Department of Planning and Environment

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Fish deaths in the Darling–Baaka River – Part A

Part A of the submission to the OCSE independent review into the February–March 2023 fish deaths in the Darling–Baaka River, Menindee

July 2023

Acknowledgement of Country

The Department of Planning and Environment acknowledges that it stands on Aboriginal land. We acknowledge the Traditional Custodians of the land and we show our respect for Elders past, present and emerging through thoughtful and collaborative approaches to our work, seeking to demonstrate our ongoing commitment to providing places in which Aboriginal people are included socially, culturally and economically.

Published by NSW Department of Planning and Environment

dpie.nsw.gov.au

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First published: July 2023

Department reference number: DOC23/195483

Acknowledgements

The Department of Planning and Environment Water acknowledges the work of Professor Darren Baldwin, which is cited in this submission.

TMP-MC-R-LC-V1.2

Contents

This document is Part A of the submission and should be read with Part B. Together, Part A and Part B make up the full submission from the Department of Planning and Environment to the OCSE independent review into the February to March 2023 fish deaths in the Darling–Baaka River, Menindee.

1 Introduction

The NSW Department of Planning and Environment - Water Group (DPEW) thanks the NSW Office of the Chief Scientist & Engineer (OCSE) for the opportunity to provide a submission to the independent review into the February-March 2023 fish death event in the Darling-Baaka River at Menindee. This Submission responds to the OCSE's Terms of Reference for the independent review, published on the OCSE's website.

1.1 Role of department's Water group

The Department of Planning and Environment's Water group (DPEW) is responsible for water security and managing water resources in NSW. From a statutory perspective, the primary role of DPEW in managing the Darling-Baaka River is to exercise its main functions under the *Water Management Act 2000* which are:

1. the development and implementation of the water sharing plan for the regulated Murray and lower Darling water sources, including a Water Resource Plan as required by the Basin Plan
2. the allocation of water
3. implementing the extreme events policy and incident response guides during extreme drought
4. participation in the management of the shared Murray resource (including the lower Darling) as required under the Murray Darling Basin Agreement
5. the management of Menindee Lakes when volumes fall below 480 GL.

Other agencies also have a role in managing the Darling-Baaka River:

- WaterNSW operates Menindee Lakes and the lower Darling in accordance with the water sharing plan and works approval, including the delivery of water orders.
- MDBA co-ordinates the management of the shared Murray resource (including the lower Darling) and is responsible for management of Menindee Lakes when water levels rise above 640GL, and until they fall below 480GL.
- The NSW and Commonwealth environment water holders manage their held environmental water portfolio.
- The Environment Protection Authority in terms of point source pollution

There is no legislative requirement for DPEW to manage water quality in the system, incl. hypoxic conditions and events, and indeed there is no single agency with overall accountability.

1.2 Responsibility for catchment outcomes

No single agency is responsible for NSW catchment outcomes, such as water quality. Both state and commonwealth agencies have high level roles but for many aspects of catchment management, there is no dedicated single, accountable agency. For other areas, such as monitoring, roles overlap or are duplicated by more than one agency. These gaps and high level roles and responsibilities for land and water management in regional NSW are outlined in the following Diagram 1

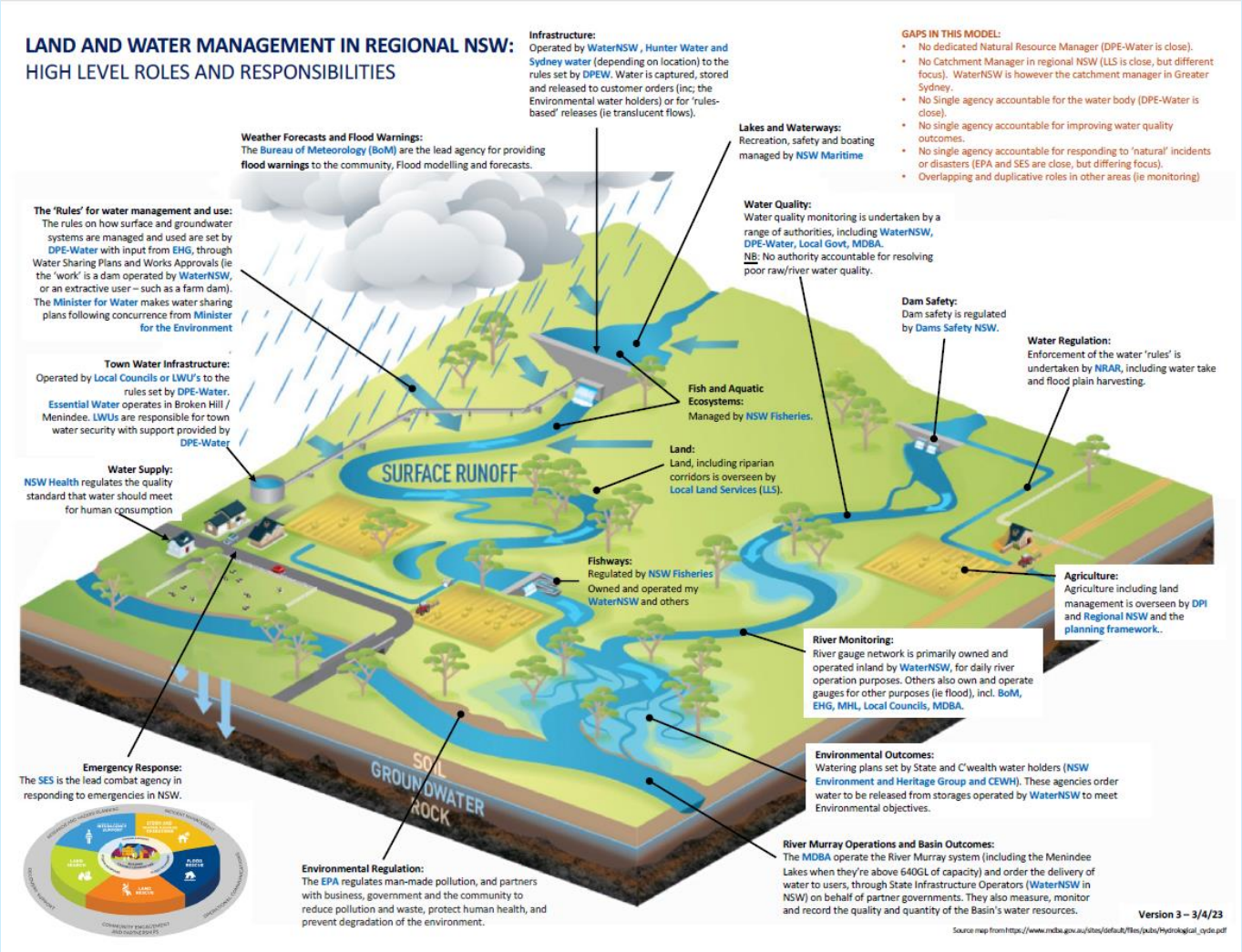


Diagram 1 - Land and water management in regional NSW

1.3 Context ahead of March 2023 event

1.3.1 The range of factors that contribute to hypoxic conditions and possible fish deaths

Hypoxic conditions are when there is low or depleted oxygen in the water body and can be caused by a range of circumstances.

As a result of the high flow periods experienced in the last 2 years, large amounts of organic material (sticks, leaves, bark, and grass) entered rivers after flooding reached parts of the floodplain that had not been inundated for a long time and where this material had time to accumulate. Blackwater occurs when the accumulated organic material breaks down in water on the floodplain and in the river. This process uses oxygen in the water which can lead to hypoxic conditions, i.e. a decrease in the oxygen available to fish and other aquatic organisms resulting in fish deaths.

In addition, algal blooms can increase oxygen levels during the day (photosynthesis), but conversely consume oxygen overnight in the absence of sunlight (via respiration). This can contribute to hypoxia in the early hours of the morning. Algal blooms may also contribute to low oxygen levels when the decomposition of dead algal cells consumes dissolved oxygen.

Respiration of organisms in the water body and sediment can also contribute to hypoxic conditions. Oxygen demand increases with increasing water temperature, yet the amount of oxygen the water can hold decreases with increasing water temperature.

If the oxygen in the water body is low enough, fish deaths can occur. As a general guide, native fish and other large aquatic organisms require at least 2 mg/L of dissolved oxygen (DO) to survive but may begin to suffer if levels are below 4 to 5 mg/L for prolonged periods.

Essentially, hypoxic conditions can occur when the oxygen demand is greater than the oxygen available. In many cases, there are limited levers available to control hypoxic conditions or any resultant fish deaths.

1.3.2 Historical incidents

Hypoxic blackwater events have been recorded in historical records since the late 1800s. A selection of historical articles relating to fish deaths, some of which are due to hypoxic blackwater, are published on the department's Hypoxic blackwater webpage In recent times, since the end of the severe drought in 2020, events have been occurring every Spring through to Summer/Autumn. Smaller scale fish death events also occurred elsewhere in the state in the wake of the 2022 record flooding, most notably along the Murray River.

1.3.3 Establishment of the hypoxic blackwater working group in 2021

In response to the clear need for active management of blackwater events by a cross section of government agencies, DPEW formed the **Hypoxic Blackwater Working Group** (working group) in 2021 to co-ordinate monitoring, communication (internal and external) and implementation of water resource management actions (where available) in response to hypoxic risks across the State.

A number of agencies contributed to the development of a draft guiding document to form the basis for the operation of the working group to respond to water quality incidents. The draft working version of that Terms of reference for the hypoxic blackwater working group is at **Appendix A.**

The working group is chaired by DPEW's Director Water Planning Implementation and has agile membership from multiple cross-jurisdictional agencies including NSW water-related agencies (DPEW, DPE Environment and Heritage, DPI Fisheries, WaterNSW), as well as Commonwealth agencies (Department of Climate Change, Energy, Environment and Water and the Murray Darling

Basin Authority) and invites representatives from Victorian and/or South Australian agencies as required. Other agencies, such as the NSW Environment Protection Authority (EPA) have attended when relevant.

There is no legislation that mandates which agency leads a response to hypoxic conditions, the creation of the working group or expressly governs the functions of the working group. Participation in the working group is entirely voluntary.

From time to time, expert advice is sought and the working group has been informed in particular by the expert advice of Professor Darren Baldwin. Management decisions and recommendations by the working group are made by consensus and are implemented by members exercising their respective functions and powers.

1.3.4 Working group's proactive response to managing river conditions from October 2022

The working group, comprising members with knowledge of the affected areas, was activated by DPEW in October 2022 when water quality conditions, specifically DO, started to deteriorate in the Murray, Murrumbidgee, Lachlan, and Barwon-Darling rivers.

The working group met at least fortnightly and, at times, held multiple meetings per week when critical conditions for ecological health were evident and management action was required. NSW and Commonwealth water agencies worked (and are still working) closely together to monitor and actively manage the situation with releases of better-quality water.

The management of releases from lakes Pamamaroo and Menindee from February 2023, through until April 2023 resulted in improved conditions in the Darling River, near Menindee Lakes. A flow chart outlining instructions made on the basis of decisions from the working group is below (**Figure 1**) and roles and responsibilities are further outlined in **Appendix B**.

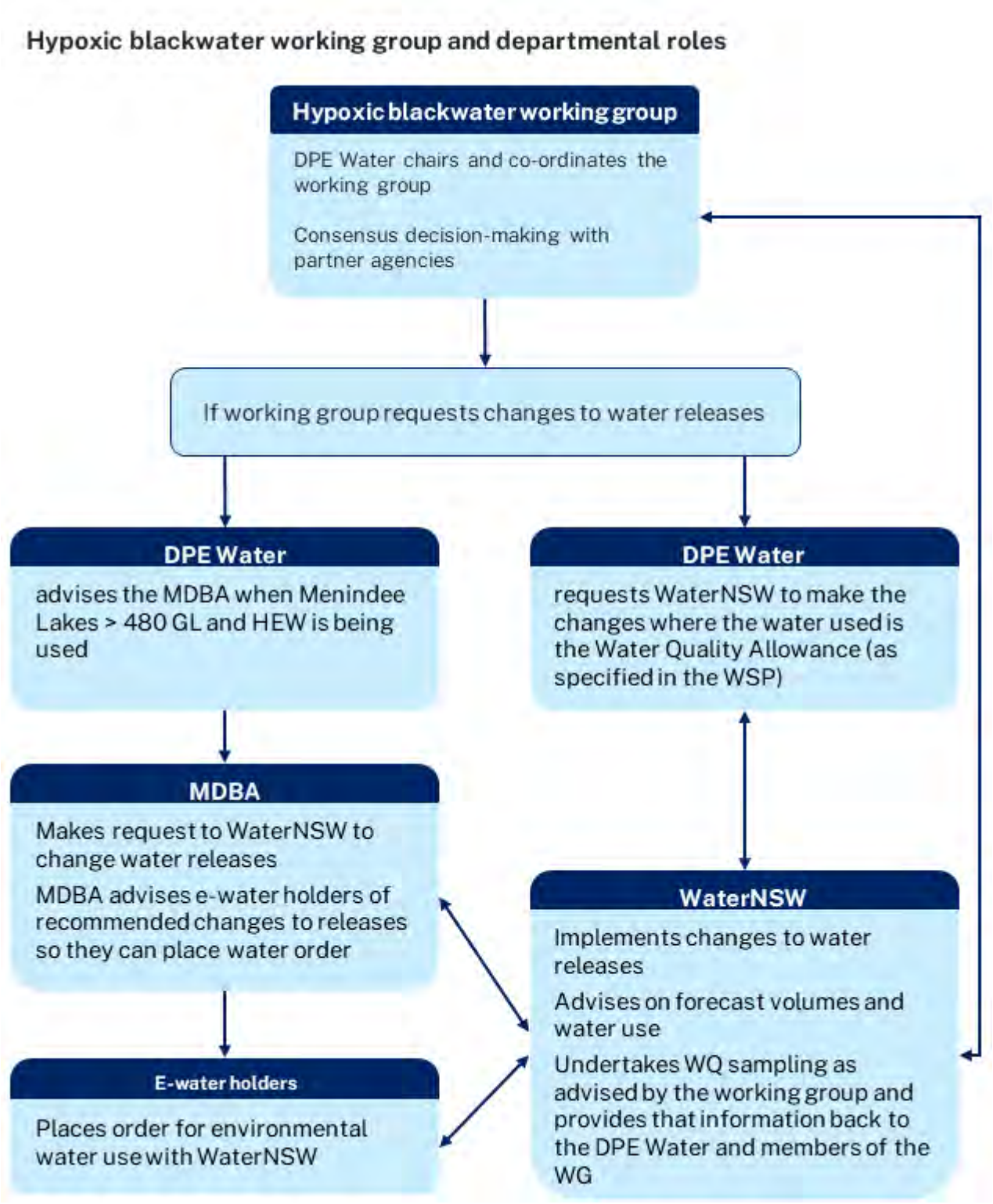


Figure 1. Flow chart outlining instructions made based on decisions from the Working Group

1.3.5 Deteriorating conditions in the river monitored and assessed regularly

The working group monitoring of dissolved oxygen (DO) from October 2022, showed deteriorating conditions across the southern and western Basin, including in the Darling River and in the vicinity of Menindee Lakes. These deteriorating conditions were caused by widespread floodwaters that

inundated floodplain areas that had not been flooded for many years, bringing a significant amount of organic material into the river as flood water receded.

In response to the critical conditions for fish health that were seen in the southern basin rivers, environmental water holders released environmental water through Murray Irrigation Limited escapes. This action assisted in providing refuge for fish of pockets of water with good DO and no large-scale fish death events occurred in the Murray during the period October 2022 to February 2023.

The event in the Darling River and Menindee/lower Darling was also exacerbated by an increase in fish biomass, particularly Bony Herring and Carp, due to ideal breeding conditions provided by 2-3 years of La Niña conditions.

Reports began to be received in late February 2023 of fish deaths occurring in the Darling River, including fish being stranded in disconnected pools as floodwater receded in the lower Darling. Large numbers of Bony Herring and Carp were affected, with increasing numbers of large-bodied native fish, such as Murray Cod and Golden Perch, also dying. As reported in the Factsheet 8 March 2023 published by DPEW, stranding of these native species in this manner was unusual, as the fish appeared to have avoided returning to the river channel, possibly because the water quality in the channel at the time was poorer, relative to that on the floodplain.

Deteriorating conditions continued as hypoxic conditions continued to generate in the reach at Menindee (between Main Weir and Weir 32) into March 2023.

1.3.6 DPEW proactive communication and engagement on blackwater events

DPEW has been proactive in keeping the community informed of blackwater events and management since December 2021, issuing regular fact sheets on emerging risks and events. These fact sheets remain on the DPEW website, with each new notification also being communicated via Twitter.

1.3.7 Increases to water quality monitoring sites

The monitoring of DO is generally the key parameter to indicate if water quality conditions are likely to contribute to fish deaths. DO (in association with flow, algal concentration, water temperature and prevailing weather conditions) can be used to identify high risk areas and provides data to establish an early warning system. Monitoring DO allows for the assessment of the ecological benefits of managed flows, flow rules and intervention measures during a critical water quality event.

The existing continuous DO monitoring network comprises 34 sites in the Murray, Murrumbidgee, Lachlan and Barwon-Darling River valleys. DPEW identified data gaps in the existing network in inland NSW through consultation with state and federal water management agencies via the working group in 2021-2022.

DPEW has identified 40 additional high priority monitoring sites and secured funding to commence installing these sensors during 2022–23 financial year. Due to extensive flooding, and damage to

the gauging station network, the installations have been postponed until 2023–24. A map showing the location of existing and proposed continuous dissolved oxygen monitoring sites is Appendix C.

The proposed sites for the Darling River include Tilpa, headwaters of Lake Wetherell, Menindee railway bridge, Menindee town, Weir 32 and Pooncarie. In addition to these fixed depth dissolved oxygen sensors, the installation of sensors at multiple depths for profile monitoring is proposed for Lake Wetherell, Main Weir, Weir 32, and Pooncarie to identify if oxygen is mixed through the whole water column and the benefits of intervention measures.

2 Likely causes of the fish death event

The conditions outlined in section 1.2.5 are supported by water quality updates provided to the working group, the updates available on the Hypoxic blackwater webpage and observation records available on the Bureau of Meteorology website for that period.

The prolonged periods of hypoxic conditions that were seen in the southern basin and Darling-Baaka River would be expected to lead to fish deaths.

Immediately after the February–March 2023 fish deaths, Professor Baldwin[1] wrote a preliminary file note report **(Appendix D)** for the MDBA and provided to DPEW on the likely causes of the fish deaths, based on the limited information that was available at that time, concluding:

Oxygen demand from a large biomass of fish, algae and other sources was more than the dissolved oxygen (DO) being supplied from Lake Pamamaroo water releases and aeration from the atmosphere.

Likely contributing factors to the fish deaths:

- *Large biomass of fish (not known at the time) that were possibly drawn to, and concentrated in, the upstream section of the weir pool between Main Weir and Weir 32, due to better quality water being released from Lake Pamamaroo.*
- *Algal biomass in the weir pool was increasing, possibly helped by nutrient recycling by the large biomass of fish, which would have contributed to a night-time sag in dissolved oxygen levels.*
- *Reducing water releases from Lake Pamamaroo to conserve water in the upper lakes meant that less oxygen was being delivered into the weir pool.*
- *High daytime temperatures at Menindee - low intensity heatwave conditions were forecast for 17 -19 March, and water temperature was in the mid-high 20s.*

To either support or discount various hypotheses, Professor Baldwin reviewed water flow velocity, hydrographs, satellite imagery, air and water temperature, visual estimates of dead fish biomass and subsequent calculations of oxygen consumption, DO levels and DO replenishment via the Lake Pamamaroo flows, and assumptions on fish movement.

Professor Baldwin concluded that the fish deaths were unable to be predicted with the information available at the time, with the significant, but unknown fish biomass being a major factor.

Professor Baldwin has since stated in a report that he has already submitted to the NSW OCSE, that the lack of fish passage at Main Weir and at the Lake Wetherell and Lake Pamamaroo outlets is a contributing factor.

[1] Professor Darren Baldwin is an independent expert in freshwater ecology with Rivers and Wetlands and is an Adjunct Visiting Professor with Charles Sturt University. Professor Baldwin has also been contracted by the MDBA and DPE Water to provide expert advice on hypoxic blackwater events, including the fish death event in 2022-23.

DPEW focused on responding to the fish death event but acknowledges Professor Baldwin's report on the potential cause of fish deaths that states "Given the available data it is not possible to unequivocally assign a definitive cause to the fish kill in mid-March 2023 at Menindee on the Darling River. The fish kill was most likely caused because of hypoxia." Key sites and locations are indicated in **Figure 2.**

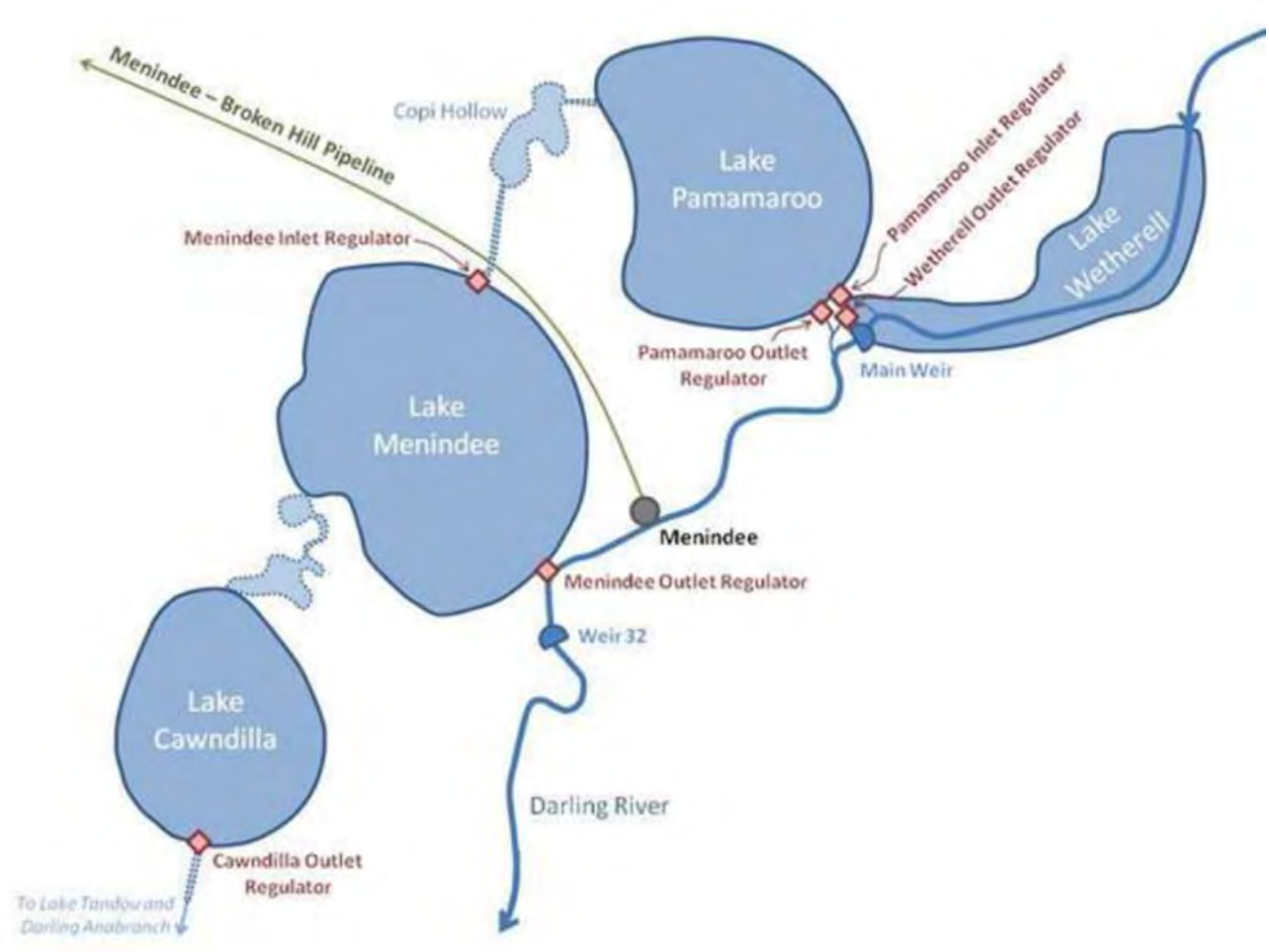


Figure 2. Schematic diagram of Menindee Lakes (Lake Tandure is omitted)

Professor Baldwin was also engaged to undertake a review of a report (**Appendix E**) that claimed fish deaths could have been caused by releases of blackwater into the Darling River downstream of Lake Pamamaroo outlet and found that there was little evidence to support such conclusions.

The EPA results of water quality analysis taken on 21 March 2023, indicated the concentration of all tested agricultural chemicals were below detection limits. The detected levels of heavy metals were below Australian Guideline trigger levels[2]. Ammonia/ammonium levels in Weir 32 weir pool on 21 March 2023 were likely to be much higher than levels during the fish deaths from 17–19 March 2023, because of the decomposition of dead fish. This analysis supports a conclusion that toxins or chemicals were not the likely cause of the February–March 2023 Menindee fish death event.

[2] Total metals have been compared to recreational water quality guidelines and dissolved metals have been compared to ecological water quality guidelines as per the National Health and Medical Research Council (NHMRC) Guidelines for managing risks in recreational waters and Australian and New Zealand Water Quality (ANZG) Guidelines for Fresh and Marine Water Quality, respectively.

NSW Health analysed water collected at the end of March 2022 during the management of the hypoxic blackwater event in 2021–22 and did not detect pesticide or cyanobacteria toxin levels above safe guidelines.

In addition to the monitoring conducted by other government agencies during the immediate period post-incident, increased water quality sampling commenced (primarily by WaterNSW as advised by the working group), and DPEW continued to monitor and report on water quality.

2.1 Monitoring data (including water data) available before the event

Water quality (WQ) reports used by the working group to support its decisions since October 2022 are at **Appendix F**. These are compiled by DPEW's surface water science team. WaterNSW also has a real-time DO monitoring network to alert agencies to emerging hypoxic conditions. Access to the network is via Real-time WQ data.

From late January 2023, hypoxic blackwater was evident in the Darling River at Wilcannia (DO<1mg/L) and Menindee Town was flooding (see WQ update dated 30 January 2023). By mid-February 2023, DO levels within the Darling River in the upper reaches of Lake Wetherell (Nelia Gaari temporary sensor site) had been critical (<1mg/L overnight, peaking at around 2.5mg/L during the day) for most of the month (see WQ update dated 23 February 2023). At this time the majority of floodwater had returned to the main channel around Menindee, and the Darling River downstream of Main Weir experienced DO levels <4mg/L at all sampling sites.

A WQ report from 14 March 2023 was provided to the Working Group immediately before the major fish death event. Additional WQ samples were taken in the weir pool on 14 March 2023 which are included in Factsheet 15 March.

2.2 Management and sufficiency of water flow at the time of the event

A timeline of key decisions and actions from February 2023 until the mass fish death event is provided in **Table 1**.

Pre-emptive management by releasing water from lakes Pamamaroo and Menindee attempted to improve water quality and mitigate against fish deaths. WaterNSW operates the Lakes according to rules that require reduced flows using a recession as per row 1 in Table 1, following flooding. Any additional water released from the lakes above normal operating requirements must be accounted for.

Normally, water releases would be made from Lake Menindee, and water would be conserved in lakes Pamamaroo and Wetherell (the top lakes) for future use. Because the impacted reach was between Main Weir and Weir 32, DPEW requested WaterNSW to release additional water from the top lakes to manage the hypoxic conditions. The Lower Darling Environmental Water Allowance of 30 gigalitres (GL), provided for in the Water Sharing Plan for the New South Wales Murray and

Lower Darling Regulated Rivers Water Sources 2016, was used first. When held environmental water was required, DPE or the MDBA requested the change and environmental water holders agreed to use of their held environmental water, placed the water order, and it was accounted for accordingly.

The commitment of environmental water use, and the volumes of that water to improve water quality is at the discretion of the environmental water holders. More information on environmental water use can be found on the websites for the Department of Climate Change, Energy, the Environment and Water and NSW Department of Planning and the Environment.

As outlined above, native fish and other large aquatic organisms require at least 2 mg/L DO to survive but may begin to suffer if levels are below 4 to 5 mg/L for prolonged periods. Given the conditions were deteriorating, actions were taken to improve DO to above 2 mg/L with the longer-term view to increase DO to above 4 mg/L. The fish biomass, and hence the associated oxygen demand, was unknown.

The working group decisions and recommendations are based on best available information and past event experience. The working group's consensus decision-making factored in the competing demands of maintaining a full storage (especially in the top lakes) to provide water for the lower Darling into the future, with the need to improve water quality and mitigate against fish deaths, and the use of environmental water that would otherwise be used for future environmental watering events.

No actions were identified that could be taken to address the hypoxic conditions upstream of Menindee Lakes, given that water on the floodplain was still returning to the river.

Table 1. Timeline of key decisions made by the Working Group and steps undertaken from February 2023 in the lead up to the Menindee mass fish deaths

Date	Action
Early Feb 2023	Menindee Lakes - Controlled recession continuing as flows go below 20,000 ML/day at Weir 32. The recession is undertaken in steps, decreasing by 1000 ML/day, then 500 ML/day, then 250 ML/day, as per WaterNSW' Work approval conditions.
24 Feb 2023	Menindee Lakes – monitoring reveals low DO and some fish deaths below Main Weir. Operations altered to try and minimise low DO below Main Weir. Following a consensus by members of the working group, DPEW requested WaterNSW to: Close the regulator between lakes Wetherell and Pamamaroo, except the Pamamaroo inlet gate with the fishway baffles. This can be left open to maintain some fish passage at the inlet regulator. This action will reduce low DO water entering Lake Pamamaroo. Regulator fully closed on 28 Feb 2023. If possible (noting the constraint at the regulator between lakes Wetherell and Pamamaroo), increase flows from Lake Pamamaroo outlet so they are maintained above current levels (3,200 ML/day), and delay any recession until the current hot weather ends (likely within the next few days). Increase outlet releases to 4300 ML/d in steps - achieved 28 February 2023. Reduce or cease releases from Lake Wetherell to ensure no low DO water enters the river downstream. Flows reduced from 2430 ML/d to minimum on 5 March 2023. Reduce releases from Lake Menindee outlet by 500 – 1000 ML/day to prevent water backing up into the channel upstream. Starting on 25 Feb at 3800 ML/d, reducing down to 3000 ML/d by 2 March 2023. As agreed at the recent working group, the water used at Lake Pamamaroo to keep flows higher than the planned recession can be accounted for against the Lower Darling Environmental Water Allowance (EWA). Use of this water has been discussed at the working group, and MDBA have confirmed that NSW can make this decision, given the EWA is part of the water sharing plan. Can WaterNSW please undertake monitoring in the Darling River between Main Weir and Weir 32 so we can assess this management action. DPEW will cover the additional costs. WaterNSW implements this and continues slower recession using additional water. The actions resulted in slightly improved DO and no further fish deaths
24 Feb–16 March 2023	30 GL of Lower Darling Environmental Water Allowance (EWA) used to provide increased flows above normal operational requirements for recession from Lake Pamamaroo to try and maintain DO levels above critical in the reach from Main Weir to Lake Menindee Outlet. EWA started 24 February 2023 and was exhausted on 16 March 2023. DPE published water quality update 24 February 2023. Resulted in slight improvement in DO and no further fish deaths reported

Date	Action
3 March 2023	Further request provided to WaterNSW, as per: "as confirmed at the hypoxic blackwater working group today, DPEW directs WaterNSW to continue the current release volumes from Lake Pamamaroo and Lake Menindee, until Monday (6th March), then commence the recession at the rate of 250 ML/day. This water is to be accounted against the WQA. I understand that the required volume will be in excess of the WQA, and the environmental water holder will confirm tomorrow, that the balance required will be met by the environmental water holder. As agreed at the working group, with our partner agencies, the purpose of the continued high releases is to reduce the risk of fish deaths in the section of the Darling River between Main Weir and Weir 32 and will do this by providing the best opportunity to maintain dissolved oxygen at higher levels than would otherwise occur, if normal operations were to occur." DPE published water quality update 3 March 2023, and WaterNSW issued an operational update.
12 March–20 March 2023	Water Quality Allowance provisionally exhausted, 24 GL of environmental water used so far to provide increased flows above normal operational requirements for recession from Lake Pamamaroo to try and maintain DO levels above critical in reach from Main Weir to Lake Menindee Outlet.
15 March 2023	Lower Darling Technical Advisory Group (TAG) meets, and reports fish have died in the Menindee town weir pool overnight and it is the opinion of the TAG that this has possibly been triggered by a reduction in flow from Lake Pamamaroo outlet (NB. The reduction is due to the recession, noting the recession is above normal works approval operating requirements and propped up by environmental water). Therefore, the TAG has recommended that WaterNSW return to a 70:30 outlet setting (70% from Menindee outlet, 30% Pamamaroo outlet) to help maintain flow of water through the town weir pool while continuing the recession plan at Weir 32. The above information is communicated to the working group. Major heatwave commenced
16–17 March 2023	DO dropped below 1 mg/L and major fish deaths occurred DPEW contacted WaterNSW and advised them to make the changes advised by the TAG. WaterNSW informed DPEW that the changes were underway. Flows increased from 1250 to 1500ML/day from Pamamaroo outlet to improve DO. Menindee outlet reduced from 3900 to 3500ML/day to improve flow-through velocity at Menindee outlet. This change is reflective of the request by the TAG on 15 March 2023.

3 Response to the fish death event

3.1 Hypoxic Blackwater Working Group actions

The working group increased meeting frequency and requested additional sampling be undertaken in response to the fish death events on 16 and 17 March 2023. Temporary dissolved oxygen sensors were also placed at two sites within the weir pool on 23 March 2023 – one at Menindee Town gauging station and the other at the Menindee pump station.

A timeline outlining key decisions and actions from 17 March 2023, in response to the mass fish deaths, up until the emergency response ceased is provided in **Table 2**. This timeline outlines a high frequency of monitoring and management of the DO levels by raising and lowering releases of water from the top lakes to improve water quality downstream. This was managed in the context of also maintaining longer term water supply in the top lakes.

Consideration was given to putting a large pulse release of water down the length of the weir pool, however the Working Group decided that this option was not feasible because it could push the low DO water throughout the weir pool and then below Weir 32.

Table 2. Timeline of key decisions and steps undertaken from 19 March 2023 to cessation of emergency response.

Date	Action
17 March 2023	Central Darling Shire (CDS) Council contacted DPEW requesting assistance from the NSW Government to help coordinate an on-ground response to the fish deaths. DPEW recommended that CDS consider the State Emergency Plan but also committed to contacting relevant agencies in order to try and identify who the lead combat agency should be as well as form a team of experts to respond.
18 March 2023	Emergency Operations Centre established by NSW Police in conjunction with agencies and the Central Darling Local Emergency Operations Committee (LEOC) formed. CDS noted a drinking water quality risk to residents using river water from between Main Weir and Weir 32 and, given the precedent of supporting these residents and the risk presented, agreed to fund water carting for these residents as has happened in the past.
19 March 2023	Struggling fish, including large-bodied native fish, observed below Lake Menindee outlet. WaterNSW is requested to increase releases from 2900 ML/day to 4000 ML/day at Lake Menindee (near maximum capacity) and the environmental water holder placed an order for that water. This action likely prevented a major fish kill downstream of Menindee outlet. Daily LEOC briefings commenced.

Date	Action
20–25 March 2023	Operational settings maintained – namely 1350 ML/day released from Pamamaroo and 4000 ML/day from Lake Menindee. Working Group meeting every 2 to 3 days, reviewing water quality results every day. Additional depth profile water quality monitoring within the weir pool, focussing on DO, commenced on 22 March 2023. Professor Darren Baldwin engaged on 24 March 2023 to assist with decision-making. The first longitudinal water quality survey, focussing on DO, commenced on 25 March 2023. Incident response plan and risk assessment updated. Town Hall meetings held Tuesday 21 March 2023 and Friday 24 March 2023.
29 March 2023	The NSW Premier, the Minister for the Environment and the Minister for Water visited Menindee. In response to continuing fish deaths and low DO levels, a flushing flow from Lake Pamamaroo was requested – releases increased by 1000 ML, taking the release rate to 2350 ML/day. Releases from Lake Menindee were decreased by 750 ML to take it to 3000 ML/day. Decreasing releases from Lake Menindee was expected to help the water from Lake Pamamaroo flow further down the river. WaterNSW issued an operational update.
30 March–3 April 2023	Releases decreased at Lake Pamamaroo by 250 ML/day until 3 April 2023 (taking releases back to 1350 ML/day) as it was advised that the reported fish deaths from 2 days prior had occurred in the stretch of river upstream of Menindee outlet. DPEW commenced communication directly with the MDBA to pass on requests to WaterNSW on water quality flow requirements. This was at the request of the MDBA.
31 March 2023	The LEOC formed to oversee the response at Menindee was stood down.
3–11 April 2023	Releases held to determine if DO improved before decreasing releases again, and while there were limited staff over Easter.
5 April 2023	The LEOC for Wentworth has been scaled back to ‘monitor’ and individual agencies remain responsible for their response to the event.

It should be noted that the risk of further fish deaths remains at June 2023, with a large volume of fish remaining and consuming large volumes of oxygen, particularly in the upper reaches of the weir pool. The working group continues to monitor water quality conditions and make recommendations to change volumes released from Menindee Lakes. Combined releases from lakes Pamamaroo and Menindee continue above the minimum base flow and this water is being accounted for against environmental water holder accounts. From 1 July 2023, any additional water used to manage water quality in this area will come from the Lower Darling EWA in the first instance. This action maintains an oxygenated flow in the Darling-Baaka River through Menindee township and reduces the risk of further significant fish deaths.

3.2 The role of different agencies/departments when responding to the event

The roles of the different agencies is outlined in sections 1.1 and 1.2.5 of this response and in detail at **Appendix B**.

DPEW also engaged Professor Baldwin who provided additional data and modelling information that assisted the Working Group in making decisions, and the group continued to collaborate and make decisions by consensus. This included making recommendations on changes to water releases from the various lakes in the Menindee Lakes System and designing the water quality sampling regime. Individual agencies were responsible for implementing and/or completing actions.

3.3 Actions taken by agencies/departments (including public health response) and others

The DPEW Chief Operating Officer represented the department on the LEOC and attended town hall meetings and meetings with Aboriginal community members.

The Working Group, coordinated by DPEW, increased meeting frequency and sampling to more readily respond to conditions. The Working Group provided recommendations and daily water quality updates to the LEOC.

DPEW coordinated a sub working group of communications, media and engagement staff from across all related departments. DPEW drafted community newsletters and FAQ updates with input from all agencies, worked with the Police Public Information Services Functional Area Command (PIFAC) lead responses to media inquiries, set up a new website, issued regular DO reports on the DPE website and via Twitter, and participated in the incident response team, providing support for proactive and reactive communications.

DPEW actively participated in the debriefing session, coordinated by NSW Police.

3.4 The role of the state emergency management framework

In scenarios where the local council may not be able to manage a local incident without additional support, the *State Emergency and Rescue Management Act 1989* (NSW) and its State emergency management plan (EMPLAN) and Local Emergency Management Committees (aka LEOC), provides a framework. The EMPLAN nominates a combat agency to lead the response for a number of different emergency situations.

However, the EMPLAN is not clear on which agency is the combat agency for fish deaths in a river. For example, NSW DPI is responsible for emergencies involving animals, the State Emergency Service is responsible for floods and the EPA is responsible for environmental incidents and at the time, the Menindee fish death event was not considered a pollution event. The newly formed NSW

Reconstruction Authority is responsible for preparing for and recovering from incidents, but not responding to them.

Due to this ambiguity, the emergency response was led by NSW Police via the LEOC.

The LEOC's main roles were ensuring there was adequate co-ordination across all relevant government agencies. Their focus was mainly on potable water supply to Menindee, water carting and treatment, and clean-up of dead fish. The LEOC also took on the role of co-ordinating stakeholder communications.

The State emergency management framework brought all agencies together to respond to the impacts of the fish deaths. This included agencies that are not core members of the Working Group e.g. Regional NSW (apart from Fisheries), NSW Health, Essential Water (local water utility), the EPA, NSW Public Works, Local Land Services, and local government.

3.5 Communications with the community including consultation with First Nations people and organisations

DPEW regularly published fact sheets about conditions across the state from October 2022 on the DPEW website. Eleven fact sheets and 8 maps were published between 8 October and 20 December 2022. Tweets were also issued during this period, to alert the broader community of information as it became available.

From November 2022, DPEW published weekly updates of a map of NSW that shows the water quality stages for hypoxic blackwater. These maps are provided at **Appendix G**. DPEW published 20 fact sheets, 20 maps, and issued 18 Tweets 11 January - 8 June 2023 to keep the community informed.

DPEW also emailed 'Community updates' to Menindee and lower Darling residents, Local Councils and stakeholder groups from 24 February 2023. 11 updates have been issued up until 5 June 2023. These updates were also published on the DPEW website, with additional webpages about the event.

Public meetings were held in Menindee on 21 and 24 March 2023, and additional meetings were convened with Aboriginal communities on 29 March 2023.

DPEW gave a presentation on hypoxic blackwater, fish deaths and incident response to the Barkandji Native Title Board on 19 April 2023 in Wilcannia. The Local Aboriginal Land Council also had an opportunity to provide comments on the response via video conference on 19 April 2023.

4 Gaps identified during management of this event

Through managing the response to hypoxic conditions, the Working Group identified a number of water management issues.

4.1 Lack of legislative direction on responsibilities for water quality, including hypoxic conditions

As mentioned earlier in this document, there is no legislation that mandates which agency leads a response to hypoxic conditions, the creation of the working group or expressly governs its functions. Participation in the working group is entirely voluntary. For the last 3 years the working group has acted in good-faith and with the good-will of partner agencies, and agency personnel, to mitigate against adverse outcomes from hypoxic conditions.

More generally, as outlined in section 1.2, responsibility for NSW catchment outcomes is currently ill defined, with some clear gaps and duplication of functions already identified (refer to **Diagram 1**). An action of The NSW Water Strategy is to adopt a more intense, state-wide focus on improving water quality. An objective of this strategy is to consider options to improve the clarity of roles, accountabilities, with frameworks for monitoring, assessing, and addressing surface water and groundwater water quality risks. Outcomes will need to articulate administrative versus operational responsibilities across relevant agencies. Any outcomes and recommendations from the Chief Scientist will be incorporated into the approach.

4.2 The State Emergency Management Plan

The State Emergency Management Plan does not specify a combat agency with respect to the on-ground response to fish-related emergencies, unless it relates to a biosecurity risk or fish-disease.

4.3 The use of environmental water to manage hypoxic conditions

The use of environmental water comes at a monetary cost (usage fees) and an opportunity cost in that the water cannot be used for other purposes such as supporting fish breeding and migration events at other times of the year. DPEW, as Chair and co-ordinator of the working group, is appreciative of the endeavours the environmental water holders have gone to, ensuring that water

was, and is, available to manage the water quality both in the southern basin and Darling-Baaka River. A policy gap remains however, in regard to environmental water holders wearing the cost of such events.

4.4 Inadequacy of appropriate fish passage

Once fish enter the Weir 32 weir pool, there is no opportunity for them to move upstream, into the lakes, or downstream of Weir 32. At the time of writing, the working group is no longer managing hypoxic conditions but, rather, managing flows to maximise water quality outcomes. The biomass of fish currently in the weir pool is competing for oxygen, food resources and habitat. If appropriate fish passage was available into and between Lake Wetherell and Lake Pamamaroo, a portion of fish that were in the weir pool at the time of the hypoxic conditions could have moved to more suitable locations e.g. within the lakes. Currently, fish are congregating where there is water flow with good oxygen levels which means there is a significant biomass immediately downstream of the Lake Pamamaroo and Lake Wetherell outlets. Permanent fish passage at Pamamaroo outlet, and Wetherell outlet would provide an ability for fish to migrate further upstream and prevent a massive congregation below Main Weir. DPEW has sought commonwealth funding for fishways in this stretch, as part of the Better Baaka program. To date, this has been unsuccessful.

Appendix A. Valley Response Group Draft working terms of reference

WATER QUALITY (HYPOXIC EVENTS)

Valley Response Group

Terms of Reference

December 2020

Published by NSW Department of Planning, Industry and Environment

dpie.nsw.gov.au

Title: Valley Response Group

Subtitle: Terms of Reference

First published: [Click to enter date. DELETE WHOLE LINE IF NOT NEEDED]

Department reference number: [Click here to enter CM9 record number. DELETE WHOLE LINE IF NOT NEEDED]

More information

[Add lines to identify author/unit/location, etc. DELETE THIS SECTION IF NOT NEEDED]

Acknowledgements

[Publication citation or credit for agencies outside the department that have provided significant input to content or funding. DELETE THIS SECTION IF NOT NEEDED]

Cover image: [name of photographer or source. DELETE LINE if not adding cover image or if no attribution is necessary]

Version history

Version	Date	Author	Reviewers
Draft	October 2020	N. van der Veer	DPIE-EES Water NSW DPI-Fisheries
Final	July 2021	N. van der Veer P. Driver	
Review	XXXX		

Contents

Introduction

Water Quality Valley Response Groups (response groups) are multi-agency groups that provide an immediate focus at a local level to short-term water quality (hypoxic) events. They are responsible for preparing for and managing the response to a Stage 2 (as described in the Water Quality Incident Management Plan – hypoxic events) or higher event.

1.1 Statutory provisions

The Water Quality Incident Management Plan – hypoxic events (management plan) provides the operational framework for the response to and the management of hypoxic water quality events by the valley response groups, in relation to the Extreme Events Policy and the Incident Response Guides (Figure 1).

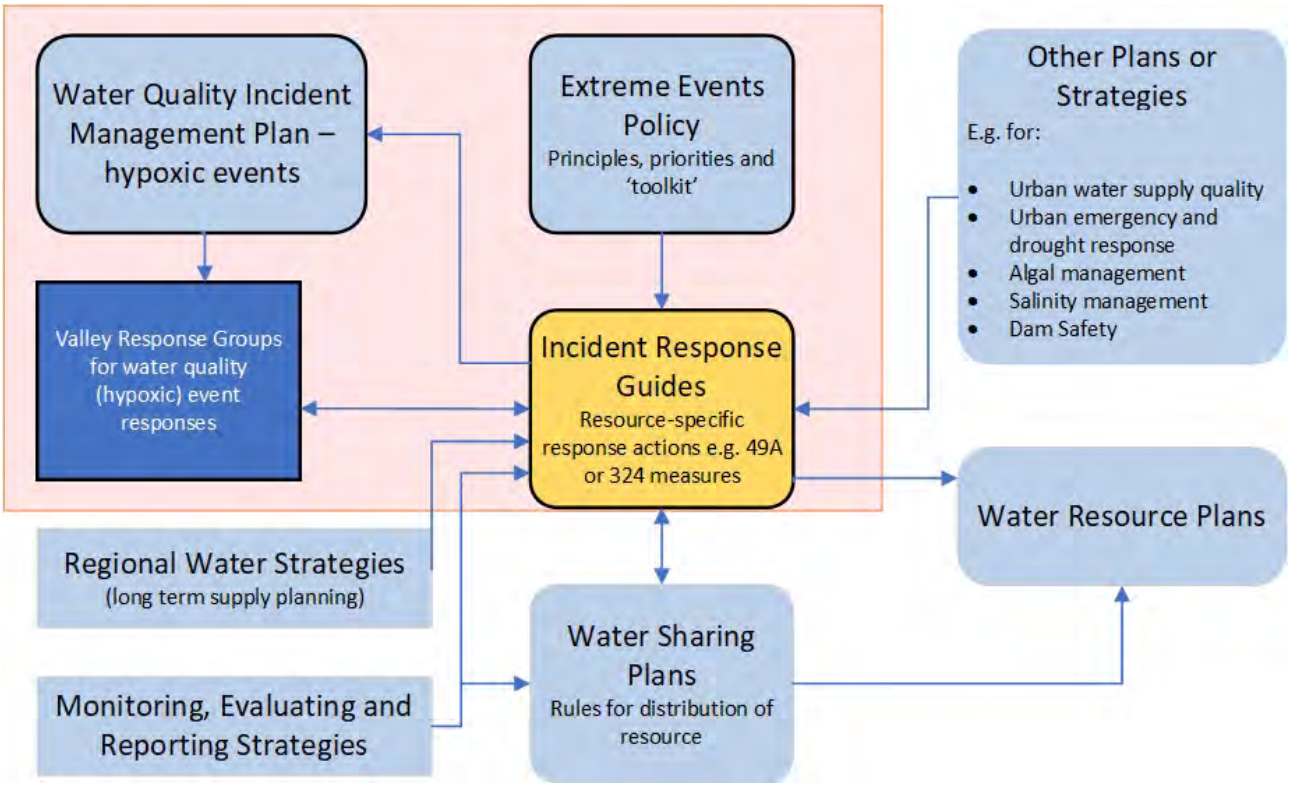


Figure 1 Relationship of valley response groups to the Incident Response Guides and other documents relevant to the WRP framework

Section 10.51 of the Murray Darling Basin Plan requires that each Water Resource Plan (WRP) must describe how the water resources of the WRP area will be managed during the following types of events:

a. an extreme dry period

b. a water quality event of an intensity, magnitude and duration that is sufficient to render water acutely toxic or unusable for established local uses and values

c. any type of event that has resulted in the suspension of a statutory regional water plan in the past 50 years (including a transitional WRP or interim WRP)

If an event of a type listed above would compromise NSW's ability to meet critical human water needs in the WRP area, the WRP must set out measures to meet critical human water needs during such an event.

To fulfil this Basin Plan requirement, NSW has developed Incident Response Guides (IRGs) for each WRP area. These documents describe how NSW intends to manage extreme events, consistent with existing NSW legislation and policies. The information is designed to be guiding, not binding, and flexibility in the prioritisation of water allocation and/or access during extreme conditions may be required.

The Extreme Events Policy sets out a staged approach for identifying water shortages and water quality events and possible response measures. The Extreme Events Policy was developed to:

- respond to the need to manage extreme events under the NSW framework
- improve the transparency and effectiveness of management during extreme events by formalising and building on existing drought and water quality measures
- outline the process that will be adopted to manage water leading up to and during an extreme event
- establish the guiding principles and tools to manage water during extreme events through water-source-specific incident response guides, which will support NSW's water resource plans (WRPs) in meeting the requirements of section 10.51 of the Basin Plan 2012 (Cth) (see Appendix B)
- promote consistency in the development and implementation of region-specific incident response guides set out the statutory functions under the NSW Water Management Act 2000 (WM Act) and the NSW Local Government Act 1993 (LG Act) that may be exercised to manage extreme events.

The Extreme Events Policy may, at times, limit options available for managing hypoxic events. Under Stage 3 of the Extreme Events Policy, catchments will have experienced prolonged periods of zero allocations and water (including carryover) being quarantined into the NSW drought account. Political pressure may be high for environmental water to be kept in dams for critical human needs rather than being used to protect the environment. By Stage 4 all water within a catchment is reserved for critical human needs and no water can be used to protect environmental health. In these instances, the Extreme Events Policy will cease the ability of the Valley Response Group to provide a response to a hypoxic event via the use of flows.

The role of valley response groups

The purpose of the valley response groups is to ensure that advice on management options and actions for hypoxic water quality events comes from a local contextual basis, while maintaining consistency with:

1. the requirements of the Water Management Act 2000, including specific provisions for the management of water quality within valley-based Water Sharing Plans
2. the Water Quality Incident Management Plan; and
3. Requirement of the Basin Plan, including documents that address Water Quality Management as part of each valley's Water Resource Plan. This includes but is not limited to the valley's IRG[1].

Of particular focus for the response group will be early, appropriate, and broad communications with potentially affected parties, and on bringing local area knowledge to the selection of management response measures.

In particular, the response group has been established to:

[1] Including the Risk Assessment, the Water Quality Management Plan and the Water Quality technical report

1. Present any relevant information or provide expert advice to assist with understanding the current status of the hypoxic event and its effects on the local dependent communities and the environment.
2. Provide advice on the relative merits and potential implications of proposed management responses within the framework of the IRG.
3. Review the effectiveness of adopted measures and suggest options for further improvement.

2.2 Valley response group objectives

In seeking to achieve the purpose outlined above, members of the group will:

1. Foster collaboration and open, respectful conversation
2. Provide information and advice in an accurate and balanced way
3. Carefully consider the implications of any proposed courses of action
4. Aim, as far as possible, to reach consensus on a recommended management approach

2.3 Authority

The valley response group has primarily an advising role to, ultimately, the Minister for Water. The advice and recommendations of the group will be consolidated by DPIE-Water for consideration by the Minister, or partner agencies (DPIE-EES, DPI-Fisheries, WaterNSW). The Minister is responsible for final decisions.

2.4 Scope of valley response groups

The primary focus of the response group is to give effect to the Water Quality Incident Management Plan – hypoxic events (INT20/367000), relevant Incident Response Guide(s) and NSW policies and procedures relating to extreme water quality incidents in affected valleys. The group cannot recommend an action contrary to Government policy, however, should identify any areas where longer term review/change is warranted.

2.5 Limits to decision making

The valley response group can make recommendations on how to manage particular events; however, the decision to act on those recommendations will be made at the agency level following the statutory requirements described in section 2.1. Funding, staffing and other resource constraints may limit the level of intervention possible in the management of hypoxic water events.

DPIE-EES is responsible for operational decisions in relation to the management and use of planned environmental water in NSW. To this end, consideration may be given by the valley group, with EES's guidance, on how water quality management before, during and after events can complement the use of water managed by CEWO or DPIE-EES for priority environmental assets and functions (consistent with water use plans and objectives). This may include to prevent critical loss of species or communities, provide refugia and/or promote recovery of threatened species and communities. The valley response groups have not been delegated decision-making powers by government. Final watering actions may take other information or considerations into account and may not be consistent with the final advice of the valley response group.

2.6 Advice

The advice sought from the response groups is in relation to the management of hypoxic water quality events and how information about those events should be communicated to stakeholders and the broader community.

2.7 Consensus decision making

Response group agencies should strive to reach a consensus in relation to the advice produced by the group. Where consensus cannot be reached, decisions and recommendations will be minuted by DPIE-Water, including information on the range of opinions and the majority position.

In reaching consensus, the decision-makers should be satisfied that the issue has been reasonably canvassed and that the proposal is, at the least, *acceptable* to all, and consistent with response group objectives.

2.8 Deliverables

A formal event report may be required depending the scale and impacts of the event. The decision to prepare an event report may be made by the response group or may be requested by the DPIE-Water executive.

If a formal report is required, it should be prepared soon after the response group has been stood down. The report is to be prepared by DPIE-Water, but input from representatives from each agency will be needed. The event report covers the event from inception to end and should contain:

1. Cause and description of the event
2. Management actions undertaken
3. Communication undertaken
4. Lessons learnt
5. Recommendations and actions (these will be provided to relevant business units for completion and closure)

The report should be registered within the CM9 folder V18/5660#8

Post-event reports may contain information not intended for general release outside of DPIE-Water. The Chair should therefore consider obtaining legal advice prior to the release of any documentation outside of the Department, including to partner agencies.

Membership

Members of this Panel will include (but not be limited to) representatives from:

- Department of Planning, Industry and Environment (DPIE) Water – (including the role of Chair)
- WaterNSW
- DPIE-Environment, Energy and Science (EES)
- Department of Primary Industries - Fisheries
- Local Land Services
- Local councils (either a regional coordinating body (e.g. Centroc) or DPIE-Water rep
- Murray Darling Basin Authority (MDBA)

- Commonwealth Environmental Water Office (CEWO)

Other members may be co-opted as appropriate, and/or expert technical advice sought.

For each meeting, the Chair will set the Agenda, ensure that key issues are discussed and that any conflicts of interest are declared.

Member roles and responsibilities

4.1 All members

The response group/s are comprised of representatives from multiple agencies. Further details on the response groups and their representatives can be found at INT/367002 in CM9. Agencies and their respective roles are presented in Table 1.

In some instances, input may be needed from additional agencies and other stakeholders as appropriate, these are presented in Table 2.

Table 1 Agency composition of Valley Response Groups and their roles

Agency/Group	Role
Department of Planning, Industry and Environment – Water	• chairing of CWTAG, and CWAPs • oversight of water quality management, including leading the collaborative development of Water Quality Incident Management Plans • chairing of response groups • analysis of dissolved oxygen monitoring results and potential or existing threats • Maintain WSP rules for distribution of access • Ensure implementation of the valley Incident Response Guide
WaterNSW	• flow and water quality monitoring • advice on river operations and infrastructure to assist in management of water quality events • coordination of Regional Algal Coordinating Committees • installation of aerators, if needed, where arrangements and funding can be agreed. WaterNSW is not responsible for installing, operating (including power/diesel supply) and managing aerators unless it is an action related to a REF (or, similarly, WSCN authorisation conditions). • Development of the Fish Health Risk Tool: optional, and subject to the level of interest from other agencies in the implementation of the tool for risk management

Department of Planning, Industry and Environment – Environment, Energy and Science (EES)	• identification of key ecological areas and water requirements in each valley • management and monitoring of use of NSW held and planned environmental water (Environmental Water Allowance) • chairing of Environmental Water Advisory Groups which recommend use of environmental water and facilitate information to stakeholders • *Implementation of LongTerm Water Plans*
Department of Primary Industries – Fisheries	• advice on critical fish refuges, thresholds, locations and requirements • contact point for information on fish deaths • advice on management measures to respond to fish populations at risk • chairing of Fish Valley Technical Advisory Groups (as needed) which recommend native fish actions during extreme events
Local Government	• advise public of water quality issues • notify DPIE-Water of water quality issues that are identified through routine council monitoring • treatment of water supplies for potable use • *Ongoing monitoring and improvement of Quality Assurance Program –Drinking Water Management System (DWMS) under the NSW Public Health Act 2010 and Public Health Regulation 2012*
Murray-Darling Basin Authority	• assist with event-based monitoring in some areas • provide hypoxic blackwater education material • cross border liaison • Use of operational water • Use of environmental water (TLM, Murrumbidgee Murray & Lower Darling only)
Commonwealth Environmental Water Office	• Management and use of Commonwealth's portfolio of licensed environmental water • Use of environmental water subject to approval by the Commonwealth Environmental Water Holder
First Nations represented by agency Aboriginal Cultural Liaison Officers	• Provide information on key cultural considerations within valleys • Assist in the design of flow responses • Provide advice on further First Nations consultation • Provide advice on culturally appropriate literature and communication
Community Groups	• Advice on local conditions • Assist in designing flow responses • Assist with dissemination of information for landholders • NOTE – Community groups also have a veto role in relation to potential third party impacts for the use of refuge flows during flood periods

Irrigation companies	• Murray Irrigation Limited (Edward/Kolety - Wakool)

Table 2 Additional agencies that may need to be involved in Valley Response Groups

Agency/Group	Role
NSW Health	• drinking water quality monitoring and testing • advice on water treatment for town supplies • provide advice on health aspects of poor water quality
NSW Environment Protection Authority	• investigate pollution incidences • licensing of any proposed chemical treatments
State Emergency Services	• Oversees response to flood events • Advice on impacts of potential additional releases during flooding NOTE – NSW SES has the power to veto decisions on response actions during a flood event
Local Land Services	• Advice on local conditions • Assist with dissemination of information for landholders
Universities	• Information on key ecological areas and water requirements in some valleys
Consultants	• Information on key ecological areas and water requirements in some valleys

4.2 Key roles and responsibilities within the valley response groups

The chair of the response group/s will usually be a DPIE-Water representative. However, where the likely management for the water quality event is primarily the delivery of discretionary environmental water the chair will be from DPIE-Environment, Energy and Science.

In the instances where water quality events emerge during a period during which a fish management or environmental committee is already established (for example, Fish Technical Advisory Committees which were temporarily established during the drought or ongoing Environmental Water Advisory Groups established where environmental account or licensed environmental water is available), DPIE-Water will work within that group. The chair of the response group will be determined at the first Group meeting for each critical water quality event.

Table 3 Key roles and responsibilities within the valley response groups

Role	Department	Responsibility
Chair	DPIE-Water (or EES)	Coordinate the response group and response group meetings

		Assign roles and responsibilities Develop event objectives against priorities Ensure meeting minutes are kept and distributed
Incident Coordinator	DPIE-Water (or EES)	The incident coordinator can be the same or a different officer to the chair. The chair might delegate the role of coordinator The coordinator implements incident protocols from the agreed objectives
Communications coordinator	Communications team	Development and management of the communications plan, which includes a stakeholder engagement record Intermediary between the response group and departmental communications team

Governance and operational guidance

5.1 Confidentiality

The discussion and provided material should by default remain confidential unless otherwise agreed by the response group or advised by the Chair.

Consistent and clear public communication will be critical to the successful implementation of any proposed management approach; however, it ought not pre-empt any announcements by the Water Minister. An event-specific communication strategy should be endorsed by the group at the earliest opportunity. Subject to such endorsement, as a default strategy DPIE Water will prepare communiqués of the meetings outcomes, which describe the broad process and outcomes but not individual contributions to these outcomes

5.2 Privacy

Personal or organisational contact details of members are maintained by DPIE-Water and shared with the response group members to facilitate good communication, and with DPIE-Water officers who need to contact Members in the course of their work. Members can access and request amendment of their contact details.

5.3 Retirement of the group

The response group is only required to meet when there is an emerging or existing hypoxic water quality event. Once the event or threat of an event has passed and all necessary reporting has been completed the group can be expected to retire.

5.4 Review of the Terms of Reference

This Terms of Reference may be varied by agreement of the response group members, at the discretion of the Chair.

Administrative arrangements

6.1 Meetings

Meetings will be closed to the general public. The Chair will determine meeting times in consultation with members. Meetings will be called to plan hypoxic event management and are likely to increase in frequency should a hypoxic water quality event occur.

6.2 Attendance and quorum

While best efforts will be made to schedule meetings so that representatives from each agency are available to attend this may not always be possible, particularly if meetings need to be called at short-notice due to rapidly evolving conditions.

6.4 Records

An accurate record of the proceedings of every meeting, any business papers, correspondence, and tabled reports or presentations, shall be kept by the Chair and entered into DPIE-Water's record management system. Minutes must record decision points and response group advice, and properly record consensus and other views.

All meetings materials should be provided to each committee member as soon as practicable after each meeting. Abridged or redacted meeting records may be used for communication by DPIE-Water or Members to a broader audience.

6.5 Valley response group communications

While valley response groups do not have a responsibility to disseminate information about the management of hypoxic water quality events, it is the aim of the group that communication undertaken by individual agencies is consistent in its messaging.

Expenses

Expense claims are not anticipated. Meetings are held virtually, as such there are no costs associated with travel, accommodation and meals.

Related documents

Document title	Document purpose	CM9 reference
Water Quality Incident Management Plan – hypoxic events	Provide the operational framework for the implementation of the management of hypoxic water quality events in relation to the Extreme Events Policy and Incident Response Guides	INT20/367000

Document title	Document purpose	CM9 reference
Extreme Events Policy	The key objective of the Extreme Events Policy is to improve resilience and provide certainty for communities: • during drought and periods of water shortage • in the event of a water quality event of an intensity, magnitude and duration that is sufficient to render water acutely toxic or unusable for established local uses and values	link
Incident Response Guide	Outline the framework for managing extreme events for each major water source in the NSW Murray–Darling Basin based off the principles outlined in the NSW Extreme Events Policy	
Where required, Valley specific documents on operations, including triggers	Describes valley specific operational details, including triggers. For example, the guideline on triggers for the use of the Lachlan Water Quality Allowance	INT18 175091 (Lachlan)

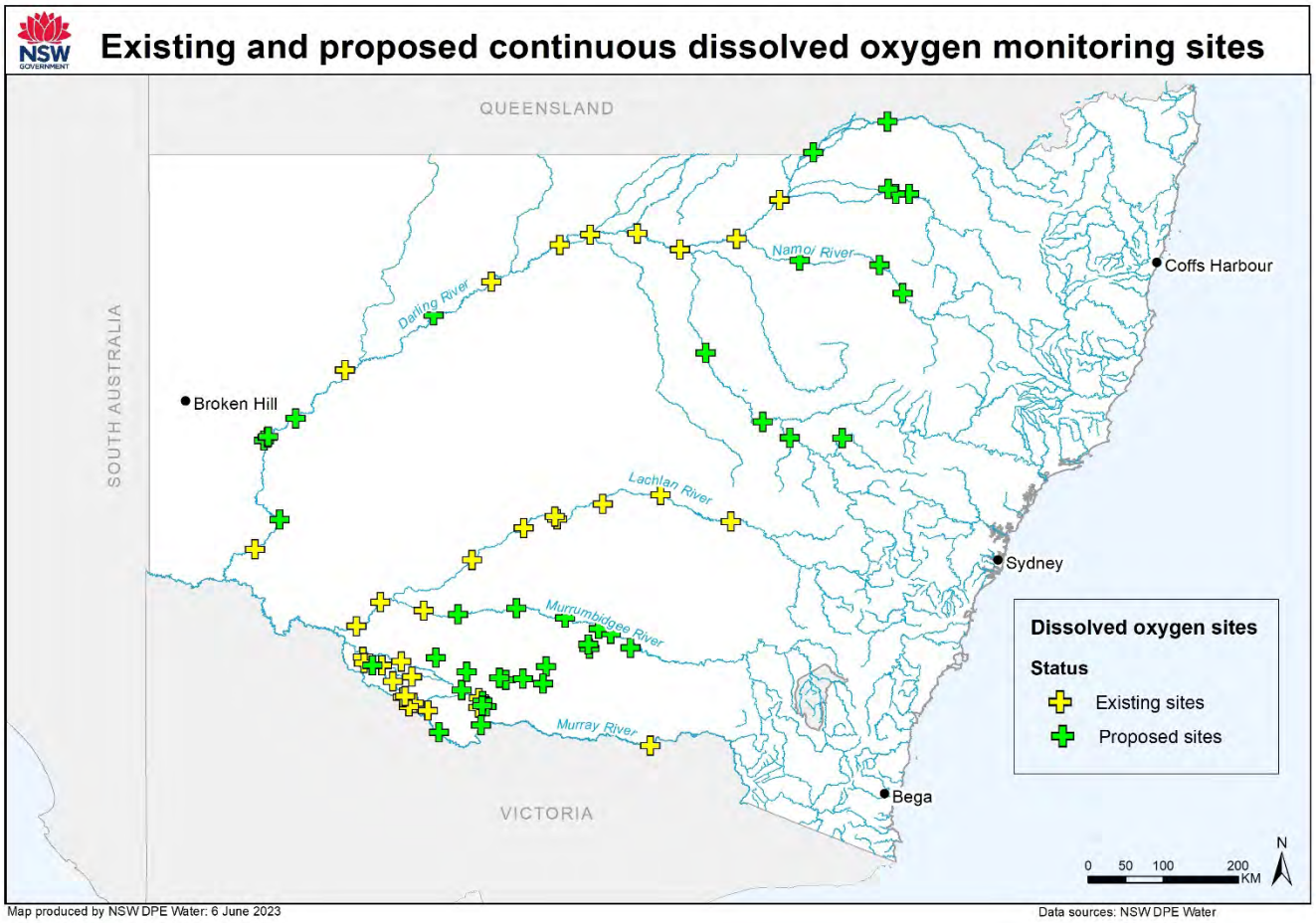
Appendix B. Roles and responsibilities of Working Group

Table 3. Agency roles on the hypoxic blackwater working group at Menindee over Summer 2022/23

Agency/Group	Role
Department of Planning and Environment – Water	• chairing and co-ordinating the hypoxic blackwater working group (HBWG) • following consensus of HBWG, request to WaterNSW for changes to Menindee Lakes water releases whilst using the Lower Darling Environmental Water Allowance • following consensus of HBWG, request to MDBA to advise WaterNSW for changes to releases where held environmental water (HEW) is used and when Menindee is in MDBA control • analysis and publication of dissolved oxygen monitoring results and advising the public of potential or existing threats • Co-ordinate media response (when not in an emergency response framework)
WaterNSW	• Ongoing flow and water quality sampling • Additional sampling as required by HBWG • advice on river operations and use of infrastructure to assist in management of water quality events • coordination of Regional Algal Coordinating Committees and publishing of algal alert maps and notices
Department of Planning and Environment – Environment and Heritage Group (EHG)	• Identification of options to assist with the management of hypoxic conditions where it involves the use of HEW • Following consensus of HBWG placed order for HEW with WaterNSW • management and monitoring of use of NSW held environmental water • Chair of Lower Darling TAG • Advise on volumes of HEW that could be made available
Department of Primary Industries – Fisheries	• Technical advice on fish ecology and requirements, thresholds, and locations • Provide updates on fish deaths and any media campaigns • contact point for information on fish deaths • advice on management measures to respond to fish populations at risk
Murray-Darling Basin Authority	• assist with event-based sampling in the shared Murray and lower Darling • provide hypoxic blackwater education material • Undertake stakeholder updates and media, where impacts are on the shared Murray resource • Following consensus of the HBWG, and advice from DPEW, advise WaterNSW for changes to Menindee Lakes water releases where HEW is used (when the Lakes are in MDBA control)

Agency/Group	Role
Commonwealth Environmental Water Office	• Identification of options to assist with management of hypoxic conditions where it involves the use of HEW • Provide updates on watering actions to address hypoxic conditions • Following consensus of HBWG, placed order for HEW with WaterNSW • Advise on volumes of HEW that could be made available
Other agencies – Parks Victoria, Mallee CMA (Vic), NSW EPA, Charles Sturt University, SA Water.	• Participate and provide advice to HBWG

Appendix C. Map of existing and proposed continuous dissolved oxygen monitoring sites



Appendix D. Prof Baldwin Potential causes of fish deaths report

File Note[1]

Subject: A preliminary assessment the of the sequence of events that led to the massive fish kill in Weir 32 weir pool (Menindee) on 16-17 March 2023

Attention: Dr Janet Prichard - Murray-Darling Basin Authority
Dr Asitha Katupitiya - Murray-Darling Basin Authority

CC: Allan Raine - NSW Department of Planning and Environment
Cameron Lay - NSW Department of Primary Industries (Fisheries)

From: Darren Baldwin, *Rivers and Wetlands*

Date: March 30, 2023

1. Purpose

On March 16-17 there was a massive fish kill in the Weir 32 weir pool, mostly focussed upstream of the town of Menindee - with an estimated 20 million dead fish. *Rivers and Wetlands* was engaged by the Murray Darling Basin Authority to assist NSW Departments of Planning and Environment and Department of Primary Industry in the on-going management of the situation to help minimise the risk of future fish kills. In doing so, an ancillary task was to develop credible hypothesis/hypotheses on the proximate cause(s) of the fish kill that is consistent with all available data. This File Note is a preliminary assessment of the likely cause of the fish kills - or more properly, the sequence of events that led to the fish deaths. It is based on incomplete data[2] and, only the most salient points/calculations are covered. [3,4] If required, this File Note can be expanded into a more detailed report.

2. Synopsis

Given the available data it is not possible to unequivocally assign a definitive cause to the fish kill in mid-March 2023 at Menindee on the Darling River. The fish kill was most likely caused because of

[1] This file note is copyright by the Crown with respect to the Commonwealth of Australia. To the extent permitted by law, the copyright holders (including its employees and consultants) exclude all liability to any person for any consequences, including but not limited to all losses, damages, costs, expenses and any other compensation, arising directly or indirectly from using this report (in part or in whole) and any information or material contained in it. The contents of this publication do not purport to represent the position of the Commonwealth of Australia or the Murray-Darling Basin Authority in any way and are presented for the purpose of informing and stimulating discussion for improved management of the Basin's natural resources.

[2] For example, at the time of writing pesticide and herbicide data wasn't available.

[3] An understanding of key limnological processes, especially with respect to the cycling of oxygen in aquatic ecosystems is assumed.

[4] For example, this file note doesn't go to the question why there was such as a high biomass of fish in Weir 32 weir pool, only that they were there.

hypoxia. After discounting a number of potential causes for the hypoxia, the most credible sequence of events that lead to the fish kill are:

1. During February 2023, water with potentially low dissolved oxygen concentrations was being released into the top of Weir 32 weir pool directly from Lake Wetherell.[5] Furthermore, water from Lake Wetherell was also diverted into Lake Pamamaroo through the Lake Pamamaroo inlet. Because of the close proximity of the inlet to the outlet of Lake Pamamaroo, some of the water from Lake Wetherell was short-circuiting Lake Pamamaroo and entering the top end of Weir 32 weir pool. Fish deaths were recorded in Weir 32 weir pool at the time (The Guardian, February 23, 2023).
2. On February 25 the Lake Pamamaroo Inlet was closed and, by March 1 the Lake Wetherell Outlet was also essentially closed This meant that the only water now entering the top end of Weir 32 weir pool was entering from Lake Pamamaroo (approximately 4300ML/day on March 1). This water was well oxygenated.
3. It is conjecture, but it is likely that the better water quality attracted fish, particularly bony bream, to the top end of Weir 32 weir pool during the oxygenated inflows (the Pied Piper effect). The large biomass of fish at the top end of Weir 32 weir pool was being sustained in a large part through oxygen in the outlet water from Lake Pamamaroo.
4. Outflow from Lake Pamamaroo to Weir 32 weir pool was slowly reduced starting on March 6. By March 16 flows from Lake Pamamaroo had reduced to 1250 ML/day.
5. The algal biomass in Weir 32 weir pool was also increasing during this period, possibly helped by nutrient recycling by the large biomass of fish, which would have contributed to a night time sag in oxygen levels
6. It is hypothesised that on the night of March 16 the combined respiratory load of the large biomass of fish and algae consumed all, or almost all of the oxygen in the water column - resulting in the massive fish kill.

The fish kill has the hallmarks of a 'Black Swan' event (*sensu* Taleb, 2007)

3. Details

3.1 Discounting other potential causes of the fish kill.

3.1.1 Destratification:

The multiple fish kills that occurred in 2018/19 in weir 32 weir pool were likely caused by sequential destratification events that led to hypoxia throughout the water column (Baldwin 2019, Vertessy et al, 2019). Work by Mitrovic et al (2011), suggests that stratification of Weir 32 weir pool only occurs at flows less than about 350 ML/day. Flows into the top end of Weir 32 weir pool exceeded this threshold for the entire period of concern. Therefore, it is highly unlikely that stratification/destratification was involved in the March 2023 fish kill.

3.1.2 Recession of the 2022/23 Flood (a "classic" hypoxic event):

There was a large flood in the Darling River in 2022/23. Floods, particularly during the warmer months can lead to hypoxia and fish kills. However, as both the hydrograph and satellite imagery (Figure 1) shows, the flood pulse had clearly passed Menindee prior to the fish deaths. There is some evidence, again from satellite imagery (data not shown) that localised recession may have led to poor water in Lake Wetherell in March 2023, but by this time Lake Wetherell was essentially isolated from Weir 32 weir pool - discussed below.

[5] For approximate locations see Figure 2.

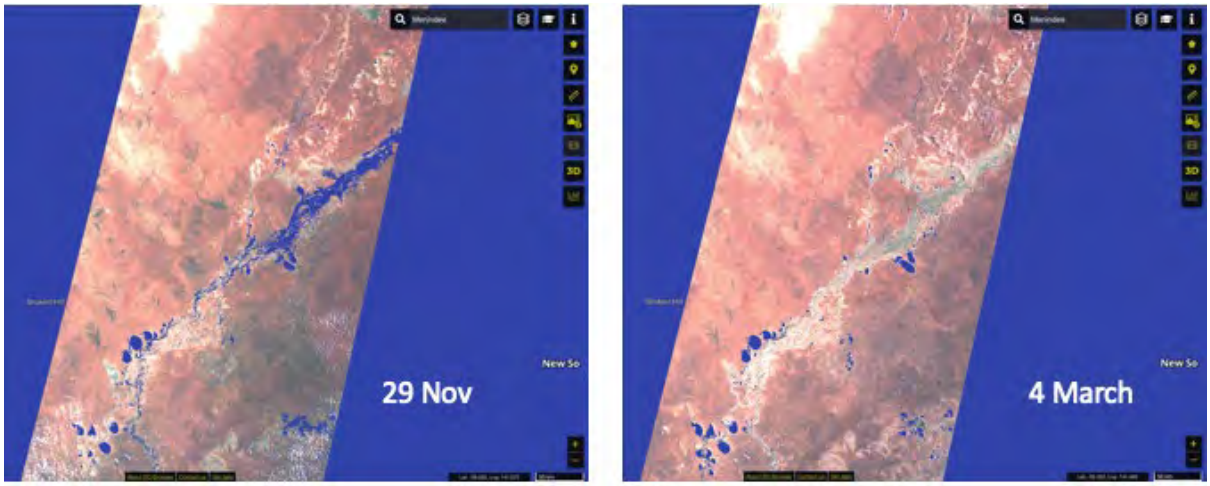


Figure 1: False colour Sentinel2 satellite imagery of the Darling River floodplain processed with the Water in Wetlands script (Willm et al, undated) highlighting water in blue.

3.1.3. Crash of an algal bloom:

During the 2018/19 fish kills at Menindee, media reports erroneously attributed the deaths to a crash in an algal bloom.[6] This idea has been previously shown to implausible (Baldwin et al, 2019).

Analysis of satellite imagery by Tracey Fulford (WaterNSW) using a custom script for algae (particularly cyanobacteria) has shown that algal biomass actually increased prior to the fish kill (data not shown but available on request). Fish, that are detritivores and/or algal consuming species are good at recycling nutrients into the water column through ingestion and excretion. It is possible (but not proven) that the large volume of bony bream at the top end of Weir 32 weir pool may have contributed to the growth of algae.

3.1.4 Diurnal hypoxia caused by the algal bloom:

Algae produce oxygen during the day (through photosynthesis) and consume it at night. If there is sufficient algal biomass his can lead to transient hypoxia in the early hours of the morning prior to dawn. It is probable that this played a role in the fish kill in March 2023 (discussed below), but the observation that the fish kill was localised to the top end of Weir 32 weir pool, and not also in, say, Lake Wetherell (Figure 2) where there was extensive algal biomass, it was highly likely not to be the only factor.

[6] This zombie idea still persists.

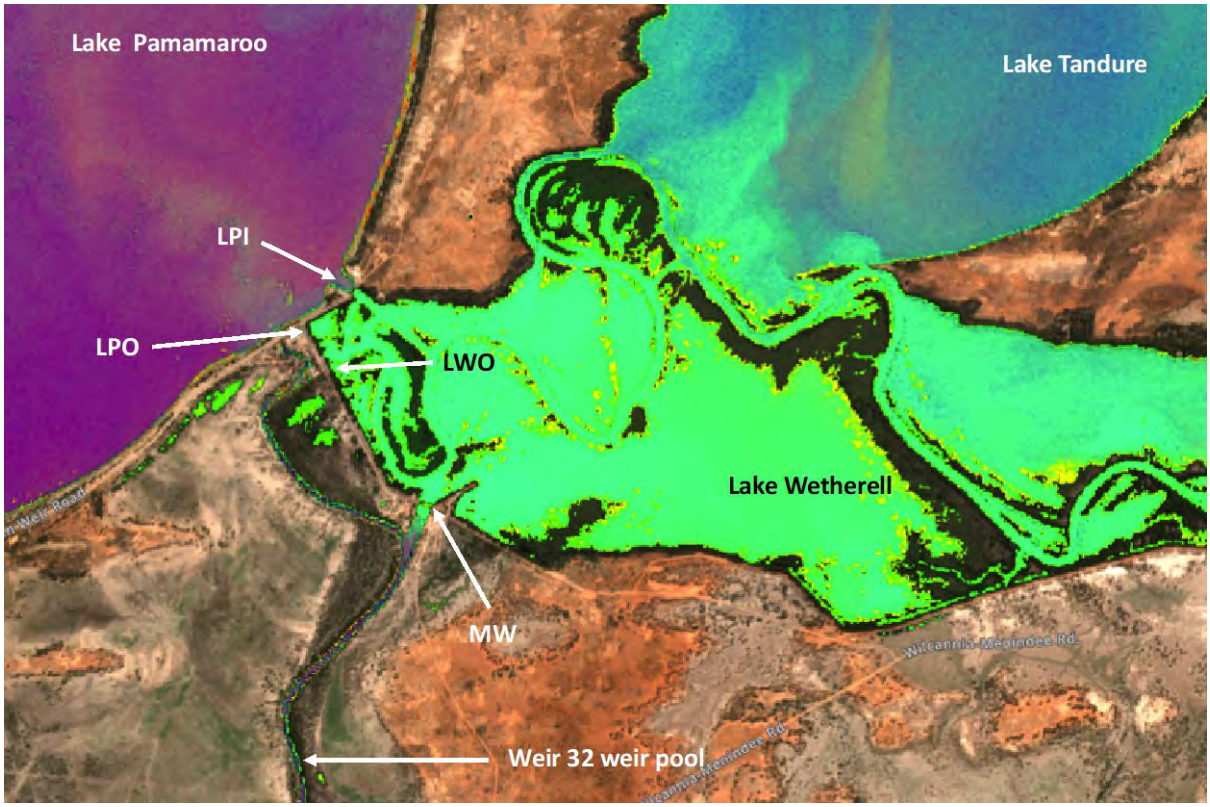


Figure 2: False colour Sentinel 2 satellite image of the bottom end of Lake Wetherell and the top end of weir 32 weir pool taken on March 14 processed with the APA script (Péliova et al, undated). Algal biomass is shown in green. MW = Main Weir; LPI = Lake Pamamaroo inlet; LPO = Lake Pamamaroo outlet; LWO = Lake Wetherell outlet.

3.1.5 Temperature:

Both the air and water temperatures were high in the area around Menindee during March. For example, water temperatures at Nellia Gaari in Lake Wetherell (Site 425060) reached above 29 ^{o}C in early March 2023 (Figure 3). At the time of the fish kill the water-temperature was still in the mid-to high 20's. Like algal biomass, the high water-temperature was probably a contributing factor to the fish kills, but because fish kills were not observed elsewhere at the same time, it was highly likely not to be the only factor. High water temperature:

- Stresses fish - the observed water temperatures are close to the putative lethal levels for some native fish
- Increases respiration - particularly microbial and algal respiration
- Decreases the solubility of oxygen in the water column.

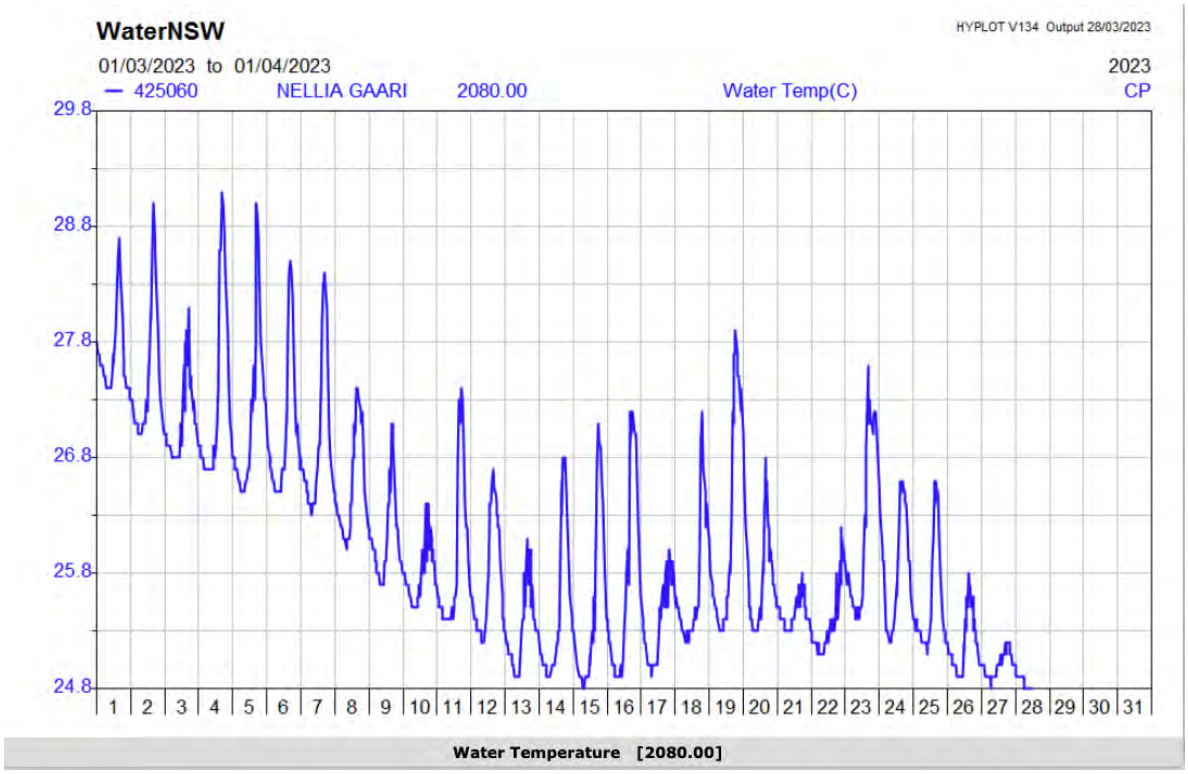


Figure 3: Temperature in Lake Wetherell at Nellia Gaari (Site 425060) during March 2023 (Image copyright the Crown in respect to New South Wales)

3.2. Factors that likely contributed to the fish kill

In the absence of any data to the contrary (e.g. pesticide analysis is pending) the most likely cause of the fish deaths was hypoxia. There is only sporadic information available so the following narrative is based on a certain degree of conjecture, speculation and approximate calculations (which I will highlight). However, the following scenario is the only plausible explanation that I can arrive at which fits all of the observations and available data. I propose that the hypoxia was caused by a combination of fish and algal respiration.

Professor Fran Sheldon, in an interview with The Guardian (The Guardian, March 23, 2023), was the first person to suggest that environmental respiration (particularly from the large fish biomass) could have contributed to the fish kill. So, the questions arise was there enough fish biomass to strip the oxygen out of the water column to the point where the fish died.

3.2.1 How much fish biomass was there?

The fish kill in March 2023 in Weir 32 weir pool was, for the most part, initially isolated to the region above Menindee township - it is approximately 20 km from Menindee to Main Weir. We don't actually know what the total fish biomass was in this reach immediately prior to the fish kill, but logically it would at least be equivalent to the biomass of fish that died during the event. Based on visual estimates (G. McCrabb and I. Ellis *pers. comm*.) somewhere in the order of 20 million fish died. Most were bony bream in the range of 20 - 100 g (wet weight). Therefore, assuming an average weight of the dead fish 50 g and assuming that the estimate of dead fish number is in the vicinity - then there was at least 1000 tonnes of fish in the approximately 20 km reach.

3.2.2 Could that large a fish biomass lead to hypoxia?

Our understanding of native fish physiology is less than ideal and, I was not able to locate respiration rates for bony bream. However, from Table 2 in Kepenyes and Varadi (1984) the average oxygen consumption for common inland aquaculture fish is 5200 ± 4100 mg O_2/kg/day (range from about 1000 - 10000 mg O_2/kg/day). Assuming a rate of 5000 mg O_2/kg/day, 1000 tonnes of fish would consume about $5x10^9$ mg O_2/day. By contrast, at reasonable oxygen concentration (6 mg/L) a 20 km reach of water would contain about 1.8 x 10^{10} mg of O_2[7]. Therefore, in the absence of any other sources or sinks of oxygen in this reach then the oxygen in the reach would be consumed within about 3.5 days. Clearly, this is an absurd scenario as some oxygen would be replenished during the day, it highlights the fact that this level of fish biomass would impose a substantial drawdown on the oxygen budget in the reach - especially if there is an algal bloom occurring at the same time. Although such a scenario seems unlikely the data presented below suggests that when conditions are less than ideal, as in the Weir 32 weir pool in March 2023, this biomass driven hypoxia is plausible.

There are other factors impacting on dissolved oxygen concentration in Weir 32 weir pool. There would have been reoxygenation coming from upstream flows (discussed later), photosynthesis and exchange with the atmosphere; while deoxygenation could occur from sediment oxygen demand, and other sources of community respiration (including night time algal respiration). However, it is not possible to quantify these sources and sinks with the available information. At the time of the fish kill there were operating dissolved oxygen loggers located at Nellia Gaari (Site 425060) and upstream of Weir 32 (Site 425012). Neither accurately represent the conditions that occurred in Weir 32 upstream of Menindee township. Nellia Gaari is in Lake Wetherell, many river kilometres upstream of Weir 32 weir pool, while the oxygen concentration at the site upstream of Weir 32 was influenced by inflows from Lake Menindee. However, the dissolved oxygen concentrations at both indicate that oxygen levels in Weir 32 weir pool were likely compromised. Because of the algal bloom in Lake Wetherell, overnight dissolved oxygen concentrations at Nellia Gaari fell to about 1 mg/L through the first part of March (Figure 4), indicating night time respiration was placing pressure on oxygen levels. The diurnal signal was not as strong at the site upstream of Weir 32, but again, it was influenced by flows out of Lake Menindee (Figure 5).

[7] Assuming an average depth of 3 metres and an average width of 50 metres

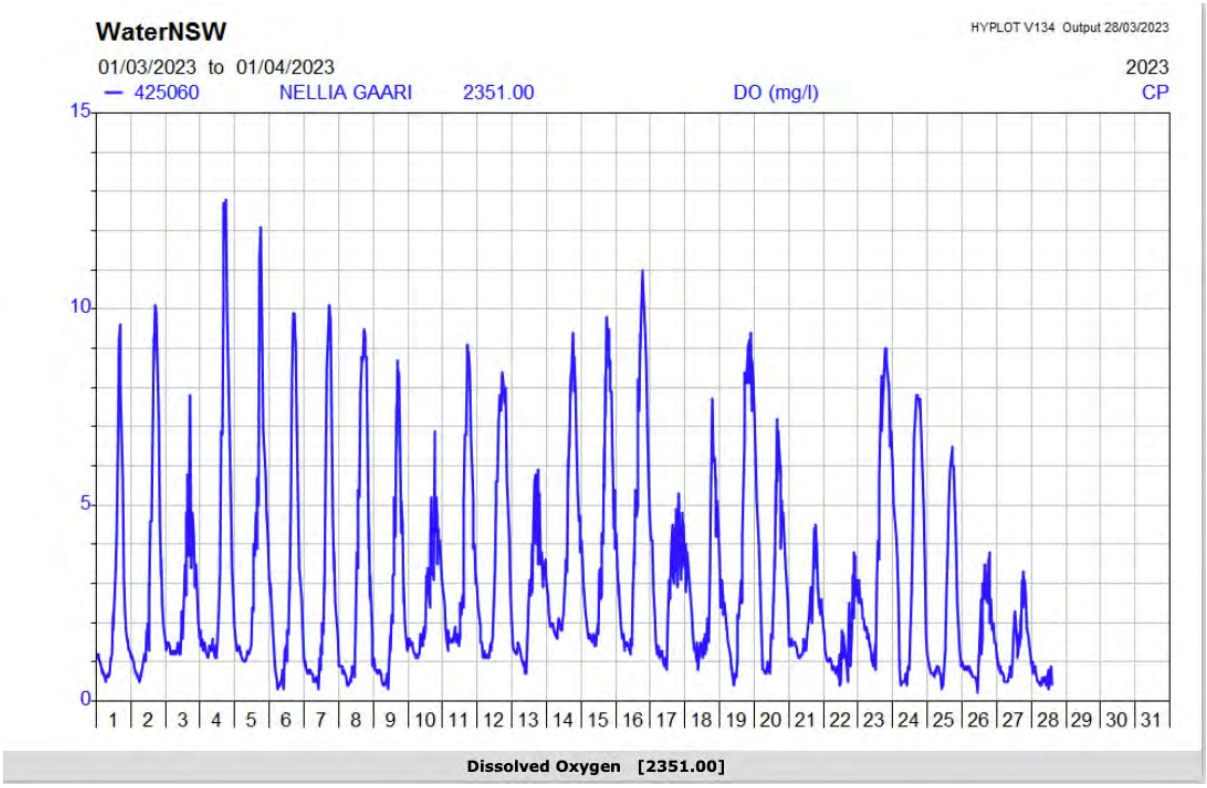


Figure 4: Dissolved oxygen concentration in Lake Wetherell at Nellia Gaari (Site 425012) during March 2023 (Image copyright the Crown in respect to New South Wales)

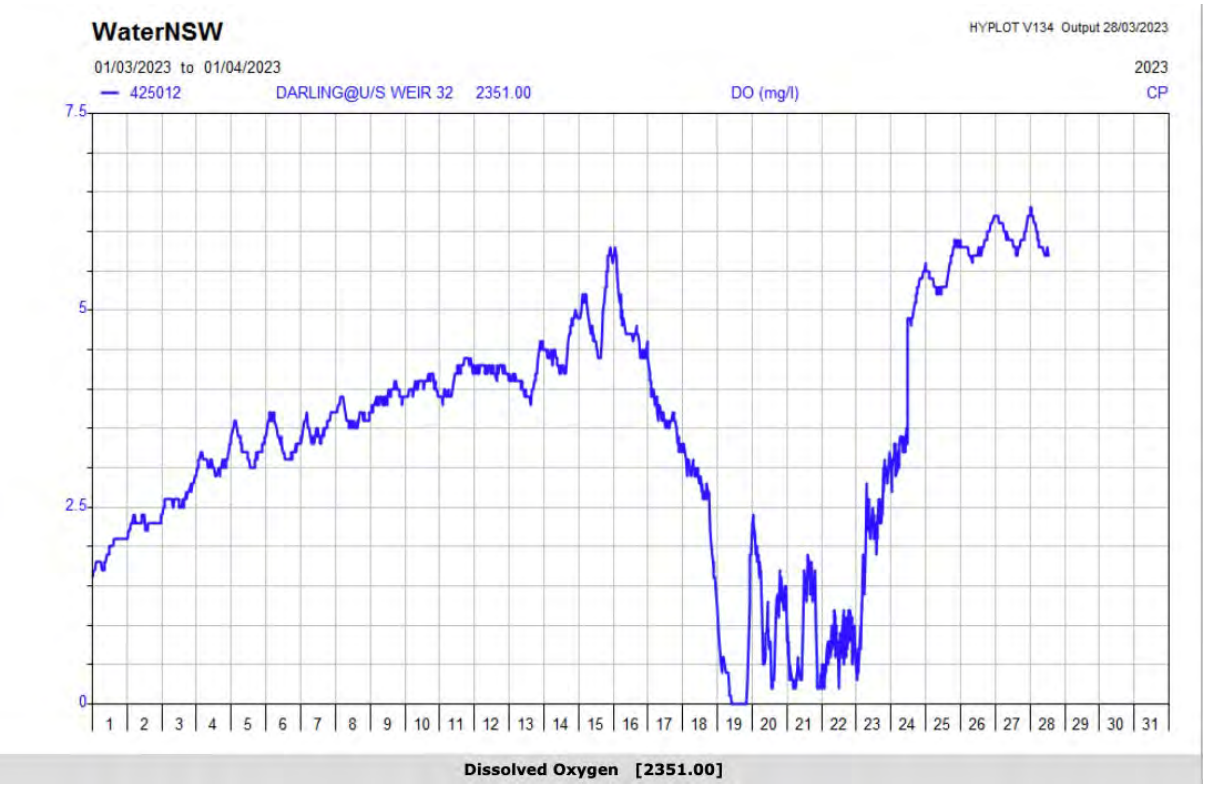


Figure 5: Dissolved oxygen concentration in Weir 32 weir pool, upstream of Weir 32 (Site 425060) during March 2023 (Image copyright the Crown in respect to New South Wales)

3.2.3 What was the impact of changing flows into Weir 32 weir pool from upstream sources?
Inflows into the top end of Weir 32 weir pool in February and March 2023, prior to the fish kill, can be divided into three distinct phases (Figure 6). In the first phase (until March 1) water was delivered to Weir 32 weir pool from Lake Wetherell through the Lake Wetherell Outlet (see Figure 2 for locations), and from the Lake Pamamaroo Outlet. However, satellite imagery shows that inflows from Lake Wetherell into Lake Pamamaroo that were occurring at the same time were being short circuited, with most of the flow from Lake Wetherell entering Weir 32 weir pool (Figure 8). In the second phase, from about March 1 until March 6 all the flows into the top end of Weir 32 weir pool essentially came from Lake Pamamaroo, at a constant rate of about 4000 to 4300 ML/day. In the 3rd phase, starting about March 6, the water entering the top-end of Weir 32 weir pool was still sourced only from Lake Pamamaroo, but the flow rate reduced in steps from about 4300 ML/day to 1250 ML/day by March 16. The fish kill likely occurred during the night of March 16/17.

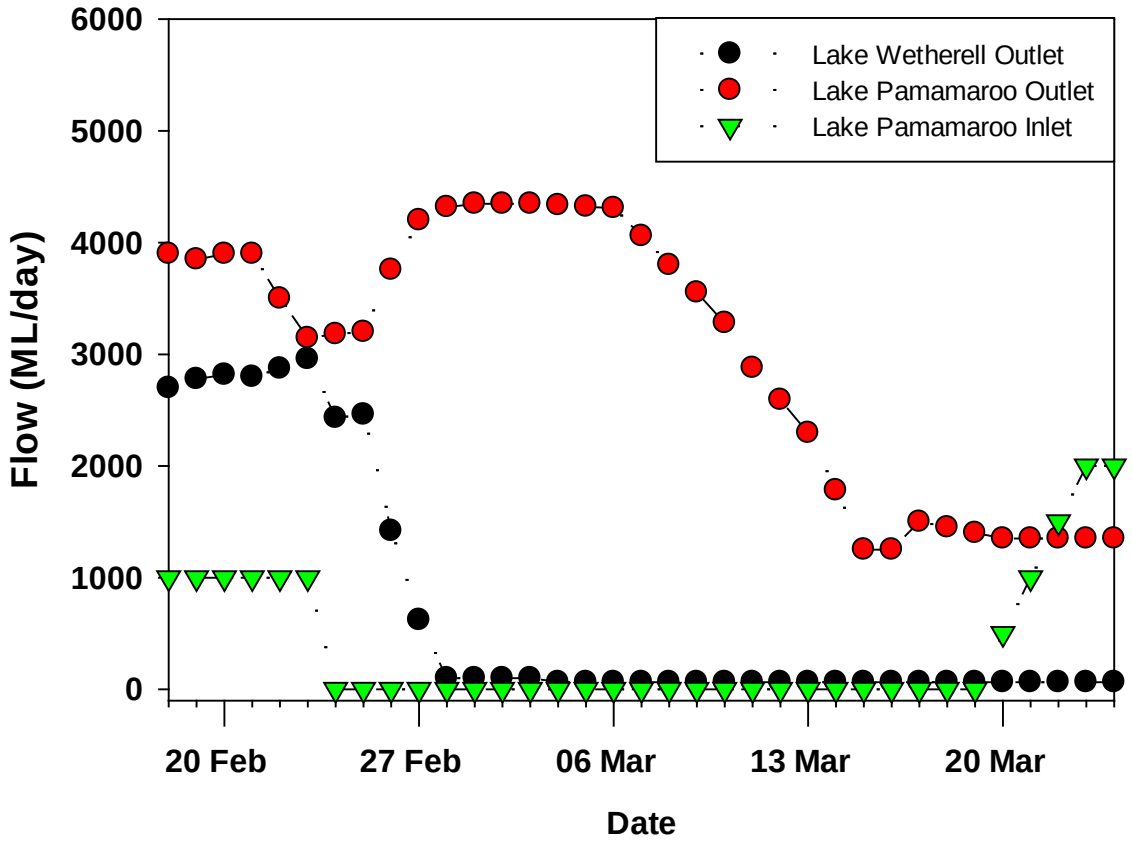


Figure 6: Flows from Lake Wetherell Outlet to Weir 32 weir pool (black circles), Lake Wetherell to Lake Pamamaroo through the Lake Pamamaroo Inlet (green triangles) and from Lake Pamamaroo to Weir 32 weir pool through the Lake Pamamaroo Outlet (red circles. for late February through March, 2023. (Data supplied by WaterNSW).

Flows from each of these phases have different implications for the fish kill. In the first phase water of unknown composition was entering into the top end of Weir 32 weir pool from Lake Wetherell - noting that fish kills were recorded in Lake Wetherell on both February 4 and 18-21 February, 2021 (DPI, 2023). During the second phase (and into the

third phase) the water entering the top end of Weir 32 weir pool would likely be well oxygenated.[8] Although this cannot be confirmed, it is not beyond comprehension, that after being subjected to a period of potentially poor water quality fish, especially bony bream, would move upstream towards the better water quality, meaning the fish would be congregating toward the top end of Weir 32 weir pool (- a Pied Piper effect to coin a phrase). Finally, during the third phase the amount of water (and hence oxygen) was declining. If we assume that the dissolved oxygen concentration in the inflow from Lake Pamamaroo in the third phase was 6 mg/L, at the start of the phase, when flows were about 4300 ML/day, the inflows would be delivering about 2.6 $x10^{10}$ mg of oxygen to the reach each day. At 1250ML/day, the inflow prior to the flows would be delivering 7.5 $x10^{9}$ mg of oxygen to the reach each day. This is about the same amount of oxygen that the fish biomass was consuming each day.

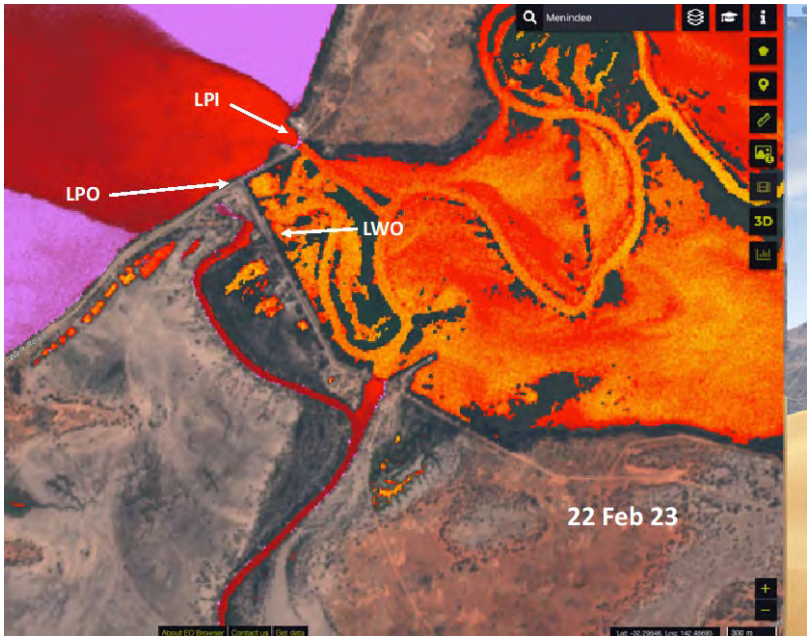


Figure 7: False-colour satellite image of Lake Wetherell, Lake Pamamaroo and Weir 32 weir pool taken on February 22 and processed with the Se2WaQ script (Sidónio and Pereira, undated) set to Parameter 4 (which optimises visualisation of both dissolved organic carbon as well as sediment). A clear plume of water can be seen exiting Lake Wetherell into lake Pamamaroo through the Lake Pamamaroo Inlet (LPI), but that plume also encroaches on the Lake Pamamaroo Outlet (LPO) indicating short circuiting.

[8] The latest data at time of writing was February 16,2023. At that time the dissolved oxygen concentration in the middle of Lake Pamamaroo was 9.35 mg/L (data source WaterNSW).

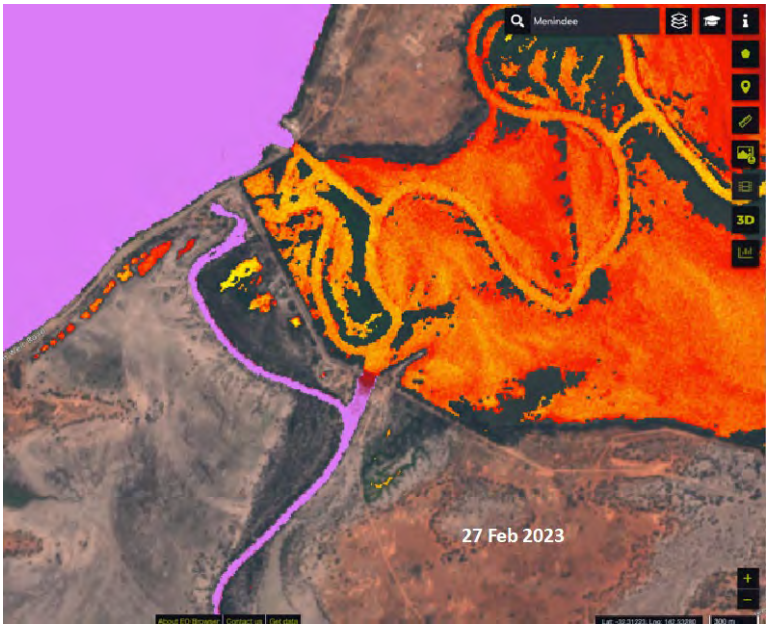


Figure 8: Same as Figure 7, but taken on February 27, after the lake Pamamaroo Inlet was closed.

3.3. Conclusion

If this hypothesis is correct we have a case where the sheer biomass of the fish was sufficient, in conjunction with other sinks for oxygen (sediment oxygen demand, night time algal respiration) to have tipped the system into hypoxia. In a sense, the fish contributed to their own death. Flow changes were not benign during the period. Inflows of oxygenated water from Lake Pamamaroo starting in March 2023 likely attracted the bony bream to the top end of Weir 32 weir pool. Then as the flows from Lake Pamamaroo were being ramped back, so was a source of oxygen to the fish.

It should be noted that this event does have the hallmarks of a 'Black Swan' event (sensu Taleb, 2007). The three attributes of a black swan events are:

- *Rarity* - As far as I am aware this is the first instance where dissolved oxygen has been impacted to the point of hypoxia by the respiration of an organism other than the microbiota (bacteria or algae) in a large, flowing system (see Baldwin, 2020).[9] In that sense the event wasn't prospectively predictable.
- *Extreme impact* - this is subjective, but at least from a human perspective this has garnered international attention, and undoubtedly has had a profound impact on the people of Menindee. Furthermore, it is probable that the decomposition of the dead fish that have accumulated on the bed of Weir 32 weir pool will lead to further hypoxic events.
- *Retrospective (not prospective) predictability* - as evidenced by this report.

4. Implications

The fish kill in mid-March 2023, has a number of implications for on-going management of water in the region (and indeed across the basin),

[9] Such events do occur when fish are isolated in pools or billabongs following flood recession or during drought.

1. Deliberately manipulating and moving water in the landscape comes at the potential risk to water quality, yet due regard is not paid to the potential for adverse outcomes. This is not the first time in the Murray-Darling Basin that changing flow regimes have resulted in the death of fish. Consideration of water quality should be integral to flow rules and water sharing plans across the basin.
2. Following on from the point above, there is insufficient monitoring to tell whether or not a management action will have an adverse outcome. Dissolved oxygen sensors are not always located in the right places, and monthly spot monitoring is insufficient to detect changes that may occur over days or weeks. Thought should be given to empowering locals by supplying equipment and training to pro-actively monitor their environment.
3. When managing flood recessions of large natural flows in highly regulated systems, there is a likelihood that a substantial amount of fish biomass can be trapped by infrastructure. Pre-emptive planning should be undertaken to minimise this eventuality.
4. At a more local level, a barrier, similar to a marine break wall needs to be constructed between Lake Pamamaroo inlet and outlet structures to prevent short-circuiting of the water (as discussed above). Lake Pamamaroo and Lake Menindee are natural aerators (Kerr et al, 2013) and should be used as such. Short-circuiting of the water in Lake Pamamaroo reduces this capacity.

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Appendix E - Prof Baldwin – Critique of Williams and Schulz (2023)

From:	Darren Baldwin
To:	Veronica Silberschneider; Allan Raine
Subject:	Critique of Williams and Schulz (2023)
Date:	Wednesday, 12 April 2023 5:20:19 PM
Attachments:	williams and schulz.docx

Dear Allan and Ronnie,
as discussed with Ronnie earlier today, I have attached a critique of the Williams and Schulz article. It only focusses on the key contention of undocumented released from Lake Wetherell and not secondary issues. For example, their Figure 14 clearly shows an algal slick, but it is labeled blackwater. (I didn't want the main issues bogged down by the less significant). If you have any questions or comments please do not hesitate to contact me.

Regards

Darren

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Google Scholar Profile

File Note

Subject: A critical evaluation of Williams and Schulz (2023)

Attention: Allan Raine - NSW Department of Planning and Environment
Veronica Silberschneider

From: Darren Baldwin, *Rivers and Wetlands*

Date: April 12, 2023

Purpose

Williams and Schulz (2023) released a report outlining their thesis on the fish kill in Weir 32 weir pool in mid-March 2023. Using Sentinel-2 satellite imagery they contend "that controlled releases of blackwater were made in the days leading up to the mass fish kill of March 2023"; and, by inference, these releases caused the fish deaths. This file note critically evaluates these claims.

Synopsis

There is little available evidence to support the central thesis of Williams and Schulz (2023). There were documented releases from Lake Wetherell outlet directly to Weir 32 weir pool (65 ML/day), but this represented (at most) only a few percent of the flows entering the weir pool prior to the fish kills. Processing Sentinel-2 imagery using scripts that can differentiate between water bodies with different algal or DOC/sediment concentrations indicate **if** there were any inflows into Lake Pamamaroo from Lake Wetherell immediately prior to the fish deaths, they would be best described as trivial, and could be from leakage across the control structure. An alternate explanation of the 'anomalies' identified in the satellite imagery of March 14 by Williams and Schulz (2023), is that it they are associated with water being drawn from other parts of Lake Pamamaroo because of releases from the lake. Finally, dilution modelling shows that 85% of inflows into the top end of Weir 32 weir pool (directly through Lake Wetherell outlet, or indirectly from short circuiting from the Lake Pamamaroo inlet to the outlet) would have needed to have come from Lake Wetherell to decrease dissolved oxygen below 2mg/L.[1]

Actual Flows

WaterNSW has supplied actual flows from Lake Wetherell into Lake Pamamaroo (Lake Pamamaroo inlet), from Lake Wetherell directly into Weir 32 weir pool (Lake Wetherell outlet) and from Lake Pamamaroo into Weir 32 weir pool (Lake Pamamaroo outlet) over the

[1] 2 mg/L is the notional concentration that large bodied native fish begin to die through oxygen starvation.

period of interest (Figure 1). Flows from Lake Wetherell to Lake Pamamaroo ceased on February 25, 2003 and recommenced on March 20 (i.e. after the fish kill). Flows directly from Lake Wetherell into Weir 32 weir pool were reduced to 65 ML/day by March 4, and remained at that level throughout most of March (Figure 1). These inflows directly from lake Wetherell into lake Pamamaroo represented between about 1 - 3% of total inflows into Weir32 weir pool above Menindee township.

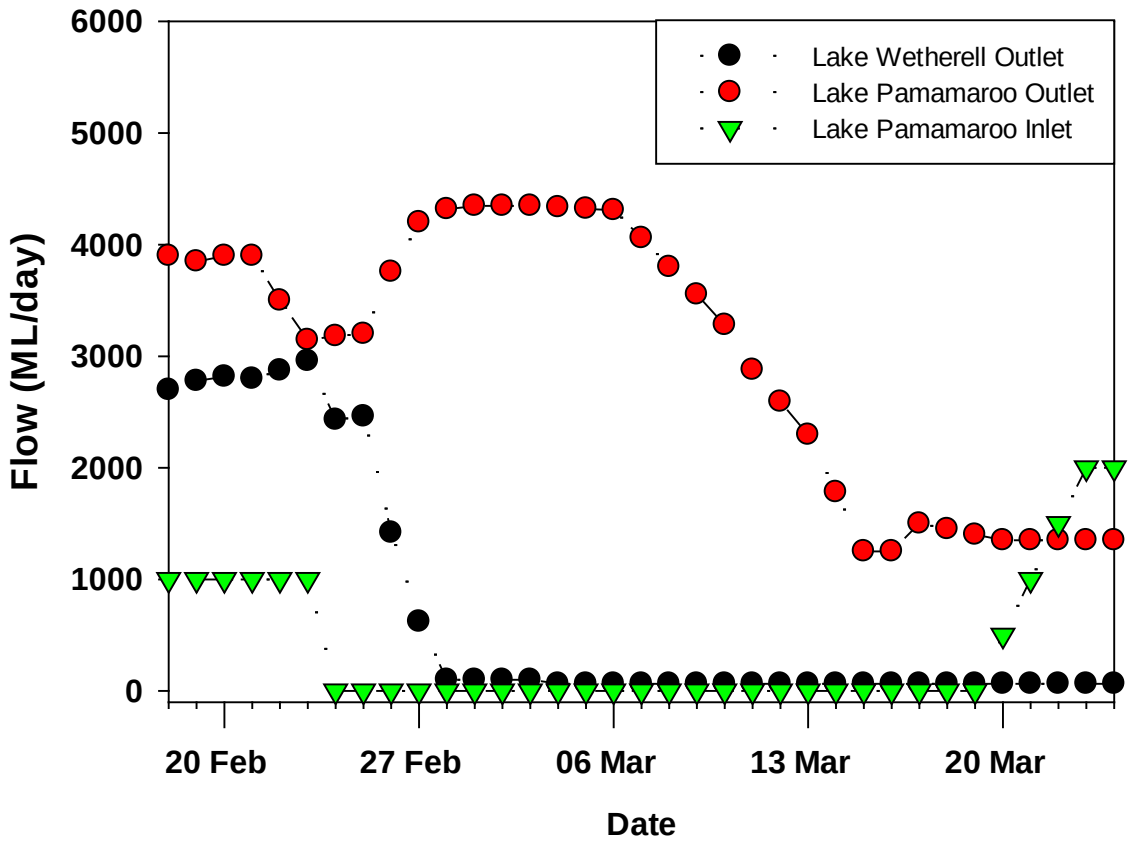


Figure 1: Flows from Lake Wetherell Outlet to Weir 32 weir pool (black circles), Lake Wetherell to Lake Pamamaroo through the Lake Pamamaroo Inlet (green triangles) and from Lake Pamamaroo to Weir 32 weir pool through the Lake Pamamaroo Outlet (red circles. for late February through March, 2023. (Data supplied by WaterNSW).

Sentinel 2 Imagery - Background

Sentinel 2 imagery is captured by 2 European Space Agency satellites, each equipped with Multispectral Imagers. The imagers collect data across 13 bands - the shortest wavelength band (B1) is centred at 442 nm (in the ultra-blue - close to the detection limit of the human eye), while the longest wavelength band (B12) is centred at 2190 nm, which is the infrared. These bands can be combined together to visualise different aspects of the environment. For example, combining band B2 (blue), B3 (green) and B4 (red) gives a good approximation of true (or natural) colour. This appears to be the basis of the images used in Williams and Schulz (2023). However, the various bands can also be combined in ways to specifically highlight different aspects of the environment. For example, the Aquatic Plants and Algae Custom Script Detector (APA; Péliova A et al., undated) is designed to highlight aquatic plants and algae, as well as suspended sediments. It shows land features in natural colour,

open water in blue, algal density in shades of light green to yellow and suspended sediment in colours from brown, through red to purple.

One advantage of processing the satellite imagery through scripts like APA and Se2WaQ Sidónio N and Pereira A (undated)) is that it can differentiate between different water sources if they have different water chemistries (e.g. algal or sediment concentrations), and therefore, can indicate how they mix. For example, Figure 2, processed with the Se2WaQ script (set to parameter 4, which highlights DOC and suspended sediments), shows the sediment plumes entering Lake King from the Mitchell, Nicholson and Tambo Rivers (yellow is lowest sediment load, purple is the highest).[2]

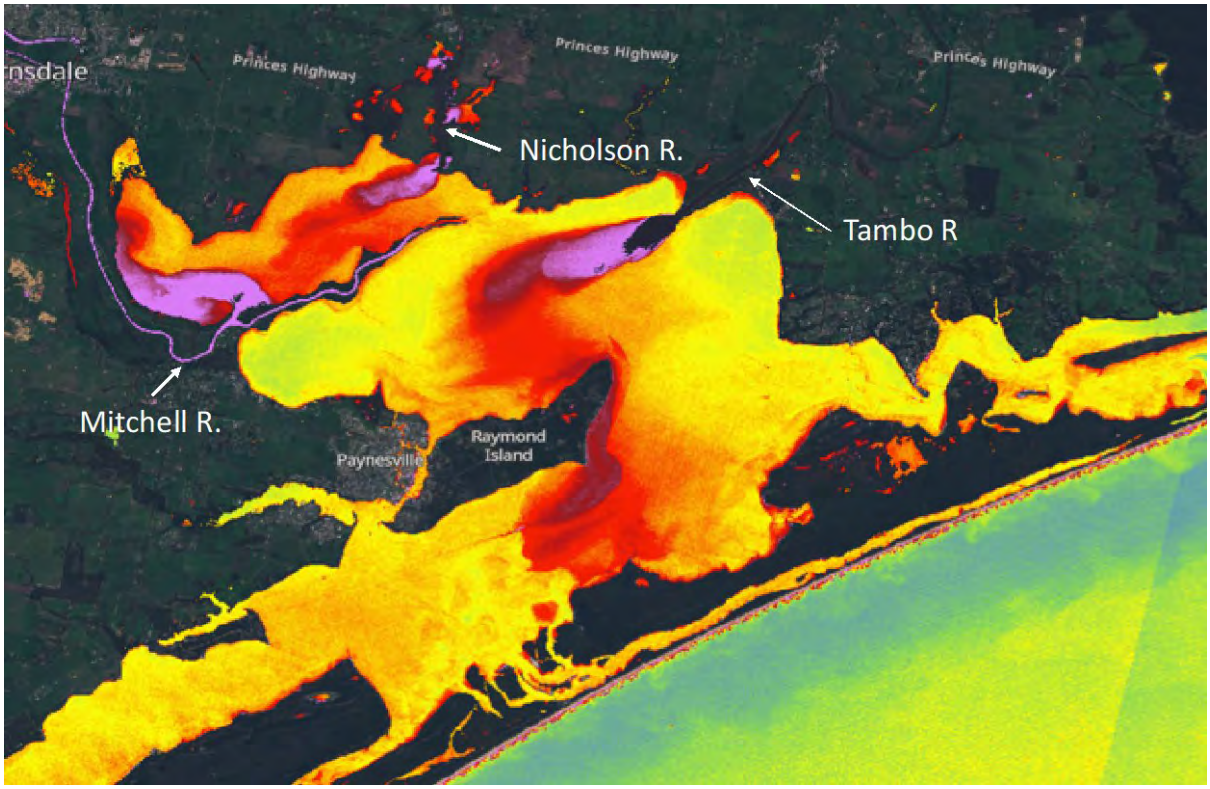


Figure 2: False colour Sentinel2 satellite images of Lake King (a Gippsland Lake) processed using the Se2WaQ script set to highlight suspended sediments. Yellow is the lowest suspended sediment concentration - purple is the highest. The image shows all the sediments are being delivered from the three rivers that flow into the lake.

Sentinel 2 Imagery of Lake Wetherell, Lake Pamamaroo and Weir 32 weir pool on March 14, 2023.

The key argument of Williams and Schulz is that water was being released from Lake Wetherell into Lake Pamamaroo on or immediately prior to the satellite pass on March 14. This 'blackwater' was then short circuited into Weir 32 weir pool. The water was low in dissolved oxygen, and this caused the fish death. There is no doubt that releases from Lake Wetherell into Lake Pamamaroo can short circuit into the Weir 32 weir pool if both the Lake

[2] July 2020, following a rainstorm, after the Black Summer Fires

Pamamaroo inlet and outlets are open. The key question then, is whether water was being released into Lake Pamamaroo from Lake Wetherell on or about about March 14. The critical evidence presented by Williams and Schulz (2023) are their Figure 9 (which is a true colour image of the Lake Pamamaroo inlet and outlet on March 14, their Figure 11 (the same image but processed using photoshop enhancement of saturation and contrast to delineate the blackwater), Figure 12 (which showed different colour swatches purporting to show mixing) and their Figure 13 (which is processed in the same as their Figure 11 but is focused on the Lake Wetherell outlet [3] (I note in passing that using Photoshop to extract data from Sentinel 2 imagery is not necessarily incorrect, but is certainly unorthodox.)

Figure 3 Shows the 'true colour' sentinel 2 image of the area around the Lake Pamamaroo inlet and outlet on March 14 (Similar to Williams and Schulz Figure 9). The anomalies relied on by Williams and Schulz (2023) to indicate releases from Lake Wetherell to Lake Pamamaroo are highlighted. A few things to note. Firstly, the water in Lake Wetherell is green, more than black, indicating an algal bloom in Lake Wetherell. Secondly, the change in colour either side of the Lake Pamamaroo inlet is quite dramatic indicating little or no mixing has occurred (discussed in further detail below).

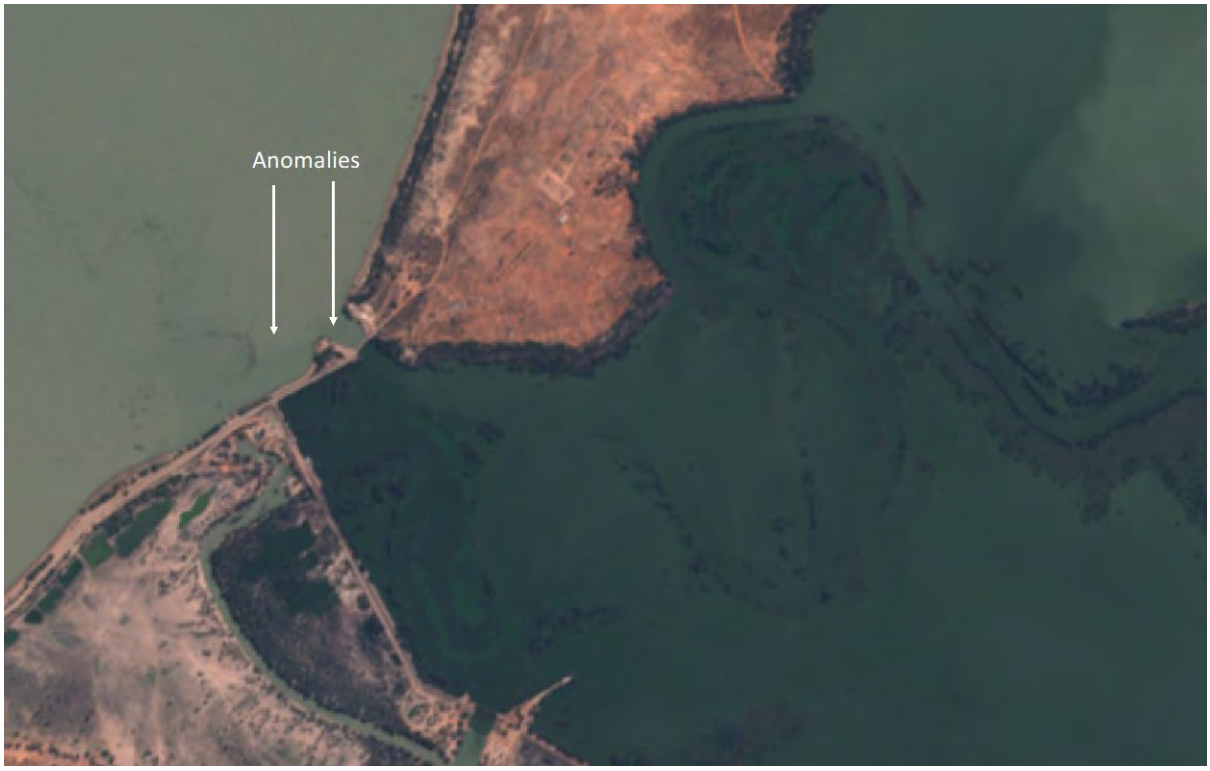


Figure 3: 'True Colour' Sentinel 2 image of Lake Pamamaroo (top left corner) and Lake Wetherell (bottom right corner) taken on March 14. Anomalies discussed in Williams and Schulz (2023) are indicated by arrows

[3] These images are not reproduced here so as not to infringe copyright - the reader is referred to Williams and Schulz (2023) to view the originals.

A similar image, although this time processed with the APA script, which highlights algal biomass, suggests that if there were flows coming from lake Wetherell they would be trivial, consist with leakage (Figure 4). Inflows from Lake Wetherell (high in algal density) to Lake Pamamaroo (low in algal density) would be obvious from the false colour satellite images. To make this point clearer, Figure 5 shows the same location as Figure 4, but taken on March 22 when the flow into Lake Pamamaroo from Lake Wetherell was 1000 ML/day.

Figure 4: False colour Sentinel 2 satellite image of the same region as Figure 3, taken on March 14 and processed with the APA script. Green and yellow represent levels of high algal density. Purple is high concentrations of suspended sediments

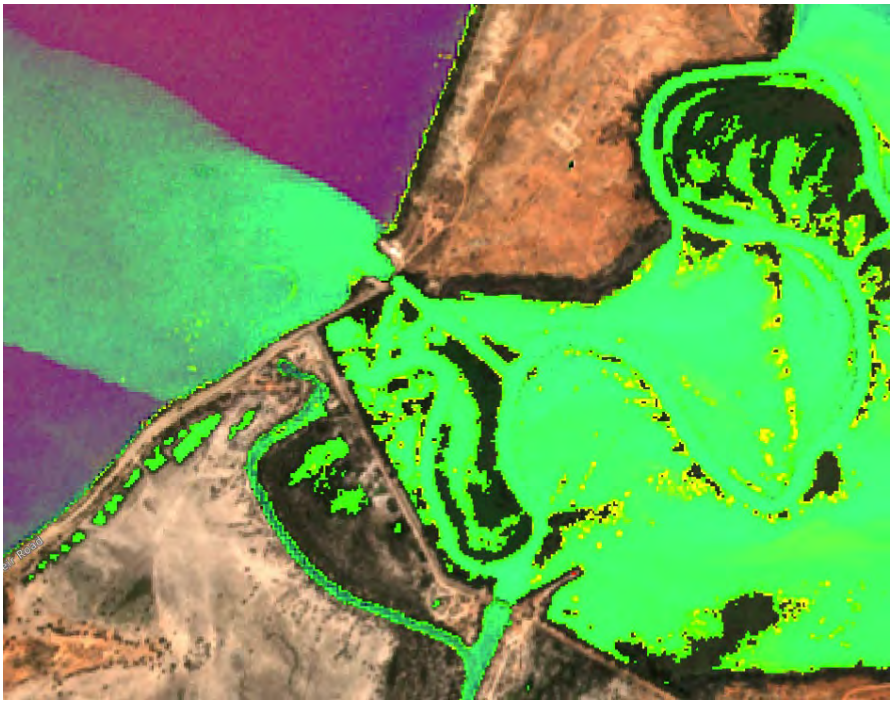


Figure 5: False colour Sentinel 2 satellite image of the same region as Figure 3, taken on February 22 (a period of moderate inflows into Lake Pamamaroo from Lake Wetherell)

processed with the APA script. Green and yellow represent levels of high algal density. Purple is high concentrations of suspended sediments

Furthermore, if we zoom out, an alternate explanation for the supposed anomalies on March 14 arises, namely the algal biomass, especially around the Lake Pamamaroo outlet, is being drawn to the outlet from the main body of the lake with the release of water into Weir 32 weir pool (Figure 6).

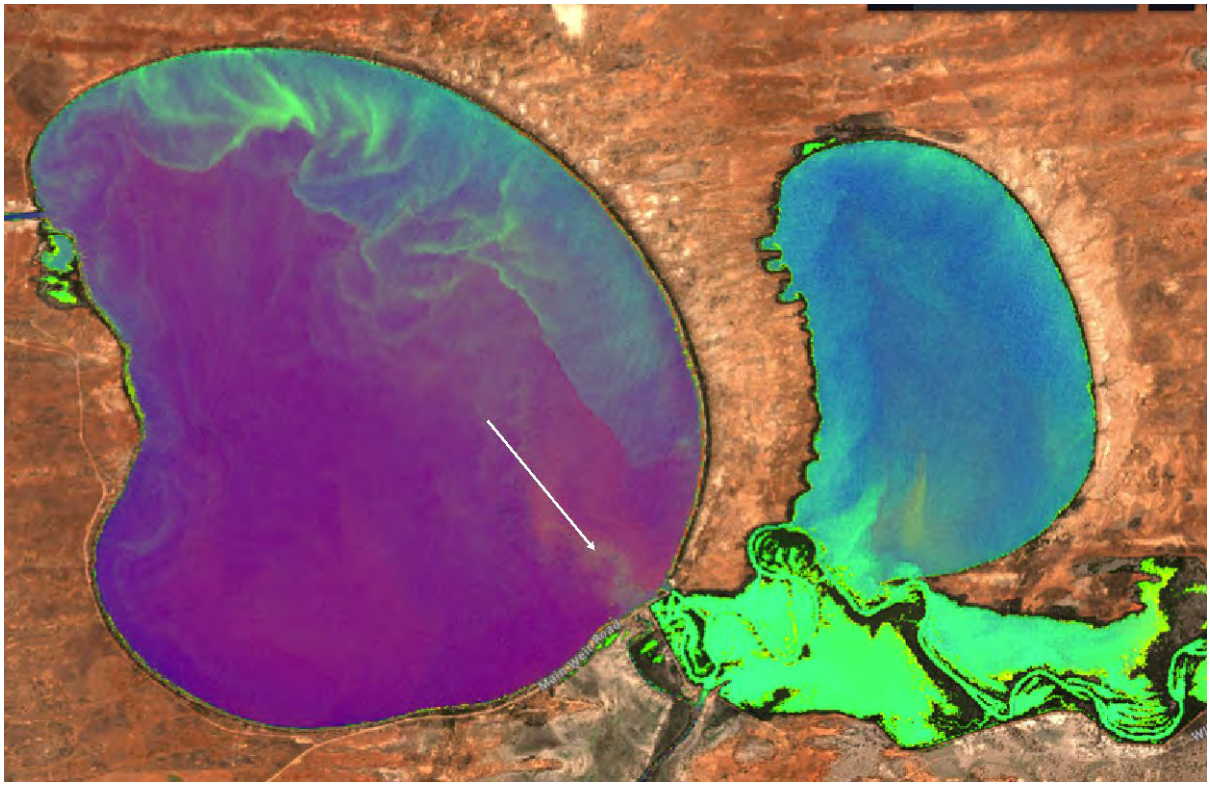


Figure 6: False colour Sentinel 2 satellite image of the whole of Lake Pamamaroo and Lake Tandure and the lower portion of Lake Wetherell taken on March 14 and processed with the APA script. Green and yellow represent levels of high algal density. Purple is high concentrations of suspended sediments. The arrow represents a potential flow path as water was being released from Lake Pamamaroo.

A similar pattern to images processed with the APA script can also be seen if the image is processed with the Se2WaQ script (set to parameter 4 which highlights DOC and suspended sediment; Figure 7). Firstly, if large amounts of water was entering Lake Pamamaroo from Lake Wetherell, we would expect to see a distinct plume where the two waterbodies (with different loads of suspended sediments) interact - e.g. as occurred on February 22 (Figure 8). Furthermore, analogous to Figure 6, one interpretation of the proposed anomalies reported by Williams and Schulz (2023) around the Lake Pamamaroo inlet and outlet is that water with a slightly lower turbidity is being drawn from the north of the lake (Figure 7).

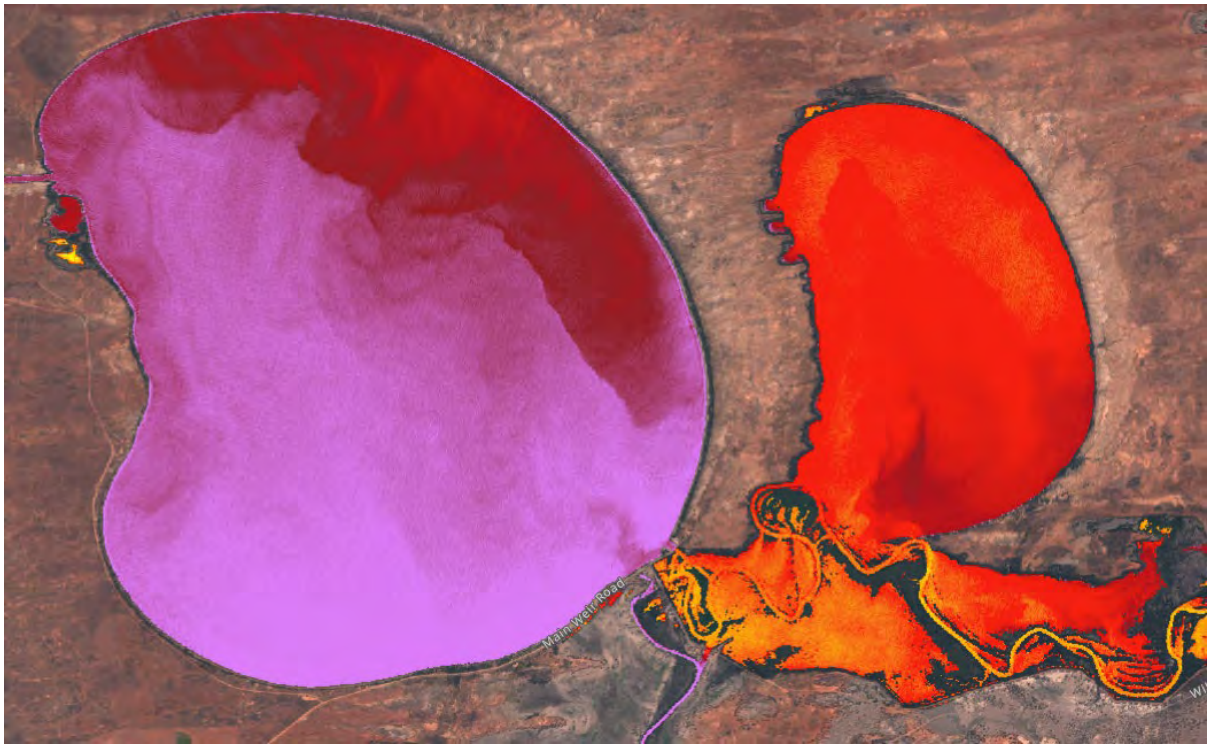


Figure 7: False colour Sentinel 2 satellite image of the whole of Lake Pamamaroo and Lake Tandure and the lower portion of Lake Wetherell taken on March 14 and processed with the Se2WaQ script. Concentrations vary from yellow lowest through red, to purple (highest)

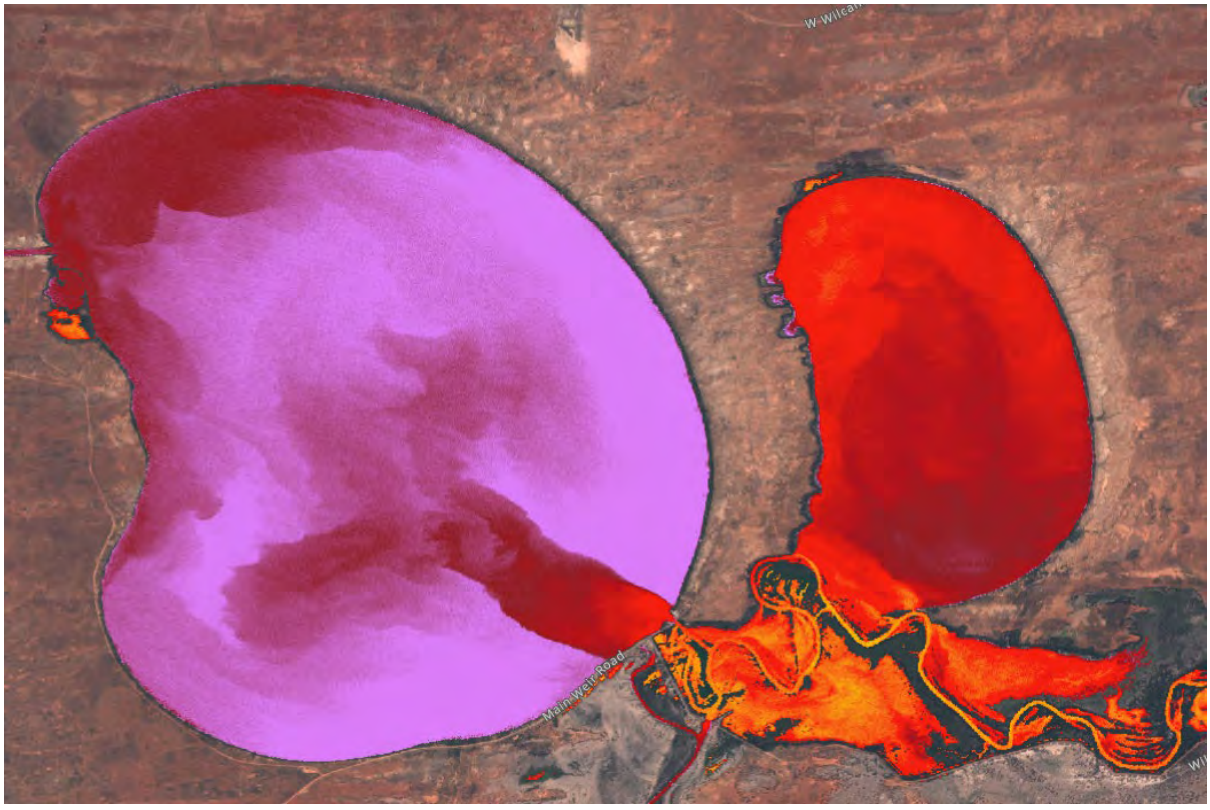


Figure 8: as per Figure 7, but taken on February 22, a period of moderate inflow from Lake Wetherell to Lake Pamamaroo.

The anomalies pointed out in Williams and Scholz (2023) Figures 12 and 13 can be explained by the 65 ML/day that was being released from the Lake Wetherell outlet (see above)

Modelled Dissolved Oxygen Concentrations

An alternate approach is a hypothetical - what percentage of Lake Wetherell water would be need to enter the top end of Weir 32 weir pool to drop the dissolved oxygen concentration to below 2 mg/L (the notional concentration that kills native fish e.g. Gehrke 1988) using a published model (Kerr et al, 2013). To populate the model we need total flows, nominal flows from Lake Pamamaroo and Lake Wetherell (which would be the sum of water both entering Weir 32 directly from the Lake Wetherell outlet and mixing with water from Lake Pamamaroo and the dissolved oxygen concentrations in both Lake Pamamaroo and Lake Wetherell.

Total Inflows: here we use the data supplied by Water NSW for March 14, 2023 ≈ 1850 ML

Ratio of Lake Wetherell and Lake Pamamaroo flows: this is the variable we are testing for.

Dissolved oxygen concentration in Lake Pamamaroo water: monthly samples were taken in the middle of Lake Pamamaroo on 21 February (average concentration 7.7. mg/L) and 27 March (8.1 mg/L). For this exercise we will use the overall average of 7.9 mg/L

Dissolved oxygen concentration in Lake Wetherell: The average dissolved oxygen concentration at station 2 in Lake Wetherell on March 27 was 1.3 mg/L.

The first model run was based on the actual inflows on March 14, 2023 (1775 ML/day from the Lake Pamamaroo outlet) and 65 ML/day from the Lake Wetherell outlet. Dissolved oxygen concentration would decline by about 0.2 mg/L (from 7.9 to 7.7 mg/L) on mixing (Figure 9).

Use of dilution flows for hypoxic blackwater mitigation

Dilution flows can be used to mitigate the impacts of hypoxic blackwater. This model predicts the immediate effect and downstream persistence of dilution water inflows for hypoxic blackwater treatment. It assumes complete mixing of the two parcels of water and that all DOC in both blackwater and dilution water is of the same reactivity. A constant, rectangular river cross-section downstream of the mixing point is assumed, and temperature is assumed to remain constant after mixing.

Enter data in yellow cells. Model outputs are in the green cells and the two charts.

Blackwater characteristics			
Blackwater discharge/flow rate	F_{bw} =	65	ML/day
Dissolved oxygen (DO) in blackwater	DO_{bw} =	1.3	mg/L
Dissolved organic carbon (DOC) in blackwater	DOC_{bw} =	-	mg/L
Temperature of blackwater	T_{bw} =	25.0	°C
Dilution water characteristics			
River/dilution water discharge/flow rate	F_{dil} =	1,785	ML/day
DO in river/dilution water	DO_{dil} =	7.9	mg/L
DOC river/dilution water	DOC_{dil} =	-	mg/L
Temperature of river/dilution water	T_{dil} =	25.0	°C
Downstream channel characteristics			
Average Channel Depth	H =	50.0	m
Average Channel Width	W =	2	m
Key outputs upon initial mixing			
Flow velocity	U =	0.21	m/s
Initial DO concentration after mixing	$DO_{ds,0}$ =	7.67	mg/L
Initial DOC concentration after mixing	DOC_0 =	0.00	mg/L
Critical DO concentration (lowest value)	DO_{min} =	7.67	mg/L

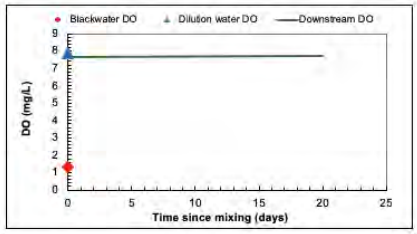
Notes:

<- If unknown, blackwater DOC is usually 20 - 30 mg/L

<- If dilution water DOC is unknown or known to be unreactive, enter 0.

Downstream time series

Time (t, days)	Distance (x, km)	Downstream DO (DO_{ds}, mg/L)
0	0	7.67
0.5	9	7.67
1	19	7.67
1.5	28	7.67
2	37	7.67
2.5	46	7.68



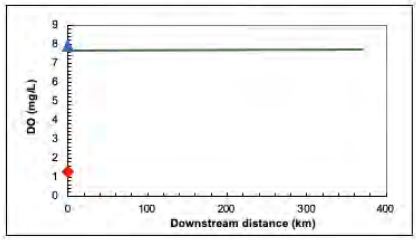


Figure 9: Screen shot of the Blackwater Intervention tool dilution model based on actual flows. The dissolved oxygen concentration on mixing is found on line 23

The ration of inflows from the two sources was then varied until the dissolved oxygen on mixing reached 2 mg/L. Approximately 85 % of the inflows into the top end of Weir 32 weir pool (1550 ML/day) would needed to have come from Lake Wetherell to drop the dissolved oxygen concentration to 2mg/L on mixing (Figure 10). To lower the oxygen concentration to 4 mg/L would still require about 60% (1100 ML/day) of flows to have originated from Lake Wetherell.

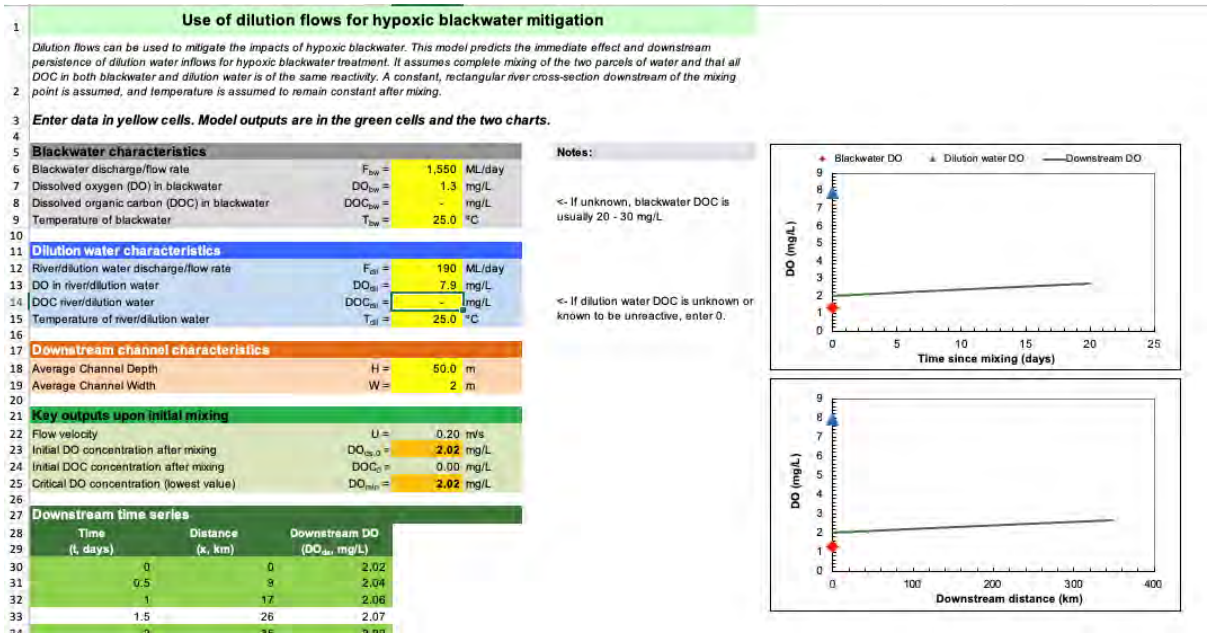


Figure 10: Screen shot of the Blackwater Intervention tool dilution model changed so that the final concentration of dissolved oxygen after mixing was about 2 mg/L (see line 23). flows.

5. References

Kerr J, Baldwin DS, Whitworth K (2013) Options for managing hypoxic blackwater events in river systems: a review. *Journal of Environmental Management* 114, 139-147.

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End of Part A