Rivers and Wetlands

Subject: Assessing likely cause(s) of the fish kill in Lake Wyangan in May 2020.

Purpose

Following a fish kill in Lake Wyangan, near Griffith in NSW, The Department of Primary Industries received data on the water quality in the lake. *Rivers and Wetlands* has been asked to comment on three issues:

- Do any of the WQ parameters analysed indicate why the fish kill may have occurred?
- Given our current understanding of releases into Lake Wyangan, could any adverse WQ parameters be related to these operations?
- What (if any) mitigation or management options could be explored to either prevent or minimise future events?

Conclusions

In all, 15 possible causes of the fish deaths in Lake Wyangan North were examined (Table 1). It was not possible to unequivocally assign the proximate cause of the fish deaths. Indeed, it may be possible that there were several contributing factors. Water quality in the lake at the time of the fish kills was very poor - extremely hard, very alkaline, saline and, a blue-green algal bloom was present. While these factors probably didn't directly lead to the fish deaths, each of these factors would have contributed to fish stress.

The data clearly rules out a number of potential causes of the fish deaths including herbicide, pesticide and most heavy metal toxicities (excluding boron).

Anecdotal evidence that fish were mouth-breathing prior to the fish deaths being reported, coupled with the observation that carp were apparently not killed in the event tentatively suggests transient hypoxia as a potential cause of the deaths; but doesn't exclude other factors that can impact on breathing including sulfide toxicity or oxygen supersaturation. Given the extreme pH in the lake at the time of the fish kill ammonia toxicity should also be considered a potential factor.

Table 1: Assessment of potential causes of the fish kill reported in Lake Wyangan

Possible Cause of Fish Deaths	**Likely to have directly contributed to the fish kill**	**May have contributed to the fish kill**	**Unlikely to have directly contributed to the fish kill**
Pesticides and herbicides			X
Lake foam			X
Metals and metalloids		Boron toxicity	X (excluding boron toxicity)
Salinity		Could have contributed to fish stress	X
Temperature		May have contributed to the death of Bony Bream. Could have contributed fish stress	X (with the possible exception of Bony Bream)
pH		Could have contributed to fish stress	X
Destratification leading to hypoxia			X
Hypoxic inflows		Could have contributed to fish stress	X
Inflows inundating terrestrial vegetation			X
Crash of a blue-green algal bloom			X
Algal bloom lowering night time oxygen levels		Could have contributed to fish stress	X
Oxygen supersaturation	If pathological examination of dead fish shows evidence of gas bubble disease	X	
Ammonia toxicity		X	
Disturbance of acid sulfate soils	If subsequently shown to be present	X	
Sulfide toxicity	If acid sulfate soils subsequently shown to be present	X	

Disclaimer

The following discussion is based on a very limited set of data, with no personal observations of the sites under consideration. Therefore, all conclusion and recommendations should be considered preliminary. To the extent permitted by law, *Rivers and Wetlands* excludes all liability for any actions taken as a result of this memorandum.

Data

Chemical data was supplied by NSW Department of Primary Industries - Fisheries. Temperature data, as well as background information on Lake Wyangan, including information on recent inflows, was supplied by Griffith City Council.

Background

Lake Wyangan is an important recreation site located about 5 km to the north-west of the City of Griffith in New South Wales. Lake Wyangan consists of two basins. The southern basin (Lake Wyangan South, with an area of about 75 ha when full) is a flooded wetland, while the northern basin (Lake Wyangan North, with an area of about 205 ha when full) is an old gypsum (calcium sulfate) mine which was flooded in 1956. Land use in the immediate area surrounding the lake includes intensive irrigated agriculture as well as peri-urban development (Water Technology, 2017). It receives inflows from natural drainage (mostly intercepted by irrigation infrastructure), irrigation return flows, local storm water and, supplementary flows ("fills") provided through irrigation infrastructure by Griffith City Council (Water Technology, 2017). Lake Wyangan is a naturally closed (terminal) lake with no natural outlet. Water is pumped from the lake to supplement irrigation flows, and at least on one occasion, has been used to supplement Griffith City's water supply.

A fish kill in Lake Wyangan was reported to Griffith City Council on 23 May 2020 (P. Harding pers. comm.). The fish were mostly Bony Bream but included Murray Cod and Golden Perch. Notably European Carp were not recorded as killed. The actual fish deaths are likely to have occurred prior to this date. There was an earlier report of fish struggling on the surface on 16 May including surface breathing. The fish deaths only occurred in Lake Wyangan North. (Satellite imagery indicates that there was no surface hydrologic connectivity between the northern and southern basins at the time of the fish kill).

There were two significant inflows into Lake Wyangan North prior to the fish deaths. The first was an inflow of serval hundred ML of storm water (peak flow of about 40 ML/day) from about 29 April until about 4 May. The second was a 242 ML "fill" of irrigation water which entered the lake over about a 6-day period staring on around 5 May.

NSW Department of Primary Industry took water sample from the main body of Lake Wyangan North by boat on 25 May and again from the shoreline on 27 May. The samples taken on 25 May were analysed by the NSW Environment Protection Agency, while the samples from 27 May were analysed by Charles Sturt University - Bathurst.

Analysis of potential causes of fish deaths in Lake Wyangan.

There are numerous causes of fish deaths in the Murray-Darling Basin. Given the limited data set present it is not possible to unequivocally assign causation for the fish kill in Lake Wyangan, but it is possible to assess how likely each of the potential causes were in causing the fish deaths.

1. Pesticides and herbicides

Given that Lake Wyangan is located in an area of intense irrigated agriculture and receives (or has received) irrigation return water, agricultural chemicals needed to be assessed. Four samples were analysed for a suite of 64 agricultural chemicals. The concentration of all 64 chemicals in all 4 samples were less than the detection limit of the analysis. It is note that the detection limit of a number of the analytes (e.g. Endrin, Chloropyrifos, Heptaclor, DDT) was greater the Australian Water Quality Guidelines trigger levels for further investigation[1]

[1] Further investigation in the Australian Guidelines usually involves toxicology testing.

for moderately disturbed systems (ANZECC & ARMCANZ, 2000). Nevertheless, the likelihood that the fish kill was caused by any of these chemicals is very low.

2. Lake foam

A number of media reports reported a white foam present near the shore of the lake. Aquatic foam is a naturally occurring phenomenon. Organic material from decaying plants and animals produce decay products that reduce the surface tension in the water (just like soap or synthetic detergents). When the wind blows across a lake (or water passes down a channel) air is mixed into the water, producing bubbles (foam), that accumulate on the windward side of the lake. Photographs on social media and news feeds indicate a decaying ring of vegetation around the lake (possibly *Rupia sp*. - I. Ellis pers. comm.). The vegetation most likely died as the lake dried out over the past several months (discussed below). Therefore, the foam is unlikely to be a cause of the fish deaths; conversely, the fish deaths could have contributed to the foam formation.

3. Metal and metalloids

The concentration of 30 metals and metalloids[2] were determined from two of the samples taken on 25 May. Both filtered ("dissolved") and acid-extractable ("total") metal concentrations were determined. Many of the metals were below the limit of detection. However, it should be noted that the limit of detection for the analyse of a number of metals was actually higher than the Australian water quality guidelines trigger levels for slightly- to moderately-disturbed systems[3]. For example, the detection level for copper was 0.03 mg/L; the trigger level for further investigation in slightly- to moderately-disturbed freshwater ecosystems is 0.0014 mg/L. Normally, this should be of some concern. However, the water in Lake Wyangan is extremely hard. Using the measured calcium and magnesium concentrations measured in the samples, the water hardness in Lake Wyangan is about 550 mg/L (as $CaCO_3$). The toxicity of heavy metals including copper, chromium, cadmium, lead, nickel and zinc is markedly reduced (by an order of magnitude) in extremely hard water (ANZECC & ARMCANZ, 2000). This would suggest that, while metal toxicity cannot be ruled out as a cause of the fish deaths, it is probably unlikely.

The only two elements that exceed the Australian Water Quality guidelines for further investigation for slightly- to moderately-disturbed aquatic ecosystems (at least for one sample) were aluminium and boron. Dissolved aluminium at pH levels below pH 6.5 is extremely toxic to fish (Exley et al., 1991). The aluminium interferes with the functioning of the gills leading to death. The toxicity of aluminium above pH 6.5 is markedly reduced. The pH in the water column at Lake Wyangan is very alkaline (with pH values between 9 and 10) and is also extremely alkaline (with an alkalinity of 600 mg/L as $CaCO_3$) indicating that the system is well buffered and the pH was unlikely to have fallen below 6.5 at the time of the fish kill. The trigger value for further investigation for aluminium in slightly- to moderately-disturbed freshwater aquatic ecosystems above pH 6.5 is 0.055 mg/L. The dissolved aluminium concentration in the two samples analysed in Lake Wyangan were <0.04 and 0.07 mg/L. Given the average is less than the trigger level, the likelihood that aluminium toxicity was responsible for the fish deaths is low.

[2] Metalloids have some metal like properties and include arsenic and boron.
[3] Specifically, copper, cadmium, chromium, lead, nickel, silver and zinc.

Boron is a chemical that is added as a fertilizer to citrus and grape crops and is also found in detergents. The trigger value for further investigation for boron is 0.37 mg/L. There is a dearth of information on the toxicity of boron to Australian aquatic organisms (Watson et al 2009). The concentration of boron in the two samples taken from Lake Wyangan were both 1.7 mg/L (for both total and dissolved analyses). Based on the limited information it is not possible to either assign, nor rule out, boron as a cause of the fish deaths in Lake Wyangan.

4. Salinity

High salt concentrations can kill obligate freshwater fish. The Australian guidelines for further investigation in slightly- to moderately-disturbed south -eastern lakes and reservoirs is 30 EC. A more realistic trigger value would be for lowland rivers (which is 2200 EC). The measured salinity in Lake Wyangan after the fish kill was between 4800 and 4900 EC, or roughly 1/11th the salinity of seawater (in other words quite saline). Based on a search of the *ISI Web of Science* data base, there is no published data on the salt tolerance of either Murray Cod or Golden Perch. However, there are reports in the aquaculture literature that suggest that Murray Cod can withstand salinities up to 8000 EC (Gooley and Gavine, 2003). Furthermore, experiments exploring the use of salt to mitigate ammonia toxicity (discussed below) exposed Golden Perch to salinities of 5 g/l (≈ 8000 EC) without any adverse effects (Alam and Frankel 2006). While the high salinities would undoubtedly have stressed the fish in Lake Wyangan, it is unlikely to have been the principle cause of their deaths.

5. Temperature

Immediately prior to the inflows at the end of April and the beginning of May, water temperature in the lake was in the high teens to low 20's (Figure 1). Following the start of inflows water temperature rapidly fell to the low teens. Bony Bream's thermal tolerance is reported to be in the range of 9 to 38 ^{o}C, but are susceptible to rapid changes in temperature (Merrick and Schimda, 1984). In the field, Murray Cod have been recorded in water temperatures as low as least 9 ^{o}C (Thiem et al, 2018), while the thermal tolerance for Golden Perch has been reported to be between 4 and 37 ^{o}C (Dulhunty and Merrick 1976). Therefore, while it is possible that the falling temperature may have led to the death of the Bony Herring, the water temperature was within the reported thermal tolerances of both Murray Cod and Golden Perch. That being said the colder temperatures would have placed additional stress on the fish.

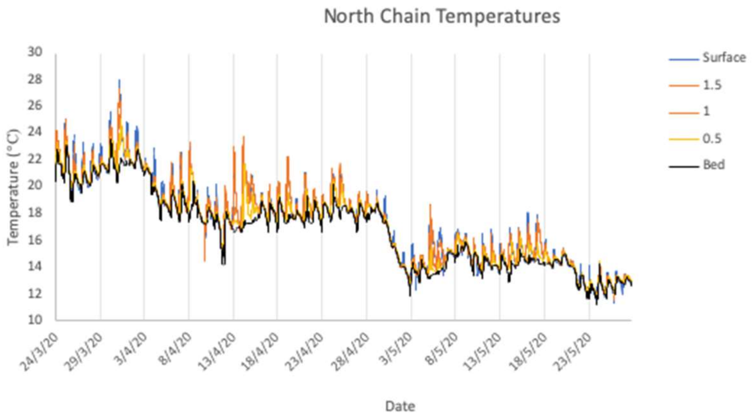


Figure 1: Thermistor data from the northern end of Lake Wyangan North (supplied by Griffith City Council).

6. pH

The Australian water quality guidelines have default trigger values for pH in lakes in south-eastern Australia that falls outside the range of 6.5 and 8 (ANZECC & ARMCANZ, 2000). The measured pH levels in Lake Wyangan following the fish kill were between about 9 and 10.2.[4] While pH values will vary during the day (because of algal photosynthesis and respiration[5]) values of pH 10 or above are at the very upper levels measured in inland Australian waterways. The extreme pH levels in the northern basin are most likely driven by carbonate-bicarbonate dynamics. The northern basin was previously a gypsum quarry. Gypsum is calcium sulfate. It is probable that not all of the gypsum deposit had been removed prior to filling of the lake in the 1950's. Therefore, it is probable that the bicarbonate/carbonate equilibrium is being dominated by residual carbonate minerals in the sediment. Furthermore, the extremely high calcium and magnesium concentrations in the water column bind the carbonate and bicarbonate, preventing the residual carbonate from being released to the atmosphere as carbon dioxide.

From this analysis, two conclusions can be derived. The first was that the old quarry should not have been filled in the first place; the second is that while extremely high, the biota in the lake have probably experienced high pH levels in the past without (putatively) negative outcomes. However, the extreme pH may have contributed to fish stress.

7. Destratification leading to hypoxia

Most of the recent fish kills in the southern Murray-Darling Basin were caused by hypoxia following a destratification. This includes the fish kills in the Darling River near Menindee and the Murrumbidgee River at Redbank Weir in 2018/19. However, this scenario is unlikely to have caused the fish kills in Lake Wyangan. The water temperature at the time of the fish kills in Lake Wyangan was in the low teens, suggesting that thermal stratification would not have been present in the first place. If thermal stratification was present, the Lake is currently only about 2 - 2.5 metres deep at its deepest point which is approximately the same depth of the surface mixed layer measured in the Weir 32 weir pool on the Darling

[4] Noting high pH values are influenced by salt concentration, so the extreme pH levels may not be accurate unless the instrument used to determine the pH had in-built salt adjustment. Nevertheless , the values are indicative.

[5] Highest at dusk, lowest at dawn.

River. Furthermore, Lake Wyangan is nearly 1km wide (west to east; the predominant wind direction is from the west). Therefore, the surface mixed layer in Lake Wyangan should actually be substantially deeper than in the Darling River because of the much greater wind fetch. Thermistor data supplied by Griffith City Council clearly shows there was diurnal mixing in the lake prior to the inflows beginning at the end of April (Figure 2).

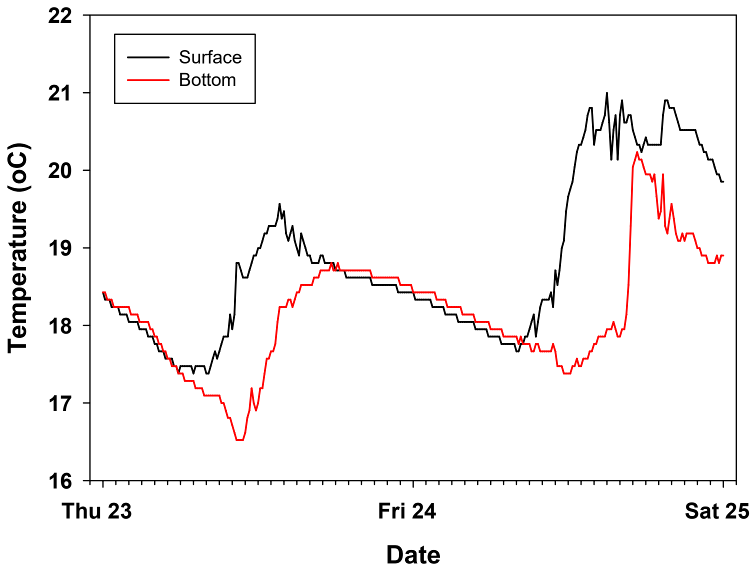
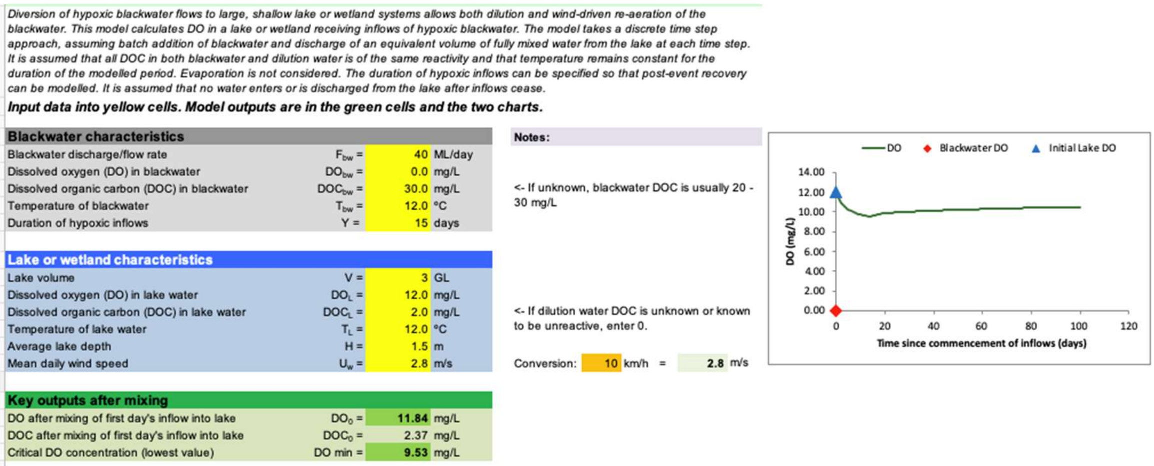


Figure 2: Diurnal changes in temperature at the surface and near the bottom in Lake Wyangan North prior to the inflows that occurred in late April clearly showing daily mixing (data supplied by Griffith City Council).

<u>8. Hypoxic inflows</u>

There were two significant inflows into Lake Wyangan North prior to the fish deaths. The first was an inflow of serval hundred ML of storm water (peak flow of about 40 ML/day) from about 29 April until about 4 May. The second was a 242 ML "fill" of irrigation water which entered the lake over about a 6-day period staring on around 5 May. The water level in Lake Wyangan is currently quite low compared to its normal capacity. If we assume a current surface area of 200 ha and an average depth of 1.5 metres, the current volume of water in Lake Wyangan should be about 3000 ML. I used the Blackwater Intervention Assessment Tool (Kerr et al, 2013) to assess a worst-case scenario where all the inflows had had an oxygen concentration of zero, had a reactive carbon load of 30 mg/L (equivalent to a blackwater event) and there was a constant inflow of water of 40 ML/day for 15 days. If the dissolved oxygen concentration was around 12 mg/L at the time of the inflow (the approximate level recorded by NSW DPI- Fisheries on 25 May) then the lowest dissolved oxygen concentration expected in the lake would have been about 9.5 mg/L (Figure 3)[6]. If dissolved oxygen concentration in the lake was 5 mg/L, the inflows would have lowered the dissolved oxygen concentration to 4.9 mg/L. Therefore, hypoxic inflows, even if they also contained high loads of reactive carbon cannot explain the fish deaths.

[6] Wind speed was assumed to be 10 km an hour. Over the time of the inflows the wind speed varied from about 2 to 40 km/hr.



Diversion of hypoxic blackwater flows to large, shallow lake or wetland systems allows both dilution and wind-driven re-aeration of the blackwater. This model calculates DO in a lake or wetland receiving inflows of hypoxic blackwater. The model takes a discrete time step approach, assuming batch addition of blackwater and discharge of an equivalent volume of fully mixed water from the lake at each time step. It is assumed that all DOC in both blackwater and dilution water is of the same reactivity and that temperature remains constant for the duration of the modelled period. Evaporation is not considered. The duration of hypoxic inflows can be specified so that post-event recovery can be modelled. It is assumed that no water enters or is discharged from the lake after inflows cease.

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

Blackwater characteristics			
Blackwater discharge/flow rate	F_{bw} =	40	ML/day
Dissolved oxygen (DO) in blackwater	DO_{bw} =	0.0	mg/L
Dissolved organic carbon (DOC) in blackwater	DOC_{bw} =	30.0	mg/L
Temperature of blackwater	T_{bw} =	12.0	°C
Duration of hypoxic inflows	Y =	15	days

Lake or wetland characteristics			
Lake volume	V =	3	GL
Dissolved oxygen (DO) in lake water	DO_L =	12.0	mg/L
Dissolved organic carbon (DOC) in lake water	DOC_L =	2.0	mg/L
Temperature of lake water	T_L =	12.0	°C
Average lake depth	H =	1.5	m
Mean daily wind speed	U_w =	2.8	m/s

Key outputs after mixing			
DO after mixing of first day's inflow into lake	DO_0 =	11.84	mg/L
DOC after mixing of first day's inflow into lake	DOC_0 =	2.37	mg/L
Critical DO concentration (lowest value)	DO min =	9.53	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.

Conversion: 10 km/h = 2.8 m/s

Figure 3: Screenshot of the output from the Blackwater Intervention Assessment Tool indicating that hypoxic inflows in Late April and early May should not have dramatically impacted on dissolved oxygen in Lake Wyangan North.

9. Inflows inundating terrestrial vegetation

When dried sediments are inundated they can release dissolved carbon. Furthermore, additional carbon can be leached from inundated vegetation (Baldwin and Mitchell, 2000). The carbon is consumed by bacteria and, in extreme cases, lead to hypoxia. Satellite images show that the inflows in late April and early May only inundated a relatively small area of previously dry lake-bed, so the amount of carbon released would only have been relatively small (Figure 4). Further the relatively cold temperatures would have inhibited microbial respiration. Taken together this would suggest inundation of dry lake bed was not likely to have been a cause of the fish deaths.

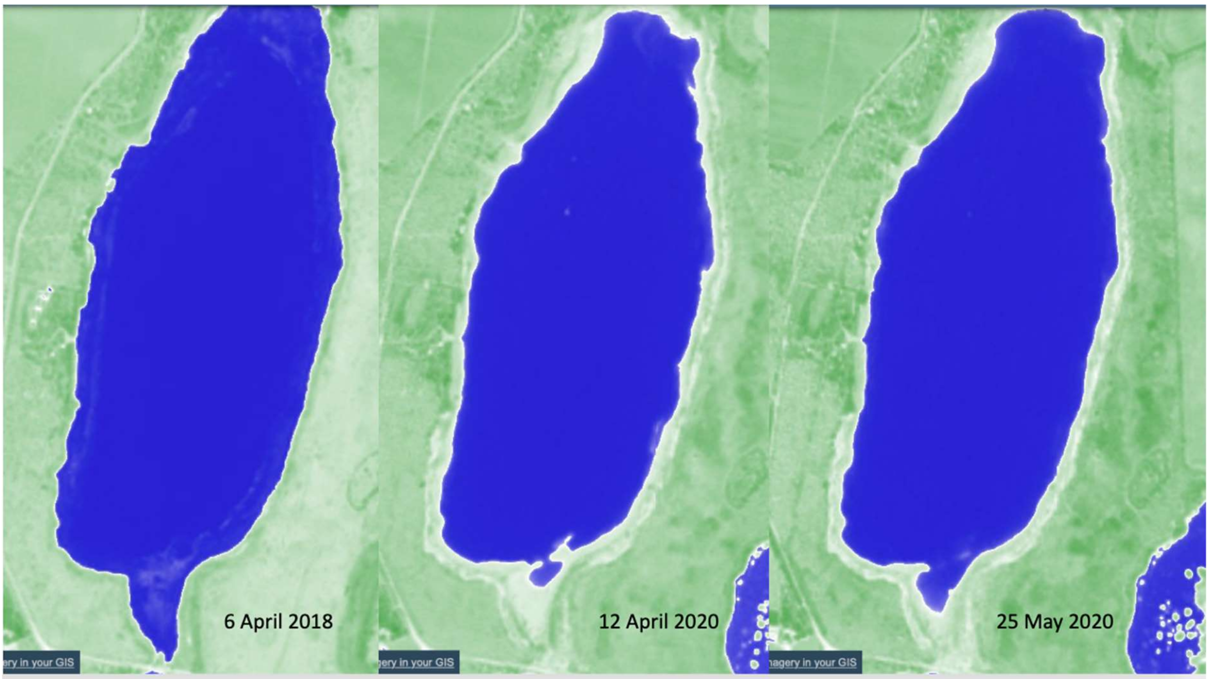


Figure 4: Sentinel satellite images of Lake Wyangan North using the NDWI script. The NDWI script highlights standing water in blue.

10. Crash of blue green algal blooms

The sudden crash of an algal bloom can lead to hypoxia. Bacteria decompose the algal cell, in the process consuming oxygen. The most infamous case of this occurring is the dead zone in the Gulf of Mexico (NOAA, 2019). As a side note, some Australian media outlets wrongly attributed the fish kills in the Darling River near Menindee in 2018/19 to a crash of an algal bloom. I used satellite imagery coupled with a script specifically written to detect chlorophyll in water (Peliova et al, undated) to track algal dynamics in Lake Wyangan (Figure 5). If anything, algal number were increasing prior to the fish kill. Therefore, the crash of an algal bloom is unlikely to have caused the fish kill.

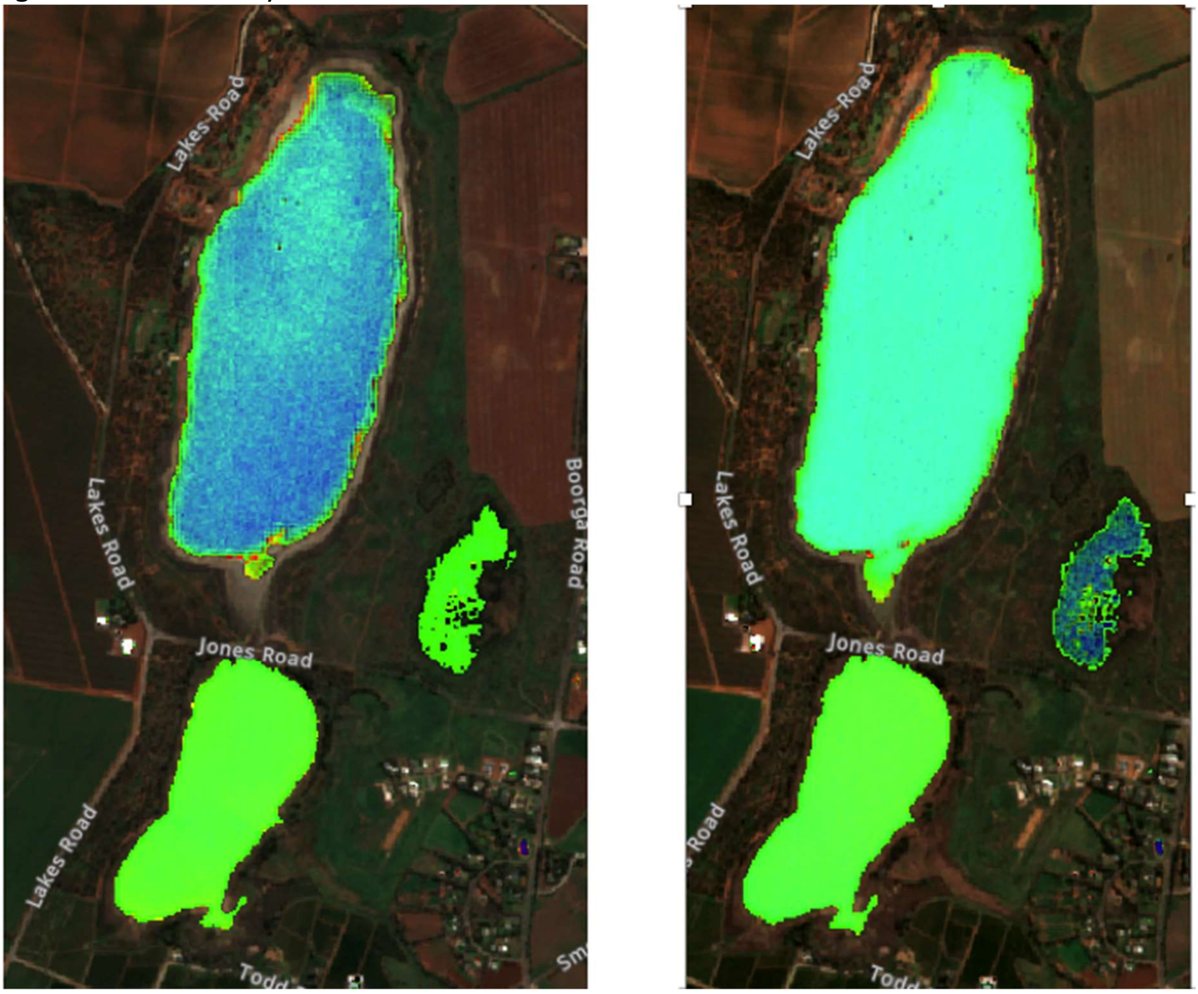


Figure 5: Sentinel satellite images of Lake Wyangan taken on 27 April (left panel) and 25 May (right panel) using a special script that highlights chlorophyll a. Blue indicates the lowest concentration of chlorophyll, while red indicates the highest.

11. Blue green algae lowering night time dissolved oxygen concentration

All photosynthetic organisms, including blue-green algae, produce oxygen during the day and consume oxygen at night. This leads to a diurnal shift in dissolved oxygen concentration in the water column, reaching a minimum around dawn. There is no diurnal oxygen concentration data available at the time of the fish kill, but the amount of oxygen drawdown can be calculated using a back-of-the envelope calculation. At the time of the fish kills there was an amber alert for blue-green algae in Lake Wyangan at the time of the fish kill. The most recent report of algal biomass in Lake Wyangan was on 22 April - with a biovolume of about 6 mm^3/L (Griffith City Council, 2020). Algal respiration varies exponentially with temperature (Robards and Zohary, 1987). Jewson (1976) reported a blue green algal respiration rate at 10 ^{o}C of about 5mg O_2/mg Chl a/hour. A biovolume of 6 mm^3/L is equivalent to about 0.013 mg Chl a/L (Felip and Catalan, 2000). Therefore, over a 14-hour period (length of night in Griffith in May) the oxygen drawdown would be about 1mg/L. Given a daytime oxygen concentration of about 12 mg/L (measured on 25 May), it is unlikely that night time drawdown of oxygen concentration was a significant factor in the fish kill.

12. Oxygen supersaturation

In oxygen super-saturated water (water that contains more oxygen than it should based on equilibration with the atmosphere) fish can develop gas bubble disease. Gas bubble disease is an outward manifestation of the formation of bubbles in the blood, skin gills or eyes of fish, and can lead to death (e.g. Machova et al 2017). The Australian water quality guidelines default trigger level for the upper level of dissolved oxygen saturation is 110%. At the time of the fish kill the water temperature was about 14 ^{o}C. The saturated oxygen concentration in water at 14 ^{o}C is 10.3 mg/L. Dissolved oxygen concentrations measured in Lake Wyangan North on 25 May varied from 11.4 to 12.6 mg/L or 111 to 122% saturation. A diagnosis of gas bubble disease would require a pathological examination of the dead (or preferably stressed) fish. However, based on the limited data oxygen-supersaturation cannot be dismissed as a possible cause of the fish deaths.

13. Ammonia Toxicity

Ammonia (NH_3) is a toxic compound produced by bacteria in low oxygen environments like sediments. Ammonia toxicity is dependent on pH, hence The Australian water quality guidelines (ANZECC & ARMCANZ, 2000) trigger values for further action for freshwater systems varies with pH. At pH 9 the trigger value is 0.18 mg/L and will be lower at higher pH values. The concentration of ammonia in the samples taken on 25 May were 0.2 and 0.4 mg/L and 0.2 and 0.3 mg/L for the samples taken on 27 May. Given the extreme pH in the lake, ammonia toxicity cannot be ruled out as a potential cause of the fish deaths.

14. Disturbance of Acid Sulfate Soils (sulfidic sediments)

Acid sulfate soils (sulfidic sediments) are sediments that contain high levels of reduced sulfur species, mostly mineral sulphides. When exposed to air the sediments can lead to acidification, release of heavy metals and deoxygenation (EPHC and NRMMC, 2011). Historically they were not considered to be important in inland waterways because sulfate concentrations (the precursor chemical) are generally low; but research over the last decade or so shows that they are more prevalent in inland waterways than previously thought.

A protocol has been developed to determine the likelihood that a particular waterbody contains acid sulfate soils (Baldwin et al 2007). Key indicators that would suggests that the wetland contains acid sulfate soils are:

- A salinity of > 1750 EC;
- A sulfate concentration of > 10mg/L and,
- If the water body receives municipal waste or irrigation return water.

With a measured salinity of nearly 5000 EC, sulfate concentrations above 300 mg/L and drains entering the lake, it is almost certain that Lake Wyangan contains acid sulfate soils.

Furthermore, the northern basin is a flooded gypsum mine. Gypsum is a calcium sulfate mineral.

Given the extreme alkalinity in Lake Wyangan it is unlikely that oxidation of the acid sulfate soils would result in acidification, but it could lead to the mobilisation of metals (see above) as well as transient hypoxia. The sediments could have been disturbed through the inflows in late April and early May or, given the shallow depth currently in the lake, through wind and/or storm events. Based on what we now about the impact of the disturbance of acid sulfate soils in inland waterways, there is a strong possibility that disturbance of the bottom sediments played a role in the fish kill.

15. Sulfide Toxicity

If acid sulfate soils are present, then there will likely be free sulfide in the sediments. Sulfide is very toxic. For example, the 96 - hour LC_{50} (i.e. the concentration of a substance when 50% of individuals die within 96 hours of exposure) for free sulfide (as H_2S - commonly known as rotten egg gas) for goldfish (*Carassius auratus*) at 25 ^{o}C is about 0.003 mg/L (Bagarinao, 1992). Sulfide toxicity is similar to cyanide toxicity, in that it impacts on the respiratory system. Sulfide concentrations were not measured in the current study - and it wouldn't be expected to be detected if it was because sulfide rapidly converts to sulfate under aerobic conditions. Sulfide toxicity cannot be ruled out at this stage as contributing to the fish deaths.

Recommendations

1. Acid sulfate soils are likely to be present in both basins of Lake Wyangan and may have contributed to the fish kill. I would strongly recommend that the sediments be assessed to determine how much acid sulfate soil material is present in the lake(s) to help inform future management.

2. Many of the water quality issues can be mitigated (at least in the short term) by maintaining water levels at the maximum capacity of the lake. This will lower the salinity, and hardness, and reduce the likelihood of disturbance of acid sulfate soils (if they are present). There is the risk that the higher levels could lead to stratification (and associated water quality issues) in summer months. Griffith City Council is actively monitoring temperature (and hence stratification) in Lake Wyangan North. Furthermore, the morphology of the lake suggests that stratification may not necessarily be an issue in the northern basin.

3. Transient hypoxia, or alternatively oxygen supersaturation, have been identified as potential causes of the fish deaths. It is recommended that at least one dissolved oxygen concentration logger is installed in the lake, including routine maintenance, to better assess oxygen dynamics.

4. High salt levels (and ancillary problems including hardness, alkalinity and potentially the formation of acid sulfate soils) is a clear, and ongoing, issue for Lake Wyangan. Salts are, for the most part, conservative meaning that they can't be exported from the gas phase Because Lake Wyangan is a closed system, unless plans are implemented to export the

saline water out of the lake's catchment, salinity will continue to rise in the lake, ultimately reaching the point where the lake has no aesthetic or recreational value. It is recommended that relevant stakeholders should assess the viability of different options for exporting salt out of Lake Wyangan and its catchment.

5. In the absence of a salt export plan, strict limits should be placed on the amount of salt that can be delivered to Lake Wyangan from either irrigation return water or storm water.

6. Griffith City Council is currently undertaking an installation of sediment traps and constructed wetlands at the terminal end of the drainage lines at the north-end of Lake Wyangan North to help mitigate excessive blue-green algal growth in the lake. Internal loading of nutrients (particularly phosphorus) will likely be an issue into the future. Stakeholders responsible for the lake's management should also explore potential strategies to mitigate against internal loading of nutrients in the lake.

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