bottom waters.

Finding 5: Sudden reductions in air temperature and increased wind associated with storms caused the weir pools to suddenly de-stratify, resulting in low oxygen throughout the water column and no escape for the fish. This was the primary cause of the fish deaths.

Finding 6: The fish deaths primarily involved Murray Cod, Silver Perch, Golden Perch and Bony Herring. Significant numbers of carp were also reported to have died. Estimates of the number of mortalities range from hundreds of thousands to over a million fish.

Finding 7: Follow-up fisheries surveys using underwater acoustic cameras, conducted immediately after the events, identified that many fish survived the event. The remaining fish populations and their health, will be crucial for subsequent recovery.

5.3 Discussion of influencing factors

In examining the causes of the fish deaths, we identified that the pre-eminent cause of the events was a lack of flows to break down stratification in the lower Darling weir pools. The current lower Darling Water Sharing Plan includes guidelines on how to prevent stratification and disperse blue green algal events. But record low inflows to the system meant that the volumes of water required could not be delivered. There are four broad influencing factors for this situation, which we examine below. These factors include (1) the climatic conditions, (2) the basin hydrologic responses and how they were further impacted by water extractions by users, (3) the operation of the Menindee Lakes scheme, and (4) fish mobility.

5.3.1 Influencing factor 1: Climatic conditions

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.

5.3.1.1 Recent climate conditions

There has been a trend toward increased year-to-year climate variability in the southern half of Australia, occurring against a background warming and 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). The most recent exception to this drying trend followed the 2015-16 El Niño event, with the winter of 2016 the wettest on record for the Murray–Darling Basin (Figure 5-13a). These wet conditions were enhanced by warm ocean temperatures to the North of Australia. In 2017, dry conditions returned, with much of the Murray–Darling Basin experiencing below average rainfall for the 12-month period from April 2017 to March 2018 (Figure 5-13b). Subsequently, from April to September 2018, almost all of the Murray–Darling Basin experienced meteorological drought conditions, defined as rainfall in the bottom 10% (decile 1) of all years (Figure 5-13c). Taken as a whole, the 22-month period from April 2017 to January 2019 has been a time of

severe meteorological drought (decile 1) over almost all of the northern Basin, with large areas experiencing the driest conditions on record (Figure 5-13d).

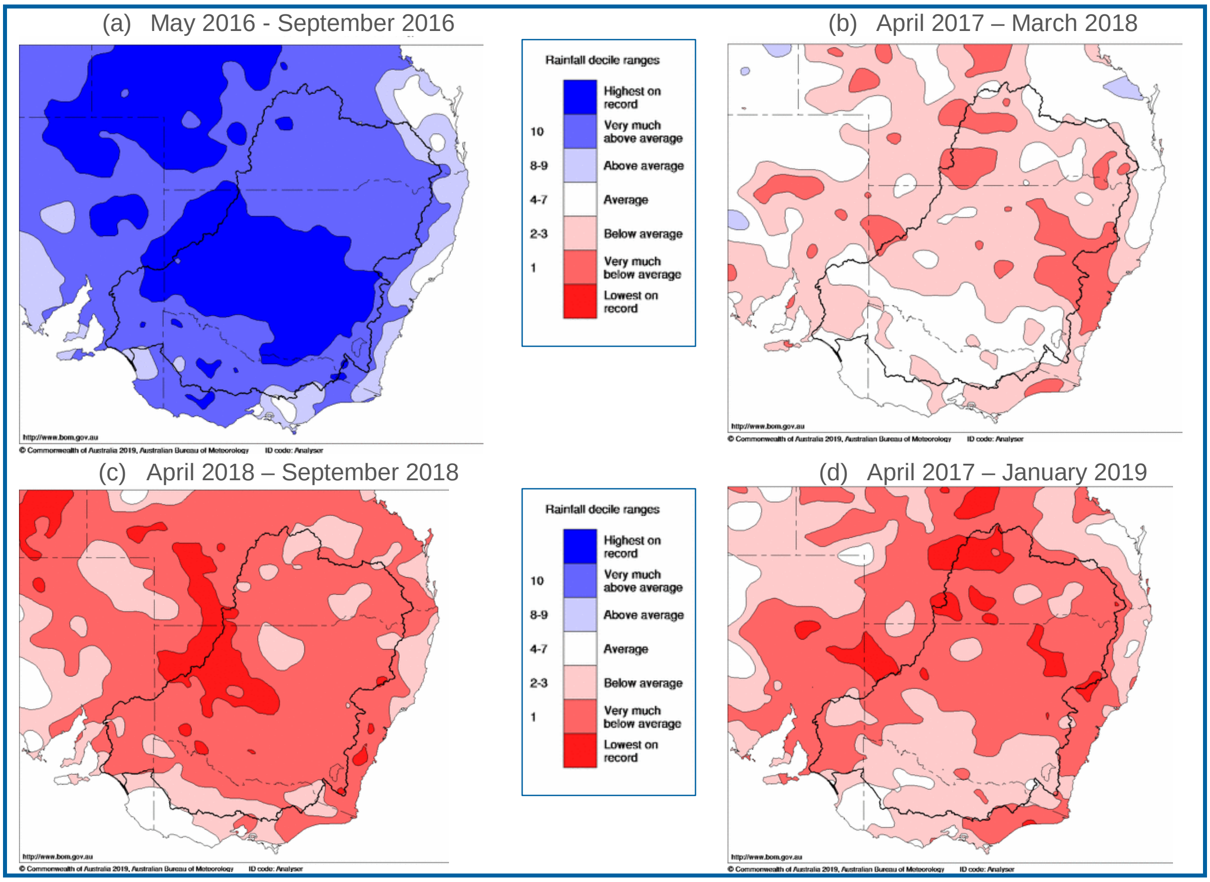


Figure 5-13: Rainfall deciles for southeast Australia for selected periods. These deciles are calculated for the specified period relative to all such periods since 1900. The Murray–Darling Basin is shown by the solid line (Bureau of Meteorology).

Low rainfall has also occurred in conjunction with high temperatures. In the northern Basin, average maximum temperatures in 2018 were the hottest on record and were 2.28ºC above the long-term (1961-1990) average. Average minimum temperatures in 2018 were the 6th hottest on record and were 1.40ºC above the long-term average. As a result of low rainfall and high temperatures, in 2018 most of the catchments in the northern Murray–Darling Basin had root zone soil moisture and runoff which were among the lowest in the last 20 years. These exceptional hydro-climatic conditions in terms of observed rainfall and estimates of resultant soil moisture and catchment runoff are shown in Figure 5-14 which ranks monthly values for each catchment in the northern Basin, within the context of the last twenty years.

(A) Observed rainfall	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Border	2	14	7	8	1	1	10	13	9	17	7	4
Moonie	1	17	10	13	1	3	8	15	6	18	9	5
Gwydir	4	10	6	8	1	1	7	11	7	14	10	3
Namoi	7	7	5	6	2	1	3	9	8	14	9	5
Castlereagh	7	7	9	4	4	3	1	10	9	11	10	11
Macquarie-Bogan	10	4	6	5	4	6	1	10	8	15	13	8
Condamine-Culgoa	1	16	10	5	1	6	7	12	4	15	7	5
Warrego	2	6	17	12	1	7	9	8	5	9	9	3
Paroo	3	3	12	9	2	5	3	8	3	12	12	3
Darling	10	3	5	5	3	4	1	8	3	16	12	6

(B) Estimated root zone soil moisture	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Border	4	6	8	3	1	1	2	1	3	11	6	4
Moonie	2	10	14	5	2	1	2	1	8	12	10	6
Gwydir	4	4	7	3	1	1	2	3	5	10	6	7
Namoi	3	2	3	2	1	1	1	2	2	5	6	6
Castlereagh	4	1	4	2	1	1	1	2	2	6	6	6
Macquarie-Bogan	3	1	3	2	2	1	3	2	2	8	7	7
Condamine-Culgoa	2	8	13	6	2	1	2	1	5	11	8	6
Warrego	2	3	13	11	3	1	5	4	3	5	4	3
Paroo	2	2	7	9	4	1	2	2	2	8	9	8
Darling	4	1	2	3	2	1	2	1	1	13	11	6

(C) Estimated runoff	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Border	5	10	8	6	1	1	9	10	8	11	5	3
Moonie	1	10	12	13	1	1	5	18	11	13	10	10
Gwydir	4	6	7	5	1	1	6	7	7	10	6	2
Namoi	4	2	4	3	1	1	1	2	2	8	4	2
Castlereagh	7	4	6	4	3	1	1	4	5	6	6	5
Macquarie-Bogan	8	5	8	7	5	3	1	6	7	8	7	6
Condamine-Culgoa	2	8	11	3	2	3	4	7	3	14	5	12
Warrego	2	5	15	4	1	1	4	1	1	4	2	2
Paroo	2	3	10	4	2	1	2	2	3	2	7	1
Darling	10	7	5	5	4	3	4	5	3	14	9	4

Figure 5-14: Ranked monthly values of (a) observed precipitation, (b) estimated soil moisture and (c) estimated runoff for each catchment within the northern Basin, within the context of the last 20 years (Bureau of Meteorology).

5.3.1.2 Extreme heat

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 5-15). The maximum temperature at Bourke was 40.0ºC 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 Menindee Post Office during the current summer was 48.8ºC, occurring three days prior to the third fish death event. This is the highest temperature recorded at the site since January 1939 (Table 5-1). Whilst the extremes recorded in the area are similar to January 1939, their duration and spatial extent have been more severe than in 1939.

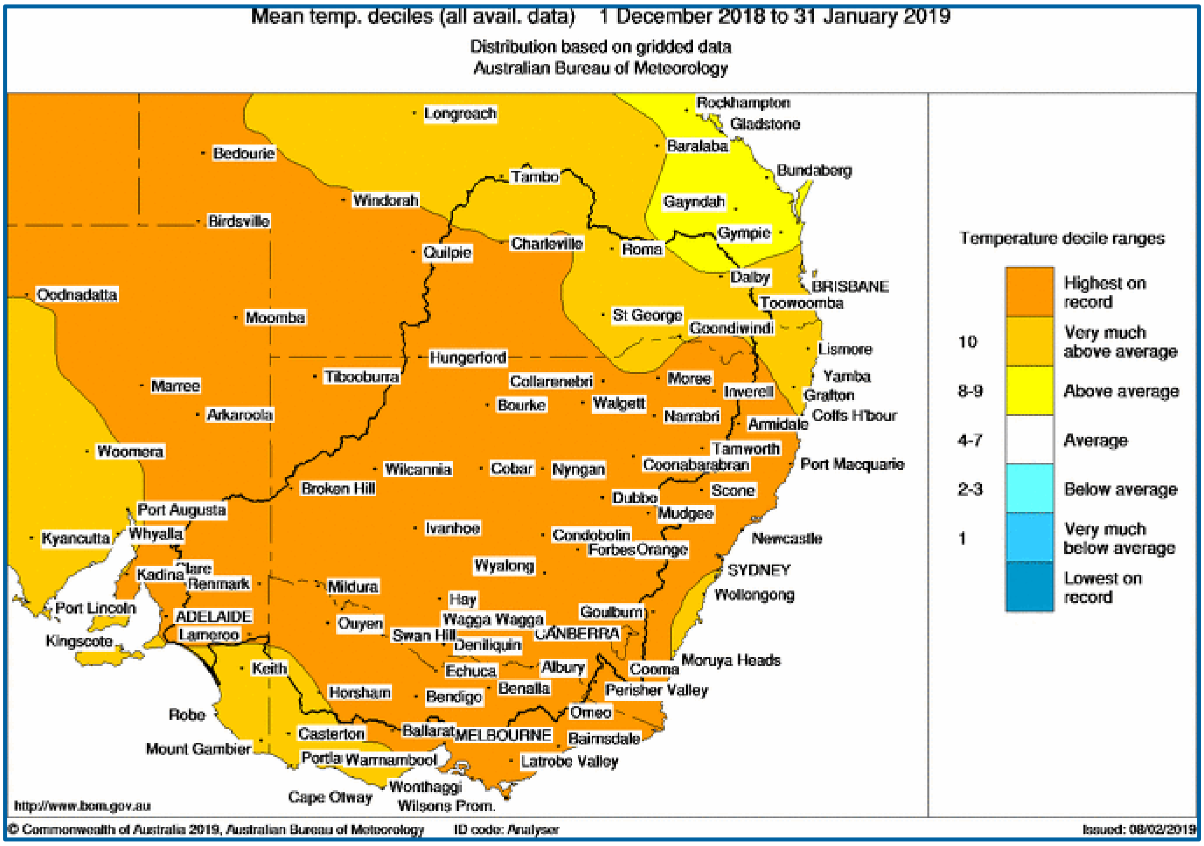


Figure 5-15: Mean temperature deciles for southeast Australia, December 2018 to January 2019. These are calculated against all December-January periods since 1910. The Murray–Darling Basin is shown by the solid line (Bureau of Meteorology).

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

Table 5-1: 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 (Bureau of Meteorology).

5.3.1.3 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. The annual mean temperature in the northern Basin is estimated to have risen by about 1.5ºC since 1910. This is statistically similar to the recently revised trend in Australia's annual mean temperature, which shows about 1.4ºC of warming since 1910. There is a marked tendency across Australia, including the northern Basin, for more extreme and persistent heatwaves (Figure 5-16). Such changes are increasing the risk of fish deaths.

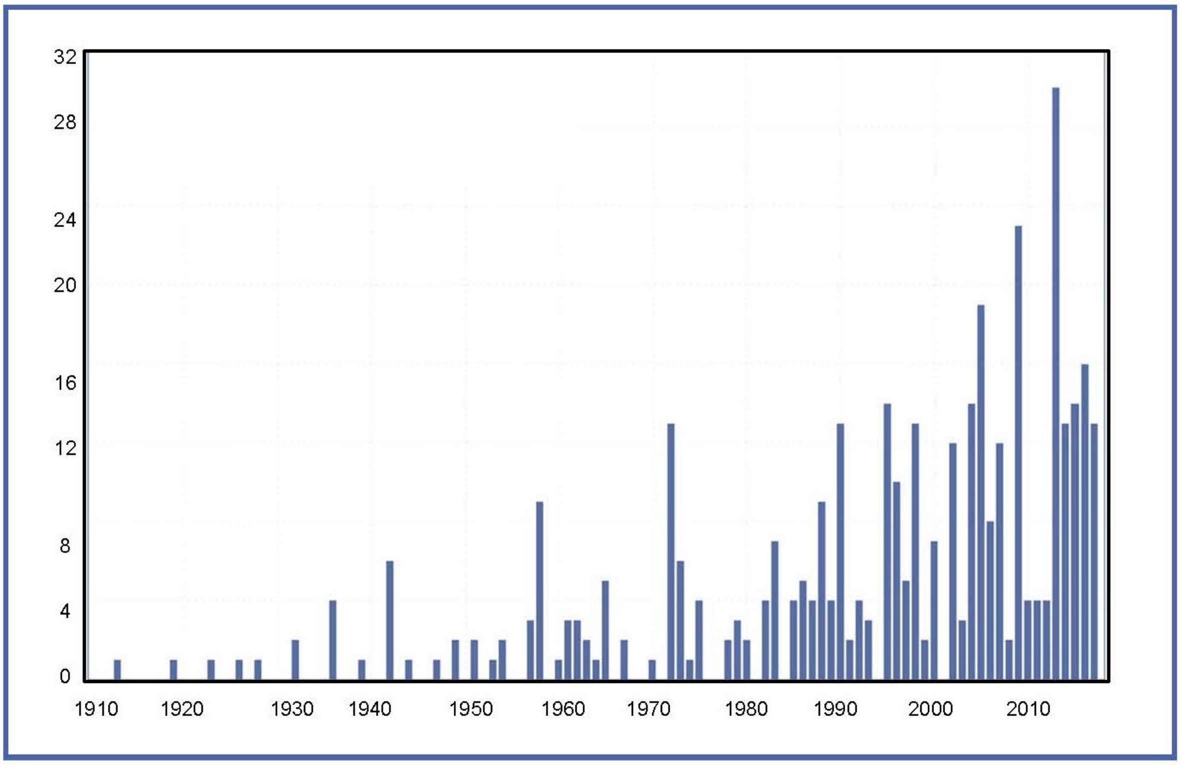


Figure 5-16: Number of days each year where the Australian area-averaged daily mean temperature is extreme. Extreme days are those above the 99th percentile of each month from the years 1910–2017. These extreme daily events typically occur over a large area, with generally more than 40 per cent of Australia experiencing temperatures in the warmest 10 per cent for that month (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 a high probability of increased temperatures in the 21st century. Under a high emissions scenario, annual mean temperatures by 2090 are projected to increase by 2.7 to 4.5ºC and 3.0 to 5.4ºC 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 for these clusters. 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 uncertainties in these estimates underscore the difficulty that water managers face in planning for the impacts of climate change on future water availability.

5.3.1.4 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 for 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 Millennium drought when compared to previous droughts. This was confirmed through an assessment of cumulative flows at North Cuerindi, a largely un-impacted catchment upstream of Keepit Dam (Figure 5-17). This trend was also observed in the study at other locations through the northern Basin. Such impacts further compound the effects of drought on water availability.

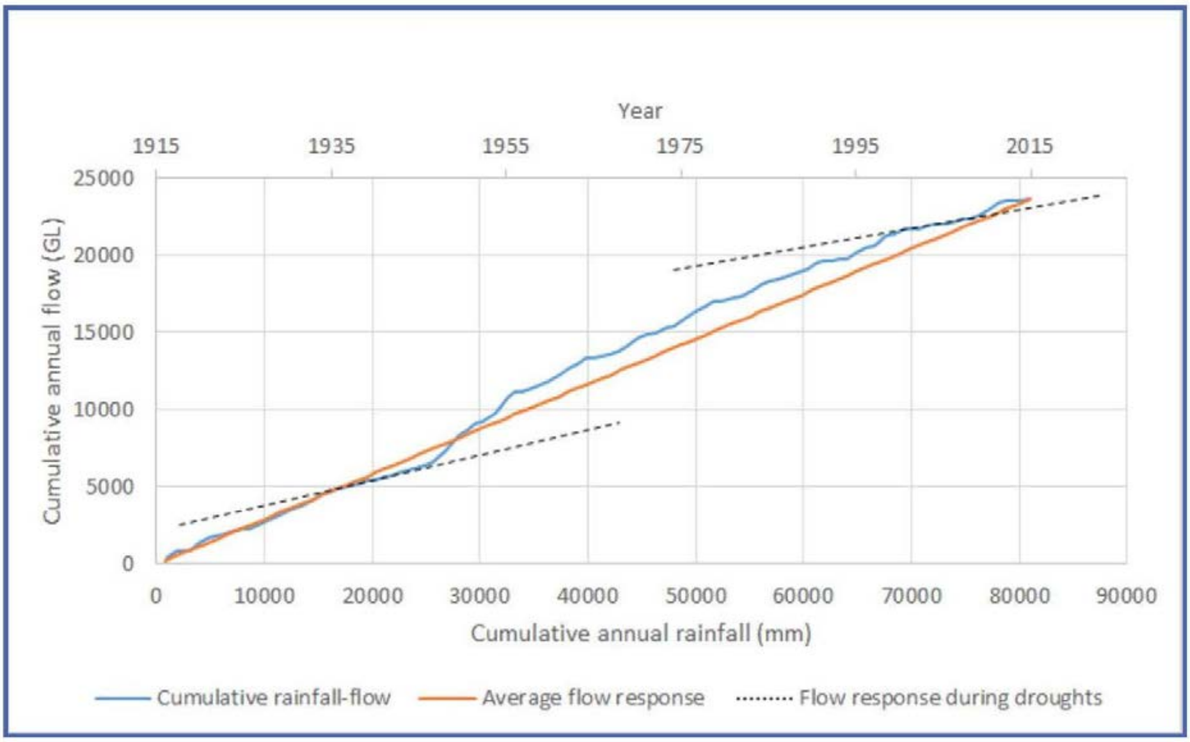


Figure 5-17: Cumulative annual flow (GL) at North Cuerindi versus cumulative rainfall (mm) (MDBA, 2018).

5.3.2 Influencing factor 2: System hydrology and water management

5.3.2.1 Inflows to major storages of the Barwon–Darling Tributaries

The recent abnormally hot and dry climate has resulted in extremely low inflows to the water storages of the northern Basin. Figure 5-18 and Figure 5-19 show the variation in 12- and 24-month total inflow sequences for New South Wales northern Basin storages above Menindee for the five driest sequences since 1893 starting in January. As can be seen, both recent sequences are the second worst on record. It is also noteworthy that four of the five worst sequences in each case are comparatively recent, indicating the growing significance of drought in the northern Basin.

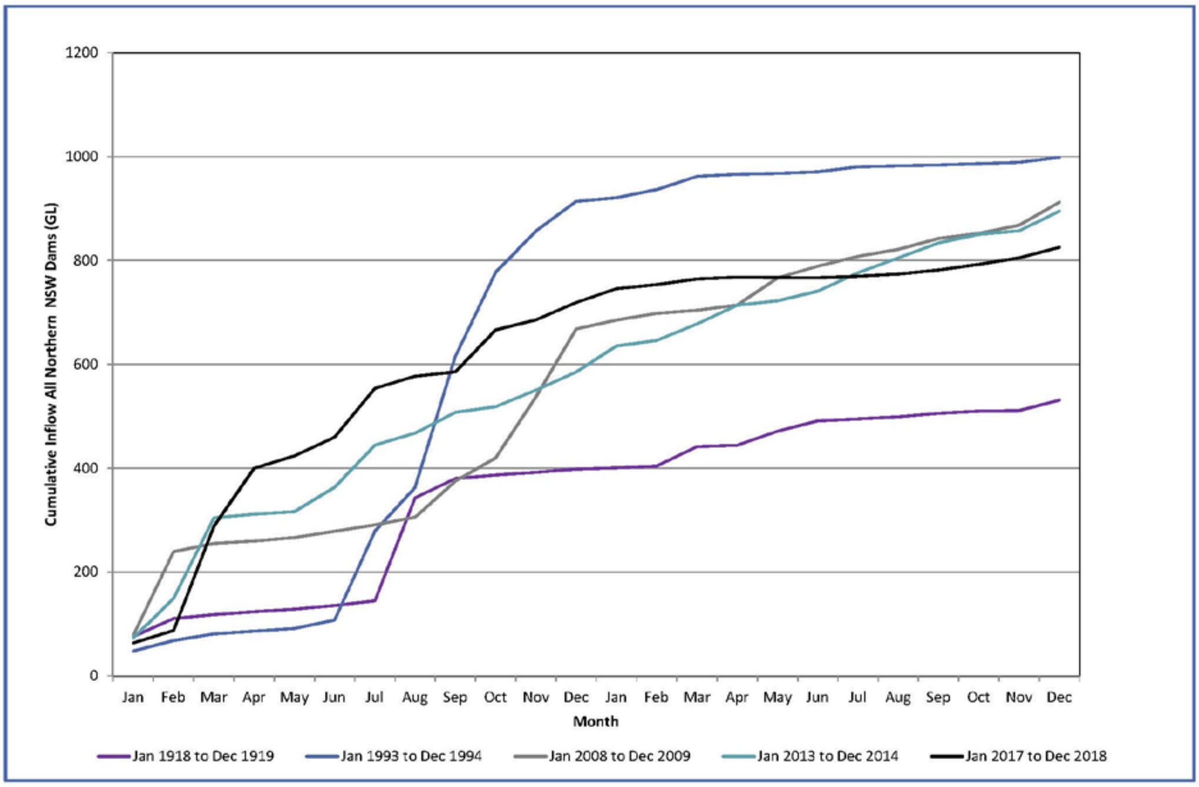


Figure 5-18: The five worst 24-month total drought inflow sequences since 1893, starting in January (shows totals for all northern Basin NSW storages upstream of Menindee) (Data sourced from WaterNSW).

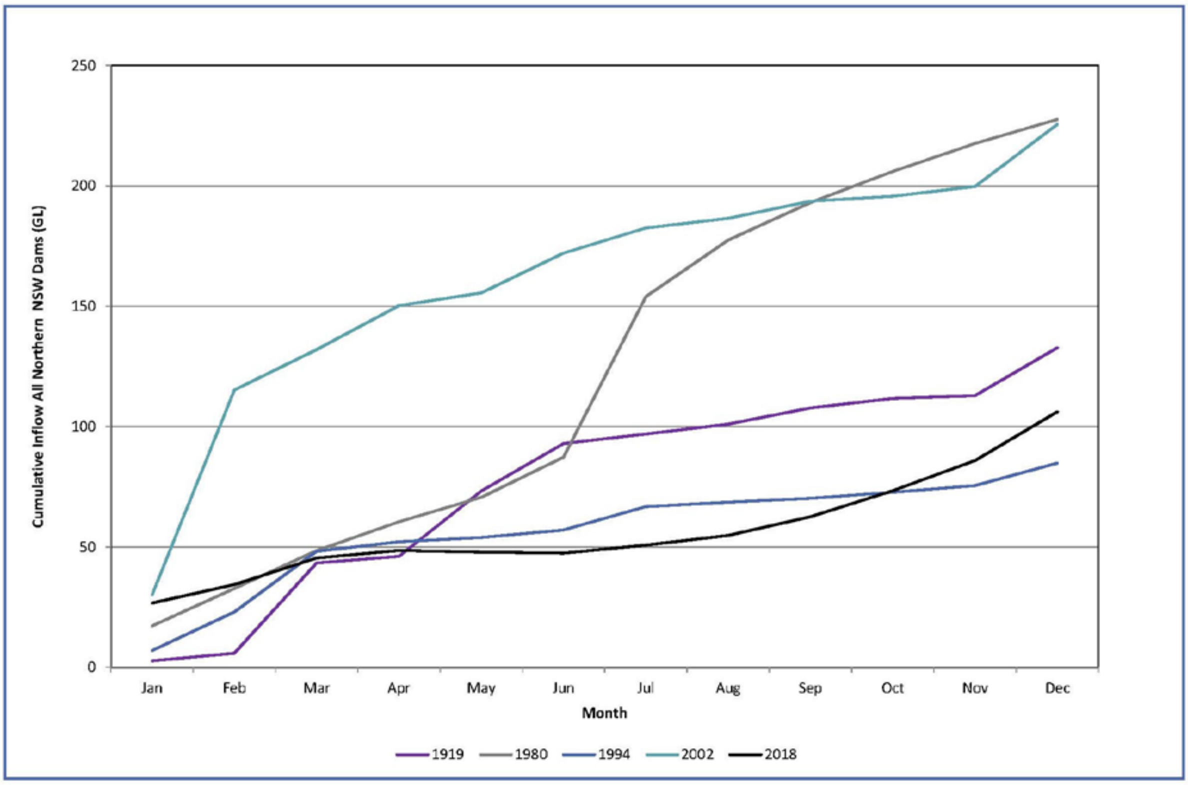


Figure 5-19: the five worst 12-month total drought inflow sequences since 1893, starting in January (shows totals for all northern Basin NSW storages upstream of Menindee) (Data sourced from WaterNSW).

5.3.2.2 Flows in the Barwon–Darling Tributaries downstream of storages

Turning to flows downstream of the storages, Figure 5-20 highlights the amount of mid-system flow (flow above major extraction points) that becomes end-of-tributary inflow to the Barwon–Darling and Table 5-2 compares historic tributary mid-system flows and end-of-system inflows into the Barwon–Darling for the past 2 and 20 (in brackets) years. Over the past 20 years, total tributary inflows to the Barwon-Darling (the light blue component of the columns) has always been less than half the mid-system flow (the total column value, grey plus light blue), with the reduction from mid-system flows to end-of-tributary flows into the Barwon–Darling being attributable to extractions combined with transmission losses.

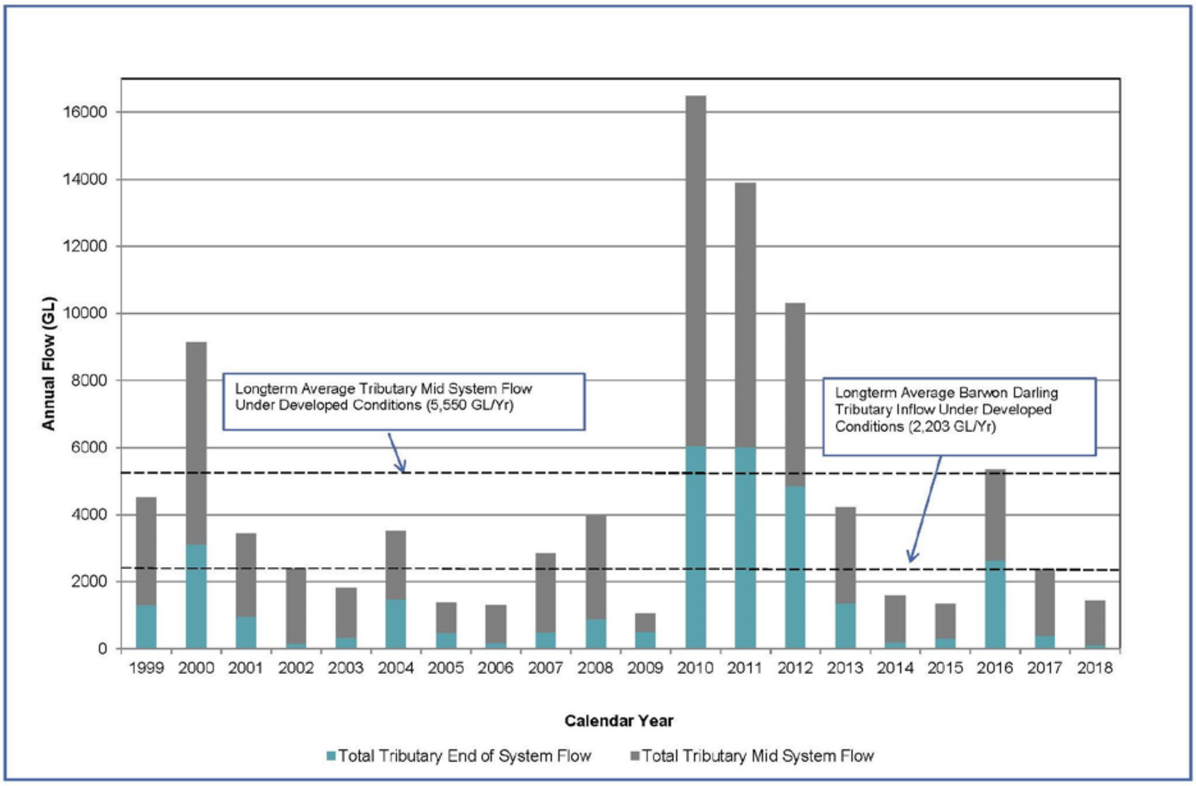


Figure 5-20: Amount of total mid-system flows that become total tributary inflows into the Barwon–Darling (Data sourced from WaterNSW Real Time Data).

	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 5-2: Historic annual average last two years (1 January 2017 to 31 December 2018) compared to last twenty years (1 January 1999 to 31 December 2018) shown in brackets. #1 denotes no data for Boomi at Neewora used Boomi at offtake #2 denotes no data for Collymongle gauge assumed zero inflow contribution #3 denotes no data for Coonamble assumed zero inflow contribution for Castlereagh #4 denotes mid-river flow likely to be an underestimate of water availability due to upstream extractions (Data sourced from WaterNSW Real Time Data).

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 also less than what would be expected over the longer term, as illustrated by the comparison with river system modelled inflows from Jan 1900 to Dec 2012 (in brackets) in Table 5-3. This indicates that although inflows into the tributaries have been naturally low, extractions within tributaries have further reduced the end-of-system flows and thus potentially flows in the Barwon–Darling during this period.

	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 5-3: Historic annual average last twenty years (1 January 1999 to 31 December 2018), compared to modelled long-term average 1900 to 2012 shown in brackets (Data sourced from WaterNSW Real Time Data).

5.3.2.3 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 5-4). Furthermore, the total two-year flow between January 2017 and December 2018 is the lowest in the last twenty 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 5-4: Barwon–Darling Streamflows - Historic annual average last two years (1 January 2017 to 31 December 2018) compared to last twenty years (1 January 1999 to 31 December 2018) shown in brackets (Data sourced from WaterNSW Real Time Data).

Streamflows in the Darling River below Bourke have been significantly below average over the past two calendar years (Figure 5-21). In the 2018 calendar year, those streamflows that did occur were mostly attributable to the managed held environmental water release from the Gwydir and Border Rivers in 2018.

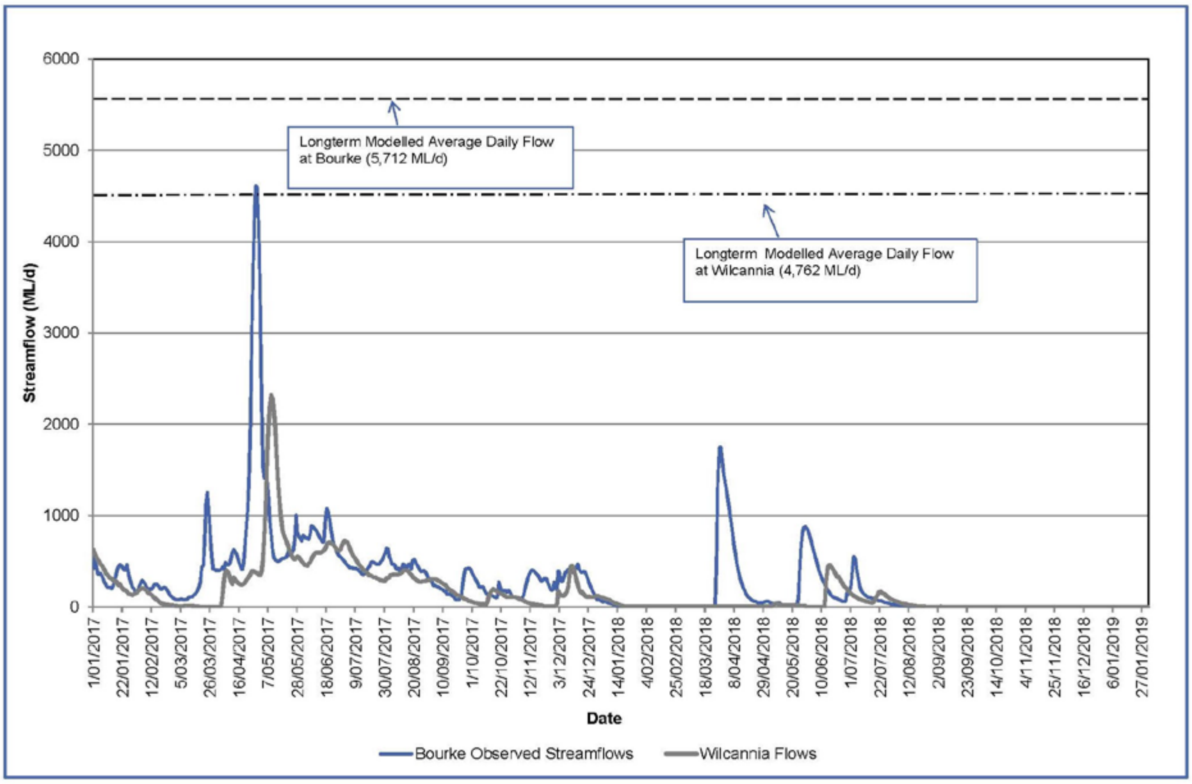


Figure 5-21: Daily Streamflow at Bourke and Wilcannia (Barwon–Darling) over the period 1 January 2017 to 27 January 2019 (Data sourced from WaterNSW Real Time Data).

Observed flows downstream of the Menindee Lakes have not been as low relative to the past 20 years as flows in the Darling above Menindee as a consequence of re-regulation of water in the storage. The total two-year flow between January 2017 and December 2018 has been lower on nine occasions over the past 20 years (refer to Figure 5-4). In the period 1915-2018 there have been periods of annual flows of similar volumes to those during the 2017 to 2018 period, with the 2018 annual flow total at Weir 32 being lower on five occasions .

5.3.2.4 Water extractions upstream of Menindee

Water extractions within the northern Basin are made up of a number of different forms of take and these are each monitored to different extents.

- Regulated extractions occur from water captured and stored in government owned water storages. This water may often not be used within the year that it is captured, and may be “carried over” into subsequent years. These forms of take are associated with what are known as *High Security* and *General Security* licenses in New South Wales, and *High Priority* and *Medium Priority* licenses in Queensland.
- Unregulated extractions occur from tributaries upstream and downstream of public storages and are opportunistic in nature. They can occur from in-stream flows or overbank events which break out of the river and flow across the floodplain. Unregulated extractions of in-stream flows are associated with *Supplementary* licenses in New South Wales, and *Water Harvesting* licenses in Queensland. Unregulated extractions of overbank flows, often referred to as floodplain harvesting, have historically been unlicensed but are currently in the process of being licensed.
- Lastly, the extraction of rainfall runoff occurs from the rainfall excess that falls directly onto the floodplain. It is intercepted before it reaches a watercourse and is often referred to as rainfall harvesting.

Some metering of regulated and unregulated in-stream extractions has occurred for many years, but it has been far from complete and not at satisfactory levels of accuracy and reliability. Improvements in the metering of these forms of take are occurring slowly with the advent of improved technology. Metering of floodplain and rainfall harvesting extractions has not occurred at all, in part due to the diffuse nature of this extraction and the difficultly in separating out this form of take from the other forms of take that occur when irrigating a crop. Consequently, there is great uncertainty regarding the volume of these forms of take and how they may have grown over time.

Extractions Over The Past Twenty Years

The pattern of total upstream extractions (excluding floodplain harvesting) over the past 20 years is presented inFigure 5-22. Owing to considerable year-to-year variability governed by high rainfall variability, there is no evident increasing trend in diversions, as is commonly assumed, and due to very low inflows the period 2018-19 is on track to be the lowest upstream diversion total over the past 20 years. Data on floodplain harvesting diversions was not included in the totals, due to no measurement taking place. Although the total diversion volume is the lowest over the last 20 years the proportion of the total available flow diverted is not.

An analysis of the proportion of tributary mid-system flows extracted over the past 20 years in the tributaries of the Barwon–Darling up until 2017-18 is presented in Figure 5-23. The sum of the three components (light blue, grey and dark blue) shown in this figure represents the total mid-system flow. Our analysis has indicated that the proportion of flow extracted is greater in years of very low mid-system flows. In these low flow years, a large proportion of mid-system flows are 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. Regulated and unregulated extractions in 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.

Unregulated extractions in the Barwon–Darling River itself have been found to represent a small proportion of tributary system inflows, even when inflows are small, such as in 2017-18 (Figure 5-24). Our analysis of extractions, mid-system flows, and tributary inflows into the Barwon–Darling indicates 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.

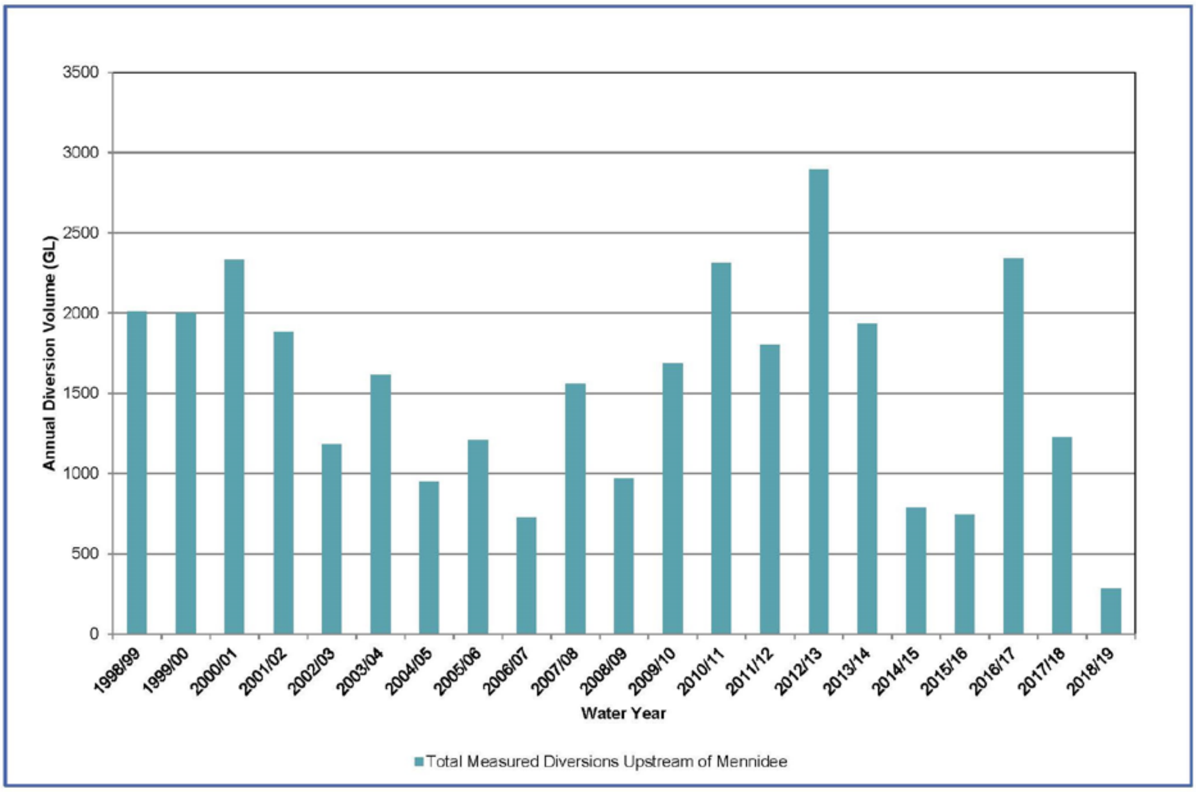


Figure 5-22: Total measured diversions upstream of Menindee, including all tributary streams (1998-99 to 2018-19) (Data sourced from MDBA).

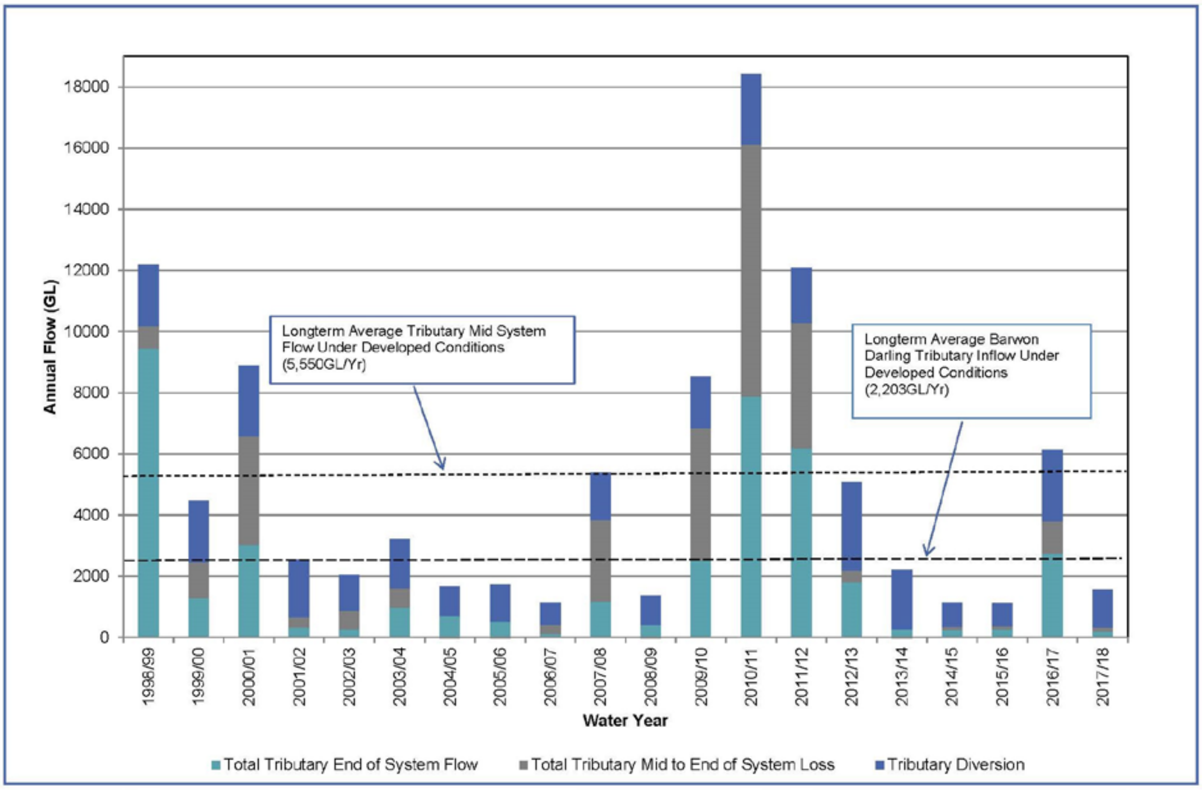


Figure 5-23: Volume of Total Mid-system Tributary Flow Extracted. (Mid-System flow equals sum of all bars) (Data sourced from Water NSW Real Time Data and MDBA).

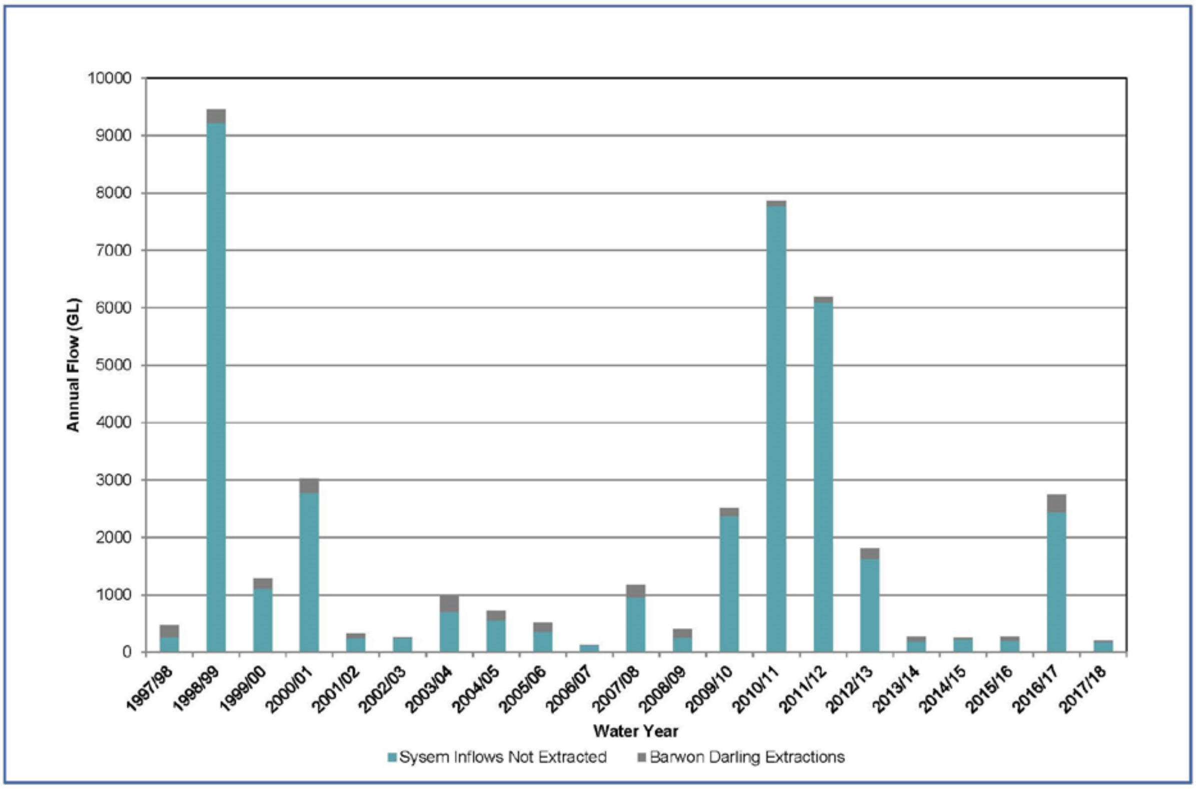


Figure 5-24: Volume of Tributary System Inflow Extracted from the Barwon–Darling only. This does not include extractions from tributary streams (Data sourced from Water NSW Real Time Data and MDBA).

An assessment of the impact of extractions on Menindee inflows over the long-term can be made by comparing pre-development and current development Menindee Inflows using river system model data from 1895 to 2009. This is shown in Figure 5-25. As can be seen, in years of low developed inflows there are significant additional flows that would have occurred under a pre-development scenario. The same analysis has also been carried out, assuming that upstream tributaries and the Barwon–Darling are at the Sustainable Diversion Limit (Figure 5-26). Whilst Menindee Sustainable Diversion Limit inflows exceed those under the Baseline Diversion Limit, they are still considerably less than modelled pre-development inflows. It should be noted that river system models generally over-predict low flows. Consequently, both modelled pre-development and developed inflows into the Menindee Scheme are likely to be over-estimated for low flow situations. This analysis indicates that under current levels of water resource development, there has been a significant reduction in the frequency, magnitude and duration of low flow events in the Barwon–Darling generally and events reaching Menindee.

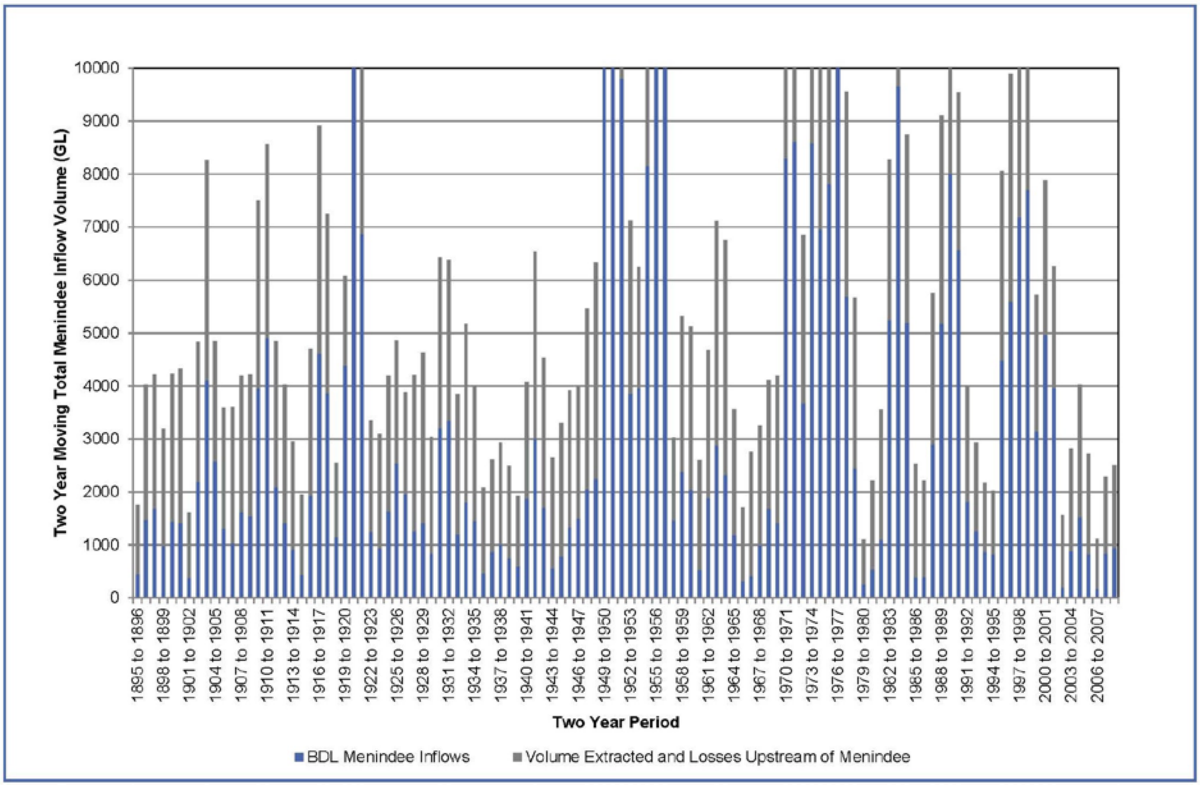


Figure 5-25: Pre-development and Baseline Diversion Limit two-year total modelled Menindee inflows (Data sourced from MDBA).

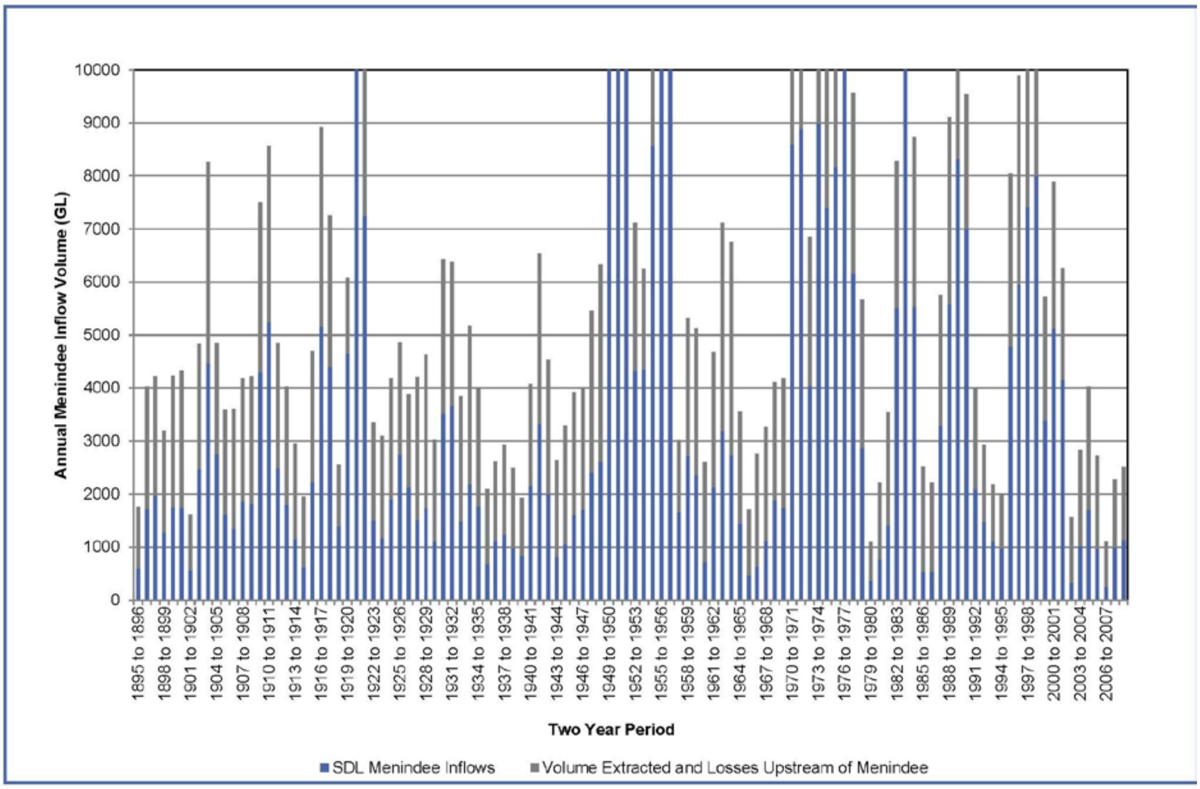


Figure 5-26: Pre-development and Sustainable Diversion Limit two-year total modelled Menindee inflows (Data sourced from MDBA).

Extractions Since Menindee Last Filled

Given its extent and varied forms, the influence of upstream extractions on inflows to the Menindee Lakes is an important consideration when assessing the causes of fish deaths downstream at Weir 32. The volumes allocated for regulated extraction from storages upstream of Menindee since it was last full in December 2016 are shown inFigure 5-27. Regulated and unregulated extractions over the past two and a half years are presented in Table 5-5 and Table 5-6. Total diversions for the entire system above Menindee are presented in Figure 5-28. Floodplain and rainfall harvesting estimates of take are not included in the totals due to not being available.

Figure 5-27 shows decreasing allocations to regulated water users over the past two years. Figure 5-28 shows the volume extracted. The large volumes allocated and extracted in 2016/17 coincided with the Menindee Lakes fill sequence, whilst the smaller allocations and extractions in 2017/18 and the current 2018/19 year reflect drier conditions. Regulated extractions made up the majority of take in 2017/18. Much of this was from allocations carried over from 2016/17.

Estimates of floodplain harvesting from 2016/17 were only available for Queensland tributaries. This data indicated large volumes in 2016/17 (242.3GL), minor amounts in 2017/18 (2.3GL) and none in 2018/19 to date. This pattern is also likely to apply to NSW tributaries.

The volumes of regulated water allocated in 2017/18 of approximately 600GL upstream of Menindee are sufficiently large to suggest that reduced upstream diversions in the 2017/18 water year may have allowed for some increase inflows to Menindee. However, much of the 2017/18 allocated volumes were in systems with poor connectivity to the Barwon-Darling, and also included allocations for held environmental water. The effect of increased Menindee inflows would have been to potentially delay the onset of Menindee releases falling below minimum levels. However, the extent of this can only be confirmed with certainty through the comparison of a current and pre-development river system model which simulates inflows into Menindee under different extraction reduction scenarios up to January 2019.

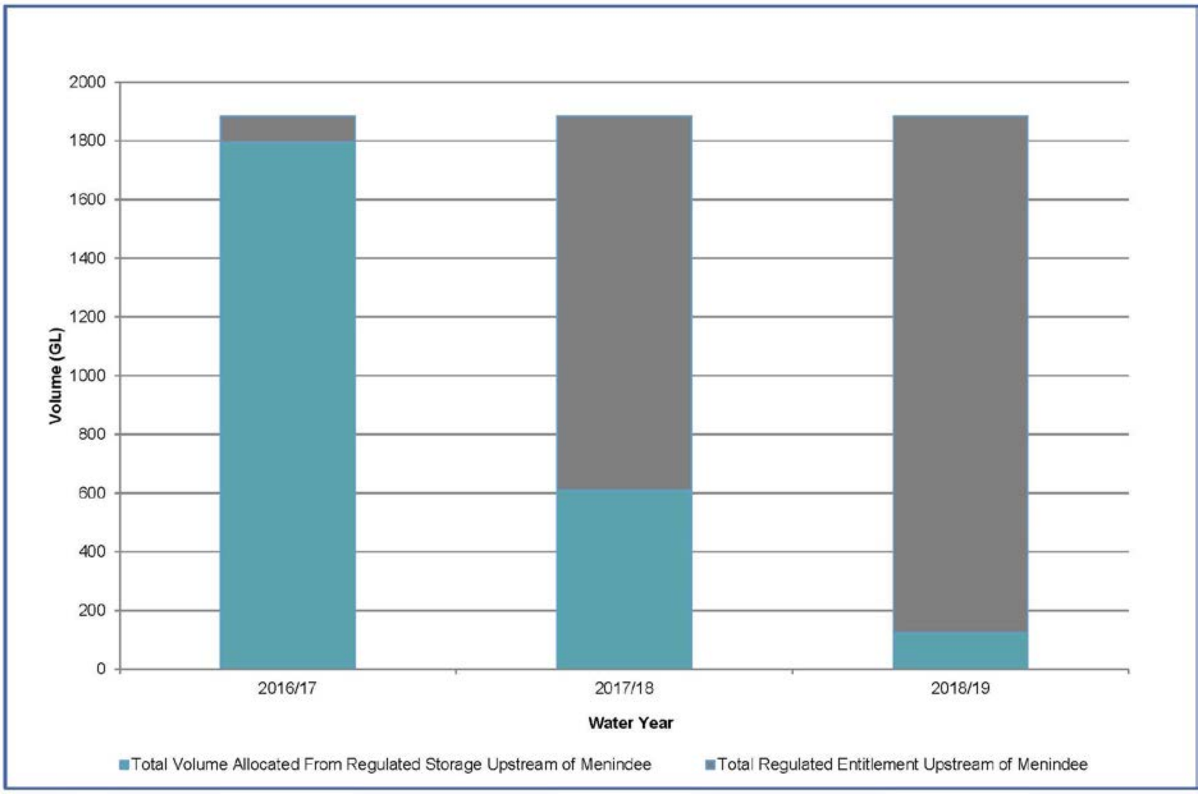


Figure 5-27: Volume allocated as a proportion of entitlement in upstream regulated systems (2016/17 To 2018/19) (Data sourced from WaterNSW and NSW DOI Water).

Valley	General Security Entitlement/Share GL	Usage 16/17 (GL)	Usage 17/18 (GL)	Usage 18/19 (GL) to Dec 31st
Gwydir	510	141.46	262.44	28.48
Namoi/Peel	277	137.23	198.99	44.85
Macquarie	613	175.49	329.93	149.32
Border Rivers (NSW)	263	107.45	123.66	59.08
Border Rivers (QLD))	101	29.85	57.61	0.00
Condamine/Balonne/ Culgoa System	122	118.84	92.47	Not Available
Total	**1885**	**710.31**	**1065.11**	**281.73**

Table 5-5: General Security/Medium Priority (Regulated) usage across the northern Basin (Data sourced from WaterNSW and NSW DOI Water).

Valley	Supplementary or Unsupplemented Entitlement/Share GL	Usage 16/17 (GL)	Usage 17/18 (GL)	Usage 18/19 (GL) to Dec 31st
Gwydir	181	177.41	8.86	0.00
Namoi/Peel	115	74.93	0.00	0.00
Macquarie	49	35.04	0.00	0.00
Border Rivers (NSW)	120	112.47	8.90	0.00
Barwon-Darling	173	298.87	19.30	0.00
Border Rivers (QLD))	150	370.81	32.39	Not Available
Condamine/Balonne/ Culgoa System	453	317.50	64.37	Not Available
Moonie River System	30	26.40	14.60	Not Available
Warrego River System	51	7.10	7.60	Not Available
Total	**1322**	**1420.52**	**156.02**	**0.00**

Table 5-6: Supplementary/unsupplemented (unregulated) usage (Data sourced from WaterNSW and NSW DOI Water).

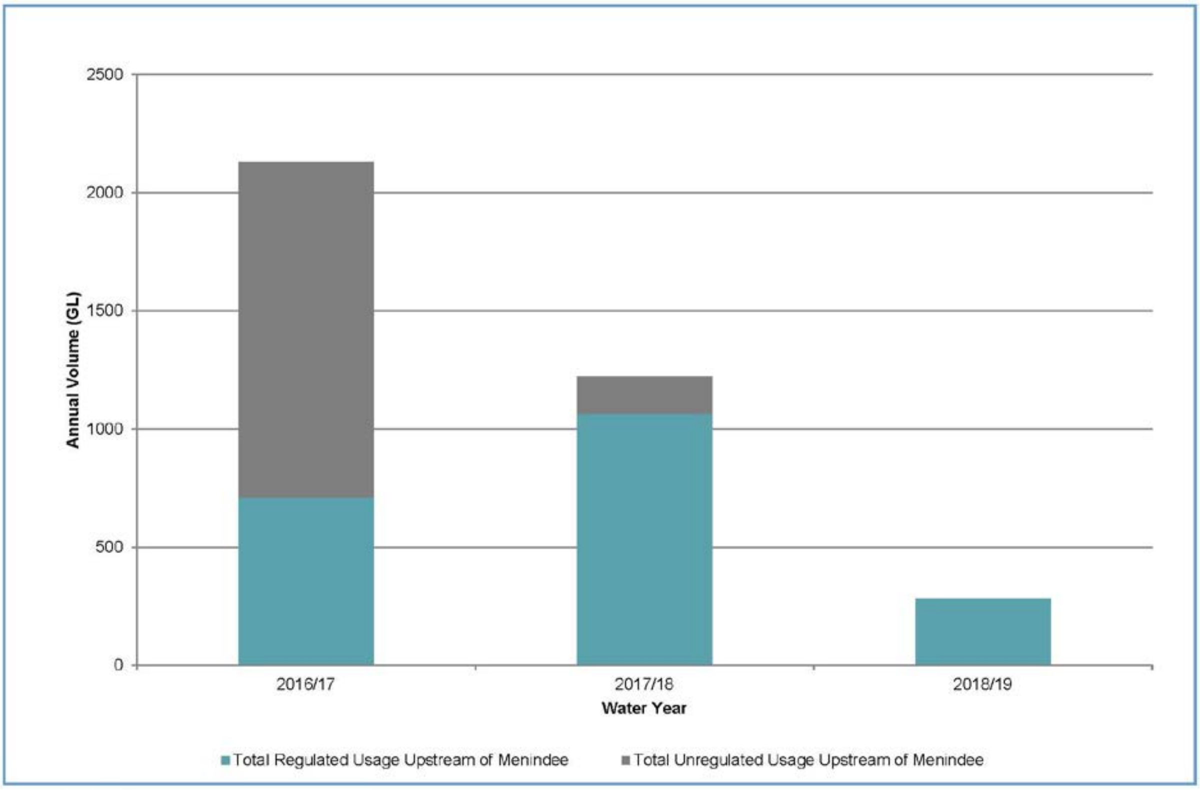


Figure 5-28: Total metered extractions upstream of Menindee (2016/17 to 2018/19) (Data sourced from WaterNSW and NSW DOI Water).

Extractions Into The Future

Whilst the impact of upstream diversions on the lower Darling fish death events are likely to be small on account of the low upstream extraction volumes since the lakes were last full, the role of increasing extractions on future fish death events across the entire northern basin and the need for additional reductions in diversions needs further assessment. The hydrologic modelling used to inform the Basin Plan indicated that environmental outcomes downstream of the Menindee Lakes were constrained by the need to adhere to sharing arrangements of the Murray–Darling Basin Agreement. An assessment should be undertaken to evaluate if improved outcomes can be achieved with existing environmental water holdings should these constraints be removed. Any such assessment should give regard to four key matters.

First, current indications are that inflows to the northern Basin will decline in the future due to increased temperatures and evaporation rates. Inflow reductions should be anticipated despite uncertainty regarding future projections of rainfall in the northern Basin. Second, long-term reductions in inflows will reduce connectivity of flows in the Barwon–Darling and increase the frequency and duration of periods with zero flows, as well as reduce the frequency of events that deliver water to Menindee and the lower Darling. Third, regular connectivity events are critical to sustaining the health of the Darling River ecosystems by helping ensure waterholes can persist during dry periods, thereby increasing the resilience of populations of aquatic biota by providing drought refuges. Fourth, any alterations to the agreement will impact users downstream of Menindee, meaning that a trade-off needs to be considered.

While the new Water Resource Plans required under the Basin Plan are still to be completed, their focus on catchment-based Sustainable Diversion Limits does not invite adequate consideration of whole-of-system connectivity. In all likelihood, additional water recovery in the northern Basin will be necessary in the future to improve system connectivity during drought sequences, which are becoming more frequent. Assessments of those connectivity flow requirements should be undertaken well ahead of the Basin Plan review in 2026, and should focus on at least three key areas.

First, assessments of water resource use should be assessed against climatic sequences that are more representative of the future. Use of the 1895 to 2009 period is unlikely to be representative going forward. Second,

improvements are needed in the capacity to more accurately model low flows and zero-flow periods. This has been a long-standing challenge in hydrologic modelling and presents a critical gap in management of rivers in the northern Basin. Over-estimation of low flows in river system models has the potential to overstate environmental outcomes under new management regimes and understate water security impacts upon water users. Third, improvements are required in the ability to properly measure and/or estimate diversions, including floodplain harvesting, rather than relying on approximation and (in some cases) long-term averages. This will ensure connectivity protection and assist in compliance of Sustainable Diversion Limits.

Impacts on low flows

Our analyses suggest that some of the major impacts to flows in the Darling River below Bourke, and consequently at Menindee, relate to a reduction in the frequency, duration and magnitude of low and moderate flow events. Low and moderate flows provide connection through the river system and build ecosystem resilience to natural drought. In recent times, one of the main impacts on the frequency, magnitude and duration of low flow events in the Barwon–Darling River is the change in the behaviour and use of A Class diversion licences in conjunction with a change in the "carry-forward" arrangements (see Section 3.2). The capacity to “carry-forward” A Class licence unused opportunity allocation to lower flow years means that licence holders can maximise their water extraction at low flows if (a) the preceding years were exceptionally dry and they could not access flows within the A Class band, or (b) the preceding years were wet, and all their allocation came from B and C Class licences. This latter strategy has led to a behavioural change in the use of A Class licences that has meant that since 2012, an increased proportion of flows in the A Class band in the Barwon–Darling have been extracted (refer to Figure 3-4). In the period 2000-2011, the average annual volume diverted in the A Class band was 1.18 (SE ± 0.23) GL compared with the period 2014-2017 where the average annual volume extracted was 22.1 (SE ± 5.7) GL. Given that low flows are spread throughout the year, these increases are likely to have impacted the transmission of low flows further down the river that are important for sustaining water levels in refuge pools. These connecting low flows are particularly relevant during dry periods, so the impact of this increased extraction will have the greatest impact during droughts.

5.3.3 Influencing factor 3: Lake operations

The panel heard community concerns about the manner in which the Menindee lakes scheme had been operated in recent years, particularly since late 2016 when the lakes were last full. Questions were raised about whether the rate of releases and the distribution of water storage across the various lakes were appropriate and may have led to the fish death events. There was also anxiety that future changes to the operation of the lakes proposed under the draft Menindee Lakes Water Saving Project might further degrade water security and environmental outcomes in the lower Darling. This anxiety relates to the perception that the water saving project will enable the lakes to be drawn-down far more rapidly than is currently allowed. In order to assess the merits of these concerns, we reviewed the operation of the lakes since late 2016 and made a comparison to prior dry sequences.

A summary of the historic and forecasted operation of Menindee Lakes from July 2016 to July 2019 is presented inFigure 5-29, Figure 5-30 and Figure 5-31using information supplied by WaterNSW. The figures show the nature of the release, where pumping within the scheme occurs from, and reasons for increases and decreases in release rates. The variation in evaporation over time is also shown. Specific characteristics of lake operation from July 2016 onwards are described in the following section.

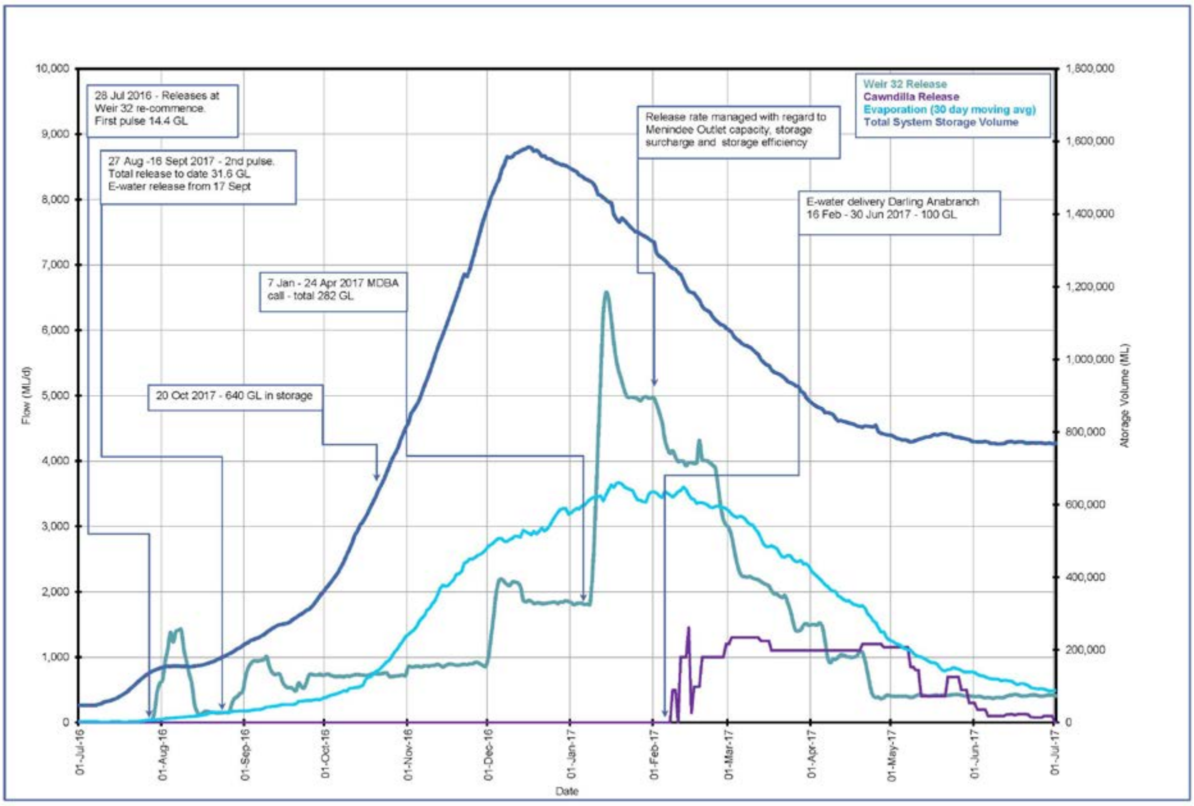


Figure 5-29: Menindee operation from July 2016 to July 2017 (Data sourced from WaterNSW).

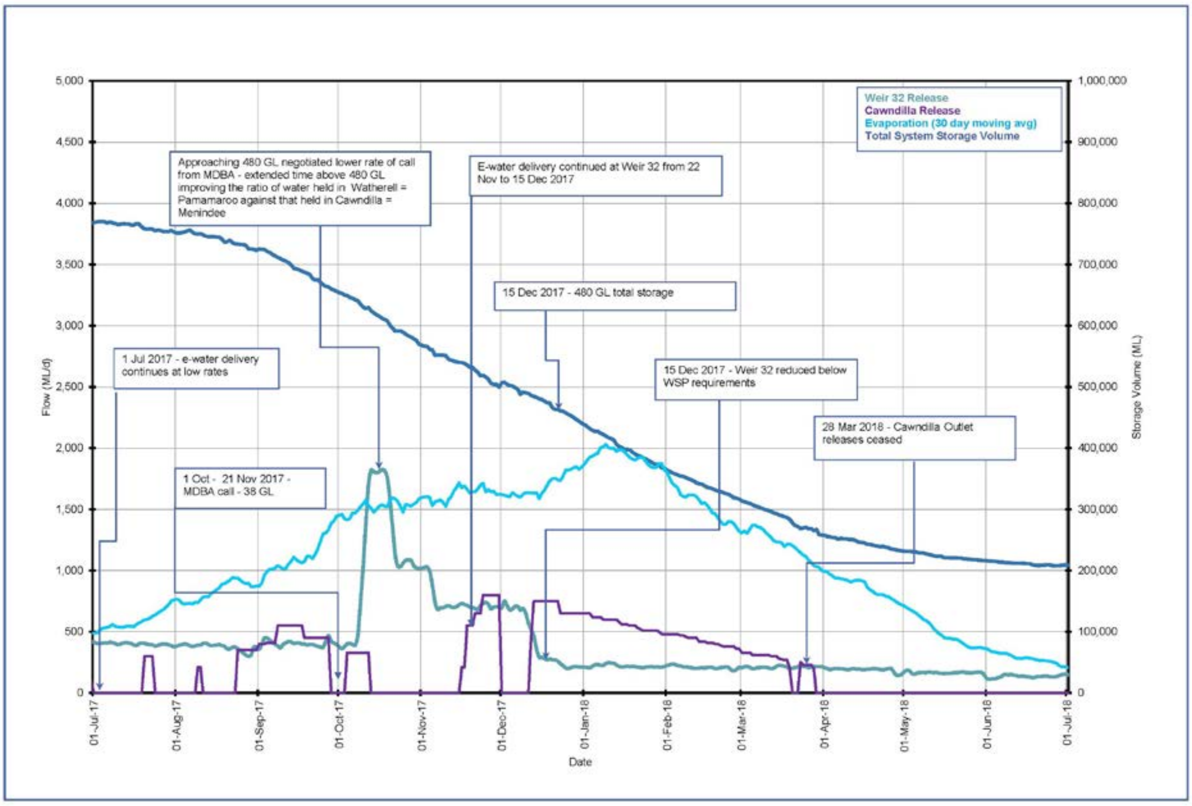


Figure 5-30: Menindee operation from July 2017 to July 2018 (Data sourced from WaterNSW).

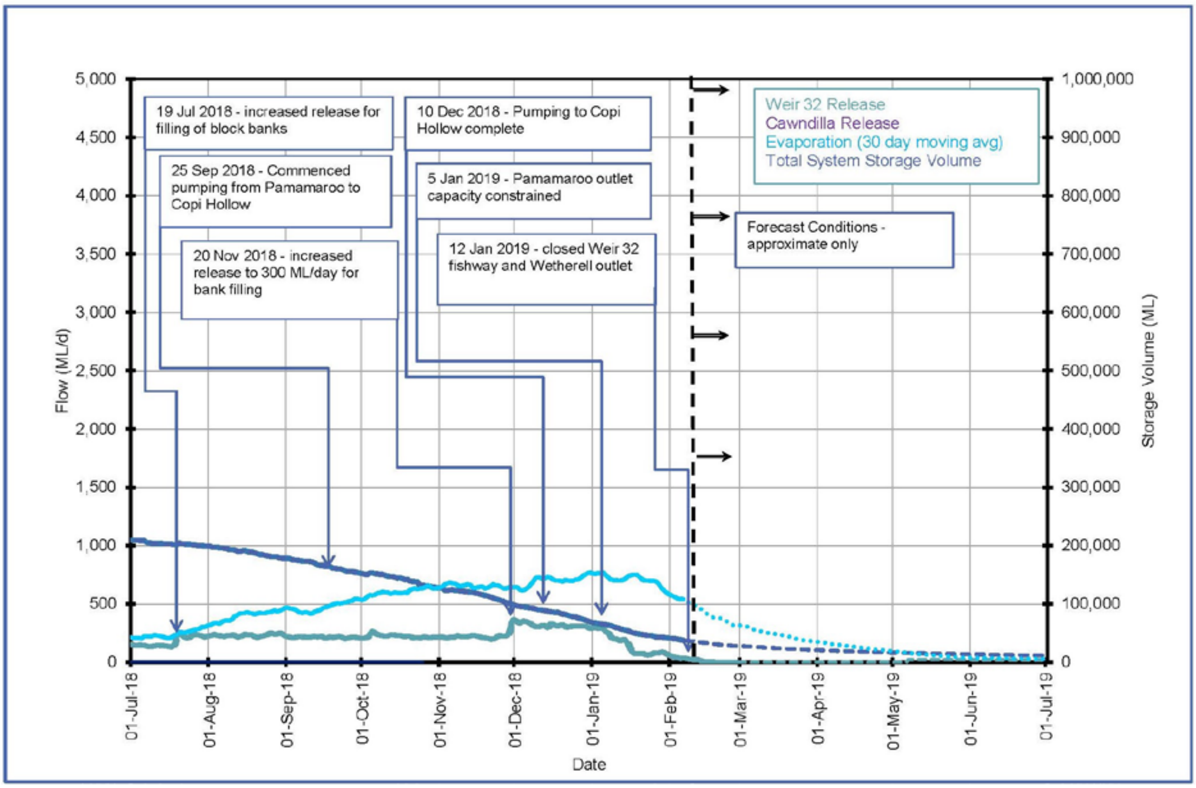


Figure 5-31: Menindee operation from July 2018 to July 2018 (Data sourced from WaterNSW).

On 28 July 2016, WaterNSW recommenced water releases at Weir 32 with a first pulse of 14.4GL. From late August to mid-September 2016, a second pulse was released taking the total release to 31.6GL. From mid-September to the start of December 2016, water was released from Weir 32 at a rate of 750-850ML/day, of which 150-200ML/d was to provide minimum flow targets, with the remainder being environmental water. This environmental water was prioritised to support spawning and recruitment of Murray Cod in the lower Darling, and monitoring determined the breeding response was strong. 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 640GL and the water within the storage became part of the shared resource of the Murray River system, with control passed to the MDBA. After the flooding in the Murray (at Wentworth) had peaked in December 2016 (and hence small releases from Menindee would not exacerbate flood levels), 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 (particularly juveniles that spawned in response to the spring 2016 environmental releases).

In early January 2017, in consultation with WaterNSW, the MDBA commenced calling on water from the Menindee Lakes to support Murray River system demands. These releases were timed to reach the Murray River 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 6,200ML/day) as water was moved off the Wetherill floodplain, but were steadily reduced to 5,000ML/day and then to 4,000ML/day as demands eased along the Murray due to rainfall in the southern catchments. By late April 2017, the end of irrigation season had returned the Murray River to low water demands.

From late April 2017 to the end of September 2017, environmental flow releases were continued to promote growth and survival of the spring 2016-bred Murray Cod larvae and dispersal of juvenile Golden Perch which had colonised the Menindee Lakes in high abundances in the 2016 flood water (verified by monitoring in the lakes). In mid-October 2017, with the 480GL 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 480GL and improve the ratio of water held in Wetherell and Pamamaroo (top storages) against that held in Cawndilla and Menindee (bottom storages).

A comparison of the variation in stored volume at Menindee with the total volumes held in upstream regulated storages is presented in Figure 5-32. Rates of drawdown for upstream storages are similar to Menindee during the summer of 2017 but are markedly different during the summer of 2018 when releases from Menindee were restricted in order to provide for drought security.

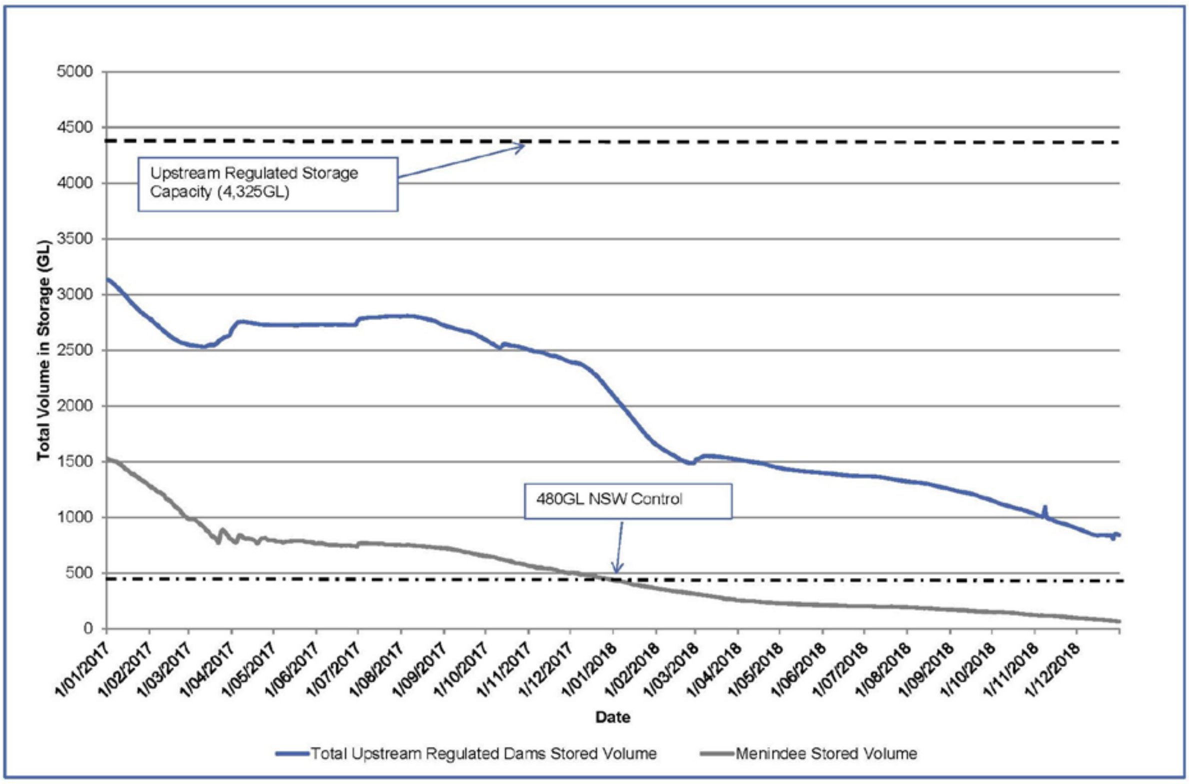


Figure 5-32: Storage volume at Menindee Lakes compared to upstream regulated storages (Data sourced from WaterNSW Real Time Data and DOI Water).

Figure 5-33, Figure 5-34 and Figure 5-35 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.

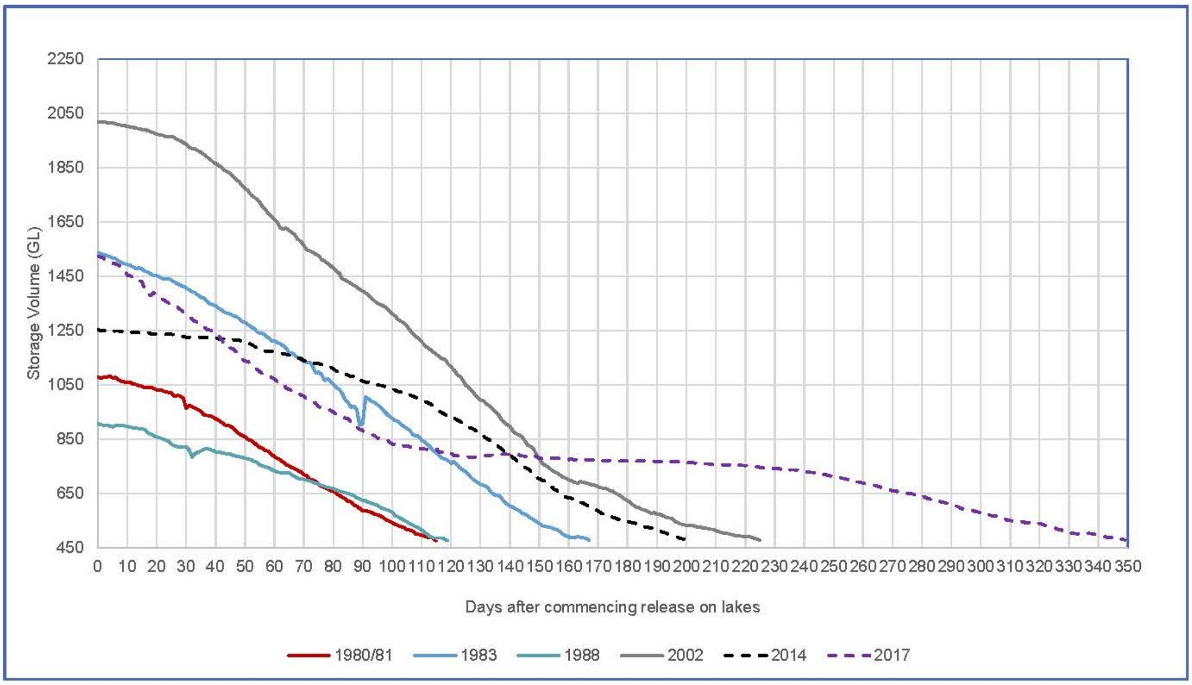


Figure 5-33: Storage fall rates from volumes above 640GL at Menindee Lakes, compared across various years. This shows that initial drawdown rates (from January to April 2017) were at rates similar to those experienced in other dry periods (Data sourced from MDBA).

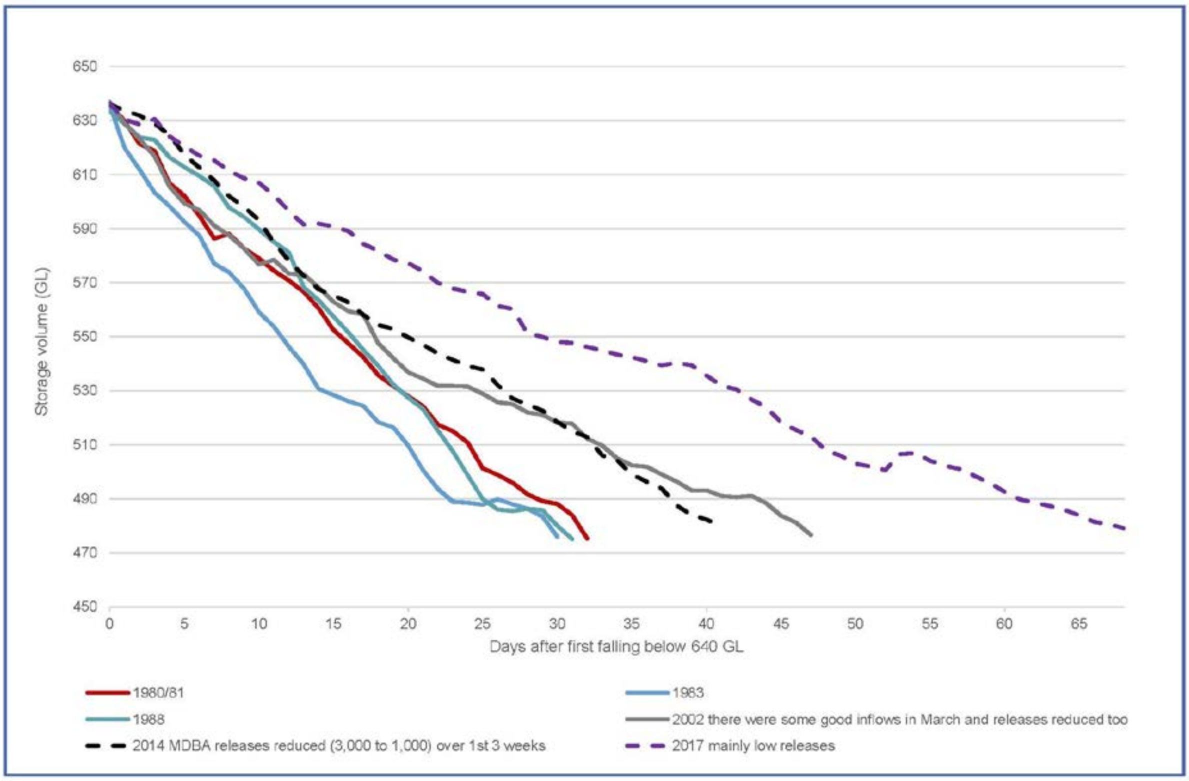


Figure 5-34: Storage fall rates from 640GL to 480GL at Menindee Lakes, compared across various years. This shows that the most recent MDBA releases were conservative, being more gradual than in prior years (Data sourced from MDBA).

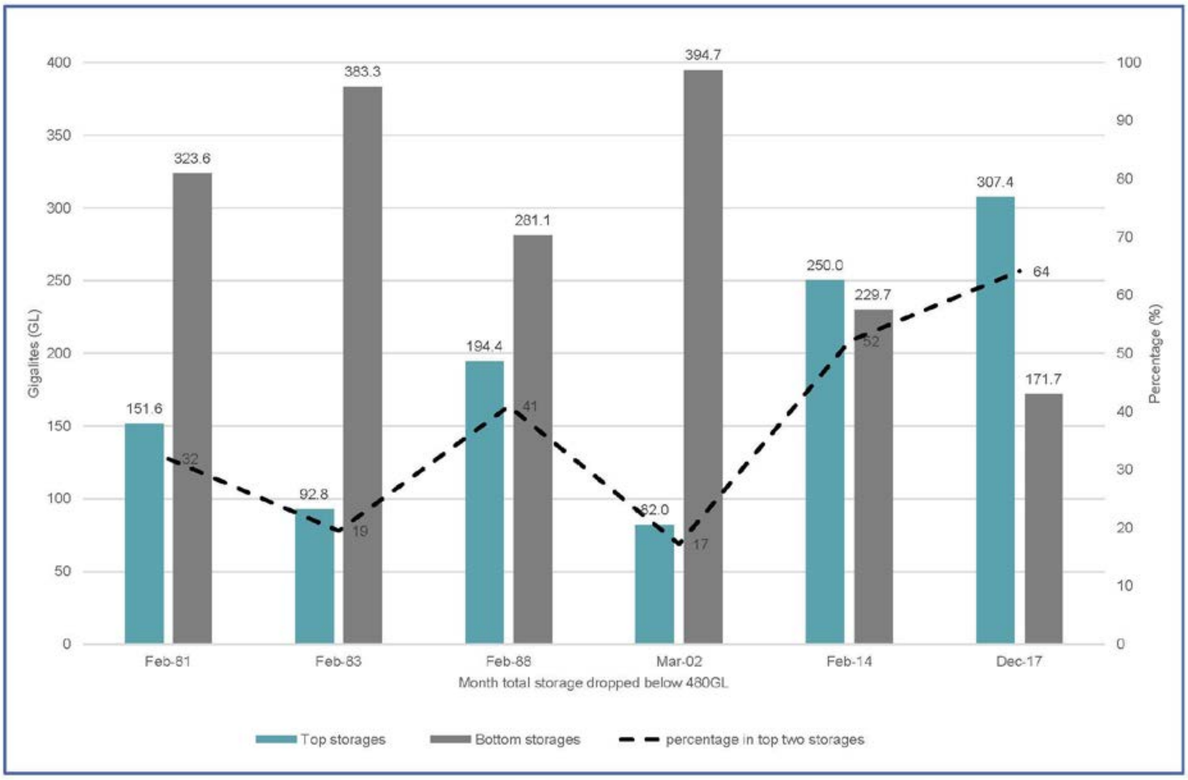


Figure 5-35: Comparison over various years of the distribution of total water storage within the Menindee Lakes system when storage volumes fall to 480GL and are handed over to NSW control. This shows that in more recent times the MDBA has sought to bias storage to the upper lakes to provide more options for later downstream use (Data sourced from MDBA).

In late October 2017, releases from the lakes were reduced due to rain on the Murray River suppressing demands. By early November 2017, MDBA releases had reduced to 700ML/day on advice from ecologists to maintain steady flows through the lower Darling River in support of 2017 spring breeding of Murray Cod. An associated reduced contribution to the Murray River System was underwritten by the Commonwealth Environmental Water Holder (CEWH). The MDBA continued delivery until mid-November, when rain along the Murray River again suppressed demands. To maintain flows at 700ML/day, environmental water was released from Menindee until the 15 December 2017, when Menindee Lakes reached a level of 480GL and WaterNSW commenced implementation of drought management measures. From 15 December 2017, when the 480GL trigger was reached, no additional environmental water releases were made to the lower Darling River from the Menindee Lakes.

During this period, water was also being released by WaterNSW from Cawndilla into the Great Darling Anabranch. Between July 2016 and January 2018, 164GL was released, of which 100GL was environmental water intended to achieve fish breeding and dispersal outcomes in the Darling Anabranch (again, downstream dispersal of juvenile Golden Perch was a priority given the potential for stranding in Lake Cawndilla). The remainder of the water released was to meet orders of local entitlement holders.

5.3.4 Influencing factor 4: Fish mobility

As noted earlier, the high flow conditions in 2016 created considerable opportunities for fish breeding and recruitment in the lower Darling River. Fish populations were further enhanced by the strategic use of environmental water, to the extent that approximately 30% of all Murray Cod and nearly 40% of all Golden Perch sampled in the Darling River between Menindee and Wentworth were estimated to have been recruited in 2016 and 2017 (Sharpe and Stuart, 2018). The lakes also provided an important nursery habitat, particularly for Golden Perch.

As water was drained from Lake Menindee in 2017, this large biomass of fish would have been transferred and concentrated into the Darling River between Weir 32 and the Menindee Main Weir. The Old Menindee Town Weir is also a possible partial barrier to movement, which may have further concentrated fish toward the section of river closest to Weir 32. Because Weir 32 and Menindee Main Weir are partial barriers to dispersal (despite the presence of fishways which largely pass fish upstream), as flows were reduced, fish became trapped within the reach, with no capacity to move to reaches with more favourable water quality. Once the first fish death event occurred, bacterial decomposition of the carcasses (which sank to the river bed after several days and had no flow to disperse), would have contributed significant additional benthic biological oxygen demand, further increasing the likelihood of subsequent turnover events. Thus, while physical factors (low flows, hot climate and stratification) are the primary factors that explain the *cause* of the fish deaths, the *magnitude* of the events can in part be attributed to the high fish numbers and poor connectivity caused by fish barriers.

5.3.5 Findings relating to climatic condition influencing factors

Finding 8: The fish death events in the lower Darling were preceded and affected by exceptional climatic conditions, unparalleled in the observed climate record.

Finding 9: The recent extreme hot-dry weather events in the northern Basin have been amplified by climate change. Future changes in the global climate system are likely to have an even more profound impact on the hydrology and ecology of the Murray–Darling Basin and increase the risk of fish deaths in the future.

Finding 10: 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 of drought on downstream long-term water availability.

5.3.6 Findings relating to system hydrology and water management influencing factors

Finding 11: Modelled flow data up to 2009 indicate 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 effect of upstream development on lake inflows during 2017-18 could not be determined, owing to the unavailability of an updated pre-development model and insufficient metering of extractions.

Finding 12: The relative effects of diversions within the Barwon–Darling tributaries upon inflows to the Barwon–Darling are greatest in dry years.

Finding 13: 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. However, when flows in the system are low, the capacity for extractions directly from the Barwon–Darling using A Class licences is a serious threat to the connectivity of the river between Bourke and Menindee

Finding 14: 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 twenty years.

Finding 15: Flows in the Darling River at Bourke and Wilcannia during 2017-18 were the lowest observed at those points over the last twenty years.

Finding 16: In recent times, one of the main impacts on the frequency, magnitude and duration of low flows in the Barwon–Darling River, which have high ecological importance, is the change in the behaviour and use of A Class diversion licences. Relaxing constraints on water access and providing more flexible "carry-forward" arrangements under A Class licenses in the 2012 Barwon–Darling Water Sharing Plan has led to significant increases in the extraction of water during low flow periods.

5.3.7 Findings relating to lake operations influencing factors

Finding 17: Contrary to public perception, 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.

Finding 18: Releases from the Menindee lakes throughout 2017-18 were lower than the minimum advised under the current lower Darling Water Sharing Plan, with the intent to prolong flows to meet stock and domestic and critical human needs requests.

5.3.8 Findings relating to fish mobility influencing factors

Finding 19: Weir 32 and Menindee Main Weir are partial barriers to dispersal (despite the presence of fishways which largely pass fish upstream); therefore, as flows were reduced, fish became trapped within the reach. This confinement likely exacerbated the scale of the fish deaths.

6 Terms of Reference 2: Fish management responses – effectiveness of responses and future strategies.

6.1 Effectiveness of response from Basin governments

Australian Government and Basin state water managers and environmental water holders met in late January 2019 to assess 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 since 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 aerators and other technologies to improve water quality in the affected areas.
- Undertaking localised fish rescues and translocations to establish ‘insurance’ populations.
- Undertaking a large clean-up effort to minimise rotting biomass that might give rise to further oxygen depletion in the weir pools.
- Embedding learnings from the current fish deaths and the subsequent emergency response into future management actions.

The Federal Minister for Agriculture and Water Resources announced a $5 million program to prepare a Native Fish Management and Recovery Strategy aimed at protecting and restoring native fish populations in the Murray–Darling Basin. This will draw on a significant body of work already undertaken by fisheries’ teams across the Basin states. Our panel was advised that the MDBA intends to convene a workshop to scope an approach to developing the strategy in April 2019.

6.2 Future Strategies and responses for native fish recovery

The lower Darling fish deaths have highlighted a need to develop and deliver an integrated native fish recovery strategy to augment works and measures being implemented under the Basin Plan. The Darling River has important cultural, biodiversity and recreational significance. This is evidenced by the myriad of aboriginal middens which contain the remains of Golden Perch, Murray Cod, river mussels and river snails. From a biodiversity perspective, the lower Darling River plays an important role as a recruitment hotspot and acts as the source population for fish in both the Lower Murray and Edward River (Sharpe and Stuart, 2018). Recent research also demonstrates that fish colonise the lower Darling from significant distances upstream (KarlTek Pty Ltd, 2018). Hence, there are several reasons why a healthy lower Darling fish community is important for ecological functioning not only for the Barwon–Darling River and the northern tributaries, but for the entire Basin also. However, given the prevalence of on-going adverse conditions across the northern Basin, and the length of time required to implement a strategic recovery program, the key elements of a fish recovery strategy need to be considered in the context of short-term (next 12 months), and medium-term (>24 months) actions.

6.2.1 Managing short-term risks to local populations

In the absence of any substantial rainfall in the northern Basin over the next few months, native fish populations in the lower Darling face significant threats. Populations of native fish are still currently isolated in natural pools and weir pools that are disconnected and separated by dry river channel. This includes the weir pools around Menindee (Main Weir pool and the weir pool of Weir 32). The drying of other pools (Wilcannia, Tilpa and Louth), and the main channel, between Menindee and Bourke and below Menindee towards Wentworth means remaining populations along the Darling River, between the lower Murray River and the northern Basin tributaries are becoming increasingly geographically isolated and increasingly vulnerable.

Persistence of drought conditions throughout 2019 would mean several fish recovery actions need to be implemented. These actions should involve a combination of risk assessments and specific site based interventions. A risk assessment founded on careful monitoring would identify key sites for maintenance of fish

populations through the Barwon–Darling system. Such an assessment should identify which of these key sites is of high risk and prioritise the actions required, if any, at each of these sites to minimise future fish deaths (Figure 6-1).

Murray Cod are presently listed as vulnerable under the Commonwealth Environment Protection and Biodiversity Conservation Act (1999) and under those provisions a detailed recovery plan has been developed – “The National Recovery Plan for Murray Cod”. The plan, specifically section 3.10-3.15, outlines the common causes of fish deaths and outlines a detailed set of actions required to ameliorate and minimise fish death risks into the future. The plan contains a detailed set of recommendations which have been fully costed for implementation.

Managing short-term risks would require:

1. Establishing a basin-scale “emergency response” group (cross jurisdiction and agency) for scoping, planning and implementing a risk assessment framework for fish across the northern MDB and associated site-specific responses;
2. Identifying sites across the northern Basin that are key to the long-term maintenance of fish populations both locally, regionally and across the entire Basin;
3. Identifying which of these sites are likely to be at significant risk of fish deaths during the remainder of 2019/20;
4. Prioritising, where possible, intervention actions for these sites;
5. Identifying the range of technological interventions available to reduce the risk of fish deaths at key sites (eg. de-stratification, oxygenation, fish removal); and
6. Continued monitoring at key sites to assess impact of any deployed intervention.

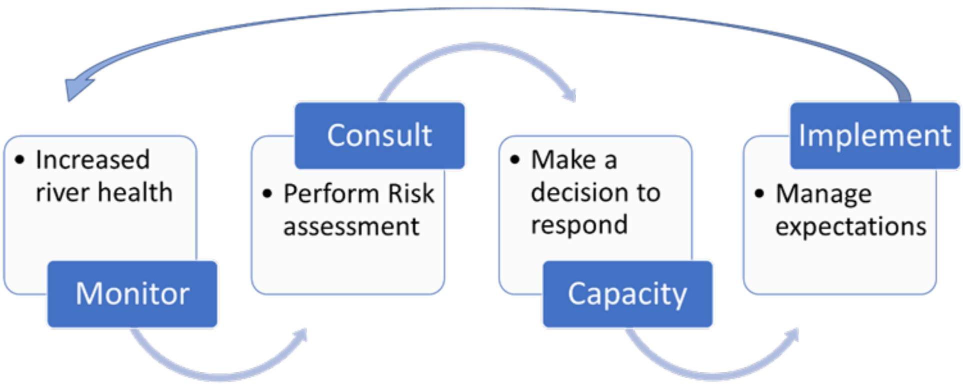


Figure 6-1: Scoping a plan to facilitate potential future responses to fish deaths. The overall outcome of river health requires a strong monitoring program that can inform a risk assessment. The risk assessment outcomes then require consultation and decision making among agencies, whether or not to respond. If sufficient capacity exists, response plans can be implemented, but not all fish deaths can be dealt with, so expectations need to be carefully managed.

6.2.2 Protecting refuge habitats

A survey by NSW DPI in 2015 suggested there were approximately 1,250 refuge pools in the Barwon–Darling between Walgett and Menindee, with average pool volumes ranging from 9 ML to 20 ML (Table 6-1). The panel notes that the aggregate volume of weir pools is small in relation to total system flows, but that it is of a similar scale to the volumes extracted from the A Class flow band since 2014 (Figure 3-2). Extractions within this flow band, and their effects on low and cease to flow hydrology, likely have a material impact on the persistence of refuge habitats downstream. It follows then that low flow extractions during drought sequences pose a threat to population resilience of both fish and other aquatic organisms.

Zone	Zone Length (km's)	Total number	Total surface area (Ha)	Mean depth (m)	Average Pool Size (ML)	Total Volume (ML)
Walgett - Brewarrina	279	297	51.5	5.1	8.8	2,614
Brewarrina - Bourke	207	216	55.9	4.5	11.7	2,527
Bourke - Tilpa	355	374	157	4.7	19.7	7,364
Tilpa - Wilcannia	275	182	65.1	4.5	16.1	2,930
Wilcannia - Menindee	*~250*	*~180*				*3,000*
						18,435

Table 6-1: Total number of refuge pools recorded between Walgett and Wilcannia (Data sourced from NSW DPI 2015). Surveys between Wilcannia and Menindee were not undertaken so the number of pools has been estimated based on the river km distance being similar to that between Tilpa and Wilcannia

6.2.3 Addressing threats to connectivity

Connectivity along river channels is vital for the maintenance of healthy fish populations. It allows fish that may have recruited in floodplain lake areas, such as Menindee, to disperse out of nursery habitats upstream into the main channels. Currently, there are a large number of in-stream barriers that impede the upstream and downstream movement of fish, concentrating them in particular areas of the river. This increases the risk of fish death events such as occurred at Menindee, and reduce population resilience more generally by limiting opportunities for dispersal throughout the river system. Overall, there is a pressing need to increase opportunities for fish movement at low and medium flows, as well as ensuring that fish are able to survive in habitats distributed along the entire river system during periods with low inflow.

In addition to managing existing structures, during prolonged or pronounced dry periods, additional temporary weirs (so-called “block banks”) are frequently created in the river to provide temporary water security for stock and domestic supply. For example, in the lower Darling River between Weir 32 and Burtundy Weir, block banks have been constructed to provide temporary water security during the current low flows. There are currently four block banks in place between Weir 32 and Burtundy Weir. However, they supply only a limited number of customers and do not address the needs of all customers along the Lower-Darling. Block banks have also been constructed to supply users upstream of Menindee.

These block banks pose a number of risks. First, while in place, these still pools (as opposed to a flowing river) are additional high-risk locations for stratification. Secondly, to restart flows, the block banks are destroyed using earth-moving equipment to allow water to pass, and are only fully removed by high flows. This contributes to bank destabilisation and hastens the rate of sedimentation of downstream water holes, harming refuges that are important during low flow periods. Once flows restart, poor water quality in the impounded pools has the potential to trigger fish deaths as a front of high salinity water moves down the river. Third, until the next period of high flows the block banks will pose significant barriers to upstream and downstream fish dispersal (for example between Menindee and the Murray River). As such, their instalation and subsequent removal are another cost associated with the increased frequency and duration of cease to flow periods in the river. Until they are removed, the block banks will significantly slow fish recovery efforts in the region.

6.2.4 A whole of system approach to fish management

While the local responses are relatively short-term and focus on anticipating a repeat of 'worst-case scenario' outcomes at the site scale, a process should be implemented for developing a longer-term fish recovery plan, which includes a better understanding of the ecology of the Barwon–Darling system, and the relationship it has to the northern MDB tributaries.

A suggested initial step in implementing a full recovery plan is the development of a conceptual model of Barwon–Darling ecology broadly, including an understanding of fish abundance, population and community structure with the role of key sites (including Menindee Lakes) within the system identified. This will provide an understanding of the meta-population structure for key species and provide a Darling River basin approach to understanding how this system functions from a fisheries productivity perspective. Current hypotheses suggest that the upper Darling is a source (where adults migrate to and spawn), whilst the Menindee Lakes are a sink (where eggs and larvae settle and grow), in terms of fisheries recruitment in the Southern-connected basin. There is significant evidence that the Menindee lakes may act as a nursery habitat under some conditions. While there is clearly a sound knowledge of how appropriate storage operation and flow management can deliver positive spawning and recruitment outcomes for native fish in the lower Darling River the influence of upstream reaches also needs to be considered. For example, it is hypothesised that Golden Perch spawned further upstream in the Darling may drift downstream and enter the lakes during periods of high flow. Further work is required to fully understand how environmental water can be managed to enhance fisheries production above the lakes. Similar questions remain in relation to the lakes themselves, and should be considered as part of both the proposed review of the Menindee Lakes operating strategies and the water savings project.

One of the impediments to understanding impacts and developing recovery plans is a paucity of data collected in a similar manner across the region. It is therefore important that a robust and scientifically defensible ecological monitoring system for the northern Basin is established. This could include a "smart" monitoring system for dissolved oxygen and other water quality variables that affect ecosystem health during low or no flow periods. The monitoring system would need to include all relevant aspects of the Barwon–Darling ecosystem and indicators that were selected specifically for their sensitivity to changes in flow.

6.2.5 A fish "demonstration reach"

A "lower Darling demonstration reach" has been suggested as useful concept to trial various approaches that could be taken to rehabilitate, and recover, impacted river reaches. Ideally, this would be designed and implemented in collaboration with lower Darling communities, particularly the Traditional Owners of the *Barka*, the Barkandji. Demonstration reaches were successfully trialed, in all Basin states, as part of the previous Native Fish Strategy and were successful on many levels. They provided a community engagement and education tool, permitted the trialling of innovative interventions to enhance native fish, and provided measurable positive impacts for native fish. Interventions that could be implemented in the lower Darling include re-snagging, fishway construction, riparian vegetation enhancement, screening irrigation pumps and other diversions and restoring flow to disperse blue-green algal blooms.

6.3 Findings relating to emergency responses and fish recovery

Finding 20: The 2012 national listing of Murray Cod as a vulnerable species was partly based impacts of previous fish deaths. Actions to address fish death events are already developed and presented in the “National Recovery Plan for Murray Cod”. The plan provides explicit recommendations on priority actions and investments needed to prevent fish deaths into the future.

Finding 21: Combined community and government actions to respond to the fish death events successfully created refuge zones that protected remaining fish. Fish that were also rescued (Murray Cod, Silver Perch and Golden Perch) and translocated to create “insurance” populations, recovered quickly and are in good health.

Finding 22: Responding agencies have been inundated with offers from private industry relating to technology which could improve conditions in weir pools. The various technology solutions are being evaluated.

Finding 23: The prospect of more fish deaths exists due to low oxygen levels in the remaining weir pools. Without significant flushing inflows, further deaths of surviving fish may be expected in the future.

Finding 24: The full extent of the fish deaths on fish populations and the broader ecology of the lower Darling River will not be known until the current adverse conditions have abated, fish are no longer stressed and targeted research investigations can commence.

7 Terms of Reference 3: Recommendations

Throughout our consultation process, we were impressed by the amount and quality of technical work going on within the MDBA and the various State agencies involved in Basin Plan implementation. Being deliberative in nature, much of this is not visible to the public. In some areas of activity, notably river operations, environmental watering and crisis response, there is good cooperation between agencies and good outcomes being realised. In the more contentious areas of water policy reform, significant improvement is required. In our view, the relevant Ministers and Senior Officials should demand and champion greater ambition and accelerated delivery in Basin Plan implementation, before public trust in the reform process is lost. Our recommendations, outlined below, are confined to our Terms of Reference, but some of them have salience to the general challenge of implementing water reform in the MDB. Our intention is to recommend 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 grouped our recommendations under the headings of (1) recommendations for Basin policy makers, (2) recommendations for Basin managers, to be implemented within one year, (3) recommendations for Basin managers, to be implemented within two years, and (4) recommendations for Basin managers, to be implemented within three years. We have placed a strong emphasis on improving monitoring, data, models, reporting and engagement with science institutions, the community and Traditional Owners.

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. Delivering on these actions effectively and in a timely fashion will require (1) further investment to accelerate progress and deepen impact, (2) support by Basin Ministers and senior officials to take effect and (3) increased community and Traditional Owner involvement with implementation.

7.1 Recommendations for Basin policy makers

***Recommendation 1:* NSW should modify water access arrangements under the Barwon–Darling Water Sharing Plan to protect low flows.**

The water access arrangements associated with the current Barwon–Darling Water Sharing Plan, issued in 2012 just prior to the commencement of the Basin Plan, have led to an increase in the extraction of low flows. While low flow extractions do not impact on flows into Menindee directly (the volumes are too small), they do impact on the ability of the Barwon–Darling River to support the maintenance and recovery of fish populations between Bourke and the lakes, where fewer refuges are likely to persist due to more frequent cease-to-flow periods.

In recent times, one of the main impacts on the frequency, magnitude and duration of low flow events in the Barwon–Darling River is the change in water user behaviour as it relates to use of A Class diversion licences. This has been enabled by changes in the "carry-over" arrangements, and the ability to link A Class licences to pumps of any size. The capacity to “carry-over” A Class licence unused opportunity allocation to lower flow years means that licence holders can accumulate allocation that can be used to increase their water extraction at low flows if (a) the preceding years were exceptionally dry and they could not access flows within the A Class band, or (b) the preceding years were wet, and all their allocation came from B and C Class licences. This latter strategy has led to a behavioural change since 2012 which has significantly increased the volume of water extracted using A Class licences. Given that lows flows are spread throughout the year, this is likely to have impacted the transmission of low flows further down the river helping to maintain water levels in refuge pools. These connecting low flows are particularly relevant during dry periods.

In preparing their new, Basin Plan-compliant Water Resource Plan for the Barwon–Darling, NSW should modify the low flow water access arrangements to redress these adverse impacts. Such changes should be possible within the agreed Sustainable Diversion Limit.

***Recommendation 2:* In preparing future Water Resource Plans for catchments in the northern Basin, QLD and NSW should ensure that they give greater attention to the need to maintain hydrologic connectivity in the Barwon-Darling River.**

Our assessment has highlighted that low flows play a critical role in sustaining the ecology of dryland rivers. It is evident that low flows in the Barwon-Darling have reduced considerably over the last two decades, in part due to climatic factors and in part due to diversions. Cease-to-flow events have become longer, resulting in the loss of critical refuge habitats that riverine biota require to survive dry times. In addition to eroding water security for water users, these changes threaten to negate the environmental benefits being pursued under the Basin Plan. A recognised risk with the new Water Resource Plans being prepared to ensure Basin Plan compliance is that they focus primarily on within-valley objectives. We recommend that in preparing these new plans, QLD and NSW place a greater emphasis on whole-of-system connectivity.

Recommendation 3: Basin governments should 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 review should identify operating procedures and water management arrangements (including those upstream and downstream of Menindee) that minimise the likelihood of the lakes being at very low levels prior to summer, whilst minimising water security and environmental impacts across the Basin.

The existing arrangements for operating 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 640GL, and until the lakes drop below 480GL. Once the storage volume within the lakes is less than 480GL, 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 in the region, the Menindee Lakes is the first storage called upon to deliver water into the Western Murray, such that changes to its operation would influence reliability in South Australia, Victoria and NSW.

Our panel was advised 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 414GL addition volume in the lakes as of January 2019. Minimum releases from Menindee from January 2017 would have resulted in 244GL 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. However, whilst maintaining greater volumes of water in storage in the lakes would confer local benefits it would also result in greater water losses and thus have negative impacts on downstream water users (due to increased evaporation of the resource) and the downstream environment, particularly in the Murray.

We were also advised that the recently commissioned Broken Hill pipeline will significantly reduce the volumes of water needed to be set aside in the Menindee Lakes to meet NSW essential requirements. This will allow for greater releases when the storage is in NSW control and consequently potentially delay or mitigate the conditions that preceded the recent fish deaths. Piping stock and domestic water for lower Darling water users could further reduce the volume of water set aside to deliver critical human needs and remove the need for block banks. Any efforts to reduce releases and maintain drought reserves in the lakes will buy more time to potentially avert fish death or allow some significant inflows to arrive from upstream. However, it will also come at a cost to the downstream Murray water resource, impacting both water users and the environment. Clearly, there is a balance to be struck.

We recommend that the Basin governments work collaboratively to review and adjust the operating procedures for the Menindee lakes to strike a new balance between the competing objectives of maintaining overall system efficiency and improving environmental protection in the lower Darling. Strategies that minimise the call on water for human needs increase opportunities for operators to flexibly manage other risks during these periods. Revised operating arrangements should minimise the likelihood of the lakes being at very low levels prior to summer when flushing flows should be available to supress weir pool stratification.

***Recommendation 4:* NSW and the Australian government should re-evaluate the Menindee Lakes Water Saving Project to place a greater emphasis on improving water security and environmental outcomes in the lower Darling. Should the revised project contribute less to the agreed Sustainable Diversion Limits, the NSW government would need to commit to addressing the shortfall.**

The NSW government has identified the opportunity to significantly reduce evaporative losses from the Menindee Lakes through the Menindee Lakes Water Savings Project being established under the Sustainable Diversion Limits Adjustment process. Key components of the project are the removal of the requirement to store approximately 200GL of water in the lakes to cover evaporative losses associated with the supply of water to Broken Hill (6GL/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 current 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.

A re-evaluation of the project should consider the following objectives. The first is to create enduring environmental water entitlements from the evaporative water savings that can be used to improve ecological outcomes in the lakes and downstream. The second is to allow the held environmental flows generated in the northern Basin to be recognised and protected to flow into the lakes and downstream. The third is to provide for active management of cultural heritage values. The fourth is to provide explicit support for the recovery of endangered fish populations. The fifth is to manage the reliability risks to downstream users and their entitlements. The final objective should be to ensure water quality risks are actively managed.

This project is an opportunity for major reform and improvements to water management and the environment in the area. The project is perhaps not tenable in its current form, but it is the best opportunity in the past sixty years to reset and update how the lakes are managed to care for this part of the landscape into the future. It is an opportunity not to be missed. It will be important that the implementation of this project can be adaptively managed so that elements can be refined in response to improved knowledge or on-ground implementation issues. It would also be important to embed operational flexibility into the design, so that the Lakes can be operated to meet a variety of objectives under a range of conditions. Significant stakeholder consultation before a final proposal is adopted will be key to ensuring a successful project.

***Recommendation 5*: NSW and the Australian government should urgently finalise arrangements to support structural adjustment of lower Darling farm enterprises with permanent/perennial crops that depend on high reliability water entitlements, including appropriately targeted strategic water acquisition and compensation for the reconfiguration of farm businesses.**

A number of farm businesses in the lower Darling are critically dependent on secure and permanent access to high security water allocations to support perennial horticultural crops such as citrus and grape production. A combination of factors including upstream development and the dry climate sequence experienced in the last 15 years have resulted in a material reduction in the security of water supply to these enterprises. Further, the risks associated with projected climate change, the consolidation of upstream water demands, construction of the Broken Hill pipeline and the proposal to reconfigure the operation of Menindee Lakes are likely to increase the risk to water supply to these enterprises in periods of very low inflows such as experienced in the current season.

Whilst the impact of these factors are not exclusively the responsibility of governments, the reality is a combination of changed climatic conditions and changes to water policy mean that the costs of ensuring permanent access to high reliability water supply to these farm businesses outweigh the benefits. There are currently too many competing objectives for river operators to effectively meet the obligation to supply water to high reliability entitlement holders.

Strategic acquisition of these water entitlements, combined with financial support to reconfigure farm businesses, will have four main benefits. First, the social and economic costs of disruptions of water supply will be permanently addressed. Second, appropriately reconfigured farm businesses will be able to access general security water entitlements to remain productive when seasonal conditions allow. Third, key economic and social capital within the region will be retained. Fourth, river operations in the lower Darling will be better able to be focused on retaining ecological function in drier periods where the system is under stress.

Our panel is aware that these issues have been actively considered by government agencies for some years. In our view, the case for change is compelling and governments have a key role in mobilising the resources required

to facilitate the required adjustments to support changes in farm businesses and maintain community cohesion. Engagement and resolution of arrangements for the necessary adjustments should be re-invigorated and brought to resolution as soon as possible.

Recommendation 6: NSW and QLD should adopt an active event-based management approach to providing flows through the Barwon-Darling system. Flow management 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. Extraction is governed by long-term rules, rather than an actively engaged river operating framework as is common in the southern Basin. 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 limited provisions to prevent pumping once those minimum thresholds are reached. Some of the historic provisions, such as limiting the size of pump that can take A Class water, have been removed more recently. As 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). Such actions have been proposed but have not yet been adopted as policy. The recent fish death events highlight the importance of implementing these reforms as quickly as possible.

It is 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 Commonwealth Environmental Water Holder 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 the Australian government work together to address any policy conflicts and resourcing shortfalls required to overcome the active management challenges in this river system.

***Recommendation 7:* NSW should initiate a program to remove barriers to fish movement and enhance mobility through improved passage at existing weirs and regulators.**

Our assessment identified that stratification in artificially-created weir pools that inhibit fish movement was the root cause of the fish deaths. Furthermore, block banks and weirs without fish passages restricted dispersal away from the impacted zone. Removing such barriers and/or installing fish passages 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, we identified that barrier removal is not widely considered as a viable management option because weirs and block banks are relied upon for providing water security during low flow sequences. However if water quality is degraded during protracted low flow sequences, this intended function of weir pools and block banks is compromised. Options must also consider alternative supply options or ways to improve water quality. Both considerations may point to the protection of low flows as the most effective strategy.

We recommend that NSW undertake a review of high-risk structures and the potential for 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 undertaken.

Along the Darling River, the ability to avoid future poor water quality, or for migratory fish to recolonise the impacted zone will require pathways for fish to disperse and migrate. At present, the movement of fish within and between river systems north of Menindee Lakes, and through Menindee main weir, remains significantly restricted by dams and weirs without adequate fish passage. These barriers will significantly restrict the speed of recovery following

the fish death events. Furthermore, many fish are also either diverted into water distribution canals, or pumped onto crops and die. Mitigating these threats will require additional fish passage infrastructure to be implemented alongside watering programs in order to expedite recovery efforts in the lower Darling. Promoting and enhancing connectivity, through the construction of fishways and other such infrastructure will be key to accelerating recovery and building long term resilience of the riverine ecosystem.

In order to measure the recovery, it will be necessary to expand an existing array of monitoring systems (including the existing passive integrated transponder network and acoustic tracking systems) from the Murray and into the Darling River. We recommend a long-term commitment to scoping and implementing these fish passage actions, including monitoring, to augment fish recovery efforts and improve connectivity. 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).

Recommendation 8: ***NSW, QLD and the MDBA should publish their joint plans for implementation of the northern Basin Toolkit Measures, and set an aggressive timeline for delivery. Immediate priority should be given to those that would support native fish population's recovery and connectivity.***

The evidence we have examined in our assessment demonstrate 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. 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 fish ways and addressing cold water pollution issues through improved dam operations, and a new package of constraints measures in the Gwydir Valley. We endorse these measures and strongly recommend a whole-of-system approach to implementing them. This will complement environmental watering programs designed to facilitate fish recovery. We recommend 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.

Recommendation 9: ***Basin governments should initiate a joint program to significantly accelerate river model development to evaluate different Basin policy options.***

The complexity of managing water as a shared resource in the Murray–Darling Basin demands the use of sophisticated hydrologic models. Such models are used to analyse how discrete policies and management actions affect particular water users and regions under different climate sequences. These models are operated by small technical teams in each State and in the MDBA.

Basin governments (and Western Australia) recently agreed to adopt a national hydrologic modelling platform, Source[1] and retire their legacy models. Progress in transitioning to Source has been slow, mainly due to human capital and resourcing constraints, as well as duplication of effort and poor coordination. Nonetheless, most, but not all, of the Basin water resource management areas have Source models built. However, these models are yet to be joined in a whole-of-Basin version that can be used to readily assess the effects of changes in one State, to outcome in another. We are advised that some of the models do not adequately represent the current state of development. We also understand that the models still contain serious technical deficiencies, particulary in relation to low flow estimation and floodplain flows. These issues have tended to breed distrust between States and within the community also. Given where Basin governments now stand in Basin Plan implementation, this is seriously problematic, as it is impossible to reliably, quickly and transparently assess the impacts of discrete policy and rule changes on a whole-of-Basin basis.

We recommend that a working group, directed by an independent Chair with river modelling experience, be established to prepare a plan on how to accelerate model development so that a single MDB model can be created, and used, as soon as possible. This single model would serve as the definitive basis for discussing the effects of different policy options associated with the Basin Plan. The working group should consider resourcing requirements, human capacity requirements, technical infrastructure, institutional arrangements and protocols for running model scenarios and communicating results to governments.

[1] https://ewater.org.au/products/ewater-source/

***Recommendation 10*: Commonwealth and State governments should significantly increase investment in research and development, co-opting the science community, to address long-standing gaps in our knowledge of riverine hydrology and ecology. A priority focus of those new arrangements should be applied research that serves the information needs associated with Basin Plan implementation.**

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.

Government investment in water research and development has fluctuated significantly over the last three decades and funding has been administered via a large number of transient programs with constantly changing objectives and requirements. This has been confusing and time inefficient for the water research community and unproductive for end users of the knowledge. In recent years, government funding for water research has fallen away sharply. The aggregate level of investment in water research and development over the last three years is about 20% of that invested in the period 2007-2009, and is now only marginally higher than it was in the late 80s before water became a significant public policy concern. While Australia has sophisticated and well-resourced institutional arrangements for supporting agricultural research[2], no such infrastructure exists for water research and development, despite the pressing knowledge demands of the water sector and the demonstrated economic benefit of investing in water research (Chudleigh et al. 2006).

We recommend that the Australian government lead a process, with the support of State governments, to establish and resource effective and enduring institutional arrangements to support critical hydrologic and ecologic research. A priority focus of those new arrangements should be applied research that serves the information needs of Basin governments in Basin Plan implementation.

7.2 Recommendations for Basin managers, to implement within one year

***Recommendation 11:* NSW should continue emergency responses such as the use of aerators and fish translocations, noting that these are short-term emergency measures and may not prevent additional fish death events if adverse conditions persist or re-occur.**

Emergency responses are critical to support fish communities during death events. We identified that 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, Golden Perch and Silver Perch. We recommend that weir pool aeration be continued until the stratification, low oxygen and blue-green algal bloom events abate. Translocated fish should not be reintroduced until inflows have returned.

A very positive feature of the emergency response was the active participation of the Menindee community, who provided situational awareness on the status of fish deaths, operated some aerators and assisted with fish translocation. Much of that input was at their own cost. We recommend that future crisis intervention plans that may be prepared by the NSW government include specific roles and funding allocations for the community and the Traditional Owners.

[2] http://www.ruralrdc.com.au

<u>Recommendation 12:</u> Once the adverse environmental conditions have abated, NSW should undertake monitoring of fish populations in the lower Darling to more fully understand the impacts of the recent fish death events on fish numbers and remaining fish population status.

Fish continue to be stressed as the current adverse conditions persist. Performing invasive research activities whilst fish are under significant physiological stress could trigger further mortality. Without the ability to perform field research, there is limited ability to report on the number of surviving fish, nor assess the impacts on other biota. We recommend that NSW and the MDBA work together under the aegis of the Native Fish Management and Recovery Strategy to plan the research and mobilise funds so that the research can commence immediately once the conditions allow. It would greatly benefit the focus and conduct of this work if there was active involvement of the Indigenous community, so we recommend that the Barkandji have a strong role in the project. Planning this research should be a priority action for discussion at the planned April 2019 workshop being hosted by the MDBA to scope the Native Fish Management and Recovery Strategy.

It is important to recognise that while fish were the most obviously impacted biota, poor water quality, and hypoxic conditions affect all aquatic life. The second fish death 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, so it will be very important to assess the status of these biota also.

<u>Recommendation 13:</u> NSW and MDBA should jointly undertake a risk assessment to identify parts of the Darling Basin that are most at risk of future fish death events. This information should be used to inform the development of future early warning systems and emergency response plans.

In the likely event that severe droughts will reoccur in the northern Basin and that it will remain a challenge to maintain sustained hydrologic connectivity throughout the Darling River, future fish deaths in the lower Darling are likely to occur. As such, it will be of great assistance for governments to have ready access to early warning systems and emergency response plans. We recommend building such capability, founded on a risk assessment that highlights parts of the Basin that are most vulnerable to fish death events.

We have found no evidence that a risk assessment for fish death events was performed at Weir 32, despite a likely blue-green algal bloom event being identified in the Water NSW lower Darling Operations Plan over the 15 months prior to the fish death events occurring. The recent events have illustrated that under very low flows, certain sections of the river may be more at risk of low oxygen conditions than others. Notable candidates are stratified weir pools with algal blooms occurring and block banks constructed to secure water for stock and domestic use. 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 organic carbon load floodwaters.

We recommend that the risk assessment to be undertaken should determine which parts of the system are most susceptible to low oxygen levels as result of thermal and oxygen stratification in weir pools, block banks and other sections of rivers and lakes. This should be based on a consideration of channel depth and morphology, algal growth, organic carbon inputs and susceptibility to stratification and mixing. Simple models of thermal stratification could be used to determine at risk areas. A risk assessment of areas susceptible to high organic carbon low oxygen events should also be updated to ensure that there is comprehensive knowledge of risk areas, and to determine if there is combined potential impact with thermal and oxygen stratification. The impact of undershot weirs on releasing low oxygen water downstream should also be considered. Areas prioritised as risks should have oxygen, temperature and other monitoring equipment installed, if not readily available. These sites should be prioritised for additional monitoring, such as for algae and water quality, if not already covered by existing programs.

The risk assessment should be undertaken over a 12 month period, involving fisheries, water quality and hydrology teams from NSW, with the MDBA providing planning, coordination and integration support under the aegis of the Native Fish Management and Recovery Strategy. Using the outcomes of that assessment, NSW should progress to develop an early warning system similar to those in use for algal bloom alerts. Concurrently, formal emergency response plans should be developed. These should be based on learnings from the response to the recent fish death events, around which government officials, science teams and community members were mobilised to mitigate impacts.

<u>Recommendation 14:</u> NSW should review and refine the flow requirements to control stratification in weir pools deemed to be at high risk of fish deaths.

The flow requirements for minimising thermal stratification in high-risk weir pools should be reviewed and refined. The procedures should 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 the occurrence of low oxygen levels in the bottom layers and also reduce occurrence of toxic algal blooms. Keeping flows above a velocity of 0.03 m/s (a discharge of > 350ML/d at Weir 32) from the beginning of October through to the end of March would reduce the chances of persistent stratification developing and reduce blooms of the potentially toxic species *Dolichospermum circinale* (Mitrovic et al. 2011). The discharge required to attain these velocities and mix the water column will vary between weir pools based on channel depth, shape and the cross sectional area. This requires that a targeted analysis is performed for each weir pool deemed to be at high risk of stratification. More sophisticated hydrodynamic model development, taking into account the effect of sudden air temperature changes and wind gusts, will allow the risks of de-stratification to be better understood and planned for.

These stratification management procedures should be developed with algal bloom management issues in mind. For instance, although it may not be desirable to release water downstream from the Menindee Lakes which has high algal biomass, its ability to mix the water column under critical low oxygen periods may outweigh the negative effect of seeding algae that could bloom downstream. If water is not available to keep flows above thresholds to stop persistent stratification forming for the entire October to March period, the time period of hottest weather (November through to February) should be targeted.

<u>Recommendation 15:</u> NSW and QLD should establish an agreed protocol to protect first flushes.

After an extended dry period, it is desirable for the first flows, known as first flushes, to pass through the system without extraction. Protection of first flushes can have large environmental benefits without impacting significantly on upstream entitlement holders. Implementation of first flush protection in the Barwon-Darling requires the notification of pumping restrictions that can be easily understood and readily communicated. NSW and QLD should agree on a first flush protection protocol to ensure that sufficient volumes of water are conveyed through the Barwon–Darling and into the lower Darling once flow recommences. Given the degraded environmental condition of the river, this protocol should be agreed as a matter of urgency.

An appropriate first flush protection protocol should clearly define (1) the geographic scope and relevant water management areas to which it will apply, (2) the categories of access licenses to which pumping restrictions will apply, (3) the anticipated timing and volume of the first flush event, (4) management arrangements during the event and (5) the compliance regime that applies. This information should be communicated to all relevant stakeholders prior to the event.

<u>Recommendation 16:</u> Basin governments should ensure that the Basin Native Fish Management and Recovery Strategy is adequately resourced and involves authentic collaboration with government water scientists, academics and consultants, local communities and Aboriginal stakeholders. This strategy should build on efforts such as the lapsed 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 and research 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 and interests need to be reflected in the strategy.

***Recommendation 17:* The Commonwealth Environmental Water Holder, the MDBA, the Victorian Environmental Water Holder and the NSW Department of Environmental and Heritage should cooperatively undertake a risk assessment to determine how best to manage environmental water during prolonged dry spells, taking into account uncertainty in future inflows.**

There is mounting evidence for recent shifts in the climate and associated runoff patterns in the Basin, in particular an increasing frequency of dry spells. This is creating new challenges for how environmental water is delivered, particularly in determining how to incorporate uncertainty in future water availability in current decision making. Risk-assessment strategies should be developed to evaluate alternative options for the short- and medium-term use of environmental water in the northern Basin in particular, but also the Basin as a whole. In relation to the fish deaths in the lower Darling, this includes how environmental water could be used elsewhere in the Basin to increase the potential for long-term fish population recovery. These risk-based approaches should consider stochastic inflow sequences that reflect the range of possible future inflow sequences.

***Recommendation 18:* The MDBA's recently announced Climate Change Research Program must be adequately resourced and supported by relevant specialist science agencies and universities. A much better understanding of how climate change threatens Basin water availability and aquatic ecosystems must be obtained ahead of the 2026 Basin Plan review.**

As well as additional risk-based planning to determine how best to use existing water reserves during dry spells, a more substantial program of work is required to understand the implications of climate change for the Basin's water resources and ecosystems. Our panel was advised that the MDBA had recently released a discussion paper on Climate Change and the Murray–Darling Basin Plan, that identifies a number of priority activities that are required to effectively plan for and adapt to climate change in the Basin. This encompasses the need to address social, economic and environmental impacts and adaptation options. Significant additional investment will be required in order to properly undertake the necessary cross-disciplinary work in time to inform the 2026 Basin Plan review. The MDBA should progress this work with the active engagement of the Bureau of Meteorology, CSIRO and leading climate science teams in Australian universities.

7.3 Recommendations for Basin managers, to implement within two year

***Recommendation 19:* NSW and QLD should introduce more accurate continuous and real-time monitoring of diversions in the Barwon–Darling, to ensure protection of managed connectivity events. Compliance around all metering requirements and overland flow extractions should be strengthened expeditiously.**

In order to protect the passage of environmental water through the Barwon–Darling, it will be necessary to improve the accuracy and currency of diversion monitoring along the river. The crudeness of the monitoring technology being used in the river currently prohibits the systematic assessment of compliance of take with licence conditions. During our consultations, we were advised that the Basin states are now committed to have fully compliant metering throughout the basin by 2025 under the Murray–Darling Basin Compliance Compact. The NSW Government has also 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 stalled in their implementation. For instance, the National Framework for Non-urban Water Metering was agreed to in 2010 and yet we are still lamenting the lack of metering in stressed catchments. Given the past record of poor implementation of metering policies, NSW and QLD should regularly review progress of future metering programs.

***Recommendation 20:* NSW and QLD should improve the reliability and transparency of the assessment of the hydrologic impacts of floodplain harvesting.**

The panel has identified 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 streamflows within and between systems can only be known with certainty through collection of accurate information on floodplain harvesting volumes. We have been advised 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.

***Recommendation 21:* The MDBA should 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 by MDBA on an annual basis.

***Recommendation 22:* Commonwealth and State environmental water managers should cooperate to 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. This will become increasingly important as Basin governments seek to mainstream complex environmental watering events like the recent northern rivers connectivity event[3].

***Recommendation 23:* NSW should initiate a project to establish a "demonstration reach" in the lower Darling, where multiple threats to fisheries recovery are mitigated to create beneficial conditions for long-term fish recovery. This demonstration reach should be a key feature of the Native Fish Management and Recovery Strategy and should heavily involve the local community, including Aboriginal stakeholders.**

Our stakeholder consultation revealed that community and Indigenous groups seek a greater voice in river and fisheries management in the Basin. As well as being a significant source of water for local towns and irrigation users, the Menindee lakes, and the nearby Darling River, are also located in an area of environmental, social and cultural significance and provide recreational, tourism and economic opportunities for the towns and surrounding region. The demonstration reach concept was developed under the Native Fish Strategy (NFS) that was developed in response to the decline in condition of river systems and native fish populations across the Murray–Darling Basin. The demonstration reach model established a practical and comprehensive planning framework that involves the local community and all relevant stakeholders. It also sets up a monitoring and evaluation program to measure progress in the rehabilitation of riverine habitat and fish communities. The model maximizes the effectiveness of rehabilitation efforts by concentrating them on a reach of river. On-ground interventions can include (but are not limited to) habitat rehabilitation, management of alien species, improvement of water quality and fish passage, provision of environmental flows and fish stockings. The panel recommends that these community and cultural perspectives are considered and embraced by river managers; and that these are fitted within the existing demonstration reach model to develop a recovery and maintenance program for native fish in the lower Darling.

***Recommendation 24:* Basin governments should ensure that the Native Fish Management and Recovery Strategy includes appropriate elements of the Murray Cod National Recovery Plan pertaining to fish kills.**

The Murray Cod National Recovery Plan included specific treatment of activities and actions which lead to fish deaths. These were included on the basis that fish death events often involve Murray Cod and involve many individuals when they occur. The National Recovery Plan includes a series of actions and recommendations, which have been costed for implementation. Given the vulnerable status of this species, the panel recommends that the relevant elements of the recovery plan be incorporated into the Native Fish Management and Recovery Strategy.

[3] https://www.mdba.gov.au/sites/default/files/pubs/Review-of-Northern-Rivers-Connectivity-event-Oct-2018.pdf

7.4 Recommendations for Basin managers, to implement within three year

Recommendation 25: ***Basin States should upgrade their Strategic Water Information Monitoring Plans to reflect the enhanced hydrologic monitoring requirements associated with the Basin Plan and the recently agreed Murray–Darling Basin Compliance Compact, and agree to commit the necessary resources to enable these plans to be fully implemented.***

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. The need to improve the credibility of water information is particularly acute for certain forms of consumptive use, such as floodplain harvesting, that remain poorly characterised.

Recommendation 26: ***NSW should redress gaps in water quality monitoring (dissolved oxygen, temperature, algae) at high risk sites in the Barwon–Darling. This could include investigating and adopting emerging technologies such as remote sensing, and improving the use of real-time data to support early warning and forecasting.***

Our assessment identified that very limited monitoring was being undertaken for key water quality indicators that would have provided early warning of a potential fish death event. The downstream site at Burtundy did have oxygen logging installed and logging information that was available online, but Weir 32 did not have such information. Real-time oxygen data would have helped in determining risks of low surface water dissolved oxygen and the high daily fluctuations in oxygen caused by algal blooms. Algal bloom warnings had been previously been issued for Menindee and the site was on Red Algal Alert. The potential risks of this high algal biomass to fish mortality events was not considered at this location, but should be adopted into frameworks for risk management going forward. The extremely high biovolume of algae should be a trigger for further investigation of other risk factors to fish death (such as stratification leading to low surface water oxygen concentrations or elevated ammonia levels).

Consideration should be given to increasing installation of real-time dissolved oxygen and temperature monitoring equipment, such as equipment used elsewhere in the current WaterNSW monitoring network. These sensors could be added to existing monitoring sites and should include probe placement throughout the water profile so that they can detect stratification. We would also recommend real-time algal monitoring through fluorometry to track algal blooms, noting that this may only work in locations with low turbidity. This could be complemented by near real-time remote sensing for estimating algal biomass and surface water temperature. To progress this recommendation, we propose that an advisory group be established to scope and cost augmentations to the water quality monitoring network.

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.

Recommendation 27: ***NSW and QLD should improve monitoring of end-of-system tributary flows that contribute to hydrologic connectivity in the Darling system, and make that data readily available.***

Our assessment has identified 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, we recommend that NSW and QLD review their end-of-valley monitoring arrangements with a view to improving information about the relative contributions made by each tributary, both on an event basis and over the longer term.

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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 Baumgartner's 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. She is currently the Dean of Learning and Teaching at Griffith University.

Attachment B: Terms of Reference

Australian Government

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

Terms of Reference

The Minister for Agriculture and Water Resources has requested an independent panel assessment of the deaths of fish in the lower Darling River in December 2018 and January 2019. The independent panel will be chaired by Prof Rob Vertessy, University of Melbourne and Chair of the Murray–Darling Basin Authority's independent Advisory Committee on Social, Economic and Environmental Sciences (ACSEES) and will involve experts in fish ecology and be informed by the investigations being undertaken by New South Wales Department of Fisheries.

The objective of the independent panel's assessment will be to identify the likely causes of the 2018-19 lower Darling fish deaths and make appropriate recommendations within the operating mandate of the Murray–Darling Basin Plan and Murray–Darling Basin Agreement (Basin Agreement). The review will also help inform the development of the recently announced Native Fish Management and Recovery Strategy.

The independent panel will:

- assess the water management, events, and conditions leading up to the 2018-19 fish deaths to identify likely causes;
- assess the effectiveness of existing fish management responses to manage fish deaths risks currently being experienced in the lower Darling River; and
- provide recommendations to the Minister, 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.

In undertaking the assessment the independent panel:

- will engage and seek advice from relevant New South Wales Department of Fisheries scientists, and other experts in relevant fields, including native freshwater fish ecology, water management and water quality;
- assess information available and interviews with State and Federal agency staff and local residents including Aboriginal stakeholders;
- provide a preliminary report and early advice and recommendations to the Minister by 20 February;
- 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; and

- provide a report to the Minister, Chair of the Murray–Darling Basin Authority Board and the Murray–Darling Basin Ministers no later than 31 March.

Both the early advice and the final report of the independent panel will be released publicly.

Background

In late December 2018 and early 2019 a number of fish deaths were reported in the Murray–Darling Basin. The most extensive were multiple fish deaths observed upstream of Weir 32 on the lower Darling River. These fish deaths in the lower Darling River resulted in hundreds of thousands of dead fish observed including iconic species such as Murray Cod, Silver Perch and Golden Perch, and very high numbers of bony bream, a key component of the aquatic food resource.

Under the Murray–Darling Basin Plan and the Basin Agreement a range of strategies and plans are employed for the effective management and operation of the Murray–Darling Basin. These include the operational plans for the management of the southern basin, the Water Quality and Salinity Management Plan and the Basin-wide Environmental Watering Strategy.

Attachment C: Record of Consultations

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
Workshop 27 February 2019	Workshop with experts from academia and government agencies. See Attachment D for agenda and attendance list.
Teleconference 5 March 2019	Marine and Freshwater Species Conservation, Department of the Environment and Energy
Canberra 18 March 2019	Murray–Darling Basin Authority technical staff
Canberra 18 March 2019	Commonwealth Environmental Water Office
Teleconference 19 March 2019	Joint briefing of NSW government agencies: • NSW Office of Environment and Heritage • Department of Premier and Cabinet • WaterNSW • Department of Industry – Land and Water • NSW Department of Primary Industries - Fisheries
Canberra 19 March 2019	Murray–Darling Basin Authority technical staff
Canberra 20 March 2019	Murray–Darling Basin Authority technical staff

Consultation with non-government groups and 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
Teleconference 5 March 2019	Lower Darling Horticulture Group
Teleconference 5 March 2019	Representatives from the Barkandji people of far west NSW
Teleconference 5 March 2019	Joint briefing for environmental groups: • Victorian Environmental Water Holder • NRM Regions Australia • OzFish • Land Rivers Network • Australian Conservation Foundation
Teleconference 5 March 2019	Joint briefing for industry groups: • Dairy Australia • Cotton Australia • National Farmers Federation • National Irrigators Council
Teleconference 6 March 2019	Menindee Water Users Group

Attachment D: Subject matter expert workshop - participants and agenda

Following is a list of subject matter experts who participated in the technical workshop to review our Interim Report on 27 February 2019:

Surname	First name	Affiliation
Ali	Shagofta	Department of Industry- Land and Water
Bailey	Anna	Department of Industry- Land and Water
Baker	Danielle	Department of Industry- Land and Water
Bamford	Heleena	Murray–Darling Basin Authority
Bettio	Lynette	Bureau of Meteorology
Bishop	Andrew	Murray–Darling Basin Authority
Brinkley	Anthony	Bureau of Meteorology
Burford	Michelle	Australian Rivers Institute, Griffith University
Chiew	Francis	CSIRO
Coleman	Matthew	Murray–Darling Basin Authority
Commens	Sarah	Murray–Darling Basin Authority
Duncan	Phil	Macquarie University Basin Community Committee
Dyer	James	NSW Office of Environment and Heritage
Hamilton	David	Australian Rivers Institute, Griffith University
Hart	Thomas	Department of Natural Resources, Mines and Energy
Jackson	Sue	Australian Rivers Institute, Griffith University Advisory Committee on Social, Economic and Environmental Sciences Australian Academy of Science Review Panel
Jacobs	Trevor	Murray–Darling Basin Authority
Joehnk	Klaus	CSIRO
Johnson	Hilary	Commonwealth Environmental Water Office
Kelly	Vincent	WaterNSW
Lay	Cameron	NSW DPI Fisheries
Lea-Perry	Kate	Commonwealth Environmental Water Office
Mallen-Cooper	Martin	Charles Sturt University
Marshall	Jon	Department of Environment and Science
Moggridge	Brad	University of Canberra
Moritz	Craig	Director, Centre for Biodiversity Analysis, Australian National University Chair, National Committee for Ecology, Evolution and Conservation Chair, Australian Academy of Science Review Panel
Pollino	Carmel	CSIRO
Pritchard	Janet	Murray–Darling Basin Authority
Robertson	John	Department of Agriculture and Water Resources
Simpson	Paul	Paul Simpson Consulting Ltd
Tamsitt	Lynn	Department of Industry - Land and Water
Thompson	Ross	University of Canberra

Lower Darling Fish Deaths Assessment
Preliminary findings and recommendations workshop

Wednesday 27 February 2019
Victoria Ballroom North
ParkRoyal Hotel, Melbourne Airport

Agenda

Time	Agenda Item	Facilitator/ Presenter
10.00-10.15am	**Welcome and introductions**	Professor Rob Vertessy (Chair)
10.15-10.45am	**Assessment terms of reference and process**	Professor Rob Vertessy (Chair)
10.45-11.45am	**Rapid scan of the room: Strengths and weaknesses of our initial analysis and proposals**	Professor Nick Bond
11.45am-12.45pm	**Gaps and missed opportunities in our report: Where our panel might focus next**	Professor Fran Sheldon
12.45-1:00pm	**Identifying topics and teams for deeper analysis in break-out groups**	Associate Professor Lee Baumgartner
1.00-1:30pm	**Lunch**	
1.30-3.00pm	**Discussion in break-out groups**	Independent Assessment Panel
3.00-3.30pm	**Summaries of break-out group discussions**	Independent Assessment Panel
3.30-4.00pm	**Wrap up** • *Reflections on feedback and advice received* • *Next steps*	Professor Rob Vertessy (Chair)
4.00 pm	**Meeting Close**	

Attachment E: Written submissions on the Interim Report received

Formal submissions received

Author	Date received
Murray Lower Darling Rivers Indigenous Nations	15 March 2019
Bureau of Meteorology - Climate Services Section	15 March 2019
Murray–Darling Basin Authority - River Operations team	15 March 2019
Barwon–Darling Water	15 March 2019
Professor Richard Kingsford, UNSW Professor Sarah Wheeler, University of Adelaide Professor Sue Jackson, Australian Rivers Institute, Griffith University. Professor Linda Louise Blackall, University of Melbourne	15 March 2019
Barkandji Native Title Prescribed Body Corporate	22 March 2019

Informal submissions received

Author	Date received
Professor Michael Stewardson, University of Melbourne	24 February 2019
Dr Martin Mallen-Cooper, Charles Sturt University Director, OzFish Unlimited	25 February 2019 and 9 March 2019
Murray–Darling Basin Authority - Metering and Measurement team	26 February 2019
Cotton Australia	7 March 2019
Australian Floodplain Association	9 March 2019
Department of Natural Resources Mines and Energy and Department of Environment and Science	15 March 2019
Craig Moritz, Australian National University	15 March 2019
Commonwealth Environmental Water Office	19 March 2019

Attachment F: Expert Reviewer Profiles

Following are the profiles of experts who undertook a technical review of our draft Final Report.

Professor David Hamilton

Professor David Hamilton is the Deputy Director in the Australian Rivers Institute at Griffith University, Brisbane. He has long-running research interests and programs in lake water quality modelling, cyanobacteria harmful algal blooms and real-time environmental sensors for measuring parameters in lakes. He has previously held academic positions at the University of Western Australia in Perth and the University of Waikato in New Zealand; the latter as the inaugural chair in lake restoration.

Professor Hamilton is editor-in-chief of the scientific journal *Inland Waters* and holds editorial board positions on a number of scientific journals. He holds an ongoing position as visiting professor with the Nanjing Institute of Geography and Limnology (NIGLAS), held a distinguished visiting professor fellowship with the Chinese Academy of Sciences in 2011, and became a Hohai Scholar with Hohai University, Nanjing in 2019.

Professor Peter E. Davies AM

Professor Peter Davies is a Professor of Zoology at the University of Tasmania, and a research and consulting scientist specialising in freshwater environmental issues. In 2012 he was appointed a Member of the Order of Australia *'for service to conservation and the environment as a contributor to national water policy development and through research of Australia's rivers and waterways'*.

Professor Davies has 30 years' work experience in aquatic environmental research and management, with skills in the conservation of aquatic biota, environmental pollution, environmental water management and bioassessment. A graduate of the University of Tasmania, with a BSc with Honours in Chemistry, and a PhD in aquatic toxicology, he worked as fisheries biologist and ecologist with the Tasmanian Inland Fisheries Service for 9 years then as national science coordinator for the National River Health Program for 10 years. In 1993 he established the aquatic environmental consultancy Freshwater Systems.

Since 2000, Professor Davies has been Chair of the Independent Sustainable Rivers Audit Group (ISRAG), the science panel reporting the ecosystem health of Murray–Darling Basin rivers. He provides science and management advice on minimising agriculture, mining, hydro and forestry impacts on streams, and works with community groups on stream restoration.

Professor Sue Jackson

Professor Sue Jackson is a cultural geographer with a PhD from Macquarie University and 25 years’ experience researching the social dimensions of natural resource management, currently with the Australian Rivers Institute at Griffith University. She has research interests in the social and cultural values associated with water, customary Indigenous resource rights, systems of resource governance, and Indigenous capacity building for improved participation in natural resource management and planning.

Professor Jackson’s expertise includes environmental flow assessment and qualitative research methods, and she is leading several projects through the Australian Research Council and the Commonwealth’s National Environmental Science Program, and is a co-convenor of Waterfuture’s environmental flows working group.

Professor Jackson is a member of several state and Commonwealth technical advisory panels, including those for Kakadu National Park, the Lake Eyre Basin Ministerial Forum and the Uluru-Kata Tjuta National Park Board of Management. In February 2019 Professor Jackson served on the Australian Academy of Science panel looking into the fish deaths.

Paul Simpson

Paul Simpson is a resource management professional with 24 years' experience in water management across NSW and the Murray–Darling Basin. He has extensive experience in the management of major regulated river systems, including the use of hydrologic modelling to inform key water management decisions.

He has been involved in the development and application of strategic policy and planning over many years with the NSW government, with a focus on translating the lessons learnt from practical experience through droughts and floods into the state water management framework. His technical and project management expertise is complimented by many years of experience in intergovernmental processes in the Murray–Darling Basin and the balancing of competing users for scarce water resources.

Dr James Horne

Between 2007 and early 2011 Dr Horne was Deputy Secretary in the Australian Department of Sustainability, Environment Water, Population and Communities, with responsibility for Water, where he led the development of water policy in the Australian Government. He was Chair of the Murray–Darling Basin, Basin Officials Committee and the Council of Australian Governments' Water Reform Committee.

James held senior executive positions in the Australian government over 20 years, including in the Department of the Prime Minister and Cabinet (as Head of the Industry, Infrastructure and Environment Division, including responsibility for COAG) and the Australian Treasury including as General Manager of its Macroeconomic Policy Division. James was Minister (Economic) at the Australian Embassy in Tokyo between 1994-1996. In 2005-2006 he was Chief Executive of South Australia's Department of Transport Energy and Infrastructure.

In January 2011, James retired from the Australian public service. He is a member of editorial board of the Journal of Water Resources Development. He is currently Principal of James Horne and Associates.

Chris Guest

An economist, Chris Guest has over 20 years' experience in water reform, working for the New South Wales and then the Commonwealth Governments. With the Commonwealth, he was part of the team that developed the Water Act (2007) and the Basin Plan (2012).

Chris' expertise is developing policy and managing complex negotiating processes to implement reforms. Recently, he was the co-author of the *Murray–Darling Basin Water Compliance Review.* The report investigated compliance practice and recommended measures to address water theft, about which there was considerable public concern, following a Four Corners program. He has written a book on the history of the Basin's politics, titled *Sharing the Water: One hundred years of River Murray politics* (2017).