Lake Ainsworth Coastal Management Program

Action 1: Trial modifications to artificial aeration

Phase 2 Aerator Trial Report

Final Report

May 2023

Disclaimer:

Acknowledgement of Country:

Hydrosphere Consulting acknowledges the Bundjalung peoples, Traditional Custodians of the lands discussed in this report and pay tribute and respect to the Elders both past and present and emerging of the Bundjalung nations.

Cover photos: Lake Ainsworth aerial drone image July 2018

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JOB 22-017 LAKE AINSWORTH AERATOR TRIAL
PHASE 2 AERATOR TRIAL REPORT

REV	DESCRIPTION	AUTHORS	REVIEW	APPROVAL	DATE
0	Draft for client review	K. Pratt	M. Howland	M. Howland	31 May 2023
1	Issued as final	-	-	-	3 July 2023

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1. INTRODUCTION

Lake Ainsworth is a tannin-stained freshwater coastal dune window lake with high biodiversity and habitat value. It is utilised for a variety of water and shore-based activities including swimming, paddling, sailing and picnicking and is also an important educational resource with a rich cultural history and significant ecological value. Continued proliferation of cyanobacteria (blue-green algae) was documented in the Lake Ainsworth Coastal Management Program (CMP; Hydrosphere Consulting, 2020) as a high risk to Lake Ainsworth's environmental, cultural and social values.

This report provides results of the Phase 2 Aerator Trial for Lake Ainsworth which was conducted over 7 months from September 2022 to April 2023 and investigated water quality in the lake during 24 hours/day (continuous) operation of the aerator. A water quality monitoring program was undertaken to evaluate the efficacy of the modified aerator regime and provide recommendations regarding aerator operation, and recommendations for any further monitoring.

The Phase 2 Aerator Trial is the second stage of implementing Action 1 of the Lake Ainsworth Coastal Management Program (CMP): Trial modifications to artificial aeration. The Phase 1 Aerator Trial was conducted in January and February 2022 and assessed water quality in the lake during 24 hours/day (continuous) operation of the aerator over a six-week period. The Phase 1 Aerator Trial reported improved water quality in the lake with 24 hours/day aeration and recommended that the Phase 2 Aerator Trial be conducted over the next swimming season to confirm results over a longer period and varying season and climatic conditions.

A key aim of modifying aerator operation was to increase dissolved oxygen levels at depth within the lake in order to reduce the release of nutrients, primarily phosphorus, from the lake sediments into the water column, thereby reducing the occurrence of cyanobacteria (blue green algae) blooms, which was identified as a key risk in the Lake Ainsworth CMP.

1.1 Stratification

Stratification is the physical layering of the water column resulting from density differences caused by temperature variation (OzCoasts, 2018). Surface water becomes less dense as it is heated by absorption of solar radiation and therefore floats above the cooler, denser water below. The dark tannin-stained water of Lake Ainsworth means that sunlight is absorbed rapidly within the surface waters and the resulting stratification of the water column is stronger than it might otherwise be.

In stratified lakes there is very little mixing between the lake surface and the water at the bottom of the lake. The unmixed bottom layer (the hypolimnion) can become extremely low in oxygen (anoxic) over time as biochemical processes consume oxygen. Anoxia can negatively impact aquatic ecosystems, either directly affecting those organisms that require oxygen for respiration to survive, or indirectly through impacts on a range of chemical processes (QLD DES, 2022). The key chemical processes known to occur in Lake Ainsworth are the release of nutrients (mainly phosphorus but also nitrogen in the form of ammonia) from the benthic sediments into the water column under anoxic conditions. This nutrient enrichment then provides the pre-cursor conditions for algal blooms which are stimulated when sunlight photoperiod and water temperature conditions are suitable.

1.2 Lake Ainsworth Aerators

Before November 1997, Lake Ainsworth was experiencing intense stratification during the warmer months between October and March (Perkins *et al*., 2015). AWACS (1996) reported that the stratified conditions were likely to be providing favourable conditions for cyanobacterial blooms due to a largely undisturbed water column and accelerated nutrient release from the sediments caused by low oxygen conditions on the lake floor.

In November 1997, an aerator system was installed to destratify the lake and increase dissolved oxygen levels with the aim of reducing nutrient release from bottom sediments and therefore reducing the occurrence of cyanobacteria blooms. The Lake Ainsworth aerator is located in the deepest section of the lake at approximately 8-9m depth (depending on lake water levels), is bar-shaped, 75m long and consists of 25 bubble fountains separated at 3m intervals through a cluster of five 1.5mm diameter holes (Perkins *et al.* 2015). The standard aerator operation regime in place since installation involved aerator operation for 12 hours each 24-hour period, generally during the night between September and April (BSC, 2017a). Figure 1 shows the typical water circulation patterns induced by a bubble plume aerator, mixing bottom waters upwards to the surface layers and also inducing some lateral movement of water.

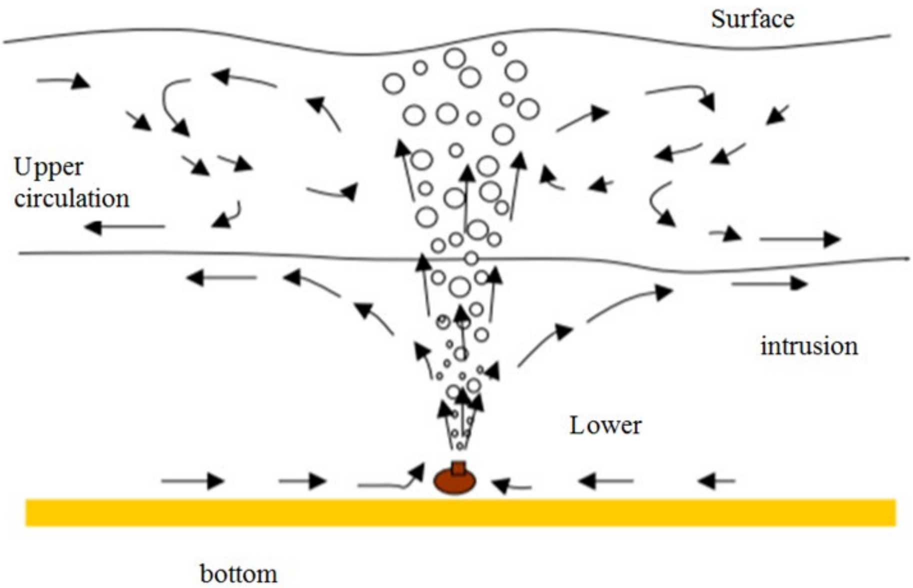

Figure 1: Typical water circulation around a bubble plume aerator (Source: Brookes *et al.*, 2008)

1.3 Aerator Performance

Previous study has reported that the aerator has achieved at least partial destratification of the lake and has been successful in maintaining elevated levels of dissolved oxygen (NSW Department of Public Works and MHL, 2001; Perkins *et al.* 2015). However, investigation as part of the Lake Ainsworth CMP (Hydrosphere Consulting, 2019) indicated that despite the success of the aerator in breaking down stratification in the lake, elevated nutrient levels (particularly with regard to bioavailable forms) remained in the lake and had increased over time since the aerator was installed. Average dissolved inorganic phosphorus levels (measured from 2015-2018) were up to four times the levels measured in 1998/99, and total phosphorus concentrations were almost double the levels measured in 1995. The bioavailable forms of nitrogen (NO_3

and NH_4-N) varied over the sampling periods, increasing by five and four times respectively compared to 1993-1995 levels. Total nitrogen concentrations were reduced compared to 1993-1995 levels. These results indicated that the aerator program (12-hours/day) was not effective at controlling the release of nutrients from sediment, despite an apparent improvement in dissolved oxygen conditions throughout the water column.

Hydrosphere Consulting (2019) discussed the possibility that while the aerator is successful at reducing stratification while functioning, when switched off and particularly during hot summer days, partial stratification or anoxia at the lakebed may form again. During the temporary anoxic state, nutrients may be released into the benthic waters. When the aerator is turned on again at night, nutrients may be recirculated to upper layers. The sediment-liberated nutrients would then be available in surface waters for uptake by phytoplankton and cyanobacteria in the presence of sunlight. This hypothesis was originally put forward in the *Lake Ainsworth Management Study* (DPWS and MHL, 2001) and could explain why the current aerator regime has not reduced nutrient levels or the incidence of cyanobacteria blooms in the lake.

Depth profile sampling was undertaken as part of development of the CMP to assess water quality conditions during the standard 12-hours/day operation of the aerator (Spring/Summer of 2018/2019). This study confirmed that when the lake was stratified (no aeration), very low dissolved oxygen conditions were detected close to the sediment/water interface and nutrients were concentrated at the bottom of the lake. The aerator was very effective at mixing the water column, and this resulted in nutrient rich, and oxygen poor benthic waters being brought to the surface into the photic zone, hence stimulating algal growth. This initial water quality investigation in Spring was focused on the aerator start-up phase and concluded at Day 6 after aerator start-up. Summer sampling after four months of 12-hour/day aeration showed that dissolved oxygen levels were improved compared to the initial start-up of the aerator in Spring, but low dissolved oxygen conditions persisted close to the sediment/water interface.

2. METHODOLOGY

2.1 Depth Profile Water Quality Sampling

The Phase 2 Aerator Trial monitored water quality conditions in the lake over seven months from 19th September 2022 to 11th April 2023 with artificial aeration occurring continuously (24 hours/day aeration), except for two periods of unexpected shutdown described below. Water quality conditions were assessed prior to the aerator being switched on in September 2022 and at fortnightly intervals after the aerator commenced operation on 23rd September 2023, with a total of 15 water quality depth profiles recorded during the sample period.

Water quality was sampled at various depths at one site (LA3) in the deepest part of the lake (refer Figure 2 and Table 1 for sampling site locations and details). This site is offset approx. 30m from the aerator bubble plume pipeline on the bottom of the lake.

Sampling activities were as follows:

- A water quality depth profile was recorded at LA3 for physico-chemical parameters measured *in situ* with a multi-parameter water quality meter at 0.5m increments down to 3m and then typically every 1m increment until the bottom. Parameters assessed: Temperature, Dissolved Oxygen, pH, EC (*in situ*).
- Water samples were collected at four different depths. Samples were taken to replicate sampling undertaken in Phase 1 of the Aerator Trial (i.e. at 0.5m, 2m, 4m and approx. 8m water depths). Lake depths varied over the sample period and bottom samples were within 0.2-0.5m of lake sediments.
    - Parameters assessed at all 4 depths: Total Nitrogen (TN), Ammonia (NH_4), Nitrate (NO_3), Nitrite (NO_2), Total Phosphorus (TP), Phosphate (PO_4).
    - Parameters assessed at surface only (0.5m): Chlorophyll *a* (Chl *a*), Algal Biomass, and cyanobacteria.
- All grab samples were submitted to the Environmental Analysis Laboratory (EAL) at Southern Cross University in Lismore within 24 hours of sampling.

The aerator was operated continuously through this period except for the following:

- A three-week period of non-operation from mid-December 2022 to early January 2023. Sometime in the few days leading up the 19th of December 2022, the aerator unexpectantly broke down and was not able to be repaired. A new aerator was installed and switched on from 10th January 2023.
- A three-week period of operation during the daytime only from 8am – 6pm from 10th to 31st January 2023. Due to increased noise from new aerator system, operation was initially from 8am – 6pm only so as not to disturb nearby residents. Acoustic dampening was installed, and 24 hours/day operation was restored on 31st January 2023.
- Approximately two to three week period of non-aeration due to a burst air hose. The lack of bubbles reaching the surface was first noticed during sampling on 13th February 2023. BSC investigated, located the damage and made repairs to the line, restoring full operation on 20th February 2023.

2.2 DPE Logger

Lake water level and water quality is recorded by a data logger located towards the northern end of the lake (Figure 2). The logger records water level (mAHD), rainfall and a limited set of water quality parameters (temperature, conductivity and salinity near to the surface of the lake) every 15 minutes at Lake Ainsworth as part of the NSW Coastal Data Network Program managed by DPE. Data for the Phase 2 Aerator Trial period was provided by DPE for analysis (refer Section 3.2 and 3.3).

2.3 Ballina Shire Council Blue Green Algae Monitoring

BSC monitors cyanobacteria species presence and abundance at four sites in Lake Ainsworth during the swimming season from October to April (Figure 2). Samples are taken from the surface of the lake and combined in pairs for analysis as follows: Sites 1 & 2 (north and east) and Sites 3 & 4 (southeast and southwest).

Table 1: Sampling site details

Site	Description	Easting	Northing	Sample Type	Parameters	Depths (m)
LA3	Central basin of the lake approx. 30m west of aerator	557778	6815854	Detailed water quality depth profile	Temperature, Dissolved Oxygen (*in situ*).	0.5m, 1m, 1.5m, 2m, 2.5m, 3m, 4m, 5m, 6m, 7m, 7.5m, 8.0m[*1], 8.5m[*2]
					TN, NH_4, NO_3, NO_2, TP, PO_4	0.5m, 2m, 4m, 8.0m[*1], 8.5m[*2]
					Chl *a*, algal biomass, cyanophyta	0.5m
DPE Logger	Northern end of lake	557863	681659	Continuous data logging (every 15 mins)	Water Level, Temperature, Conductivity, Salinity	Surface water quality samples (approx. 0.5m)
Site 1	Northern end near boat ramp	557844	6816262	BSC blue green algae monitoring site	Algal ID and count, total cyanophyta, total biovolume	Surface water quality samples (approx. 0.25m)
Site 2	East side approx. middle of lake	557851	6815984			
Site 3	Southeast corner	557882	6815698			
Site 4	Southwest swimming bay	557665	6815694			

*1 Readings below 7.5m taken at 0.5m increments until within 0.2-0.5m of lake sediments

*2 Deepest sample taken within 0.2-0.5m of lake sediments.

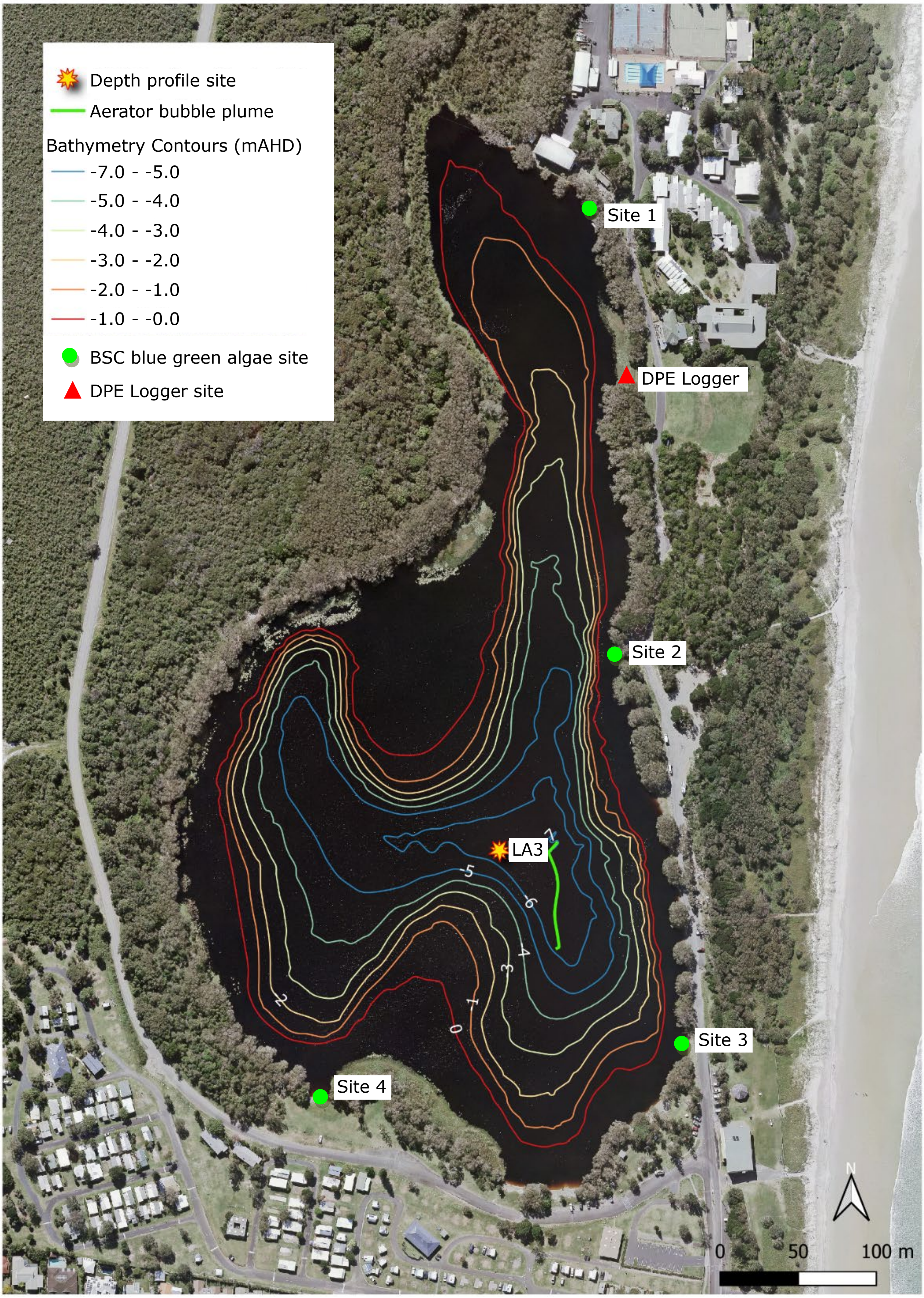

Figure 2: Sampling sites showing bed elevation contours of the lake (m AHD, assessed July 2018)

3. RESULTS AND DISCUSSION

3.1 Weather and Rainfall Conditions

Figure 3 shows the monthly rainfall totals during the Phase 2 Aerator Trial compared to long-term averages. Rainfall in September and October 2022 was more than double the long-term average monthly rainfall in each respective month. Rainfall in the remaining months of the trial was below the long-term monthly averages for all months except for February 2023, which was slightly above the long-term average. Figure 4 shows daily rainfall over the sample period and the fortnightly water quality sample dates for the trial.

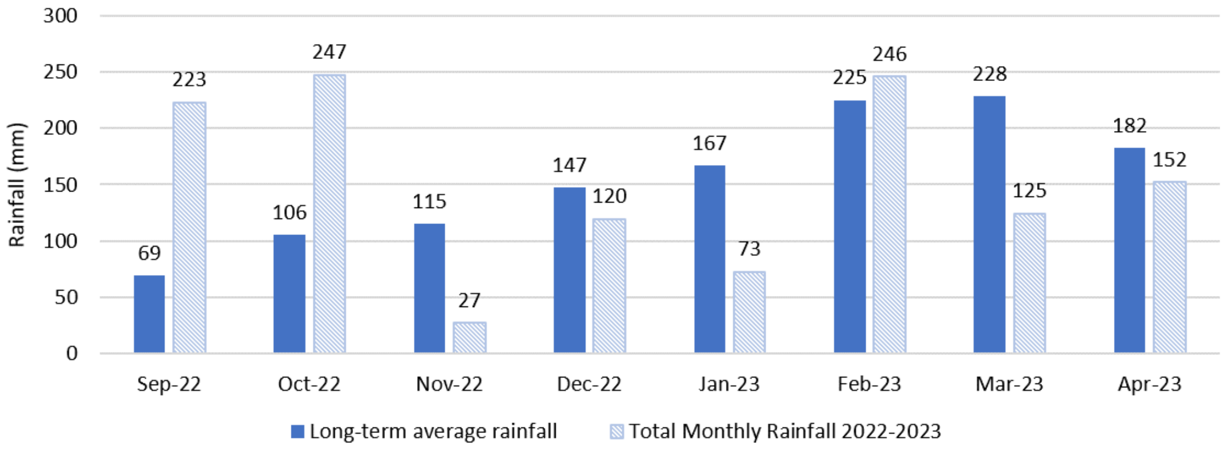

Figure 3: Monthly rainfall totals September 2022 – April 2023 compared to long term averages

Data Source: BOM, 2022

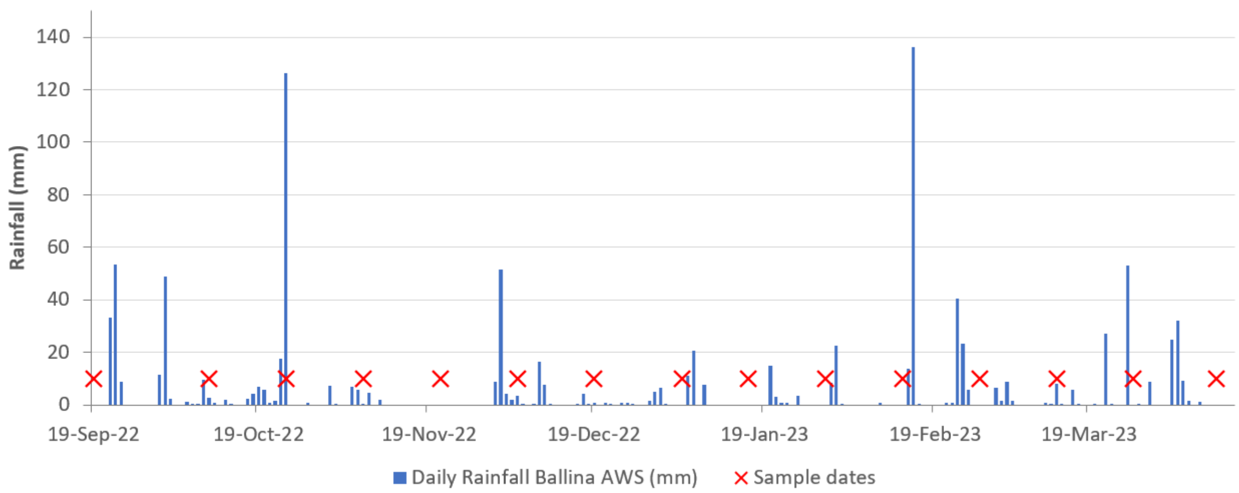

Figure 4: Ballina Airport AWS rainfall for September 2022 to April 2023 showing sample dates

Data Source: BOM, 2022

3.2 DPE Logger Lake Water Level Data

Lake water level is recorded by a data logger located towards the northern end of the lake. The logger records water level (mAHD), rainfall and a limited set of water quality parameters every 15 minutes at Lake Ainsworth as part of the NSW Coastal Data Network Program managed by DPE. Water levels steadily decreased during the aerator trial ranging from approx. 3m AHD and 2m AHD at the end of the trial in April

2023 (Figure 5), which is close to the long-term average water level for the lake (approx. 1.98m AHD). The decreasing lake levels observed during the Phase 2 trial were a continuation of the downward trend following the record high lake levels (4.14m AHD) and major flooding that occurred in March 2022 following major Northern Rivers rainfall and flood events (Figure 6).

Lake levels during the first half of the trial (September to December 2022) were higher than levels experienced during the Phase 1 Trial. For the second half of the trial, lake levels were within the same range as lake levels during the Phase 1 Aerator Trial (2 – 2.5m AHD).

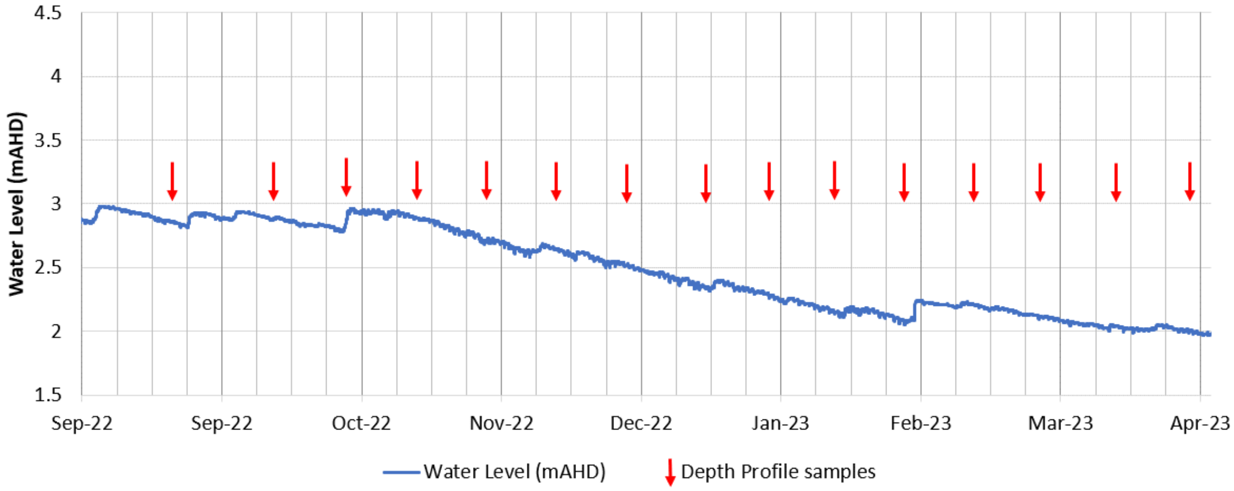

Figure 5: Lake water level over the sampling period from September 2022 - April 2023.

Data Source: Raw data provided by DPE (2022)

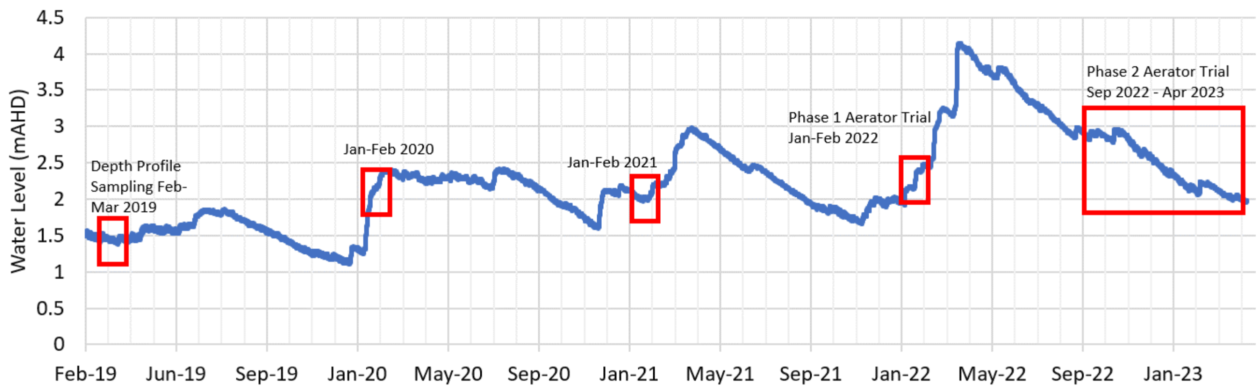

Figure 6: Lake water level March 2019- April 2023, showing phase 1 and phase 2 aerator trial sample periods.

Data Source: Raw data provided by DPE (2023)

3.3 DPE Logger Water Quality Data

A timeseries of DPE logger water quality results are provided below for temperature (Figure 7) and conductivity (Figure 8). Temperatures ranged from 16°C to 31°C during the trial varying diurnally and in response to rainfall events. Conductivity gradually increased over the sampling period as lake water level dropped and salt concentrations increased. The range of conductivity over the period was relatively constant between 150-193 µS/cm, within the classification for a freshwater system and slightly below the range of previously reported average conditions for the lake (228 µS/cm, Hydrosphere Consulting, 2019).

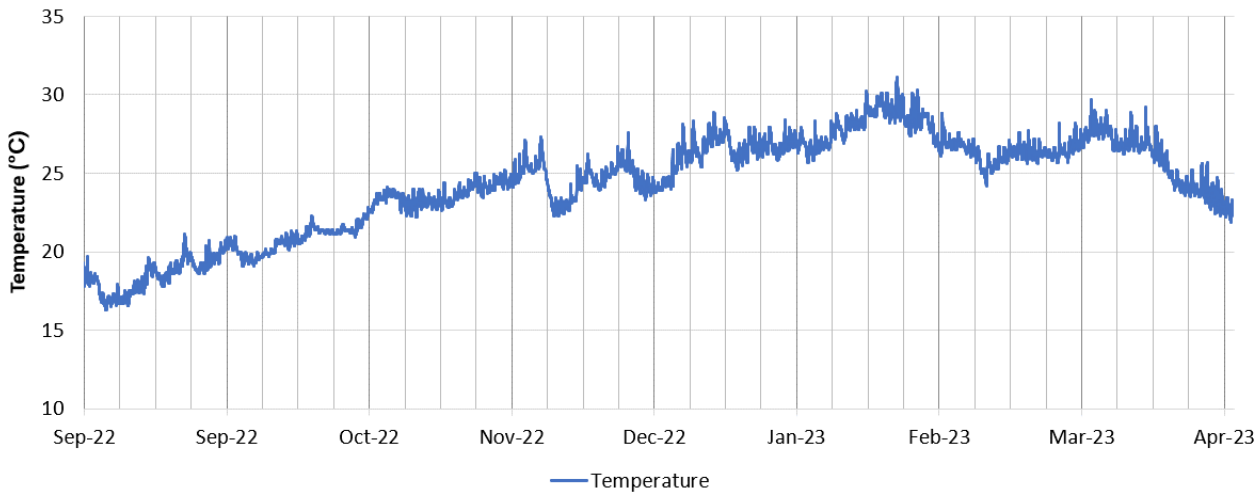

Figure 7: Lake surface temperature over the sampling period from September 2022 - April 2023.

Data Source: Raw data provided by DPE (2023)

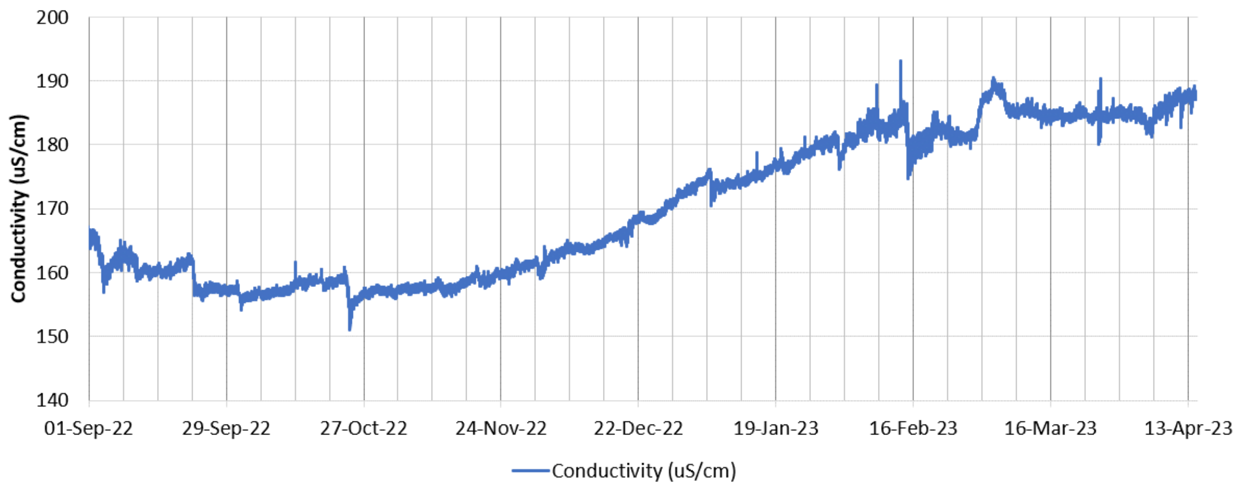

Figure 8: Lake surface conductivity over the sampling period from September 2022 - April 2023.

Data Source: Raw data provided by DPE (2023)

3.4 Ballina Shire Council Blue Green Algae Monitoring

Total Cyanophyta cell counts and biovolume for the current season are shown in Figure 9 and Figure 10 respectively. Public health alerts are issued when levels are elevated in accordance with the National Health and Medical Research Council (NHMRC) *Guidelines for Managing Risks to Recreational Water* (2008) (Figure 10).

There are numerous factors influencing cyanophyta counts, some of which are influenced by the aerator, (e.g. water quality, nutrient levels, circulation patterns). Some factors are partially influenced by the aerator (e.g. surface water temperature). Other factors are natural variables that are influential but not able to be controlled by the Lake Ainsworth aerator (e.g. sunlight photoperiod, sunlight intensity, air/surface water temperature, wind-induced currents, waves and localised circulation). No analyses were made (or likely possible) to separate the effects of weather patterns encountered during the trial although observations during sampling provided additional insights into the natural dynamics of the lake.

Low cyanophyta cell counts and biovolume were observed during Spring 2022 (Sep-Nov) during aerator start-up and continuous (24 hours/day) operation. There was only one green public health alert (17th November) issued for the lake over this timeframe. This was in contrast to the previous year when cyanophyta cell counts and biovolume were highest in the Spring (Oct-Nov 2021) and public health alerts were issued every week from early October to early December 2021. The aerator was non-operational during this time (Spring 2021).

Cyanophyta cell counts began to increase in mid-December 2022 following the unexpected shutdown of the aerator. Levels dropped slightly with the commencement of 10hr/day aeration in early January 2023 (new aerator installed). Cyanophyta cell counts and biovolume increased dramatically to the highest levels observed during the Phase 2 Trial when the aerator was non-operational again due to a burst air pipe in mid-February 2023. Red public health alerts were issued by Council in the two weeks following this event due to cyanophyta above safe swimming levels. Levels dropped again following repair and startup of the aerator on 20th February 2023. One amber public health alert was issued in the last week of February followed by two green alerts in early March as cyanophyta levels decreased. There were no more public health alerts issued for the remainder of the swimming season during 24 hours/day operation of the aerator.

Due to the unexpected shutdown of the aerator on two occasions during the Phase 2 Aerator Trial, it was not possible to assess the 24 hours/day operation regime continuously throughout the seven-month trial period. However, when the aerator was operating continuously, measured cyanophyta cell counts and biovolume levels were relatively low and were well below the long-term average conditions for the lake, with only one green public health alert issued in Spring and two issued in summer following a period of aerator shutdown. This is consistent with the results of the Phase 1 Aerator Trial undertaken in Summer 2022, when no public health alerts were issued, and cyanobacteria levels were much lower than long-term average summer conditions. The unexpected shutdown of the aerator demonstrated how quickly cyanobacteria levels can increase during the high-risk summer season.

The results also suggest that continuous 24 hours/day operation in the lead up to the first aerator shutdown may have been sufficient to build up a reservoir of oxygenated water in the lake which mitigated conditions following shutdown. Conversely, the 10hr/day operation following installation of the new aerator may have not been sufficient to mitigate against adverse conditions created during the second shutdown.

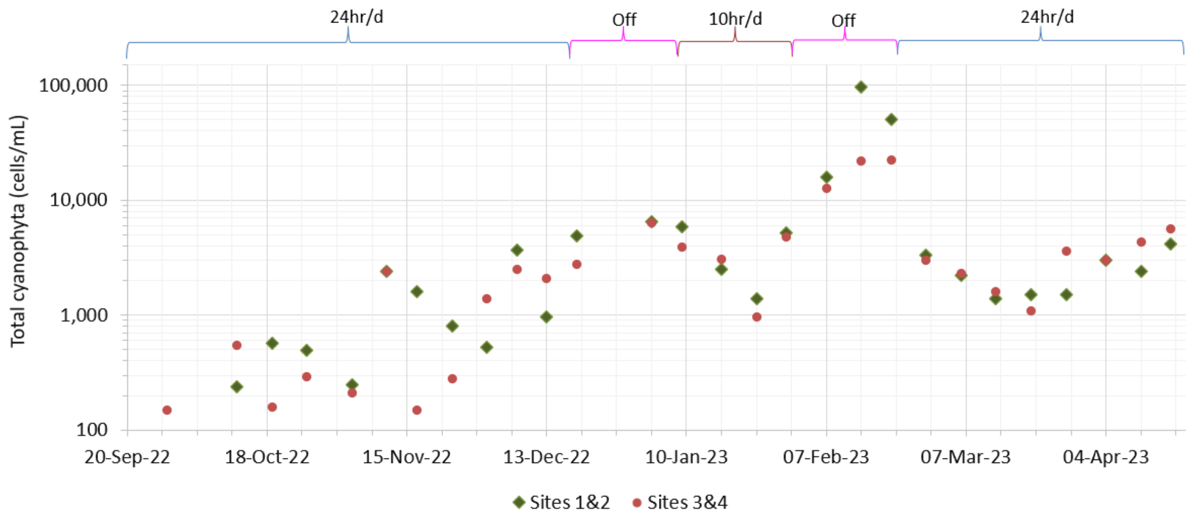

Figure 9: Total cyanophyta cell counts over the Phase 2 Aerator Trial September 2022 to April 2023 showing aerator status. Note this chart uses a log scale.

Data Source: Raw data provided by BSC (2023)

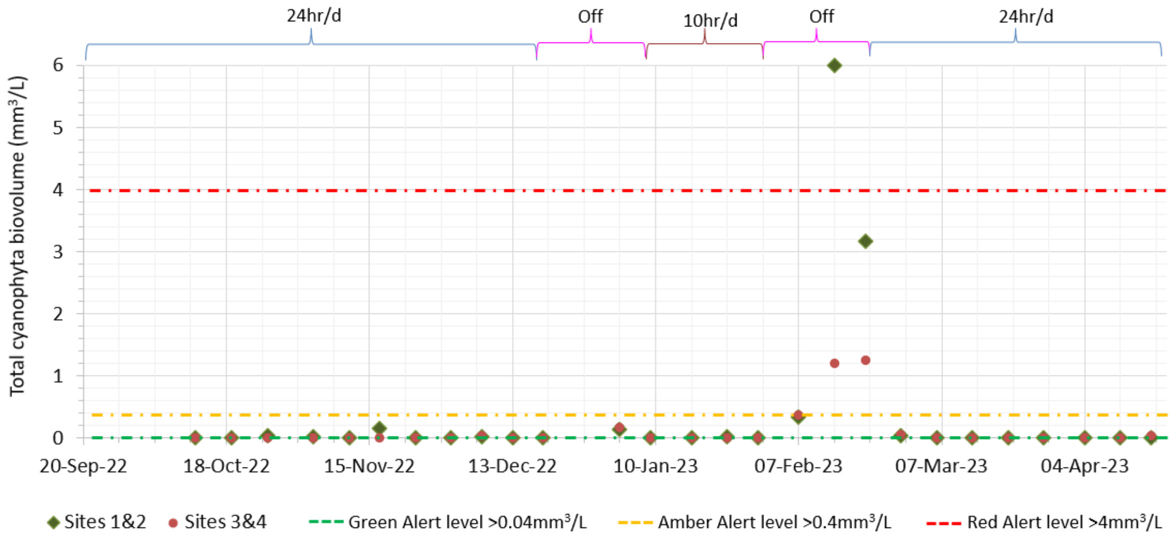

Figure 10: Total Cyanophyta biovolume over the Phase 2 Aerator Trial September 2022 to April 2023 showing aerator status and alert levels.

Data Source: Raw data provided by BSC (2023)

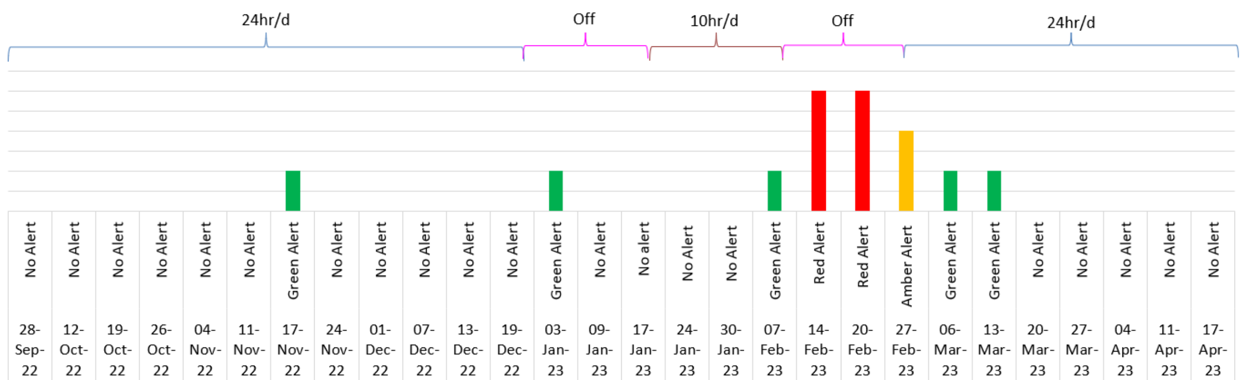

Figure 11: Cyanobacteria public health alerts issued over the 2022/2023 swimming season.

Source: Raw data provided by BSC (2023)

3.5 Depth Profile Water Quality Data

3.5.1 Temperature

Figure 12 shows depth profile temperature data at all sites from September 2022 to April 2023 from the surface of the lake to the deepest point at approximately 8m from the water surface. The depth profiles present water quality observations during spring stratified conditions (before the aerator was turned on) and through the duration of the trial which included various aeration states as described in Section 2. Figure 13 shows temperature measured through time (all depths) showing aerator operation status. Key observations are discussed below.

Spring stratified conditions assessed on 19th September 2022 (pre-aeration):

- The lake was strongly stratified when sampled on 19th September after the aerator had been non-operational throughout autumn and winter (approx. 7 months).
- The temperature was 22.3°C at the surface of the lake and 16.7°C at the deepest point (a temperature difference of 5.6°C).

Aerated 24 hours/day (23rd September to mid-December 2022):

- The first post-aeration depth profile samples were taken approximately two weeks after the aerator was switched on. At this time thermal stratification had completely broken down and the water column was well mixed with a constant temperature around 20.5°C.
- The water column during monitoring between October to early December remained well-mixed with some weak surface stratification evident in the top 1m of the lake. Lake temperatures gradually increased over time corresponding to warming air temperatures into the summer months.

Aerator off (mid – December 2022 to 10th January 2023):

- At Day 87 (19th December 2022) the lake remained fairly well-mixed with very weak thermal stratification observed at approximately 3m depth. It was believed that the aerator had shutdown sometime between the 13th and 19th of December 2022 and the relatively well-mixed conditions on the 19th of December indicate the breakdown occurred not long before that sample (although extremely windy conditions on the 19th may have contributed to lake mixing).
- The following sample two weeks later on the Day 103 (4th January 2023) showed that the lake was strongly stratified after approximately two to three weeks with no aeration. Water temperature was very high (30°C) at the surface of the lake, and 23.5°C at the deepest sampling point (a temperature difference of 6.5°C).

Aerated 10 hours/day from 8am to 6pm (10th January to 31st January 2023):

- At Day 115 and 129 of the trial (16th January and 30th January 2023), six days and twenty days respectively after switch-on of the replacement aerator and operation for 10 hours/day, weak surface stratification was still evident down to approximately 2m.

Aerator off (early February to 20th February)

- At Day 143 (13th February 2023) thermal stratification was observed down to 2m depth.

Aerated 24 hours/day (20th February to mid-April 2023):

- From Day 157 to the end of the trail at Day 200, the lake was generally well-mixed with slight thermal stratification down to 1m likely due to solar heating of surface layers during warm weather at this time (max air temp 29-33°C).

Temperature depth profiles collected over the phase 2 Aerator Trial have demonstrated that after two weeks of 24 hours/day operation, the aerator was effective at breaking down thermal stratification and maintaining destratification while in operation. The unexpected shutdowns of the aerator have demonstrated that stratification can redevelop quickly following aerator shutdown, particularly during hot, calm conditions.

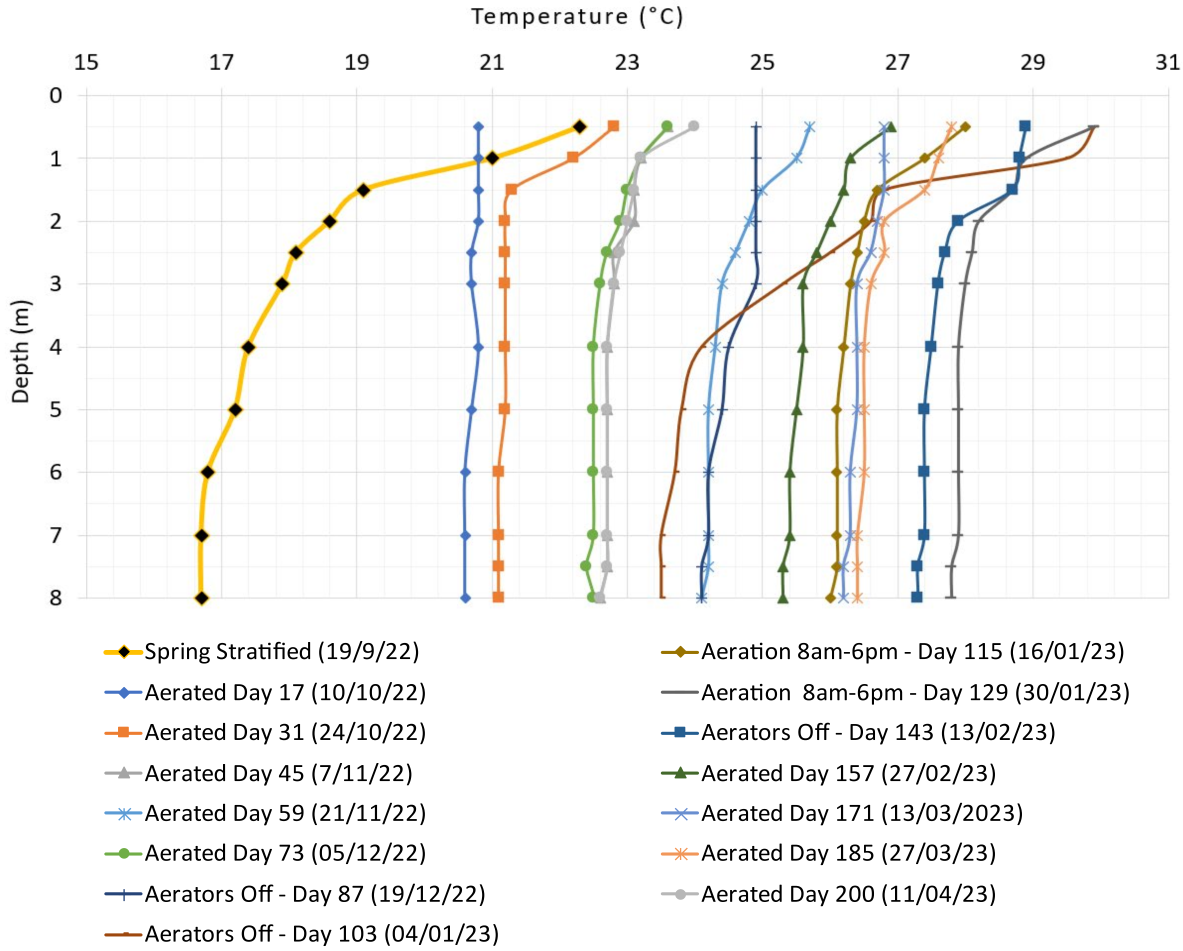

Figure 12: Temperature depth profiles

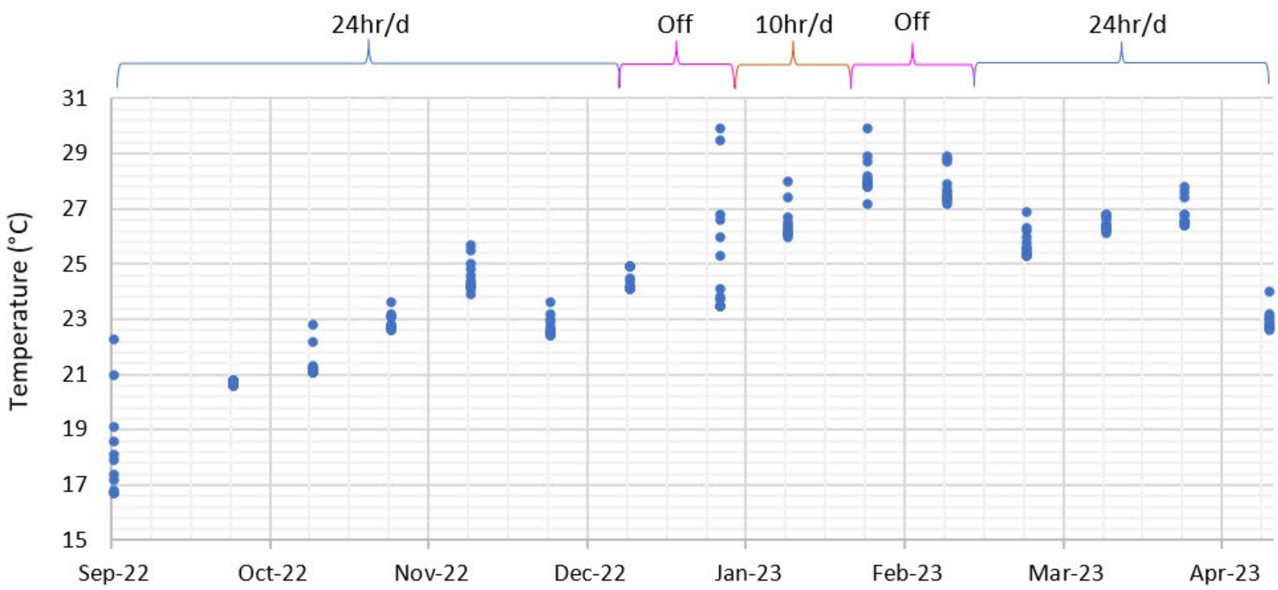

Figure 13: Temperature timeseries (all depths) showing aerator operation status.

3.5.2 Dissolved oxygen

Figure 14 shows depth profile dissolved oxygen data at all sites from September 2022 to April 2023. Figure 15 shows dissolved oxygen measured through time (all depths) showing aerator operation status. Key observations are discussed below.

Spring stratified conditions assessed on 19th September 2022 (pre-aeration):

- Corresponding with temperature results, lake dissolved oxygen levels were stratified when sampled on 19th September after the aerator had been non-operational throughout autumn and winter (approx. 7 months).
- Surface water was well oxygenated (80% saturation). Dissolved oxygen decreased with depth to low level (44% saturation) at the deepest point close to the sediment/water interface.

Aerated 24 hours/day (23rd September to mid-December 2022):

- The first post-aeration depth profile samples were taken approximately two weeks after the aerator was switched on. At this time the water column was well-mixed with a high dissolved oxygen levels throughout all depths and a weak surface stratification evident down to 1m (83.8% saturation at the surface and 76.1% saturation at 8m depth).
- The remaining samples from October to early December remained well-mixed with some weak surface stratification remaining in the top 1m of the lake.

Aerator off (mid – December 2022 to 10th January 2023):

- At Day 87 (19th December 2022) dissolved oxygen concentrations were beginning to decrease below 5m depth.
- The following sample two weeks later on the Day 103 (4th January 2023) showed that the lake was strongly stratified after approximately two-three weeks with no aeration. Dissolved oxygen concentrations were close to anoxic at 8m depth (3.3% saturation), while remaining high at the surface of the lake (87% saturation).

Aerated 10 hours/day from 8am to 6pm (10th January to 31st January 2023):

- At Days 115 and 129 of the trial, six days and twenty days respectively after switch-on of the replacement aerator and operation for 10 hours/day, dissolved oxygen levels had improved but remained lower than during the 24 hours/day aeration (ranging from 50 – 70% saturation). Weak surface stratification was also still evident down to approximately 2m.

Aerator off (early February to 20th February)

- At Day 143 (13th February 2023), following the second unexpected shutdown of the aerator, the lake was in a stratified state with dissolved oxygen concentrations very low at 8m depth (18.9% saturation), and moderate at the surface of the lake (64.2% saturation).

Aerated 24 hours/day (20th February to mid-April 2023):

- From Day 157 to the end of the trail at Day 200, the lake was generally well-mixed with slight stratification down to 2m. Dissolved oxygen close to the sediment/water interface remained above 55% saturation during all samples.

The current trial has demonstrated that the 24 hours/day aerator regime generally maintained destratification and higher levels of dissolved oxygen throughout the water column, and notably close to the sediment/water interface, compared to periods of non-aeration and 10 hours/day aeration. This was in line with results of the Phase 1 Aerator Trial and confirms the 24 hours/day aerator regime increases dissolved oxygen levels at depth within the lake.

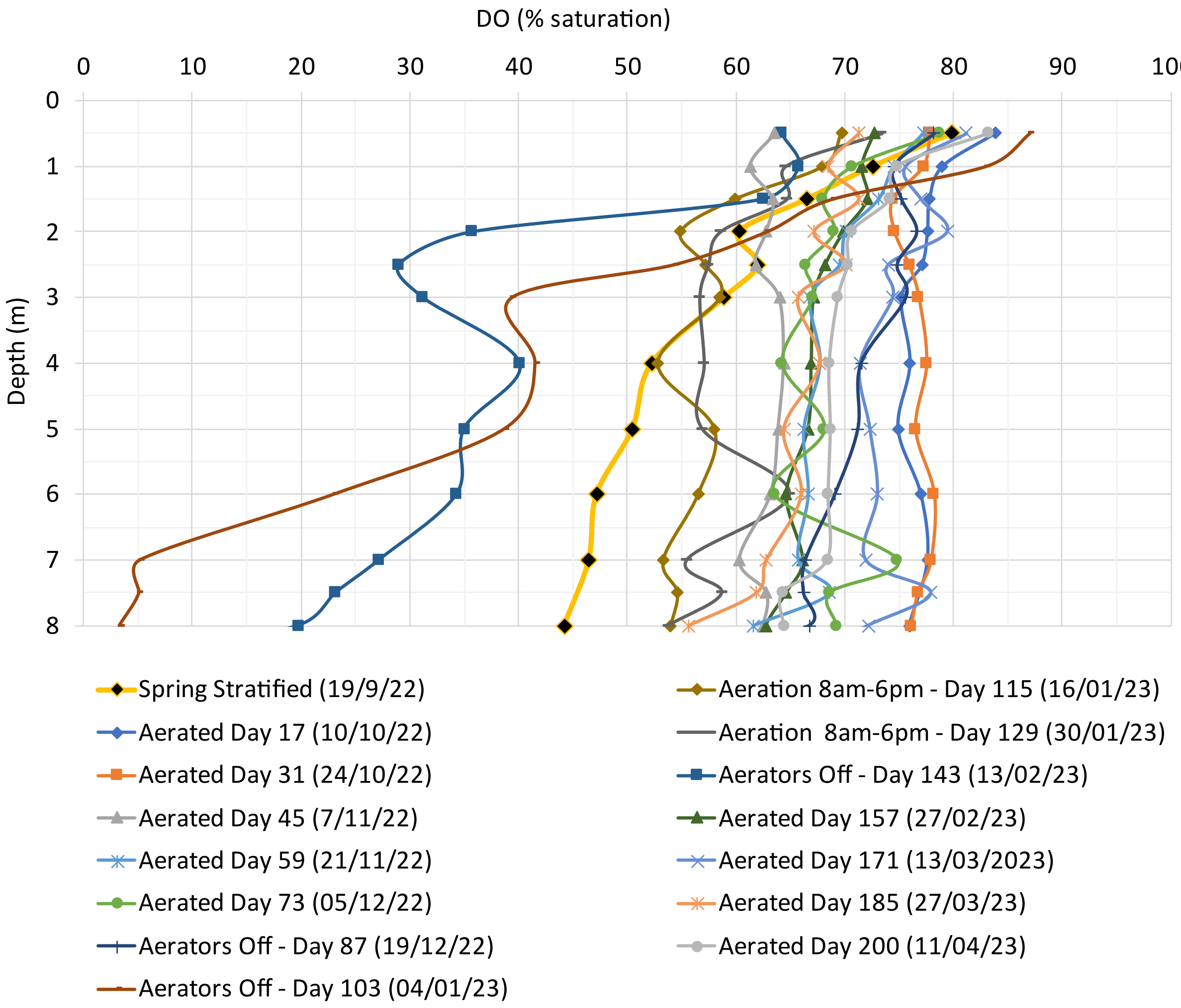

Figure 14: Dissolved oxygen depth profiles

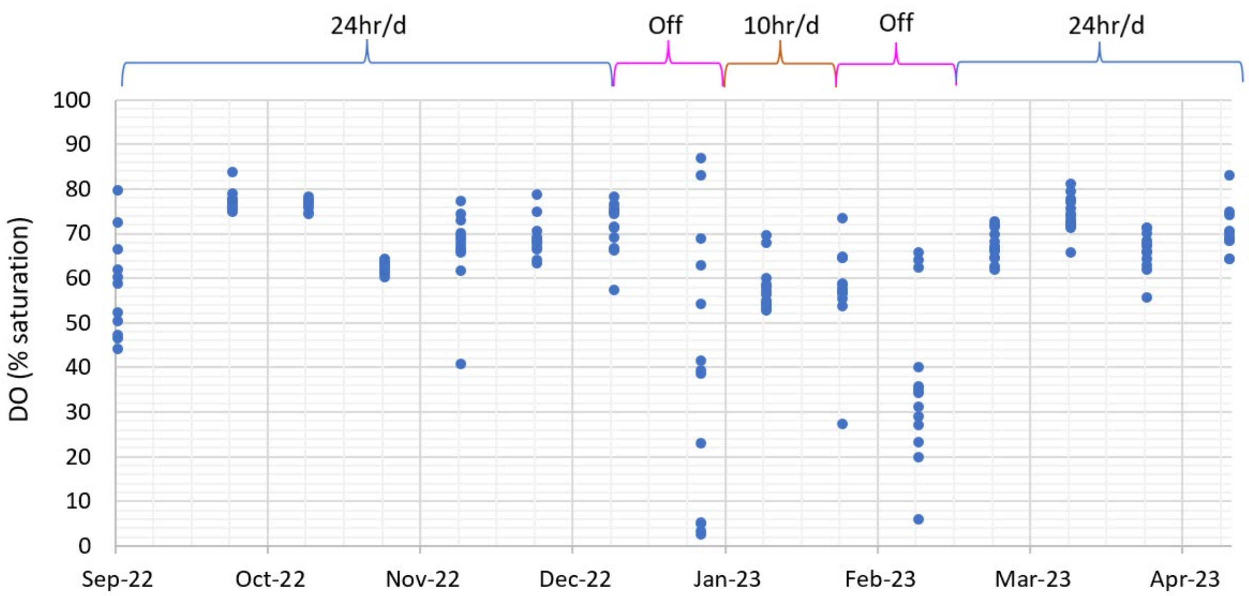

Figure 15: Dissolved oxygen timeseries (all depths) showing aerator operation status.

3.5.3 Phosphorus

Figure 16 and Figure 18 show depth profile dissolved phosphorus (PO_4) and total phosphorus (TP) data at all sites from September 2022 to April 2023. Figure 17 and Figure 19 show PO_4 and TP concentrations measured through time (all depths) showing aerator operation status.

Spring stratified conditions assessed on 19th September 2022 (pre-aeration):

- Phosphorus concentrations measured during stratified conditions in September were only slightly higher in benthic samples (0.143 mg/LTP and 0.124 mg/L PO_4) compared to surface layers (0.134 mg/LTP and 0.113 mg/L PO_4).

Aerated 24 hours/day (23rd September to mid-December 2022):

- At approximately two weeks after the aerator was switched on, phosphorus levels were well mixed through the water column.
- Phosphorus levels remained well mixed and fairly constant during 24 hours/day aeration from September to December 2022. PO_4 levels ranged from 0.105 - 0.124 mg/L during this time and TP levels ranged from 0.121 – 0.196 mg/L.

Aerator off (mid – December 2022 to 10th January 2023):

- On Day 103 (4th January 2023) phosphorus levels were elevated at the bottom of the lake after approximately two to three weeks with no aeration. Levels of both PO_4 and TP were over double the concentration at 8m depth than during the 24 hours/day aeration regime (at 0.217 and 0.299 mg/L respectively). As near anoxic conditions were observed at 8m depths, this increase in phosphorus is likely due to release of phosphorus from sediment under these conditions. This has been observed in the Phase 1 Aerator Trial and previous monitoring.
- Surface concentrations of PO_4, and to a lesser extent TP, decreased on Day 103 during stratified conditions. This is likely due to uptake of bioavailable phosphorus by rapidly multiplying algae as indicated by a spike in Chlorophyll *a* values on this day (refer Figure 23).

Aerated 10 hours/day from 8am to 6pm (10th January to 31st January 2023):

- At Days 115 and 129 of the trial, six days and twenty days respectively after switch-on of the replacement aerator and operation for 10 hours/day, phosphorus concentrations had decreased in bottom layers and were more consistent through the water column, although were slightly elevated compared to the 24 hours/day aeration period.

Aerator off (early February to 20th February)

- At Day 143 (13th February 2023), following the second unexpected shutdown of the aerator, the lake was in a stratified state and phosphorus levels were again elevated at the bottom of the lake and were also relatively high in the top 4m of the lake, compared to previous samples.
- The high phosphorus levels at the surface of the lake are likely to have fuelled the cyanobacteria blooms that occurred at this time and resulted in closure of the lake to swimming in the weeks of 14th February and 20th February 2023 (Figure 11).

Aerated 24 hours/day (20th February to mid-April 2023):

- Following recommencement of 24 hours/day aeration, phosphorus levels reduced and were generally consistent through the water column. This is likely due to both the effect of aeration reducing phosphorus release from sediments and mixing of nutrient rich hypolimnion with the epilimnion having a dilution effect and reducing overall phosphorus concentrations.
- By the final sample in April 2023, TP and PO_4 were well-mixed through the water column. PO_4 surface concentrations were lower than during non-aerated conditions in Spring 2022 (0.111mg/L).

The current trial has demonstrated that the 24 hours/day aerator regime generally maintained destratification and prevented the release of phosphorus from benthic sediments. When aeration ceases, phosphorus (primarily in the bioavailable form PO_4) is released from sediments and can fuel blooms of cyanobacteria in the lake.

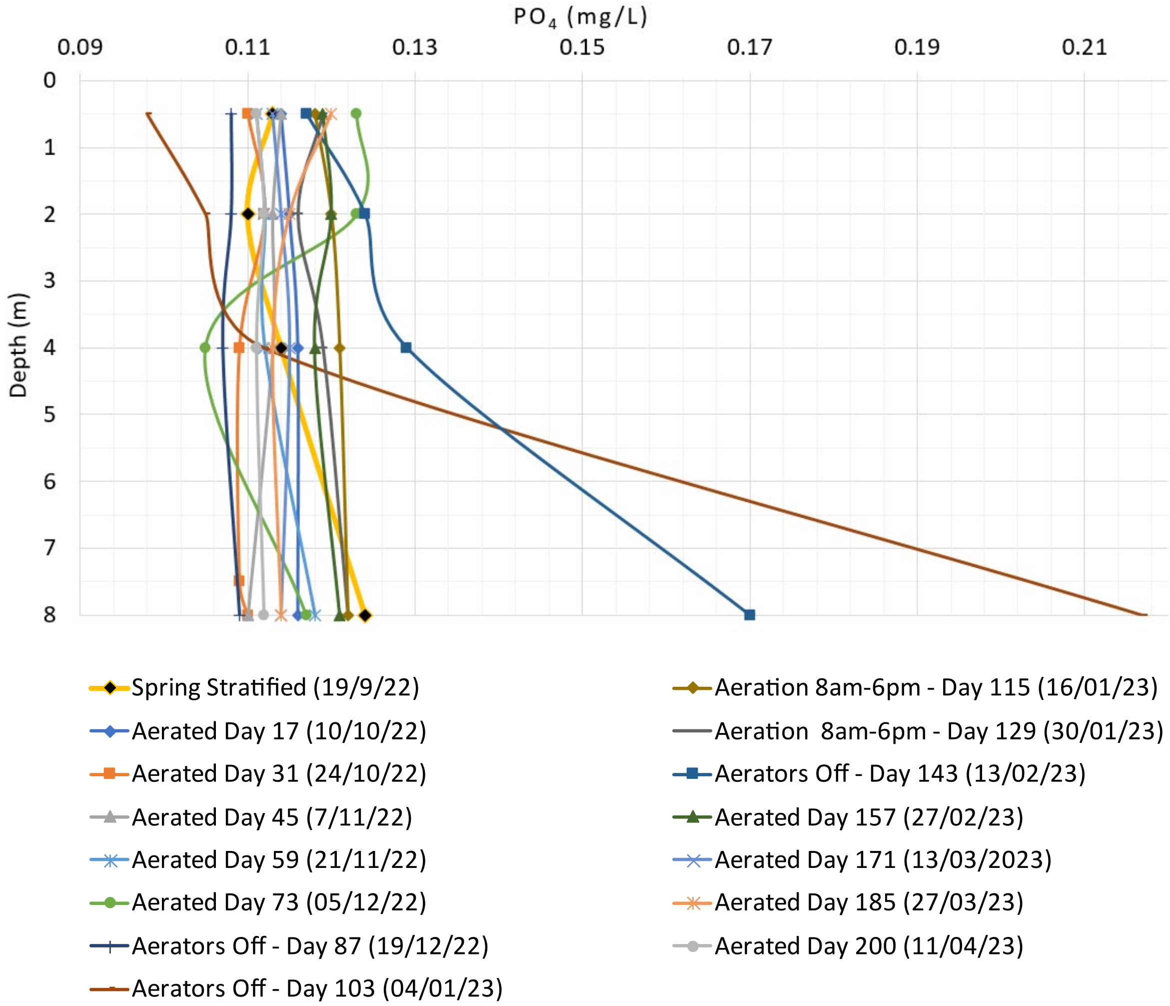

Figure 16: Phosphate (PO_4) depth profiles

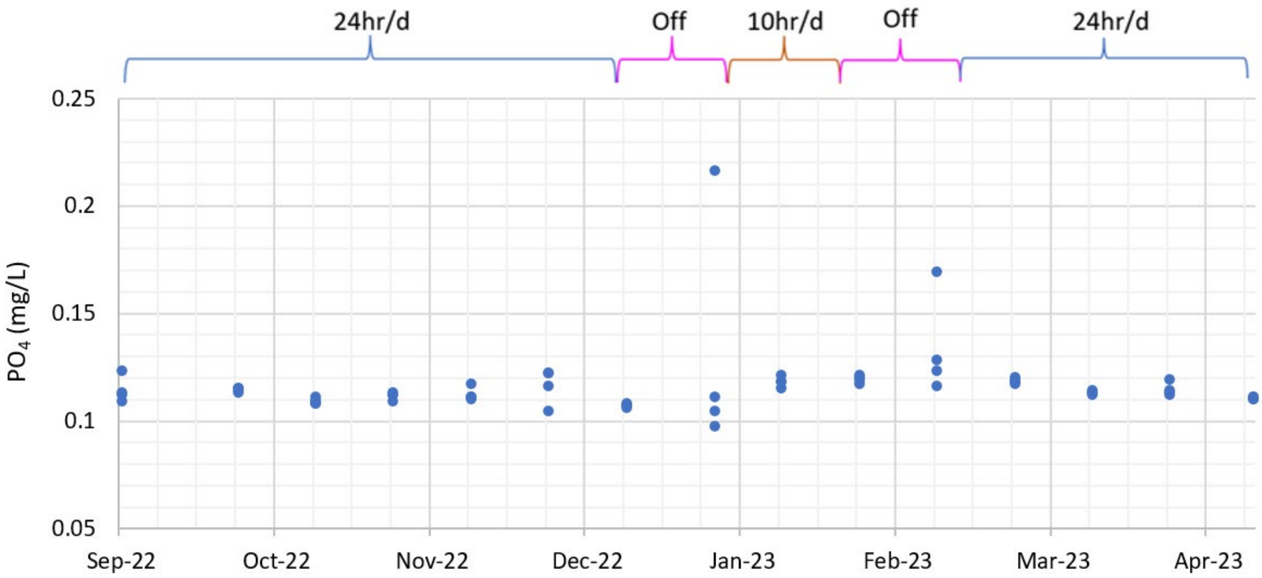

Figure 17: Phosphate timeseries (all depths) showing aerator operation status.

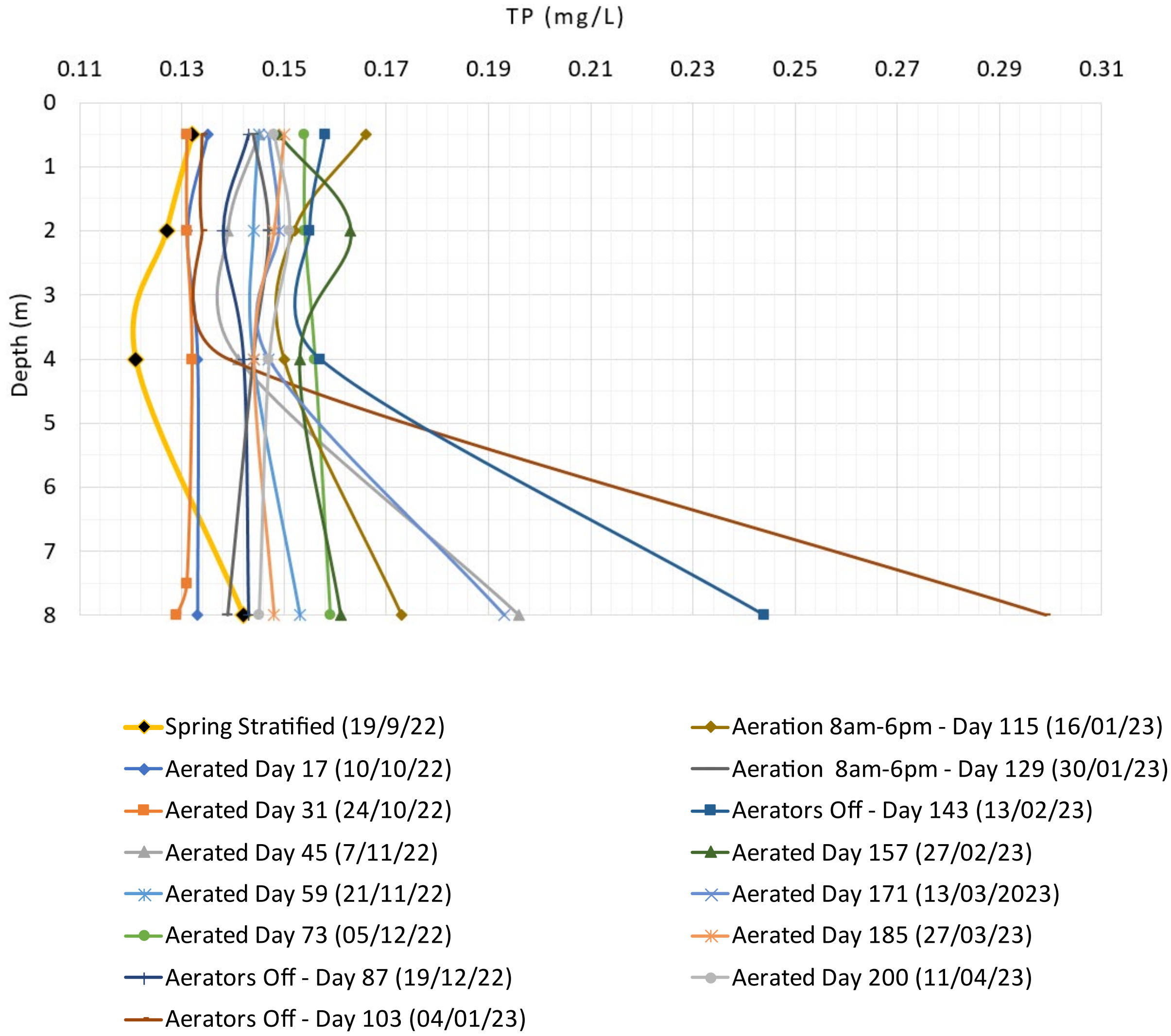

Figure 18: Total Phosphorus depth profiles

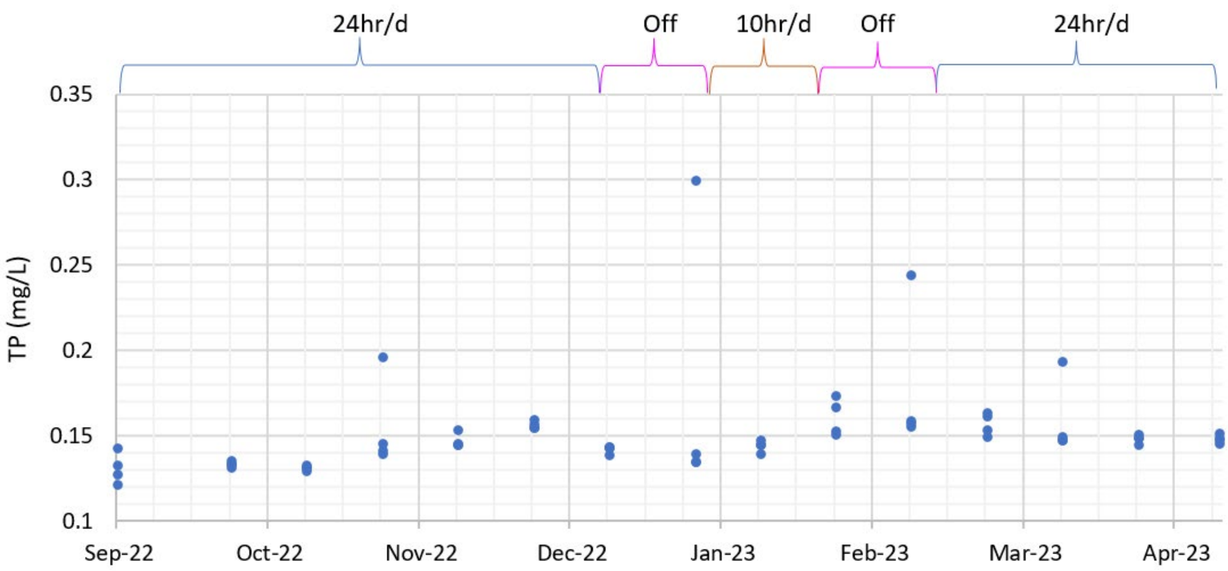

Figure 19: Total Phosphorus timeseries (all depths) showing aerator operation status.

3.5.4 Nitrogen

Figure 20 shows depth profiles for TN, TKN, NO_x and NH_4 data at all sites from September 2022 to April 2023. Figure 21 shows TN measured through time (all depths) showing aerator operation status. Key observations are discussed below.

Spring stratified conditions assessed on 19th September 2022 (pre-aeration):

- Nitrogen concentrations were indicating only a slight level of stratification with TN, TKN, NO_x and NH_4 concentrations all only slightly higher in benthic samples compared surface layers.
- Organic forms of nitrogen were dominant, comprising approximately 80% of TN in benthic samples. NH_4 comprised approximately 15% of TN and oxidised forms of nitrogen (NO_x) were comparatively low making up the remaining 5% of TN in benthic samples.

Aerated 24 hours/day (23rd September to mid-December 2022):

- At approximately two weeks after the aerator was switched on, nitrogen levels were generally well mixed through the water column.
- Nitrogen levels remained well mixed and fairly constant during 24 hours/day aeration from September to December 2022. TN levels ranged from 0.6 - 0.7 mg/L during this time with the exception of one high result at 8m depth on 7th November 2022 (1.194 mg/L) which comprised almost 90% organic nitrogen. It is unclear what caused this isolated spike in nitrogen, but as the sample location is close to the sediment/water interface, it is possible that bottom sediments and organic matter could have been disturbed during sampling on this occasion.

Aerator off (mid – December 2022 to 10th January 2023):

- On Day 103 (4th January 2023) nitrogen levels were elevated at the bottom of the lake after approximately two-three weeks with no aeration. Organic nitrogen remained dominant (making up 66% of TN), but NH_4 had increased to 31% of TN. The near-anoxic conditions observed at 8m depths, is likely to have favoured the release of NH_4 from sediment under these conditions. This was also observed in the Phase 1 Aerator Trial.

Aerated 10 hours/day from 8am to 6pm (10th January to 31st January 2023):

- At Days 115 and 129 of the trial, six days and twenty days respectively after switch-on of the replacement aerator and operation for 10 hours/day, nitrogen concentrations had decreased in bottom layers and were more consistent through the water column, although were slightly elevated compared to the 24 hours/day aeration period.

Aerator off (early February to 20th February)

- At Day 143 (13th February 2023), following the second unexpected shutdown of the aerator, the lake was in a stratified state and nitrogen levels were again elevated at the bottom of the lake.

Aerated 24 hours/day (20th February to mid-April 2023):

- Following recommencement of 24 hours/day aeration, nitrogen levels reduced and were generally consistent through the water column.

- By the final sample in April 2023, nitrogen was well-mixed through the water column. Oxidised forms of nitrogen (NOx, 0.036 mg/L) surface concentrations were slightly lower than during non-aerated conditions in Spring 2022 (0.04mg/L).

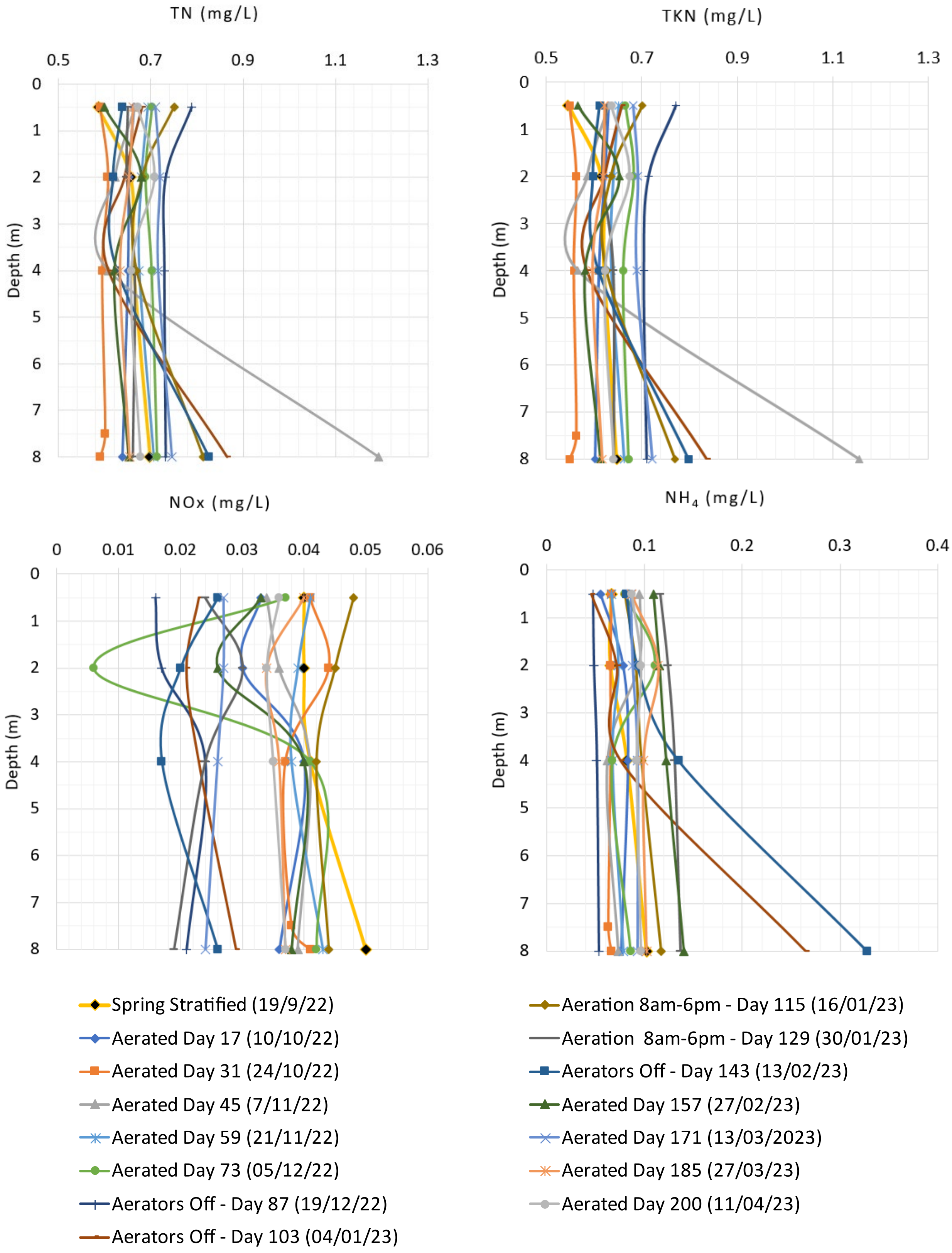

Figure 20: TN, TKN, NOx and NH_4 depth profiles.

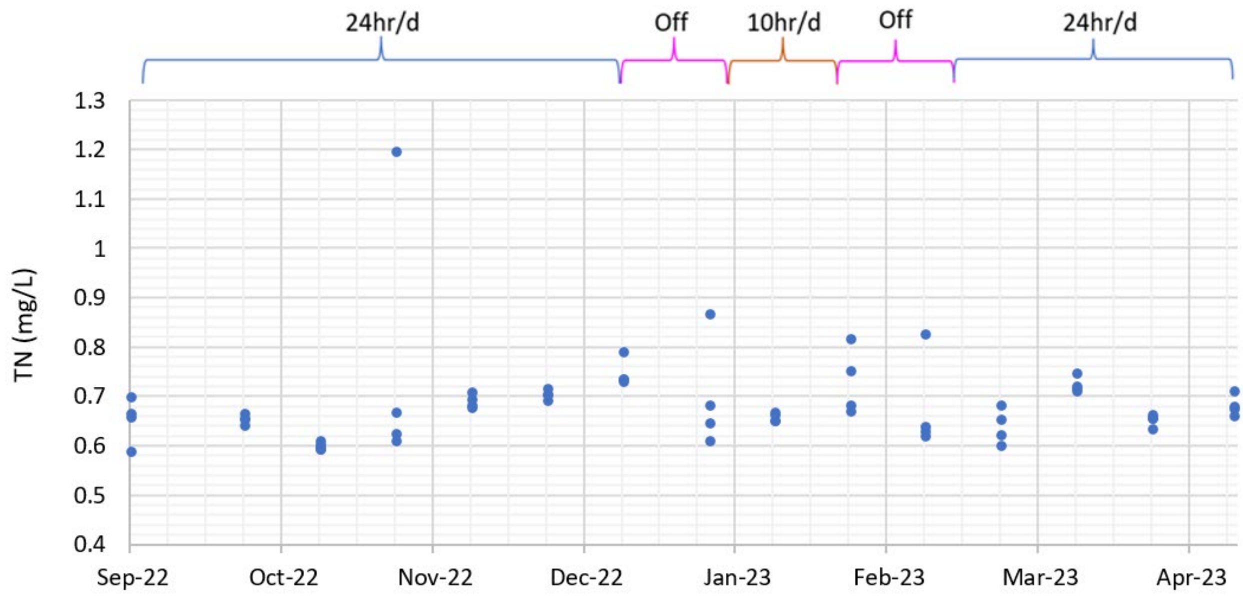

Figure 21: Total nitrogen timeseries (all depths) showing aerator operation status.

3.5.5 Chlorophyll *a* and cyanobacteria

Figure 22 and Figure 23 show total cyanophyta and Chlorophyll *a* surface concentrations throughout the Phase 2 Aerator Trial respectively.

Spring stratified conditions assessed on 19th September 2022 (pre-aeration):

- Surface Chlorophyll *a* was at relatively low levels during spring stratified conditions. No cyanophyta cells were detected at this time.

Aerated 24 hours/day (23rd September to mid-December 2022):

- Levels of both Chlorophyll *a* and total cyanophyta remained relatively low during the 24 hours/day aeration period in September – December 2022. There was one higher value of total cyanophyta recorded on 5th December 2022 (5,200 cells/mL).

Aerator off (mid – December 2022 to 10th January 2023):

- On Day 87 and Day 103 (19th December 2022 and 4th January 2023 respectively) Chlorophyll *a* levels were elevated at the surface of the lake (73 µg/L). Total cyanophyta levels remained relatively low (<1000 cells/mL).

Aerated 10 hours/day from 8am to 6pm (10th January to 31st January 2023):

- Chlorophyll *a* levels decreased with start-up of the new aerator operating 10hrs /day but remained at higher levels than were observed during the 24 hours/day aerator regime in September to December 2022. Total cyanophyta levels remained relatively low (<1,400 cells/mL).

Aerator off (early February to 20th February):

- At Day 143 (13th February 2023), following the second unexpected shutdown of the aerator, the highest level of total cyanophyta was recorded (22,000 cells/mL) indicating a bloom of cyanobacteria. This was consistent with Ballina Council blue green algae monitoring which also detected high levels at this time and required closure of the lake to swimming (refer Figure 11). Chlorophyll a levels were also elevated (37 µg/L).

Aerated 24 hours/day (20th February to mid-April 2023):

- Following recommencement of 24 hours/day aeration, total cyanophyta levels reduced down to low levels for the remainder of the trial (<1,000 cells/mL).
- Chlorophyll *a* concentrations remained elevated compared to the initial period of 24 hours/day aeration in September to December 2022 and this corresponded to sustained higher surface temperatures at this time, compared to the initial Spring/Summer monitoring period.

The Phase 2 Aerator Trial was demonstrated that 24 hours/day aeration was effective at controlling levels of cyanobacteria and Chlorophyll *a* at the surface of the lake. Highest Chlorophyll *a* and total cyanophyta concentrations were experienced during periods of aerator shutdown.

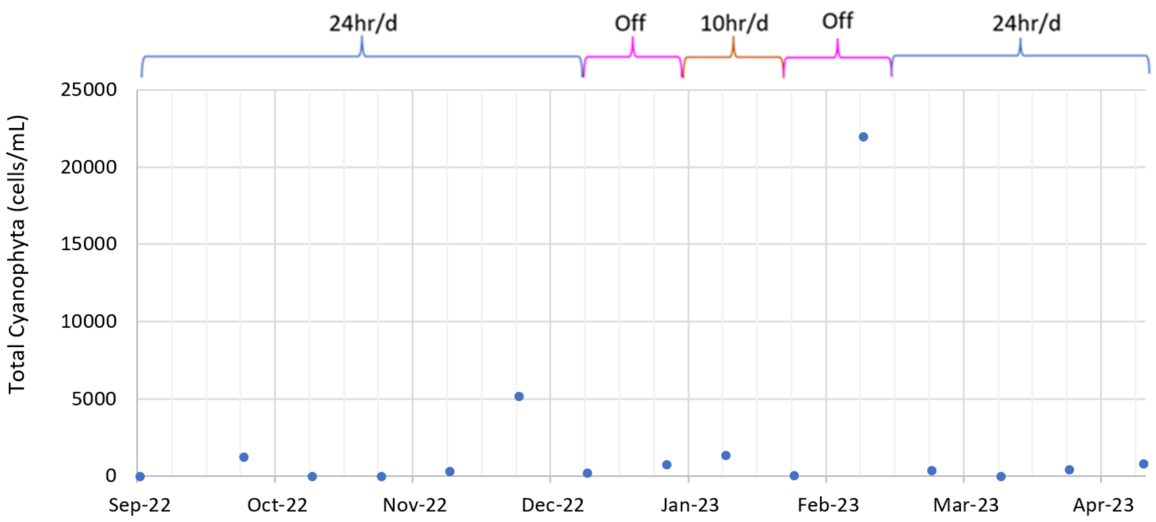

Figure 22: Total Cyanophyta surface concentrations throughout the Phase 2 Aerator Trial showing aerator operation status.

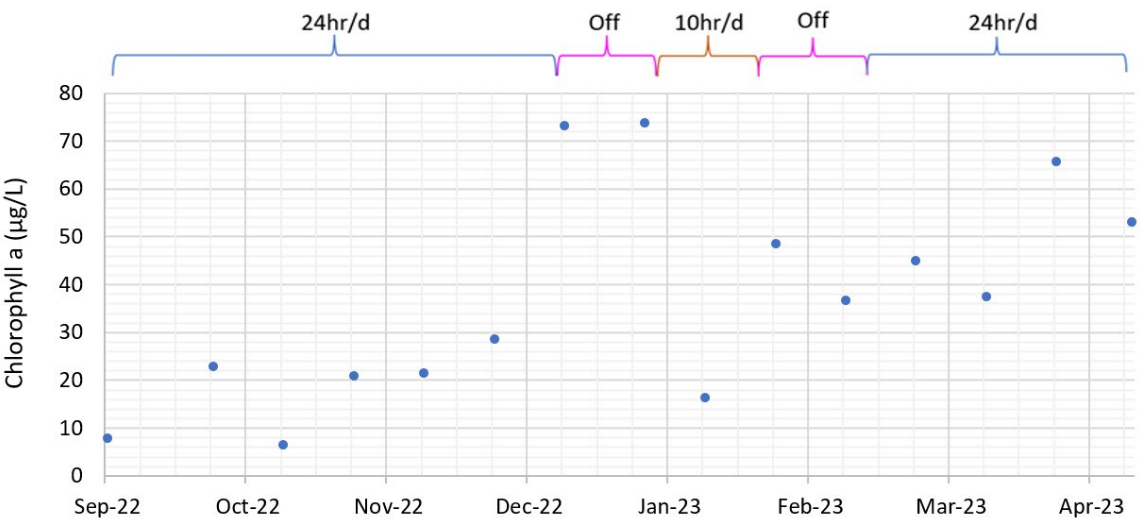

Figure 23: Chlorophyll *a* surface concentrations throughout the Phase 2 Aerator Trial showing aerator operation status.

4. CONCLUSIONS AND RECOMMENDATIONS

The Aerator Trial has demonstrated that a continuous 24 hours/day aerator regime maintained destratification and reduced the amount of nutrients within the water column (primarily the bioavailable form of phosphorus PO_4). When aeration ceased, due to equipment failure, phosphorus levels increased and blooms of cyanobacteria in the lake were observed leading to public health alerts being issued and closure of the lake to swimming.

It is considered that aeration and prevention of stratified conditions is a key factor in maintaining oxygenated conditions at the sediment-water interface and reducing the release of algae-stimulating nutrients (particularly PO_4) under anoxic conditions.

The importance of continuous aerator operation was demonstrated during both trial periods with the rapid re-development of stratification that occurred following the unexpected shutdowns of the aerator in both Phase 1 and Phase 2 of the trial. The Phase 1 Aerator Trial demonstrated it can take at least six days of 24 hours/day operation of the aerator to overcome stratified conditions and increase dissolved oxygen close to the sediment/water interface for the deepest parts of the lake. After the initial six-day mixing period, destratification was generally able to be maintained by the 24 hours/day aerator regime except in periods of low wind and/or high temperatures when weak stratification of the water column was apparent. The fact that partial stratification is able to redevelop under these conditions is not necessarily problematic if sufficient dissolved oxygen levels near the sediment/water interface can be maintained and subsequent phosphorus release from the sediments avoided. As such, it is important that a permanent reservoir of high dissolved oxygen water is maintained at the bottom of the lake such that the short-term effects of hot weather, low wind or equipment malfunction can be mitigated.

Because of the unexpected shutdown of the aerator on two occasions during the Phase 2 Aerator Trial, it was not possible to assess the 24 hours/day operation regime continuously throughout the seven-month trial period. However, the results are considered to be sufficient to demonstrate the effectiveness of the aerators in controlling blooms of cyanobacteria. The deteriorating water quality observed during shutdown periods have further confirmed the importance of aeration in controlling cyanobacteria blooms.

Considering the results of the Phase 1 and Phase 2 trials, recommendations are as follows:

- Due to the improvements in water quality observed with 24 hours/day operation of the aerator, it is considered appropriate to continue with this continuous aeration regime in the next swimming season.
- A few weeks after the conclusion of the Phase 2 Trial, a bloom of cyanobacteria was observed in the lake (4th May 2023), following the shutdown of the aerator. Given this result, it may also be prudent to extend the aeration period until the start of Winter (early June) when lake temperatures have dropped sufficiently to limit algal blooms. This would extend the aeration period from September to June (9 months), with a winter shutdown period during June, July and August.
- The reliability of the aerator system is paramount to prevent mid-season failures and subsequent blooms of cyanobacteria in the lake as was observed on several occasions during the Aerator Trial.
- The implications of running the aerator 24 hours/day for long periods from a mechanical point of view has not been determined by this study. Aerator running costs and energy consumption also have not been considered by the current study. It is recommended that Council confirm that equipment

specification is adequate for maintaining aerator functionality in the long term. In doing this, Council should consider not only the duty rating of the system, but also expected lifespan of wear items, seals, air lines, fittings etc. It is also recommended that an effective maintenance and inspection schedule is in place to ensure optimal performance and swift rectification of any issues as they arise.

- Considering the above, there may be additional motivation to optimise aerator operation to minimise costs or maximise equipment longevity. This could be completed as a Phase 3 Aerator Trial which tests the impact of turning off aerators for a short time during low-risk conditions to reduce energy consumption and strain on equipment. In this case, any potential mechanical implications of increased cycling on equipment should be considered. Further work would be required to confirm optimal low risk periods at the lake, but the following is provided as a preliminary guide:
    - Low risk conditions are considered to be when dissolved oxygen concentrations are at their highest and natural mixing due to wind is occurring. These conditions are most likely during mid to late afternoons when daily oxygen levels typically peak due to photosynthesis (whereby aquatic plants produce oxygen) and wind speeds are also typically higher.
    - Night and early mornings are likely to be calmer periods when wind-induced mixing is typically lower. Additionally, respiration (oxygen consumption) by aquatic organisms, without the balance of oxygen-producing photosynthesis will typically lead to depressed dissolved oxygen at night. For these reasons aerator shutdown from approximately 8pm – 8am should be avoided.

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