Mannus Lake – Investigations into the contributing factors for the 2018 blue-green algal bloom and management recommendations

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Summary

Mannus Lake recently experienced a severe algal bloom of the potentially toxic cyanobacteria *Chrysosporum ovalisporum*. The bloom was noticed between late 2017 and early 2018 after public complaints about downstream water quality. UTS were engaged to do a short study of the bloom. Sampling and analysis were undertaken for 5 weeks with some samples supplied for a further few weeks. Without data prior to and during the initiation of the bloom it is difficult to determine conclusively the causes of the bloom. However examination of the limited available data before the bloom formed and data collected after the bloom indicates several factors that may have led to the bloom forming. Firstly, thermal stratification occurs over summer in the dam, leading to anoxic conditions in the bottom water and release of sediment-bound nutrients, particularly ammonia. These nutrients are kept within the bottom waters, separated from the surface waters by a thermocline. In December 2017 a high rainfall event occurred which led to a large influx of water into the dam which resulted in mixing of the water column. This mixed the water column and brought bottom water nutrients to the surface and may have also brought in nutrients into the lake from the catchment. The inflow may have also brought in sediments that may have reduced the light penetration depth to a lower level. This combination of high nutrients and reduced light levels may have benefited buoyant cyanobacteria when the lake re-stratified approximately a week later. The stratified water column, low light penetration, and high nutrients may have allowed the bloom to develop to the high densities measured. The timing of the bloom is consistent with this hypothesis.

As cyanobacterial blooms have been detected at Mannus Lake, regular sampling for public health safety should be adopted. This would involve surface samples being taken from at least 2 locations (suggest near offtake and near recreational area). Sampling should be done monthly from April to September then fortnightly from October to March. If cyanobacterial biomass increases into the Amber alert zone (0.4 to 4 mm^3/L) then sampling should increase to weekly or fortnightly intervals.

It is recommended that a research program to better understand the causes of blooms for management actions be implemented. Cyanobacterial blooms can be managed in lakes after the conditions that are causing the blooms are understood. A good understanding of the causes of the blooms is required through a well-designed monitoring project encompassing all the main factors influencing blooms. This will indicate the best management approach. A possible approach may be to include artificial mixing of the water column with a propeller. This stops stratification from forming and reduces the ability of cyanobacteria to float to the water surface and reduces sediment nutrients from being released (stopping the formation of anoxic bottom waters).

Background

Algal blooms and management

Algae are naturally present in many Australian waterways, usually at relatively low concentrations. Under certain conditions they bloom, and when dominated by cyanobacteria pose a major problem due to the potential for exposure to cyanotoxins. During these blooms, drinking water, stock watering, and recreation must be restricted. As well as posing a potential public health risk, cyanobacterial blooms also have a negative impact on the environment, as well as economies due to costs of water treatment, sourcing alternative supplies and loss of tourism.

In general terms, the growth rate of algae is dictated by water temperature and the supply of nutrients and light (for photosynthesis). These relationships are not simple, for example the light exposure depends on lake turbidity and the algal cell's position within the water column, which is influenced by thermal stratification and is variable through time. Thermally stratified conditions have been identified as an important trigger for some cyanobacteria. When turbulent mixing is reduced under thermal stratification, cyanobacteria can maintain position within the upper mixed layer through buoyancy mechanisms and stay in an area of increased light availability, which confers a considerable growth advantage. The underwater light environment in the lake is very important during these periods, as very clear water will not offer great advantage to cyanobacteria, so the fastest growers, typically diatoms or green algae, usually dominate. However, where light is reduced, buoyant cyanobacteria have a distinct advantage. Nutrients also influence algal growth and the formation of blooms. These nutrients enter lakes through runoff, inflows, and also importantly from the bottom waters when the lake is stratified. When bottom waters go anoxic (very low oxygen), the chemistry of the sediment changes and this can lead to release of phosphorus, nitrogen, and metals such as iron from the sediment. This supply of nutrients when mixed into the surface waters is also known to cause blooms.

Understanding these conditions and processes is crucial to determine what is triggering a bloom at a certain location, and what can be done to prevent its formation. To do this effectively a purpose specific monitoring program is required where samples are taken at the correct frequency and locations and all important parameters are measured. This necessitates a planned approach and cannot be done retrospectively such as after a bloom occurs. However, collection of targeted data after a bloom occurs and looking at available data can give some clues to what may be driving the formation of blooms and contributing factors. Determining the causes of the bloom where no algal data is available prior to the bloom forming is not possible, but some potential factors in its formation can be hypothesised.

Conditions at Mannus Lake

Mannus Lake recently experienced a severe algal bloom of the potentially toxic cyanobacteria *Chrysosporum ovalisporum*. The bloom was noticed between late 2017 and early 2018 after public complaints about downstream water quality. UTS were engaged to

do a short study of the bloom. Sampling and analysis were undertaken for 5 weeks with some samples supplied for a further few weeks.

Results of investigation

Analysis of the bloom shows it to be an extensive high density bloom apparent throughout the reservoir, forming scums for a substantial proportion of the dam. Cell count data collected indicates that the bloom is not in the inflowing streams (Table 1) suggesting it is forming within the reservoir. Cyanobacteria were detected downstream of the lake in the Red Alert range on the sampling date of 19/1/18, but counts were lower for subsequent weeks. The bloom in the dam was in the Red Alert range until the 13/2/18. Samples taken on the 21/2/18 showed reduced cyanobacterial concentrations and on the 7/3/18 the bloom had ended and no cyanobacteria were detected. Secchi depth transparency was between 0.25 and 0.4 m for all dates tested and suggest the euphotic depth (available light for phytoplankton growth) was between 0.6 and 1.0 m in depth from the surface.

Table 1. Biovolume of toxin producing cyanobacteria in Lake Mannus, upstream of the lake, and at downstream sites. Colours refer to recreational guidelines, Red alert (> 4mm^3/L), Amber alert (0.4 to 4 mm^3/L), Green alert (0.04 to 0.4 mm^3/L). The pale green are biovolumes below the standard alert levels. nt = not tested.

	19.01.18	24.01.18	02.02.18	06.02.18	13.02.18	21.02.18	27.02.18	07.03.18
Upstream								
Munderoo creek	0.00	0.000	0.00	0.00	nt	nt	nt	nt
Mannus creek u/s	0.00	0.015	0.00	0.00	nt	nt	nt	nt
Lake								
Lake Mannus pontoon	82.64	67.05	26.41	27.92	9.46	0.05	0.08	0.00
Lake Mannus outlet (0 m)	55.00	37.65	5.46	10.12	17.94	0.01	0.31	0.00
Lake Mannus outlet (2 m)	26.17	39.54	nt	6.08	8.84	nt	nt	nt
Lake Mannus outlet (5 m)	18.25	4.35	nt	5.70	7.73	nt	nt	nt
Downstream								
Mannus Creek at Webbs Bridge	0.28	0.03	0.079	0.01	0.04	0.06	0.07	0.00
Mannus Creek at Tooma (near Tooma rd Bdg)	nt	0.010	0.00	0.01	0.00	0.00	0.00	0.00
Tumbarumba Creek d/s Mannus confluence	9.49	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Tooma river at Greg Greg (near Tooma Rd Bdg)	4.08	0.02	0.00	0.00	0.00	0.01	0.03	0.00

The formation of scums in the lake is due to the buoyancy regulating ability of some cyanobacteria including *Chrysosporum*. Buoyancy regulation occurs when the water column is relatively stable such as during stratified conditions. Phytoplankton, and in particular cyanobacteria, can maintain position in the surface waters under these conditions. Profile data within the dam supplied by Snowy valleys Council revealed that the water column was stratified during the bloom and also during most of the summer (Figure 1). Examination of the algae through time showed that cyanobacteria cell counts were throughout January at a very high concentration and maintained high concentrations through to mid-February. Examination of cyanobacteria through depth in the water column showed that cyanobacteria were maintaining a higher density at the surface of the water with usually lower concentrations at 2 m and 5 m depth (Figure 2).

Thermal stratification is likely to happen most years in the dam (as it does in most relatively deep dams) and thus was likely to have occurred the previous two years the dam was in operation. Hence this alone is unlikely to be responsible for the bloom. The stratification in the dam began to form in October 2017 illustrated by the differences in temperature (colour) in Figure 1. By November stratification was quite strong with warmer water on the surface (yellow colour). Typically in dams this stratification will maintain throughout the stratified summer period. However, in this year a rainfall event led to a large input of water to the dam in early December which led to mixing of the water column (the yellow turned to green throughout the water column – Figure 1) indicating temperatures were the same throughout the water column and hence mixing of water column (bottom waters mix with top waters).

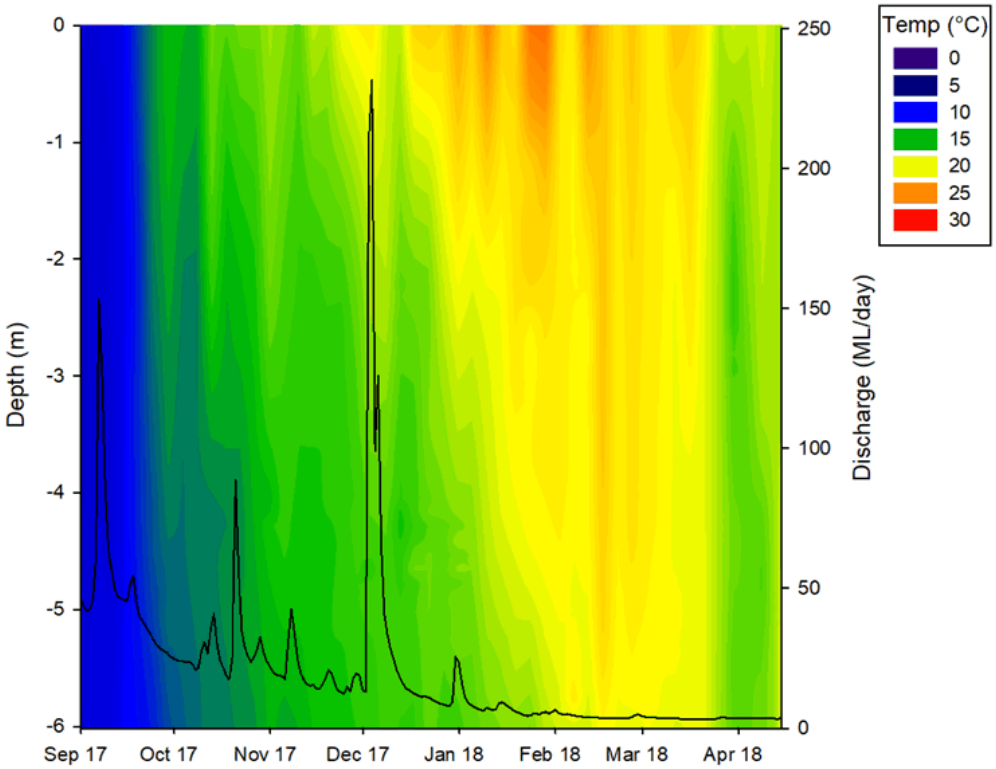

Figure 1. Thermal profiles in the lake from September 2017 to April 2018. The right axis shows discharge into Lake Mannus measured at the gauging station at Yarramundi.

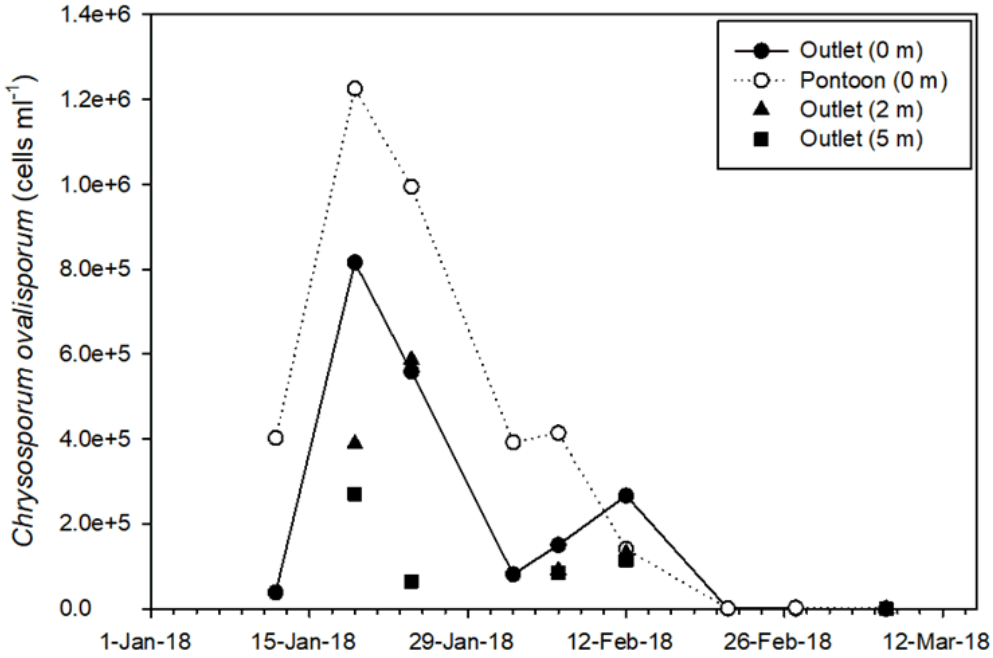

Figure 2. *Chrysosporum* concentrations through time and depth at Mannus Lake.

Profiles of temperature and oxygen taken in January and February 2018 revealed thermal and oxygen stratification (Figure 3). Of particular note is the very low oxygen concentrations in the bottom water. These conditions were anoxic (little to no oxygen in the water). In some lakes this can lead to nutrients within the sediments being released into the water column as the chemistry changes under anoxia. The released nutrients are generally held within the bottom water (hypolimnion) that is separated from the surface water (epilimnion) by the thermocline (rapid zone of temperature change). Released nutrients may stay within the bottom waters for the entire summer and not be available for algal growth in the surface waters. However, the mixing event that occurred in December (Figure 1) during a storm and inflow to the dam may have brought nutrients released from sediments into the surface waters. Secchi depth was low during the study (0.25 – 0.4 m) indicating that light for phytoplankton growth was only available in the epilimnion (surface waters). So algal growth would be minimal in the bottom waters due to a lack of light.

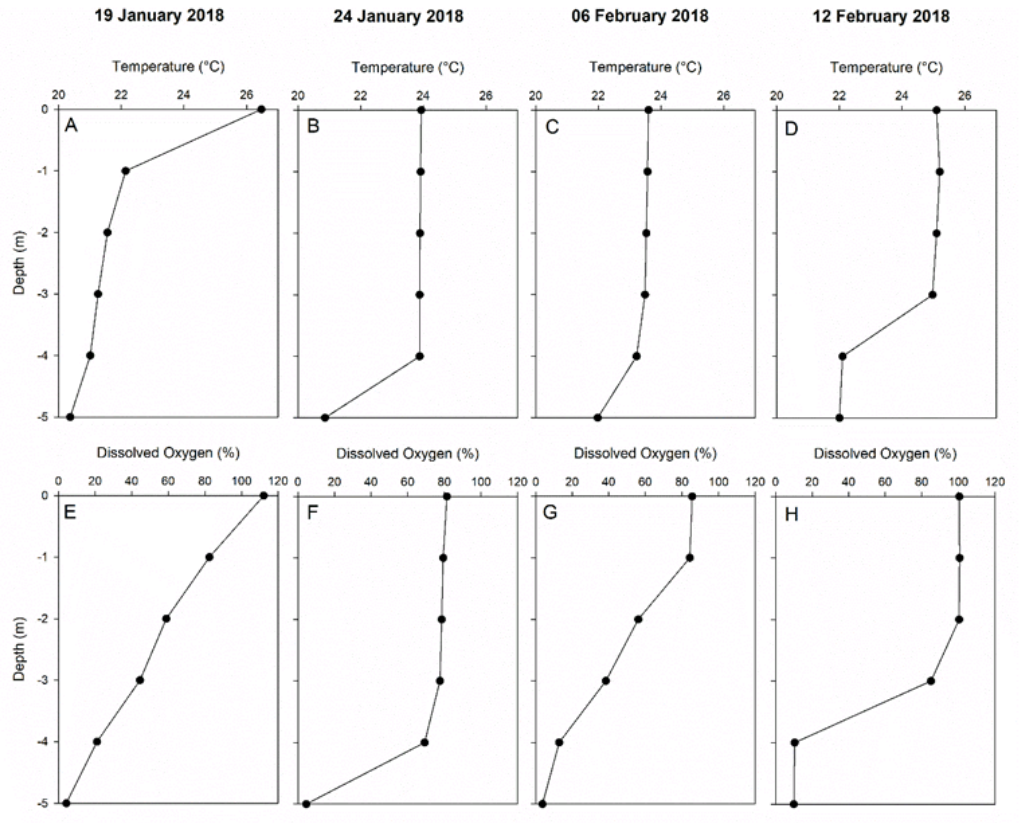

Figure 3. Temperature and dissolved oxygen profiles with depth in Mannus Lake.

Nutrient samples

Samples were taken for surface water and bottom water nutrients in January and February 2018 (Figures 4a-c). Phosphorus concentrations were generally low and not greatly different between the surface and bottom waters (Figure 4b). Nitrate/nitrite were also low during the study period and concentrations were also not very different between surface and bottom waters (Figure 4a). Ammonia concentrations were however very high in bottom waters (over 6 mg/L). This is an extremely high concentration of ammonia. Ammonia is a very bioavailable form of nitrogen and can be used by phytoplankton as a nutrient in the same way that nitrate can be used.

Higher surface concentrations of ammonia were detected on the 6th of February which coincided with a windy day and reduced thermal stratification (Figure 3). This suggests that nutrients from bottom waters may have been mixed into surface waters at this time. An increase in *Chrysosporum* concentrations was apparent after this increase in ammonia in the surface waters.

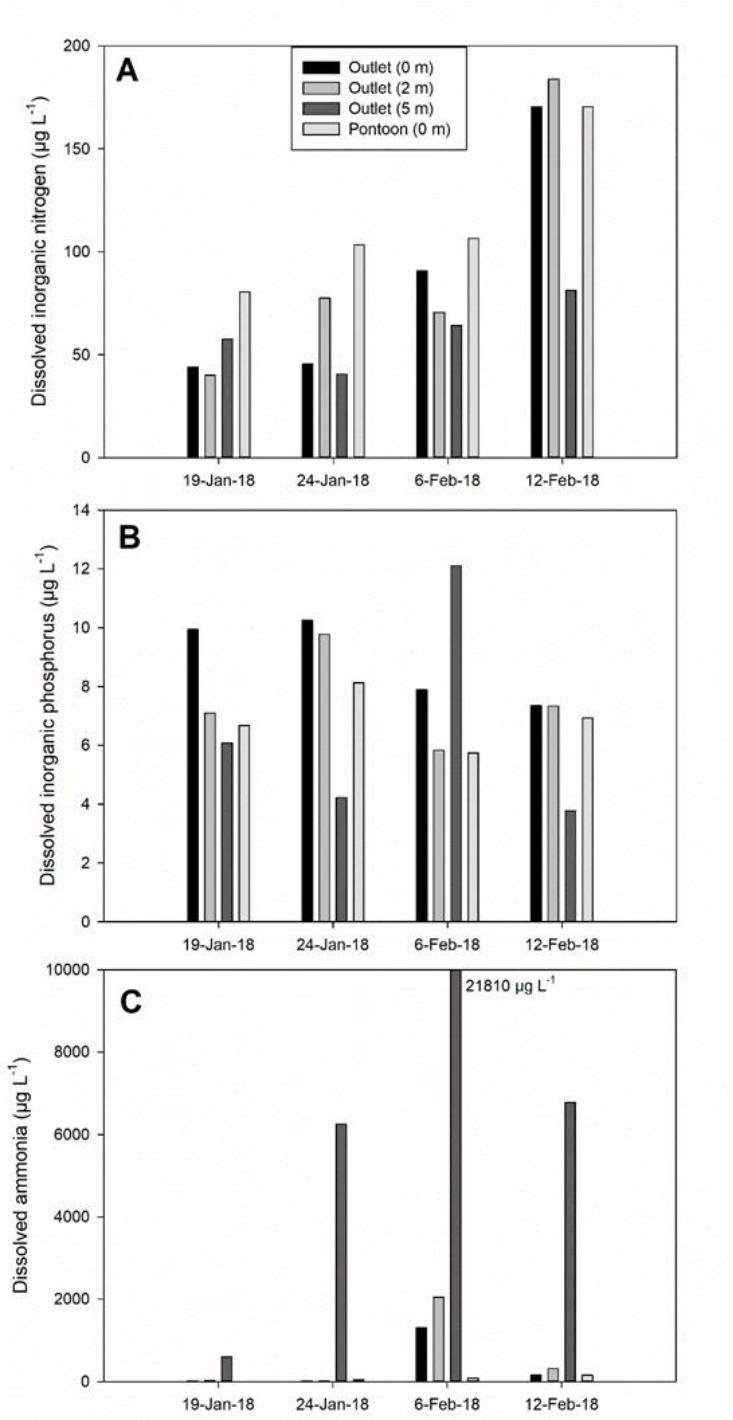

Figure 4. Nutrient concentrations in surface waters and through depth in Mannus Lake. Outlet is the offtake for downstream release and pontoon is within the recreational area.

Trace metal concentrations were tested on one occasion (6th of February) and were also higher in the bottom waters than in the surface waters. Iron (Fe) was approximately 5 times higher in bottom waters while manganese (Mn) was approximately 9 times higher (Figure 5).

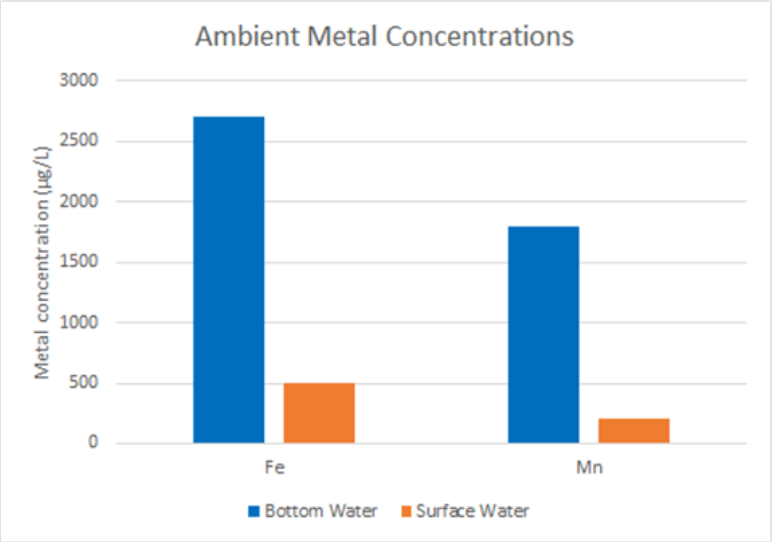

Figure 5. Iron (Fe) and manganese (Mn) concentrations in surface and bottom waters on the 6/2/2018.

Nutrients limiting phytoplankton growth

To investigate the limiting nutrients for all phytoplankton and specifically cyanobacteria in Mannus Lake, two different nutrient limitation experiments in 1 L microcosms were performed. Adding or changing combinations of nutrients and monitoring algal growth in response can help determine if algae have enough nutrients for growth or which particular nutrient is stopping them from growing more. The information is useful for understanding what may trigger a bloom, and if controlling particular nutrients or mechanisms for nutrients reaching algae, may be useful for preventing blooms.

In the first microcosm experiment we added nitrogen, phosphorus, and metals to surface waters. When adding nitrogen (N) or phosphorus (P) alone no growth was apparent (Figure 6A, 6C, 6E). This suggests that neither of these nutrients alone were limiting (stopping) growth measured as chlorophyll *a* (a surrogate measure for the total volume of algae), as total phytoplankton biovolume, or as *Chrysosporum* biovolume. When a combination of the two were added (NP) the chlorophyll *a* showed an increase, but the total biovolume of phytoplankton and *Chrysosporum* did not. This suggests there were enough nutrients in the

lake for phytoplankton and cyanobacteria to maintain growth or another factor was limiting growth. For all treatments cyanobacteria remained the dominant algal group (Figure 7).

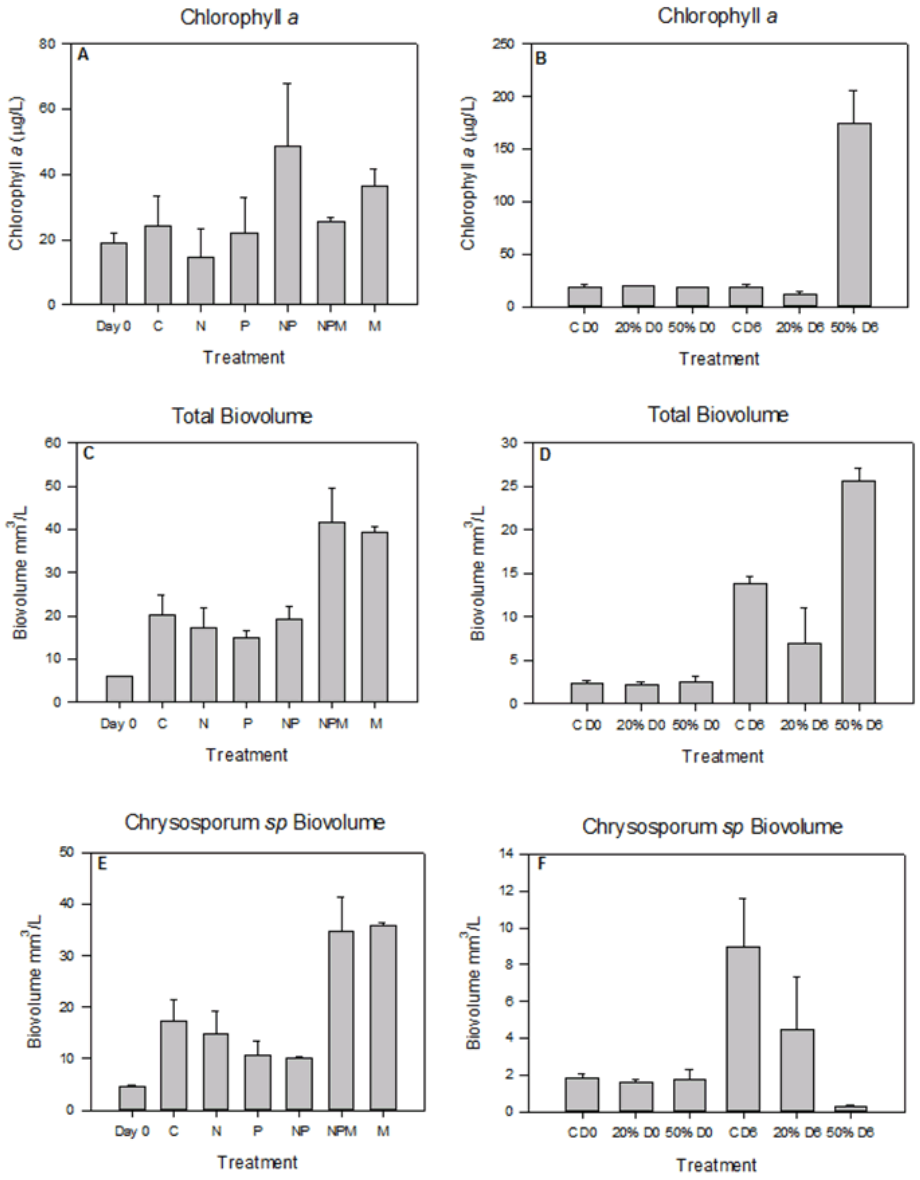

Figure 6. Results from the nutrient limitation experiments including nitrogen and phosphorus addition (A, C, E) and bottom water addition to surface waters (B, D, F). Refer to the text for the explanation of the x-axis categories.

Trace metals were also tested in combination with nitrogen and phosphorus to see if they may be limiting growth. This was a mixture of iron, manganese, cobalt, copper,

molybdenum and zinc. Trace metal addition did not influence chlorophyll *a* but did increase the total phytoplankton biovolume and that of *Chrysosporum* (Figure 6). Again community composition was still dominated by cyanobacteria with the metals addition (Figure 7). Trace metals were limiting cyanobacterial growth at this point in time.

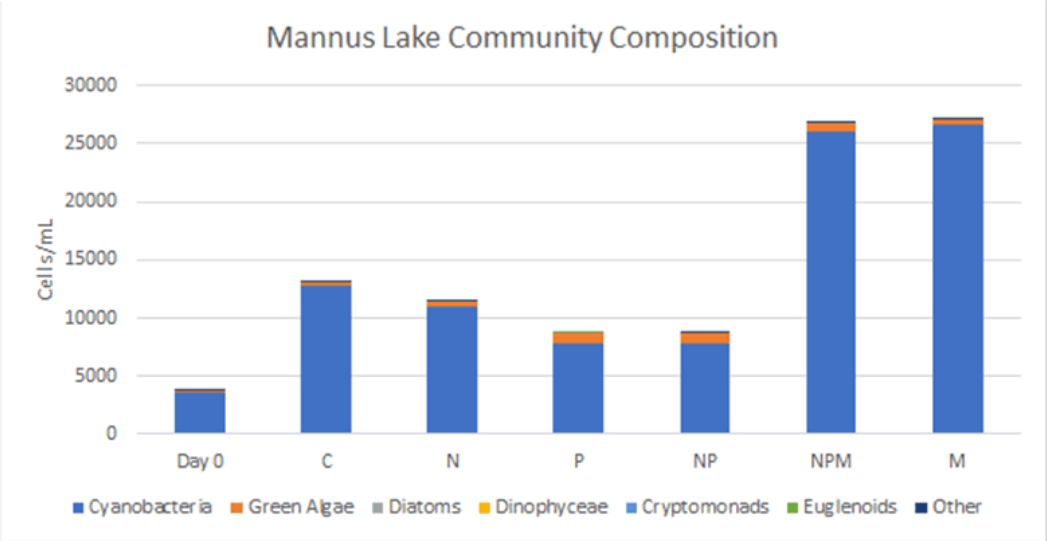

Figure 7. Phytoplankton community composition during the nutrient limitation experiments where nitrogen (N), phosphorus (P) and metals (M) were added in different combinations. C indicates the control where no nutrients were added.

A second series of experiments took bottom water from the dam and added it to surface water at 20% and 50% mixtures (i.e 20% bottom to 80% surface and 50% each of bottom and surface water). The phytoplankton concentrations at the start of both experiments were the same. After six days (D6) for chlorophyll *a* and total biovolume there was a very large increase in growth for the 50% bottom water treatment (Figure 6). However, this was not due to *Chrysosporum* (Fiogure 6F) or any other cyanobacterium. Figure 8 shows the community composition during this experiment where a switch to green algae occurred with the 50% bottom water addition but not for the 20% bottom water addition which resembled the control.

This indicates at the time of the study bottom water additions could increase phytoplankton biomass. This supports the notion that bottom water intrusions of nutrients (either as trace metals or nitrogen/phosphorus) into surface waters, may increase the growth of phytoplankton and helped trigger the initial bloom. It is important to note however that *Chrysosporum* did not increase in these experiments. Part of the reason for this may be due to changing volumes at the start of the experiment; in order to create balanced conditions we had to reduce the total volume of algae through filtration which may have given an

advantage to other algae species. The timing of this experiment (6/2/18 – 12/2/18) was also near the time when *Chrysosporum* declined in growth in the lake. It may have been that another factor in combination with the bottom water was changing dominance away from *Chyrosporum* such as changes in micronutrient availability, grazing pressure from zooplankton, or competition with another algal species.

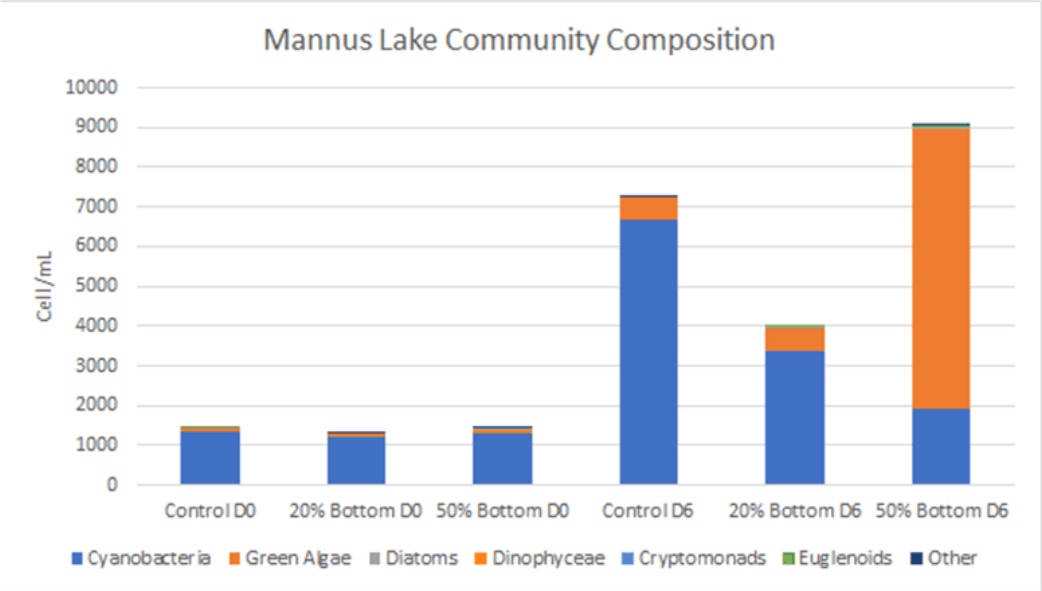

Figure 8. Phytoplankton community composition during the nutrient limitation experiments where bottom water was added to surface water.

Overall summary of potential factors contributing to bloom formation

Without data prior to and during the initiation of the bloom it is difficult to determine conclusively the causes of the bloom. However, examination of the limited available data before the bloom formed and data collected after the bloom indicates several factors that may have led to the bloom forming. Firstly, thermal stratification is likely to occur over summer every year in the dam. This leads to anoxic conditions in the bottom water and release of sediment-bound nutrients, particularly ammonia. These nutrients are kept within the bottom waters, separated from the surface waters by a thermocline. In December 2017 a high rainfall event occurred which led to a large influx of water into the dam which resulted in mixing of the water column. This may have led to an influx of nutrients into the lake from upstream, and also mixed the water column and brought bottom water nutrients to the surface. The inflow may have also brought in sediments that may have reduced the light penetration depth to a lower level. This combination of high nutrients and reduced light levels may have benefited buoyant cyanobacteria when the lake re-stratified approximately a week later. Algae were seen to use buoyancy to maintain position in surface waters allowing greater amounts of light to be harvested. The stratified water

column, low light penetration, and high nutrients may have fulfilled niche conditions for *Chrysosporum* to flourish and allowed the bloom to develop to the high densities measured. The timing of the bloom is consistent with this hypothesis. A modest starting concentration of 20 cells/mL of *Chrysosporum* on the 10th of December, and assuming a constant doubling time of 2 days (as recorded for similar cyanobacteria) this would give a final concentration of around 2 million cells/mL on the 12th of January, approximately what was measured. Light would not be limiting due to buoyancy regulation and experiments showed little limitation by nitrogen and phosphorus, although there was some limitation by metals found. The bloom reduced quickly in mid-February 2018 and was gone by early March. The reason for the decline is not clear.

There is the possibility that blooms of *Chrysosporum* at lower densities may have occurred in previous years and not have been noticed. This would explain the seed bank/inoculum available for the bloom to occur this year. As *Chrysosporum* is a filamentous cyanobacteria with akinetes (resting spores) as the bloom declined a substantial deposition of the spores will now be in the sediment. This will make future blooms potentially more likely and intense.

Management recommendations

Develop a routine sampling program

As cyanobacterial blooms have been recorded in Mannus Lake, regular sampling for public health safety should be adopted. This would involve surface samples being taken from at least 2 locations (suggest near offtake and near recreational area). Sampling should be done monthly from April to September then fortnightly from October to March. If cyanobacterial biomass increases into the Amber alert zone (0.4 to 4 mm^3/L) then sampling should increase to weekly or fortnightly intervals.

Undertake a research program to better understand the causes of blooms for management actions

Cyanobacterial blooms can be managed in lakes after the conditions that are causing the blooms are understood. A good understanding of the causes of the blooms is required through a well-designed monitoring project encompassing all the main factors influencing blooms. This will indicate the best management approach.

Several management approaches can be taken. These may include artificial mixing of the water column with a propeller or air bubbles pumped into the lake (bubble plume aerator). This stops stratification from forming and reduces the ability of cyanobacteria to float to the water surface and reduces sediment nutrients from being released (stopping the formation of anoxic bottom waters). This has been useful in Manly Dam to stop blooms. UTS monitors the algae in Manly Dam and previously installed the propeller mixer. It has solved the algal bloom problem and the only bloom in the last 10 years occurred when the propeller mixer broke down and was not functioning last summer. This would be the most effective and fast acting management approach if the monitoring program supported the implementation.

Other techniques can include chemicals that can be added to cap the sediments to stop them releasing nutrients or added to the water column to flocculate nutrients. Nutrient reduction activities can also be used to manage blooms in the longer term. The nutrients which limit growth i.e. P, N or P and N or micronutrients such as iron can also be targeted such as from controlling point sources or by using macrophytes to capture nutrients. These methods are generally less effective and take longer time periods for improvements to be seen.

UTS has developed a project to undertake research over a two year period to determine more clearly the causes of blooms in Lake Mannus. This project would also alleviate the need for routine monitoring as this would be done (and in more detail) within the study. If a destratification mixing system seems feasible after the first year of data collection, it could be installed before the second year of the project allowing a summer period to be monitored with the destratification system operational.