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Public Submission to Independent Review into the February-March 2023 fish deaths in the Darling-Baaka River, Menindee 22 May 2023

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To: Office of the NSW Chief Scientist & Engineer (OCSE)

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Background

My professional career began as a livestock veterinarian before spending 5 years as NSW DPI Fisheries Aquatic Animal Veterinarian investigating many fish kills (2000-2005). I transitioned to become one of Australia's few independent fulltime fish veterinarians 18 years ago as founding Director of Future Fisheries Veterinary Service. I have had adjunct appointments at Sydney University Veterinary School for Farm Animal Health and more recently at Charles Sturt University, Faculty of Veterinary Science. Through hundreds of disease investigations in aquaculture and wild capture fisheries I've come to appreciate the increasing role of aquatic contaminants as our aquatic ecosystems have degraded.

Methodologies for veterinary epidemiological fish kill investigation

I hope that the chief scientist is aware of the methodologies taught to veterinary undergraduate students to undertake outbreak investigation and deploys these epidemiological approaches to assist in investigating this kill. There are also extensive fish kill manual guidance documents developed by FRDC in 2006 and more recently in 2023. There are also fish kill investigation manuals prepared by Qld EPA and by WA Fisheries which are worth referring to for guidance on how to investigate. FFVS would be open to discussing these methodologies with the Chief Scientist.

Biological requirements of aquatic biota and importance of history

There are multiple sources of fisheries data which illustrate the Darling River and upper Darling catchments health is continuing to demonstrably decline (Stocks, Ellis, van der Meulen, Doyle, & Chesire, 2022) (Gell & Reid, 2014). Native fish and other aquatic organisms require more of their water, than for it to be just wet. They require water quality and flow to support their ecosystem to function, which in turn supports them. They require passage to move up and down the system to complete their lifecycles. They require natural hydrology to fill their wetlands and spill onto the floodplains.

We have modified the system a long way from the natural hydrology that historically supported substantial fishery productivity and environmental health. The complex operation MD Basin does not ensure that water is of sufficient quality, volume/flow rate to maintain the ecological health of the river. The consequence of the chosen method of water regulation/management and agricultural systems for food/fibre production have dire consequences for aquatic ecosystems and have effectively created the necessary pre-conditions to trigger large deoxygenation fish kill events.

The impacts from the catchment on the water are evident in longitudinal data sets of floodplain wetlands where excess nutrients, macrophyte loss and huge fluxes of increased sediment have all been caused (Gell & Reid, 2014)

Prior to this most recent Menindee fish kill event the Darling River has suffered dramatic declines of turtles, native fish species, crayfish, mussels and snails. These all point to a long-term problem with catchment and water management. The dramatically altered hydrology was installed to control the flow of the river (Mallen-Cooper & Zampatti, 2018) primarily for agricultural access to water.

The Menindee fish kills are symptomatic of an aquatic ecosystem in collapse. The collapse stems from issues which begin much further upstream but has become visible and gained media notoriety at Menindee.

An entire shift in the paradigm of land and water management is needed to return health to the waterway. As the water which enters the river is a mirror to the landscape which it runs off.

The frequency and extent of fish kills in recent history, due to deoxygenation, is at risk of becoming normalised as an expected outcome of rainfall or drought. The historical record does not suggest that such events occurred prior to the significant and progressive catchment modification which has happened over the last century. Shifting baselines, as described by Daniel Pauly (Pauly, 1995), is occurring as few alive today can recall when the river was a clear-running abundant fishery. The volumes of fish, crustacea and other biota which were thriving in the productive aquatic ecosystem are inconceivable to most people alive today.

This was not a 'natural' event. It is a consequence of our management of water and the landscape which drain into the river. The good news is we can fix it- but it requires significant change and political will. The history of socio-management of the river and water resources offers some further insights as to where corrective actions are needed in a social policy context (Jackson & Head, 2020).

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Factors potentially contributing to fish kill

1) Upstream water quality deterioration and water extraction

To appreciate the cause of the Menindee fish kills it will be essential to look up the catchment to the sources of the degraded water quality and understand the complex of factors generating it.

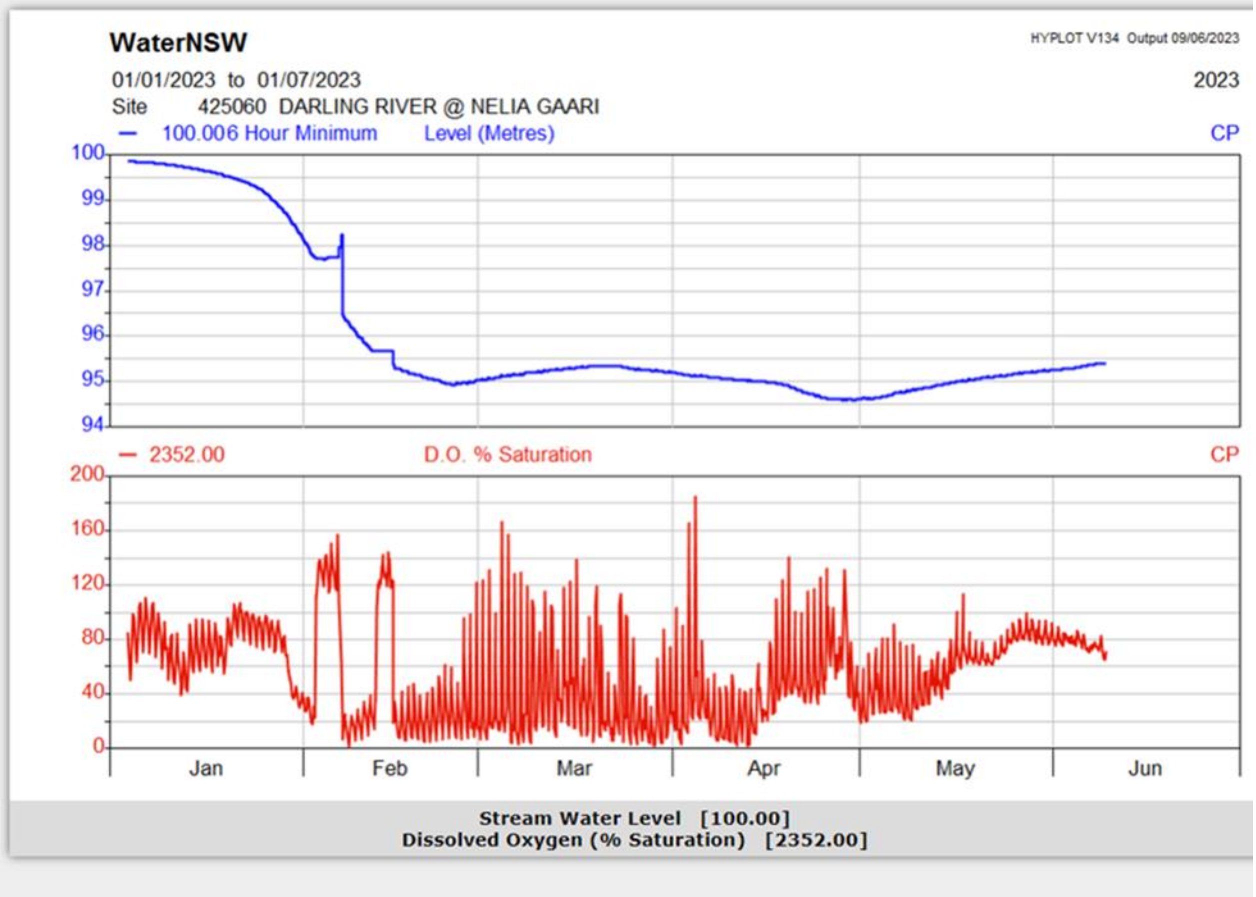

Figure 1: Water NSW water quality data Nelia Gaari Darling River 2023

The Nelia Gaari monitoring station is above the area of the large fish kill that occurred around 16 March at Menindee. The large flood in the upper Darling catchment resulted in dramatic deoxygenation of water from late January onwards (Figure 1). Clearly a large volume of poor quality water was created upstream from this monitoring station, and was headed for Menindee. Commensurate with this mass of poor quality water there were fish kills reported at Bourke and Louth prior to the major fish kill at Menindee in mid-March. The data clearly demonstrates from late February the presence of a significant algal bloom driving massive diurnal oxygen swings.

The wind speeds recorded at Menindee weather station (Appendix 1) recorded low wind speeds in the week prior to the kill all less than 9km/hr. Such conditions are conducive to algal blooms where nutrient levels are elevated. There was nil cloud cover in the period leading up to the kill, permitting maximum sunlight to drive algal productivity. More data is needed to assess the relative roles of these factors.

The Water NSW monitoring data at Menindee upstream weir 32 which is below where the fish kill began (Figure 2) shows oxygen dropping on 18 March below viable levels for fish. Substantial mortalities were reported kilometres upriver from this gauge from 16 February.

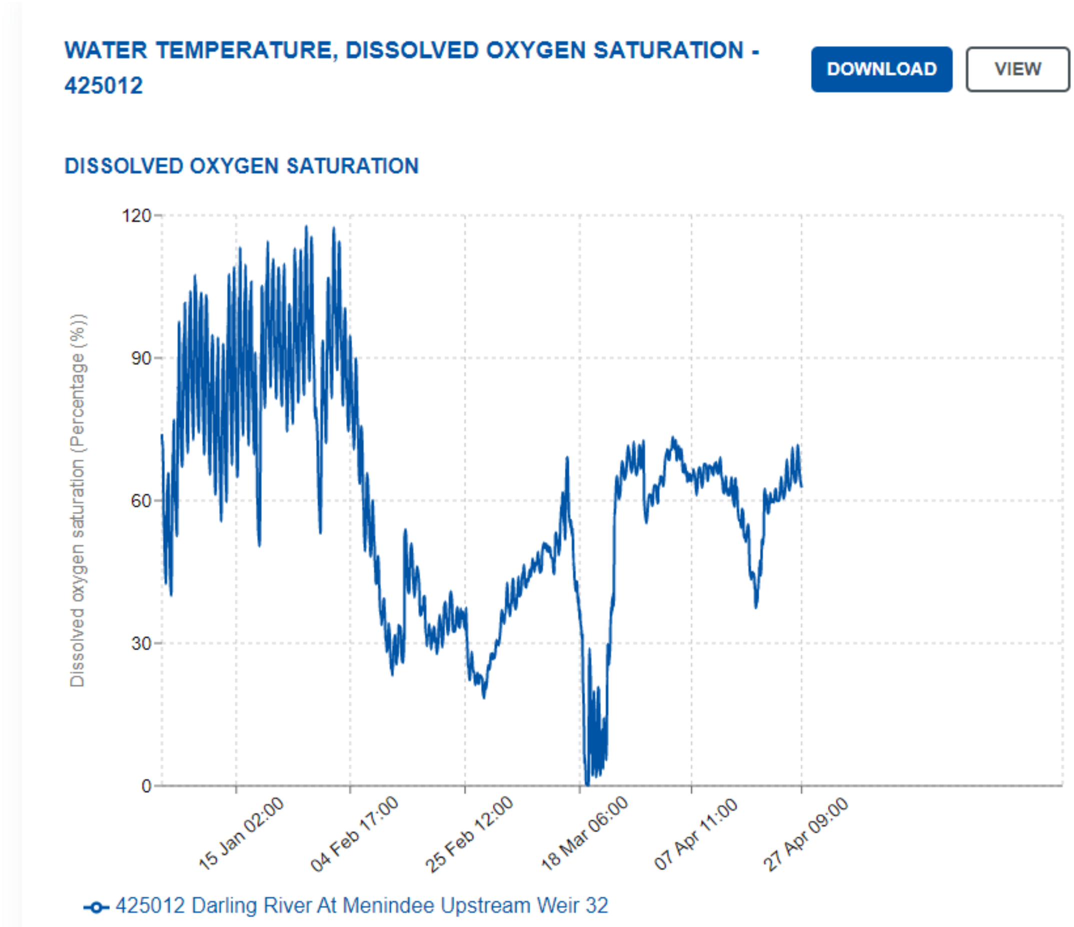

Figure 2: Dissolved oxygen saturation Menindee Upstream Weir 32 Water NSW

Upper Darling water extraction has a role and has been implicated in recent historic Darling Fish kills in 2018-19. The extent to which upper Darling historic water extraction/over-extraction have contributed to this 2023 Menindee fish kill is not explored in detail in this submission.

(Wheeler, Carmody, Grafton, Kingsford, & Zuo, 2020) and others have highlighted the issue of governance of extraction in the northern Murray-Darling Basin, contributing to changed flows. The extent to which upper Darling catchment extraction has reduced bank over-topping and thence reduced frequency of floodplain organic carbon flushing is also not examined in this submission. There is evidence to support this as a co-contributory cause to creating conditions that trigger deoxygenation and fish kills (Francis & Sheldon, 2002)(Whitworth, Baldwin, & Kerr, 2012). However, there are other factors, apart from the flooding frequency, which influence the amount of organic carbon on floodplains. These other drivers of deoxygenation risk are less well researched and will be expanded upon in this submission.

Floods

Historically floods did not cause massive fish kills, like they do now. Actually, floods historically caused booms in aquatic productivity for native fish and crayfish- as documented in historic literature lower in the MD system. There were small areas of deoxygenation that mobile biota could move away from, but nothing like the scale of kills of recent years.

"Harvests of Murray crayfish were discussed as <u>being considerably more productive during years with high flows and floods</u>. This pattern corresponds to significant commercial harvests of Murray crayfish

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in the Murray River in 1953–1954 and 1973–1975, periods of significant high river flows (Asmus 1999)"[1]

Blackwater

Floods now coincide with mass mortality and oxygen crashes in the MD and other rivers. Even after 3 very wet La Nina years back to back, blackwater and severe kills continued.

This speaks to the poor quality of the water re-entering the river and the health/abundance of the river's ecology to manage the influx of organic matter.

Today, blackwater events are quickly put down to so called 'natural' organic matter inundation associated with flooding by Government, as was the case with Menindee in 2023 (Williams & Schulz, 2023). However, it is clear that in early colonial history that floods did not drive such devastating fish kill events prior to weirs, flow control, wetland drainage, degradation and unseasonal filling for use as storage, and landscape modification for irrigated agriculture in the northern basin. These modifications are the principal reasons why run-off is now more toxic, and the river less able to assimilate the water and keep its resident biota alive.

Collectively, they signal a need for a paradigm shift in landscape and flow management to prevent future kills and halt the further decline of the ecological health of the Darling aquatic ecosystem.

The monitoring station above the fish kill area at Nelia Gaari suggests the kill was 'telegraphed' down the river from upstream. After an initial oxygen level crash in early February, a clear boom in algal productivity is evident in the data with huge daily diurnal fluctuations in oxygen saturation from 5-125% from late February. Given the intense fertiliser use in agriculture in the upper Darling catchment and mobilisation effect of rainfall on nutrient, combined with release of nutrient from upriver fish kills, this deleterious situation is to be expected.

Some scientists claimed the blackwater from floods was being stored in Lake Wetherell and when this was run into Lake Pamamaroo and released into the weir pool above Menindee (Figure 3) it triggered deoxygenation[2] (Williams & Schulz, 2023). I will leave it for others to explore the many machinations of the local water releases and their impact on water quality and focus on the larger landscape scale issues.

There is clearly more to this story, looking upstream, as there appear to be already longstanding issues with water quality, prior to this flood pulse. Significant fish kills occurred at Walgett, Bourke, Brewarrina[3] and Louth and smaller fish kills are reported to have occurred in Lake Wetherell in late February and early March and all were attributed to low oxygen.

[1]https://www.researchgate.net/publication/268425619_Scoping_the_knowledge_requirements_for_Murray_Crayfish_Euastacus_armatus

[2] https://www.theguardian.com/australia-news/2023/apr/11/menindee-mass-fish-kill-satellite-images-researchers-blackwater-release-darling-baaka-river-australia

[3] https://www.australiangeographic.com.au/news/2023/03/menindee-fish-kill/

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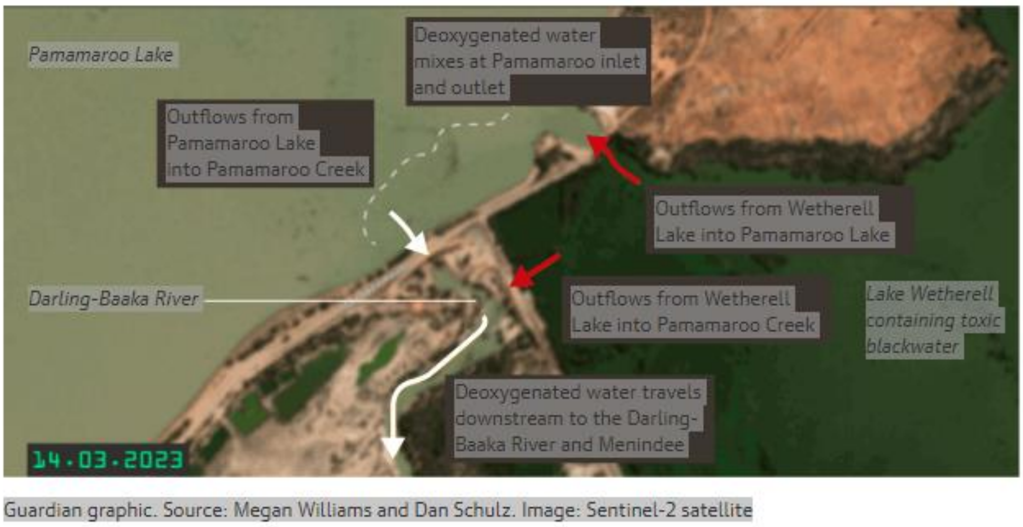

Figure 3: Graphic of suspect blackwater flow from Wetherell into Pamamaroo and into Darling-Baaka River Source: Williams & Shultz 2023 copied from Guardian article.

It is notable that oxygen levels at the Weir 32 data logger were very low at 20-25% saturation from 19 Feb-2 March, well before the major Menindee kill, which align with the upstream data indicating deoxygenated water moving down the system. These levels are stressful to native fish.

Whilst the role of mobilisation of accumulated organic carbon on floodplains in driving deoxygenation is appreciated it appears an incomplete explanation for the Menindee events. The high frequency of recent flood history, might have been expected to have flushed away some of the excess carbon, were this theory to be the dominant driver.

There are other significant landscape and water management factors that are driving the creation of deoxygenated blackwater. The role of nutrient excesses appears a necessary cause to create the water conditions that were observed.

Terrestrial insect loss and effects on flood plain organic carbon

The high levels of pesticide use as sprays and within GM crops like Bt cotton are strongly implicated in insect population declines. One of the consequences of the dramatic global terrestrial insect decline reported by (Sanchez-Bayo & Wyckhuys, 2019) (Wagner, Fox, Salcido, & Dyer, 2021) (Harvey, et al., 2022) is likely the slowing of the decomposition process of organic plant matter on the ground. For example, Christmas beetles have dramatically declined[4], and these feed on eucalyptus leaves, which comprise a significant component of flood plain organic matter in some areas of the upper Darling basin. The lack of consumption of leaf litter by insects, leaves it available for bacteria to drive up biological oxygen demand when carbon is released into the water during flooding.

Insects like moths are the critical carriers of some fungal spores which hasten decomposition and shift nutrient and carbon into the soil food webs (Crowther, Boddy, & Jones, 2012). The increased soil biota help hold the soil together and reduce the erosive effect of water[5]. This in turn reduces loss of soil to the river. The loss of insects is likely to catalyse an increase in the loadings of floodplain organic carbon which can then become intercepted by flood waters. Having recently driven through the upper Darling catchment the

[4] https://australian.museum/learn/animals/insects/christmas-beetles/
[5] https://www.nrcs.usda.gov/sites/default/files/2022-10/Rangeland_Soil_Health_Soil_Biota_SD-FS-85b.pdf

lack of insects splattered on the car windscreen was a striking difference to childhood trips through that region.

The dependency of industrial monoculture agriculture on pesticide inputs and on synthetic fertiliser drive down soil health, deplete insect fauna and contribute to these downstream consequences for water quality in the receiving catchment.

Pesticides impact on riverine health

Waterways that flow through farmland and from roadside drains are all regularly contaminated by pulses of pesticides from a range of sources from agricultural spray drift, farm run-off, council weed control and urban uses. Their presence is often transitory, so they are not always detected. Unfortunately, pesticides leave a legacy even after they have passed through the system, adsorbed into the river floor sediment or been broken down into other metabolites.

None of the pesticides which NSW EPA screened for in post-kill sampling were detected in grab samples of water. I did not identify any test results for sediments. This is perhaps unsurprising as there is little use in the areas immediately upstream of the kill. Much further upstream there is significant cotton and other cropping cultivation. The absence of compulsory data recording of where, when and which pesticide is used preclude detailed analysis. Like many riverine impacts, upstream events can materially alter downstream outcomes, through modifying water quality, altering assemblage of zooplankton and other invertebrates. Thus, failing to find a residue at a downstream site, cannot rule out the ecological role of pesticide use upstream.

Australia continues to permit many chemicals that have been removed in the EU due to their adverse toxic impacts on the environment, such as neonicotinoids and fipronil insecticides. These compounds have severe impacts on insects at parts per trillion exposure levels. The declines in insects across agricultural areas have been largely attributed to pesticides and loss of vegetative habitat (Sanchez-Bayo & Wyckhuys, 2019). The levels of neonicotinoids reported in Australian waterways are rising, where there is monitoring (outside of the MD basin) taking place (Warne, Turner, Davis, Smith, & Huang, 2022).

I was not able to identify monitoring data for the upper MD as reported by recent report for Commonwealth Department of Agriculture by Chris Lee-Steere and Rohan Rainbow[6]. It is a large data gap given the vast amount of pesticide applied to the basin annually. Total volumes of application have roughly doubled in the last decade, based on the increase in sales value reported by the APVMA[7].

Insects play a vital role in the functioning of the aquatic environment, helping maintain oxygenated sediments by burrowing through them, and forming part of the food web for fish. Fewer insects mean less healthy sediments in rivers and wetlands. One consequence is that rivers become less able to manage normal influxes of organic matter that accompany rainfall.

Unfortunately, some of our aquatic macrofauna, like crayfish, are also acutely sensitive to these chemicals, contributing to some species now being listed as threatened species. Species like crayfish are critical to consuming the influx of organic matter to rivers. Through eating the plant material, the crayfish make it unavailable to bacteria and help reduce its deoxygenation potential. Further, the crayfish assimilate the organic material into high value proteins and fats which can then benefit the consumers of the crayfish like our predatory and native fish like Murray Cod and Golden Perch and freshwater turtles and omnivores like

[6] https://www.agriculture.gov.au/sites/default/files/documents/sources-of-agvet-data-australia.pdf
[7] https://apvma.gov.au/node/10756

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silver perch. Surveillance by the Arthur Rylah Institute reported at the World recreational fishing conference in Melbourne in 2023, has found silver perch to now be functionally extinct from the northern Darling basin.

Whilst the Murray Crayfish is not endemic to the Darling it is indicative of the trend of macroinvertebrate numbers. As DPI reports below on the Murray Crayfish show from lower in the MD catchment- pesticides are a clearly implicated cause in their declines. It is important to note that even more toxic pesticides (neonicotinoids and fipronil) have been released since the date of the 2007 report. The below excerpt is relevant to the Menindee kills also, as other species of crayfish (*Cherax destructor*) populations are reportedly lowered from where they should have been.

"4.2.2. Pesticides and pollution Walker (1982), O'Connor (1986), Geddes (1990), Horwitz (1990a) and Geddes et al. (1993) referred to threats posed by pesticides and pollution. O'Connor (1986) noted that the areas of major decline in crayfish numbers were downstream of major irrigation systems, where synthetic organochlorine pesticides such as DDT were applied liberally in the late 1940s and 1950s (Radcliffe 2002). Run-off from irrigation is one of the most important contributors to the transport of pesticides into waterways and their subsequent accumulation in sediments and aquatic organisms (Nowell et al. 1999). Spray-drift also results in the input of pesticides to waterways (Raupach and Briggs 1998). Given the sensitivity of crayfish to pesticides and pollution (Geddes 1990; France and Collins 1993; Davies et al. 1994; ANZECC and ARMCANZ 2000) (section 3.6.2), their persistency in aquatic sediments (Radcliffe 2002) and ecosystems, and the bio-accumulative and bio-magnifying nature of the toxins (Radcliffe 2002), it is highly likely that this may have been a critical factor in the decline of not only Murray crayfish, but the entire aquatic ecosystem in the 1950s. For example, the reported declines of Murray crayfish in the Edwards and Wakool Rivers coincide with the construction of the Coleambally Irrigation scheme in 1960, which drains agricultural run-off into the Edwards River via Billabong Creek (O'Connor, 1986). Further, O'Connor (1986) cites L.F. Reynolds as stating that fishermen suggested that spraying of locust plagues in South Australia in the early 1950s left residues in the soil that entered the river during the 1956 flood, and that the demise of crayfish could be associated with this single input of pesticides. Pesticide monitoring in waterways in the north-west of New South Wales indicates that the impacts of pesticide residues and agricultural pollution increase in a downstream direction (Muschal and Warne 2001). Therefore, it would be expected that Murray crayfish populations in the Lower Murray River would be most affected by pesticide use in irrigation schemes upstream. The spatial and temporal patterns in the disappearance of Murray crayfish from the lower Murray and Edwards, Wakool and Niemur Rivers are more closely associated with the advent and Project No. 05/1066 Murray crayfish review, Gilligan, Rolls, Merrick, Lintermans, Duncan & Kohen NSW Dept of Primary Industries 65 proliferation of use of pesticides than any other threatening process. However, the most persistent of the organo-chlorine family of pesticides, such as DDT, were banned from use in Australia in 1987 (Radcliffe 2002) and the environment has now had time to purge accumulated residues in aquatic sediments. As a consequence, the threat posed by some of this particular group of chemicals has been removed. However, crayfish are sensitive to numerous pesticides and agrochemicals that remain in use. Further, the quantities of those pesticides used, continue to increase (Radcliffe 2002), albeit under reasonably comprehensive regulations governing their use in areas adjacent to waterways." [8]

Critically, at sub-lethal exposures many pesticides also lower the maximum water temperature that native fish can tolerate by up to a few degrees (Patra et al 2007). Without knowing the mixture of potential

[8] https://www.researchgate.net/publication/268425619_Scoping_the_knowledge_requirements_for_Murray_Crayfish_Euastacus_armatus

exposures that the Menindee fish experienced in the weeks prior to the kill, it is difficult to appreciate whether pesticides may have made them more vulnerable to the ambient temperatures.

Loss of health of river hyporheic zone

Very limited surveillance elsewhere in the MD catchment has shown that sediments of the river have become toxic to invertebrates (Townsend, Pettigrove, Carew, & Hoffmann, 2009). These invertebrates are essential to maintaining the health of the hyporheic zone of the river and are an essential component of aquatic ecology. It is likely that the same drivers of toxicity are present in the upper Baaka-Darling River.

With loss of these invertebrates there is a loss of ecological function to process incoming organic matter which is normal in rainfall events.

The loss of health of the hyporheic zone (river benthos) has also been exacerbated by the influx of fine sediment into the river, due to long terms losses in riparian vegetation, loss of natural flow and filtration through wetlands and the changes to land-use that resulted in loss of native vegetation soil cover and widespread bare earth farming practices (tillage and broad-acre herbicide application for cropping) in combination with over-grazing livestock and feral animals (goats/pigs).

With loss of function of the hyporheic zone, the river is less able to process nutrient, less able to metabolise pollutants and less able to recharge groundwater.

The decline in soil health/soil biology and native vegetation cover in agricultural areas, reduces water penetration from rainfall, leading to higher run-off co-efficients and elevated risks of scouring water velocities which clog up the hyporheic zone with ever more fine sediment.

The decline of all of these top-order species of fish, crayfish and turtles from well before the most recent fish kills, speaks to the co-contributory causes of the decline in riverine health.

The turtle numbers are now not there to clean up dying fish, before they rot and add to the deoxygenation process as described by researchers (Santori, et al., 2020).

Glyphosate, fertiliser and blue-green algal blooms

The glyphosate-based herbicides are the most extensively used pesticides in NSW in terms of volume. Their use has grown around 10-fold in the last decade, although catchment level use data is not collected. With improvements in chemical detection, glyphosate-based herbicides are now recognised as common water contaminants. Glyphosate promotes blue green algae through its phosphate metabolite and its modifying effect on the algal assemblage (Lin, et al., 2023) (Wang, Jiang, & Sheng, 2020) (Drzyzga & Lipok, 2018). Blue green algal blooms are also promoted by nutrient enrichment (eutrophication), the primary source being synthetic fertilisers, with some livestock contributions, particularly where they have direct access to waterways. Only around 30% of the applied N from synthetic fertiliser is used by the crops, the remainder can run-off towards the aquatic environment and contaminate groundwater with elevated nitrate.

NSW EPA identified very high nitrogen and phosphorus levels in the water post-kill. These levels are not "natural" and place the ecosystem at destabilising risk of algal blooms. Elevated levels of nitrogen and phosphorus are intermittently reported across the basin, but comprehensive monitoring is lacking. NSW EPA also reported elevated levels of blue green algae in monitoring after the kill. I could not find data to illustrate conditions pre-kill.

(Figure 1) demonstrates the development of a significant algal bloom in the river above Menindee in the few weeks prior to the Menindee fish kill, based on the massive diurnal oxygen saturation fluctuations, suggesting significant nutrient enrichment driving significant algal productivity and respiratory demand. When algal blooms crash out, they leave a significant load of nutrient on the flood of the water body which can be remobilised under higher flow conditions if not rapidly assimilated by biota.

Synthetic fertiliser run-off from upper catchment farming and release of nutrient from upper catchment fish kills likely fed the algal blooms. The algae's photosynthetic activity increases the dissolved oxygen content of the water during the day, but at night can draw levels down to lethal concentrations for fish. Blooms can also become so dense that some of the algae become starved of light, leading to a bloom crash. The dead algae is broken down by a boom in bacteria, which consume the oxygen from the water through Biological Oxygen Demand (BOD). This can create deoxygenation sufficient to kill fish.

The pink and brown lines in the Water NSW (Figure 5) show how the oxygen rose, before crashing below the levels that support fish life, as mass deaths were advancing down the river towards the gauge station. This oxygen data may have been impacted by flow entering just above the monitoring site from Lake Menindee, however the primary role of excessive nutrients and algal blooms remains relevant.

These unnatural cycles of algal booms and busts also drive the river sediments to become increasingly anoxic. They are primarily a function of eutrophication, but also of wider water ecology disturbance where predatory grazing zooplankton may be reduced, such as from pesticide effects.

Loss of aquatic vegetation

Before European settlement the river and wetlands had aquatic vegetation that could only have grown with high water clarity. That clarity has been lost with the continued loss of catchment soil and riverbank destabilisation leading to higher turbidity. This turbidity cuts out the light and the native aquatic vegetation dies. The use of pesticides, tillage and synthetic fertiliser as part of industrial agriculture practices have resulted in increased mobilisation of soil, driving up turbidity.

The use of wetlands as water storages and allowing them to dry out completely in the drought has the consequence of altering the vegetation types that grow there. Allowing wetlands to dry out, allows vegetation types to invade which are not flood tolerant. Similarly a change to overbank flooding alters the plant assemblage away from water tolerant species. When these water intolerant species are flooded, they die and contribute significantly to the creation of black water. Better management of hydrology could support flood tolerant vegetation.

Terrestrial vegetation, cover crops and water run-off

The movement of fertiliser, pesticide and animal manure into rivers escalates through elevated rates of run-off, which are a direct consequence of our land management practices. The dramatic loss of ground vegetation in farming landscapes from clearing and repeat broadacre herbicide applications combined with drainage, promote rapid water run-off, rather than slowing water to encourage it to soak into the ground, where it would naturally course back via groundwater to support the riverine flow in dry times. The effects of over-grazing by stock and feral animals (goats and pigs) further destabilise the vegetative cover on the soil and accelerate erosion. The lack of vegetation leads to reduced water penetration and higher run-off coefficients. This in turn leads to faster and higher flood peaks which have more erosive force, and a rapid decline in stream flow persistence. This lack of streamflow persistence is difficult to determine from data I was able to access due to the control of flow at weirs. The level appears to have dropped very rapidly in the area of the fish kill, prior to the kill, suggesting a dramatic reduction of inflows (from weir and from groundwater).

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Improved landscape hydration is a substantially better water storage solution than open dams, which lose vast amounts of water through evaporation. Maintenance of ground covers also cools soil, the roots help retain precious soil, boost carbon and microbial soil life. The vegetatively boosted water penetration and ground storage help filter water, keep organic matter in paddocks and sustain riverine flows supporting healthier aquatic ecosystems.

The water management which has resulted in drainage of wetlands has also allowed invasion by non-flood tolerant vegetation, which now rots and contributes to deoxygenation when inundated.

The rapid drop in river levels seen at Menindee can be altered, both through better controls on extraction, controls on flow, and improved landscape hydrology. Removal of Weir 32 would prevent the risk of stratification by increasing water flow rates.

Water temperature and stratification

The weir data, albeit downstream of where the major kill occurred, show high water temperatures **were not** to blame, as there was very little increase in water temperatures. The water temperatures were not at the top end of the thermal tolerance of the species that died. The water temperatures spiked after the fish had already been dead for 2-3 days.

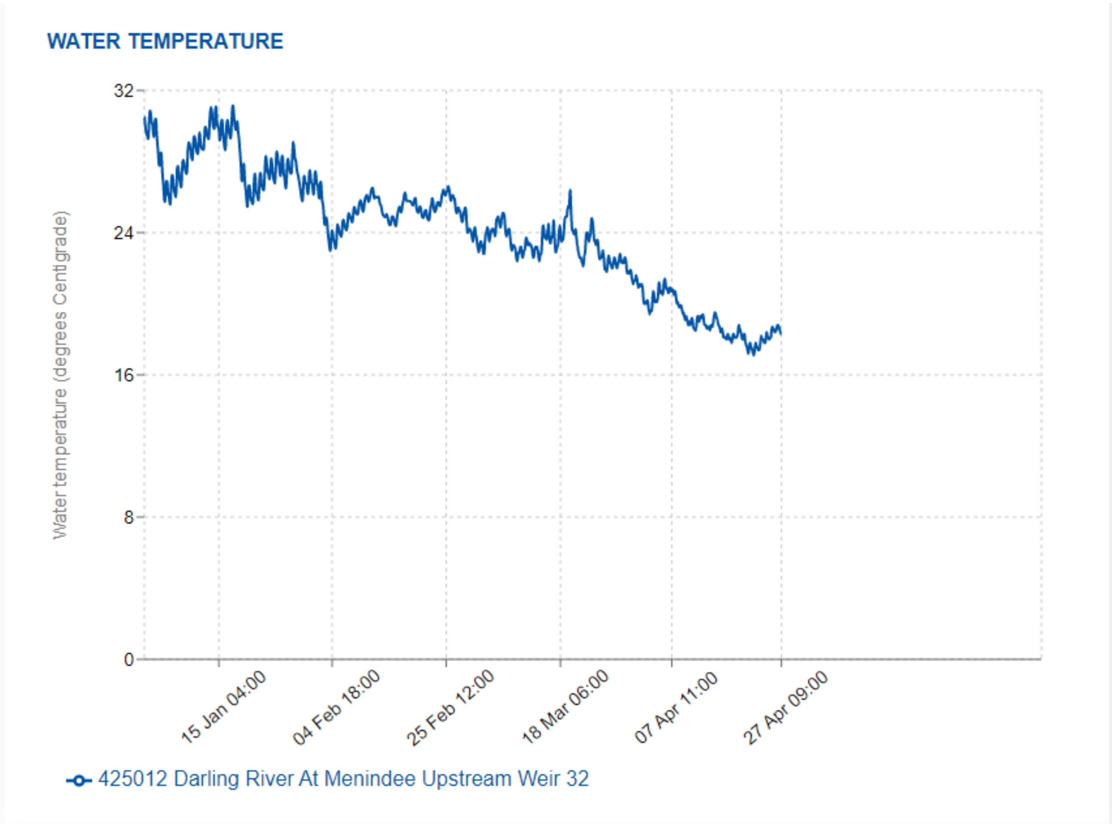

Figure 4: Water temperature log at Upstream Weir 32 Menindee Water NSW data

The lack of flow has been highlighted as a critical component of why weir pools are not ideal to support native fish populations (Mallen-Cooper & Zampatti, 2020) as they tend to create conditions with nutrient enriched waters for algal blooms, stratification and fish kills due to deoxygenation. At Menindee in 2023 it seems water flows were sufficient to avoid stratification, however I have not analysed flow data in detail.

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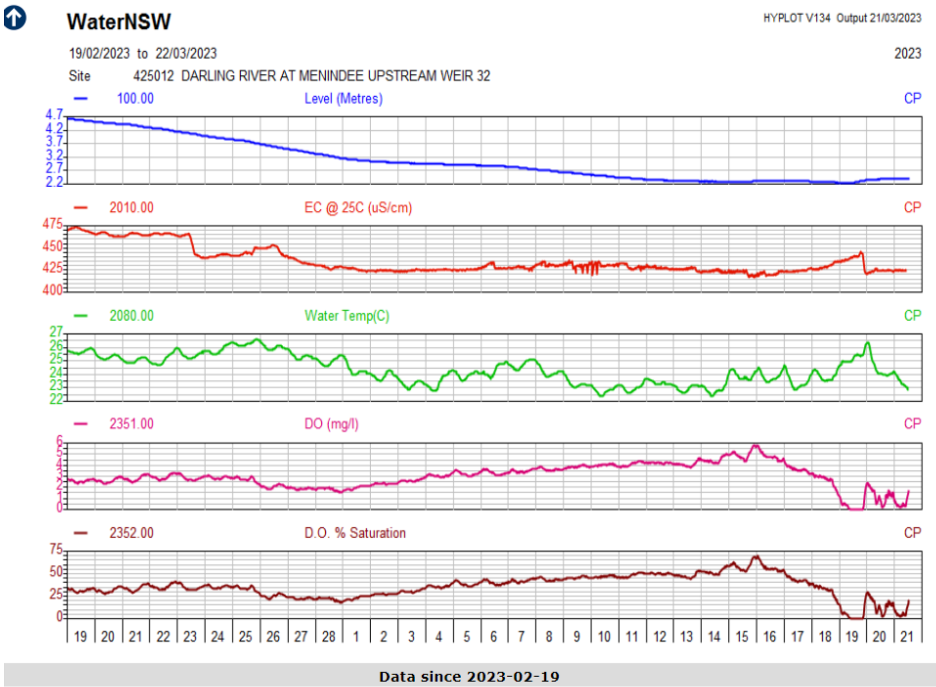

Figure 5:Upstream Menindee Weir 32 NSW Water data February-March 2023

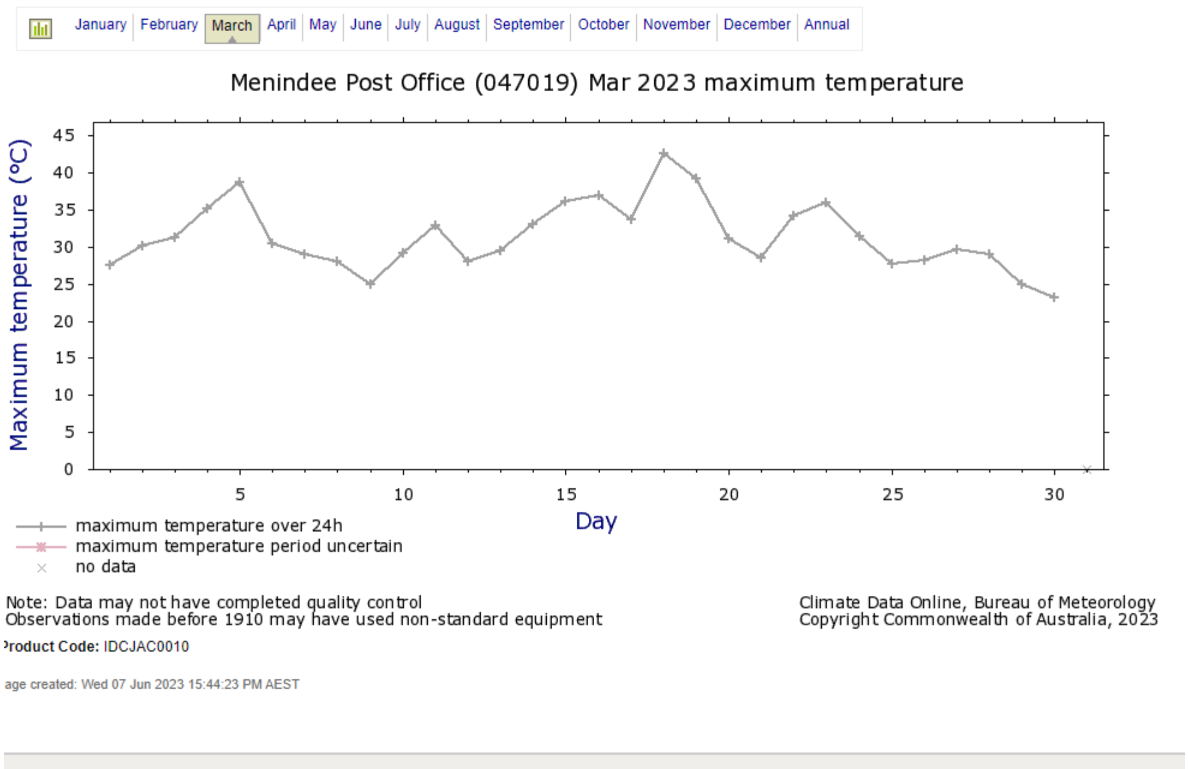

Figure 6: Air temperature log Menindee March 2023 (Source: BOM Climate data)

The water temperatures preceding the kill were not associated with a decline in dissolved oxygen levels in the water. The loggers recorded a rise in dissolved oxygen before the crash at the location of the data logger. Even as river levels were dropping the oxygen levels increased.

Volume of fish

As water levels dropped to their minima a week prior to mortality, it is not obvious that the numbers of fish affected the oxygen concentration of the water – rather the oxygen levels increased through that time at the monitoring site. This may not have reflected the conditions upstream where the kill commenced, however, with continual flow down past the logger, an oxygen shadow might have been expected if fish oxygen consumption was sufficient to deplete the water body. It would not be expected to significantly reoxygenate in a slow moving nutrient rich weir pool as water moved towards the data logging point.

It is possible that historical abundance of fish was higher than today and occurred without precipitating spontaneous deoxygenation mass mortality events.

Response to fish death event

NSW DPI should utilise the public and private aquatic veterinary capacity to lead scientific aspects of fish kill investigations. Outbreak investigation methodologies are a core component of veterinary training including epidemiology. Multiple resources are available to support such endeavours to ensure that the appropriate skill set (veterinarian) leads the investigation and assists in directing the involvement of a multi-disciplinary team to enable the assembly of information to understand causation.

Under the NSW Veterinary Practice Act Part 2 Practice of Veterinary Science, section 4 the restrict acts of veterinary science are defined to include:

*"1(a) **examination of or attendance on any animal***
*the examination of or attendance on any animal **for the purpose of diagnosing the physiological or pathological condition of the animal,** including for the purpose of diagnosing pregnancy in a horse, but not for the purpose of diagnosing pregnancy in any other animal,"*[9]

Further, the veterinarian who leads such fish kill investigation under the Act must:

"4 Knowledge of current standards of practice

(1) A veterinary practitioner—

*(a) must **maintain knowledge to the current standards of the practice of veterinary science in the areas of veterinary science relevant to his or her practice**, and*

(b) must always carry out professional procedures in accordance with those current standards.

*(2) A veterinary practitioner **must base professional decisions on evidence-based science or well-recognised current knowledge and practice, or both**.*

5 Utilisation of skills of colleagues

*A veterinary practitioner **must utilise the skills of colleagues, by consultation or referral, where appropriate**.*

6 Professional conduct

*A veterinary practitioner **must not mislead, deceive or behave in such a way as to have an adverse effect on the standing of any veterinary practitioner or the veterinary profession**."*

[9] https://legislation.nsw.gov.au/view/whole/html/inforce/current/sl-2013-0490

Farmers need support

There is an urgent need to transition farmers away from fossil fuel dependent farm inputs of synthetic fertiliser and pesticides. These inputs are components which degrade water quality and impair the health of the aquatic food webs. These impacts are additional to the climate change impacts flowing directly from the gas used to make synthetic nitrogen fertiliser and oil and gas inputs for pesticides. It requires a paradigm shift of an unprecedented scale in Australian agriculture.

We need to support farmers to transition to locally adapted regenerative farming techniques to recover our rivers and our own health. We can start with supporting farmers to get off-river watering for stock and riparian restoration as critical steps in this journey.

Other complimentary measures to increased environmental water have been talked about (e.g. Baumgartner et al 2018[10]; to support healthier aquatic environments. These include pest fish control (e.g. carp (manage through commercial fishing incentives and habitat restoration of predatory native fish) and gambusia, sustainable irrigation infrastructure like pump screens and fish-friendly weir designs, addressing salinisation consequences of irrigation, cold water pollution from dams, restoration of habitat through restoring hydrology to wetlands, and replacing snags in river.

Change needed to prevent more kills and further ecological collapse

You don't just get a 'lack of oxygen' that kills millions of fish.

It is water flow controls that are unable to deliver healthy water quality downstream, diffuse source pollution by nutrient and pesticides, and inadequate wetland management that set the scene for the kills. These changes are decades in the making and will take time to unwind and restore.

Over time we have polluted rivers with excessive loads of nutrient and fine sediments. We've degraded the aquatic ecological functionality with ever more pesticides. We've lost aquatic vegetation from excessive turbidity and herbicides. We've promoted toxic blue green algal blooms with glyphosate and the nutrient overload. We've impaired river passage contributing to loss of species and an inability of fish to move away from the poorest water quality. We've disturbed the ecological function of wetlands to process organic matter from floods, leading to increased BOD entering the mainstem of the river. We've lost native vegetation and landscape rehydration across vast areas of the catchment. We've lost insects to help degrade terrestrial organic matter and cycle it.

We can change this, and we must, for it is more than fish dying – a piece of us is dying too as life spans in the Barwon are decreasing.

Recommendations

Early engagement with aquatic veterinarian expertise from public and/or private sector to lead outbreak investigation.

A coordinated response to lower the eutrophication requires a seismic shift to change farming practices away from use of synthetic fertilisers and pesticides and towards more regenerative techniques.

[10] https://onlinelibrary.wiley.com/doi/epdf/10.1002/rra.3438

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Detailed pesticide/contaminant surveillance using passive sampler devices is needed to assess this risk like those utilised by SEQ water to explore contaminants in water supply dams in SE Queensland[11].

Sediment quality should be monitored using invertebrate exposure models (Townsend, Pettigrove, Carew, & Hoffmann, 2009).

Change hydraulic management of the river to maintain flow, consider removal of Weir 32.

Where pesticides or toxicants are detected, they must be traced to their source and mitigations put in place to prevent aquatic contamination including consideration of the removal of unsafe chemicals from use. Australia continues to maintain more than 70 agricultural chemicals in use that have been removed from use in the EU due to environmental and human health concerns.

Require compulsory reporting of pesticide types and volumes to be recorded at the sub-catchment level on a publicly accessible database to support public and environmental health research. Data should lead the ecological recovery.

Improved real time water quality monitoring with sufficient spatial coverage including addition of Chlorophyll A and turbidity are useful measures to understand prevailing water quality conditions and manage critical water events.

There also appears to be a significant educational shortfall in the knowledge of managers. That the CEO of the MDBC thinks blue green algae blooms are an entirely natural phenomenon indicates a need for education. NSW DPI has suggested the fish kill is a natural event. It is very clear these events are man-made.

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[11] https://www.seqwater.com.au/sites/default/files/2021-03/Enclosure%202b%20%20Catchment%20and%20Drinking%20Water%20Quality%20~%20Monitoring%20Program%20%E2%80%93%20QAEHS%20Passive%20Sampling%20Summer%202020%20Report.pdf

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Appendix 1- Weather data Menindee- Bureau of Meteorology

Menindee, New South Wales
March 2023 Daily Weather Observations

Date	Day	Temps		Rain	Evap	Sun	Max wind gust			9 am						3 pm					
		Min	Max				Dir	Spd	Time	Temp	RH	Cld	Dir	Spd	MSLP	Temp	RH	Cld	Dir	Spd	MSLP
		°C	°C	mm	mm	hours		km/h	local	°C	%	8th		km/h	hPa	°C	%	8th		km/h	hPa
1	We	16.3	27.5	0						16.5	60	6	S	17							
2	Th	15.5	30.2	0						18.1	58	0	S	17							
3	Fr	15.7	31.3	0						18.5	60	0	S	9							
4	Sa	16.0	35.2	0						22.0	45	0	S	4							
5	Su	18.6	38.8	0						24.4	48	0	N	4							
6	Mo	17.6	30.5	0						19.3	69	0	S	17							
7	Tu	17.3	29.0	0						19.0	59	0	SW	9							
8	We	15.0	28.0	0						17.7	61	0	W	9							
9	Th	12.7	25.0	0						15.5	64	0	SW	4							
10	Fr	11.2	29.2	0						17.0	54	0	SE	9							
11	Sa	14.4	32.9	0						18.9	50	0	E	4							
12	Su	18.2	28.1	0						19.1	64	0	SSW	9							
13	Mo	14.5	29.5	0						17.0	61	0	S	9							
14	Tu	14.2	33.0	0						19.3	59	0	S	9							
15	We	16.0	36.2	0						19.5	59	0	SW	4							
16	Th	19.0	37.0	0						24.0	39	0	SW	9							
17	Fr	16.0	33.8	0						20.0	71	0	S	4							
18	Sa	19.2	42.6	0						22.4	48	0	N	4							
19	Su	20.6	39.2	0						23.1	52	0	SSW	4							
20	Mo	19.2	31.2	0						20.8	58	0	S	17							
21	Tu	19.4	28.5	0						20.0	40	6	S	9							
22	We	18.0	34.2	1.2						22.0	81	7	E	17							
23	Th	17.6	36.0	0						20.2	91	0	S	4							
24	Fr	18.2	31.4	0						19.0	63	0	SW	17							
25	Sa	16.2	27.8	0						18.8	73	0	S	4							
26	Su	12.9	28.2	0						14.7	62	7	S	4							
27	Mo	14.0	29.7	0						21.7	64	8	NE	9							
28	Tu	18.4	29.0	0.2						20.0	86	8	S	4							
29	We	17.1	25.0	9.2						18.0	76	0	W	17							
30	Th	12.0	23.2	0						13.7	81	0	SW	9							
31	Fr	10.8		0						14.0	80	8	SW	4							
Statistics for March 2023																					
	Mean	16.2	31.4							19.2	62	1		8							
	Lowest	10.8	23.2	0						13.7	39	0	#	4							
	Highest	20.6	42.6	9.2						24.4	91	8	#	17							
	Total			10.6																	

IDCJDW2081.202303 Prepared at 13:00 UTC on Saturday 3 June 2023