Evaluation of management options for City of Gold Coast lakes and focus on effectiveness of a Phoslock^{TM} trial and other algal bloom mitigation options for Lake Hugh Muntz

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June 2019

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Report citation

Frassl MA, Hamilton DP, Burford, MA. 2018. Evaluation of management options for City of Gold Coast lakes and focus on effectiveness of a Phoslock^{TM} trial and other algal bloom mitigation options for Lake Hugh Muntz. ARI Report No. 2019/0004 to Gold Coast City Council. Australian Rivers Institute, Griffith University, Brisbane.

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Executive summary

In response to blooms of the toxic blue-green alga, *Chrysosporum ovalisporum* in Lake Hugh Muntz, and after a review of possible management options by Griffith University, the City of the Gold Coast (City) undertook a whole-lake trial with the commercial clay-modified product, Phoslock™. The aim was to reduce the nutrient (= food) supply, i.e. phosphorus, for this species and any other blue-green algae that could potentially cause blooms. This report examines the effectiveness of this trial, and looks at four options for assessing future trials to manage blooms using a lake model.

Examination of City monitoring data from before and after the Phoslock™ trial showed overall that there was little evidence of a reduction in phosphorus levels in this system. While the duration of the bloom of *Chrysosporum* was less than the previous year, it is impossible to conclude whether this change was a response to Phoslock™. The lack of effectiveness of the trial could have been due to:

1) akinetes (= resting spores that are formed by *Chrysosporum* periodically) germinated from the bottom sediments to support the rapid growth and ultimate bloom formation by *Chrysosporum*

2) the *Chrysosporum* filaments were not flocculated to any great extent by the Phoslock™ and may have benefited from increased light once the water clarity improved following the Phoslock™ application

3) the *Chrysosporum* had sufficient stores of phosphorus within the cells such that a short term reduction in phosphorus following the Phoslock™ application did not affect them.

In terms of potential next steps for managing the blooms, a lake model was used to simulate how different management options would affect the bloom. It was validated with existing monitoring data for LHM. After consultation with the City and the Griffith University review of algal bloom mitigation strategies (Burford et al. 2018), four scenarios were shortlisted to be further analysed to assess the effectiveness of reducing algal blooms in Lake Hugh Muntz. This work will enable a future multi criteria analysis to be completed by the City to determine the feasibility, environmental, social considerations and associated costings prior to progressing a whole of lake trial or application.

It should be noted that hydrogen peroxide has not been selected as a management option as it is not approved for use as an algaecide in environmental waters. The four scenarios selected are outlined below:

1) aeration with bubble plumes to mix the water column (150 L/s)
2) Use of Phoslock™ and sand capping to reduce phosphorus release from bottom sediments to 30% of base case
3) Use of Phoslock™ to reduce phosphorus release from bottom sediments to 60% of base case
4) all three options in tandem, where the Phoslock™ would be applied to mop up residual phosphorus from the water column and any that persisted in the sediment layer after capping.

The effect of these management options on salinity, oxygen levels and *Chrysosporum* blooms was simulated using the mathematical model and compared with doing nothing, i.e. base case simulations.

The key findings were:

- Of the four scenarios tested, aeration with bubble plumes was the most effective strategy for increasing salinity and oxygen levels
- However, aeration did not consistently reduce *Chrysosporum* blooms across the simulation period. This may be because aeration mixes bottom nutrients into surface waters, which would enhance blooms despite more mixing of the water column.
- Sand capping and application of Phoslock™ did not reduce *Chrysosporum* blooms in the early stages of the simulation, i.e. 1.5 years. However, later in the simulation, it appears that these strategies started to impact on *Chrysosporum* blooms. This simulation requires further data to substantiate (allowing longer simulation times).

Based on this study, we have a number of recommendations, however the City will need to determine, through a multi criteria analysis, the feasibility and costings of progressing any of these recommendations prior to a whole of lake trial or application. It appears that, if the scenarios tested, the use of sand capping and application of Phoslock™ has the greatest potential to reduce *Chrysosporum* blooms. We would propose that sand capping be undertaken first, then assessed, and based on the effectiveness of capping, Phoslock™ could be applied to remove additional phosphorus. However, prior to incurring the additional effort and expense of implementing a full-scale in-lake remediation measure, there is additional data needed to substantiate the model findings. This includes:

1) Test the effect of salinity in limiting or preventing growth and bloom formation of *Chrysosporum.* Salinity testing will tell us whether there are benefits in aeration to mix higher salinity water into surface water and hinder or kill the *Chrysosporum*. Additionally, determine the phosphorus storage capacity of *Chrysosporum* to evaluate how much reduction in phosphorus is needed via capping and Phoslock™ application to control the *Chrysosporum* blooms.

2) Undertake small scale experiments with sediment cores and sand application (5-10 cm bottom layer) to observe the response of the bottom sediments to the applied sand layer. This will test whether sand will sink below the sediment.

3) Model predictions would be improved through better knowledge of the volume and composition of inflows, i.e., the saline groundwater intrusion and the stormwater inflows.

4) Carry out additional Phoslock™ experiments to ascertain its effectiveness at different salinities, at different dosages, and effect on flocculating *Chrysosporum* filaments.

There are still large uncertainties in the amount of surface (stormwater) and groundwater inputs (saline intrusions) into the lake and the nutrient concentrations associated with these inputs. The implementation of groundwater monitoring by City (5 groundwater bores around lake) is a positive step towards gathering data for calibrating the model. Reducing these uncertainties is important to identify how to optimise the effectiveness of treatment options.

Background

Lake Hugh Muntz (LHM) has experienced a major bloom of the cyanobacterium (= blue-green alga), *Chrysosporum ovalisporum,* commencing in 2017 and persisting through winter 2018 and into 2019. This species occurs around the world and often produces toxins that can affect humans and other animals. Blooms occur when nutrients are present in excess amounts and when there are suitable light, temperature and mixing conditions. The bloom in LHM appears to have increased in recent times based on measurements at four stations across the lake (Fig. 1).

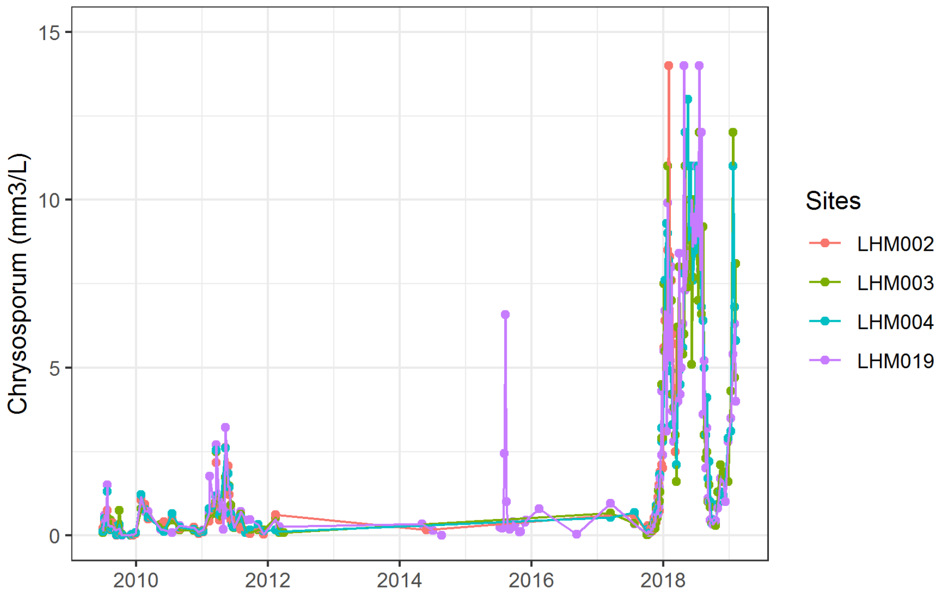

Figure 1: Biomass (= biovolume in mm^3/L) of the blue-green alga Chrysosporum ovalisporum *at the surface of LHM, 2009 to 2019.*

In the case of LHM, nutrients come into the system from stormwater runoff, via a series of discharge pipes. These nutrients have been accumulating in the lake for many years (e.g., total nitrogen concentrations shown in Figure 2). There are limited options to substantially reduce the nutrients coming in from the stormwater, and even if this could be done, there is still an accumulation of nutrients on the bottom sediment and in the bottom waters.

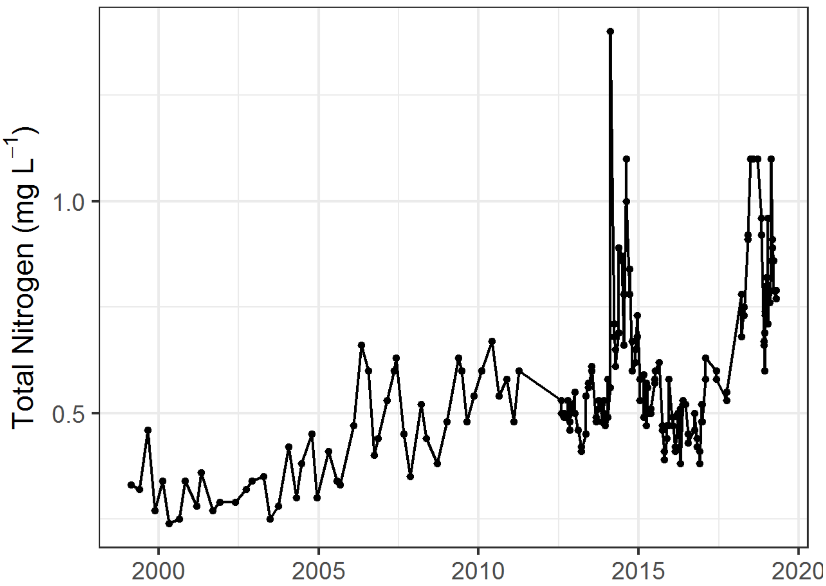

Figure 2: Total nitrogen concentrations (mg/L) at the surface of LHM, 1999 to 2019.

In order to reduce the blooms it is necessary to consider within-lake options. As outlined in the Burford et al. (2018) report to the City, there is a wide array of options to manage the blooms. Our 2018 report summarised these options and identified those most likely to be effective in LHM.

2018 Phoslock™ trial

In December 2018, the City approved the application of a commercial clay product, Phoslock™ to the lake. This product has been useful in reducing algal blooms in a range of lakes and ponds around the world by binding up the phosphorus which makes the blue-green algae (and other algae) grow. It can also trap the algae (flocculation) and they then sink to the bottom. Griffith University researchers were asked to assess the effectiveness of the trial and suggest additional management options.

Based on measurements of total phosphorus undertaken by the City (see example data in Figure 3), it is not clear that Phoslock™ application had a substantial effect. There may be an indication that some of the phosphorus was stripped from the surface waters (e.g., 0.3 m) and possibly from mid depth (e.g., 6 m), but it probably accumulated temporarily at the bottom depth (12 m). We suspect that the large increase in total phosphorus at 11 m on 31

Dec 2018 may be related to the accumulation of phosphorus that had flocculated out from the upper water column (Figure 3).

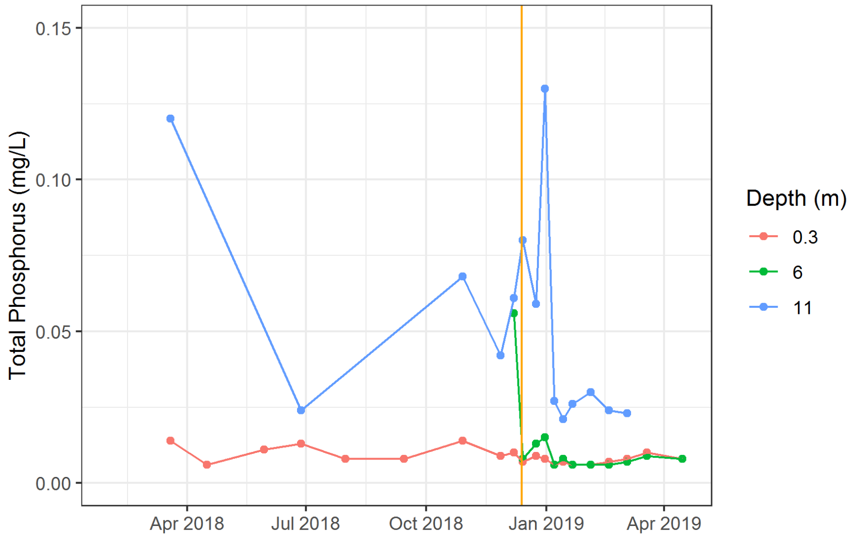

Figure 3: Total phosphorus concentrations (mg/L) at three depths in LHM (0.3, 6 and 11 m), before and after the Phoslock™ application, denoted by the vertical orange line. Note different measurement frequencies for the three depths and only one measurement at 6 m before the application.

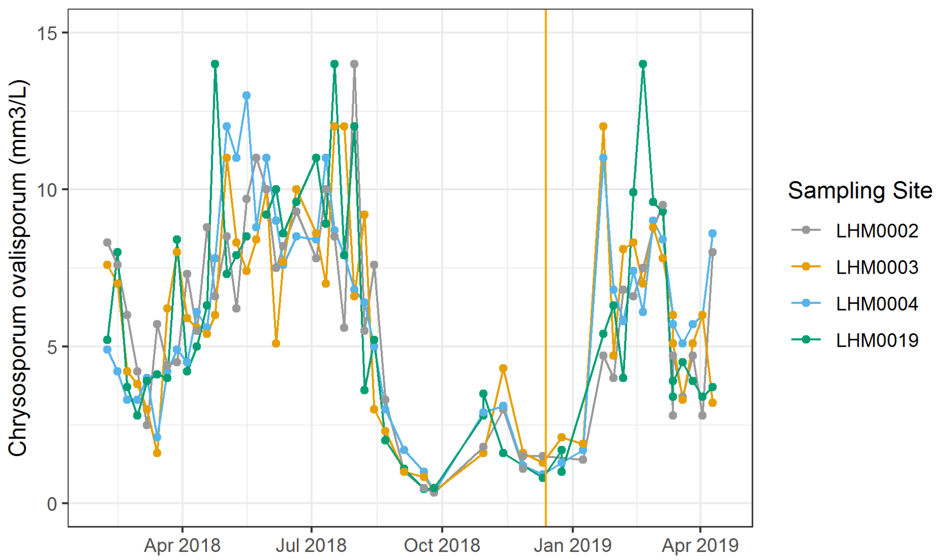

Figure 4: Biomass (= biovolume in mm³/L) of the blue-green alga Chrysosporum ovalisporum *at the surface of LHM, February 2018 to April 2019.*

The Phoslock^{TM} application did not have any obvious effect in reducing the magnitude of the *Chrysosporum* bloom. The bloom was less sustained than the previous year but it is unclear if this is due to the Phoslock^{TM} application. The lack of effectiveness of Phoslock^{TM} may be due to the following:

1) akinetes (= resting spores that are formed by *Chrysosporum* periodically) germinated from the bottom sediments to support the rapid growth and ultimate bloom formation by *Chrysosporum*

2) the *Chrysosporum* filaments were not flocculated to any great extent by the Phoslock^{TM} and may have benefited from increased light once the water clarity improved following the Phoslock^{TM} application

3) the *Chrysosporum* had sufficient stores of phosphorus within the cells such that a short term reduction in phosphorus following the Phoslock^{TM} application did not affect the *Chrysosporum* to any great extent.

An automated water quality profiler (= vertical profiler) positioned within the lake provided valuable data for us to better assess how lake measures, such as temperature and salinity, change over time and through the water column. The data from this profiler has previously been reported on in the LHM update in April 2019. The profiler was useful in showing that there is a lower layer of salty water in the deep section of the lake below about 4 metres (see example in Figure 5) separated from an upper fresh to brackish (slightly salty) water layer above. This may be the result of tidal exchange of subsurface saline water into LHM with an adjacent canal through the land berm between these systems. Evidence for this is the regular spikes in salinity in bottom waters in the lake (Figure 5).

There is also a lot of hydrogen sulphide in the lower water layer, which produces a ‘rotten egg gas’ smell if it is brought to the surface, and this layer is also devoid of oxygen as see in the profiler data (Figure 6). All of these aspects of the lake put some limitations on the management options, e.g., if the lake was suddenly mixed through aerators then there may be a possibility of asphyxia or hydrogen sulphide poisoning of fish in the surface water layer.

There will also be rotten egg smell experienced lakeside. By contrast to Figure 6, in a ‘healthy lake’ we would expect to see a more even distribution of oxygen through the water column with levels approaching 100% of saturation.

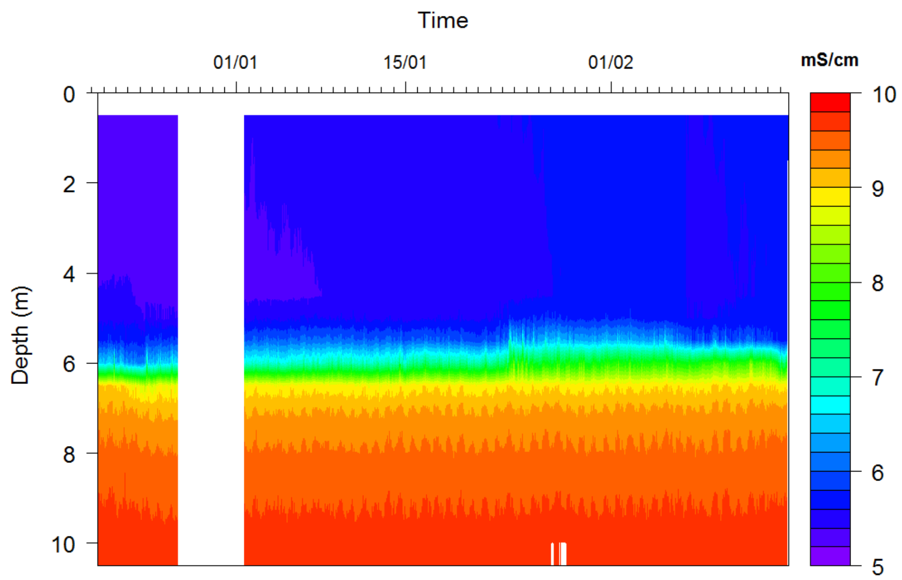

Figure 5: Salinity, measured as conductivity, profile in the central deep section of the lake showing the saltier water (orange/red) underneath a fresh water layer (blue-purple). The vertical break is when no measurements were taken. Note the spikes of conductivity deep in the lake, which is likely due to subsurface tidal exchanges through the sand barrier separating the lake from the canal.

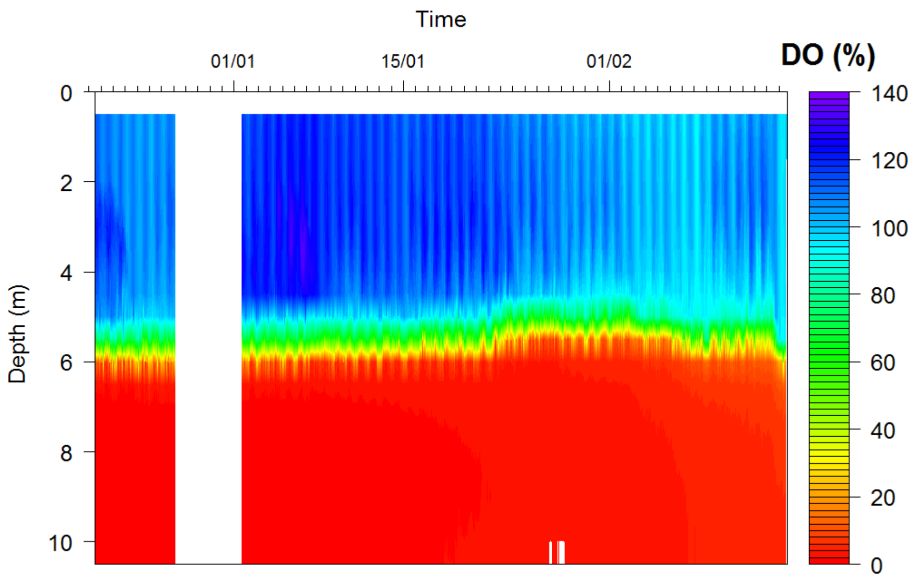

Figure 6: Oxygen saturation profile in the central deep section of the lake showing the oxygen depletion in the bottom waters (red) underneath the well aerated surface waters (blue-purple). The vertical break is when no measurements were taken.

Modelling

Mathematical models have been developed for lakes to provide a means to predict the effectiveness of lake management options. These models require considerable input data which includes information on climate, inflows and outflows. Predictions from the models can be improved by additional data related to in-lake water quality measurements and trials, as well as experiments in the laboratory. The value of the model for providing insights into lake management options can be improved as more data and experimental results become available.

The model that we applied here has been described in our previous report (Burford et al., 2018) and has been updated for an additional nine months beyond June 2018. We therefore focus here on the description of particular results of interest. An example of the model simulation for dissolved oxygen profiles is given in Figure 7 to indicate the close match between measurements and simulations. These results also hold for other physical measures such as salinity and water temperature. However, the model was less accurate in predicting the *Chrysosporum* cell counts (Figure 8). We call this prolonged simulation the **base case simulation**.

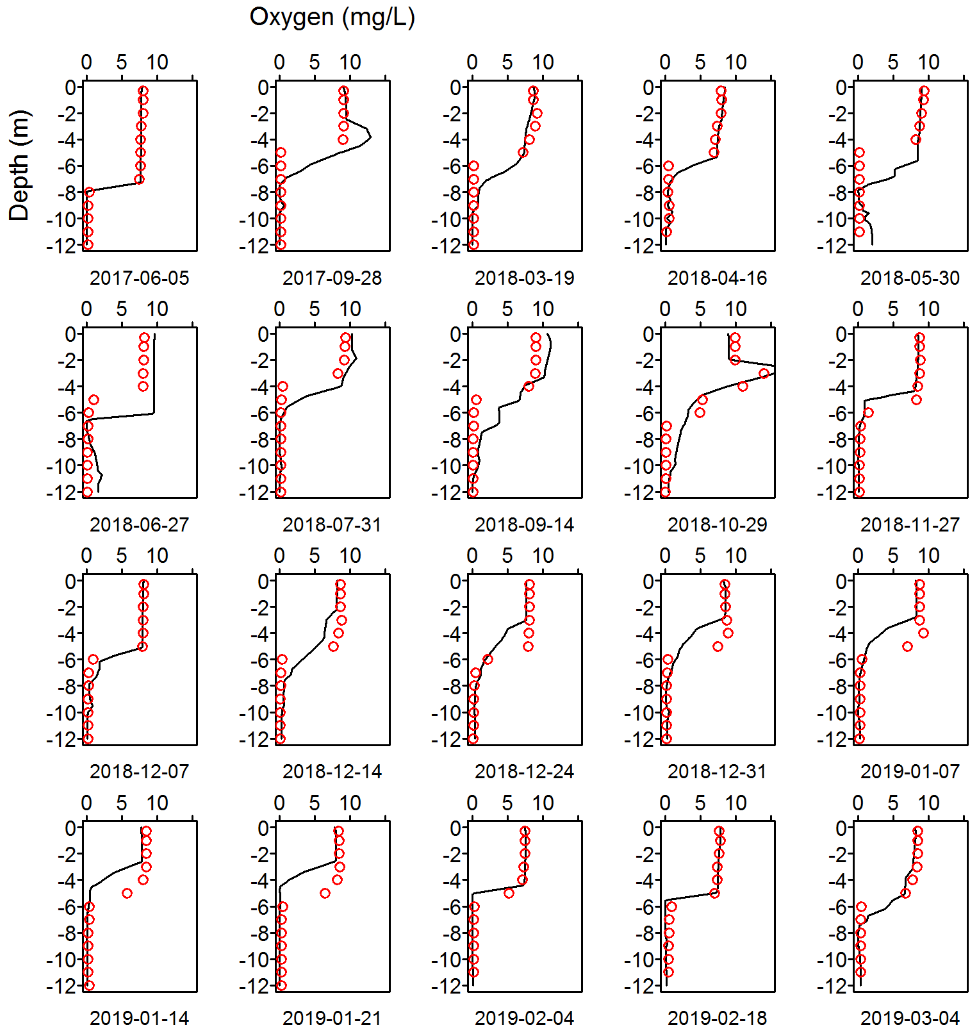

Figure 7: Dissolved oxygen levels at the central deep site in LHM (maximum depth 12 m) from 5 June 2017 to 4 March 2019. The red dots are measurements taken at 1-m intervals, and the black line is the model simulation over the full water column profile.

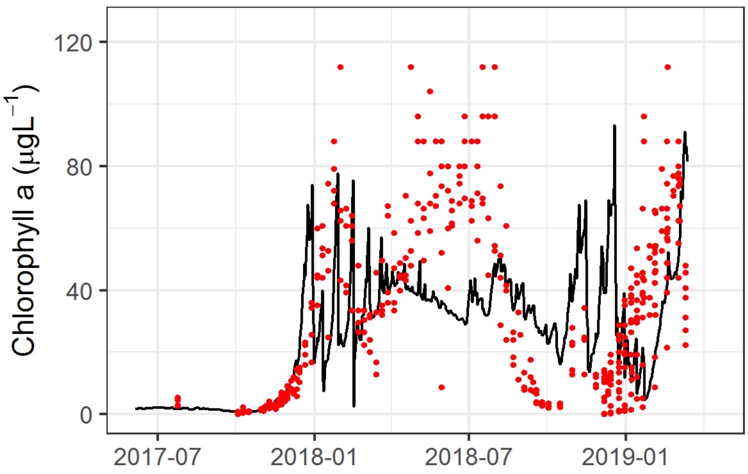

Figure 8: The blue-green algae Chrysosporum ovalisporum, *measured as chlorophyll* a *(µg/L) at the surface of LHM, June 2017 to March 2019. The red dots are measurements taken at the surface and the black line is the model simulation.*

The simulation showed the increase in late 2017 and captured most of the summer blooms, but does somewhat more poorly in capturing the extended bloom in winter 2018. These observations of winter blooms occur for some species, and may be linked to processes or data inputs that may not have been represented well in the model.

A range of management options was identified after consultation with the City and a review of the Burford et al. (2018) report which reviewed over twenty algal management strategies used globally. Four potential options were chosen to determine their effect on salinity, dissolved oxygen levels and *Chrysosporum* blooms and enable a future multi criteria analysis to be completed by the City. These included:

1) aeration with bubble plumes to mix the water column

3) a sand capping of the bottom sediments plus further application of Phoslock^{TM} to reduce phosphorus release by sediments to 30% of base case release

2) further application of Phoslock^{TM} to reduce phosphorus release by sediments to 60% of base case release

4) all three options in tandem, where the Phoslock™ would be applied to mop up residual phosphorus from the water column and any that persisted in the sediment layer after capping.

The choice of two phosphorus release proportions (30 and 60%) for the simulations was due to the uncertainties of specific sediment response to capping and Phoslock™. Because of uncertainties in the response of the sediments to capping, we used two simulations with different sediment properties, i.e. capping to 30% of currrent release rates, and capping to 60% of release of phosphorus.

Scenario simulations

Effect on salinity

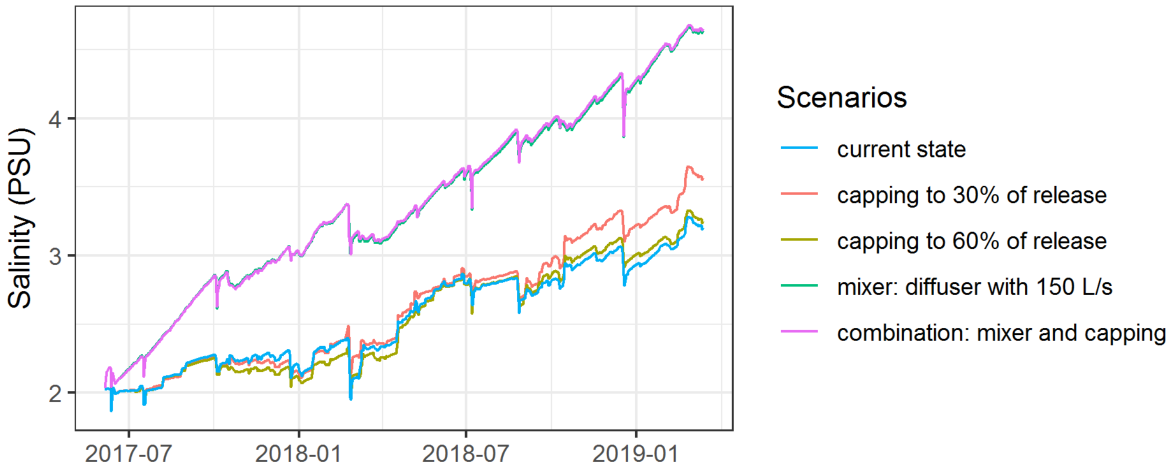

Figure 9: Salinity at the surface of LHM from June 2017 to March 2019 for the different lake management scenarios. The blue line is the base case, that is the lake as it is, the capping to 60% of release refers to a Phoslock™ application, capping to 30% of release refers to Phoslock™ plus sand, and the green line is a simulation with an aerator installed that mixes the water column. The pink lines simulates all three options in tandem.

The model was used to simulate what would have happened to salinity in the last few years if the management options outlined above had been undertaken. As expected, the only major change in salinity in any of the simulations compared to our base case simulation, i.e., no management applied, was 1) aeration, which mixed high salinity water from the bottom waters into the surface water (Figure 9). Salinity would be about 50% higher in the aeration case. However, we have preliminary information from laboratory experiments that this salinity would not be sufficient to limit the bloom of *Chrysosporum,* i.e. we found that growth did not slow at 50% seawater (A. Chuang, *pers. comm.*). The management option 4) combination of mixer and capping, was no more effective.

Effect on dissolved oxygen

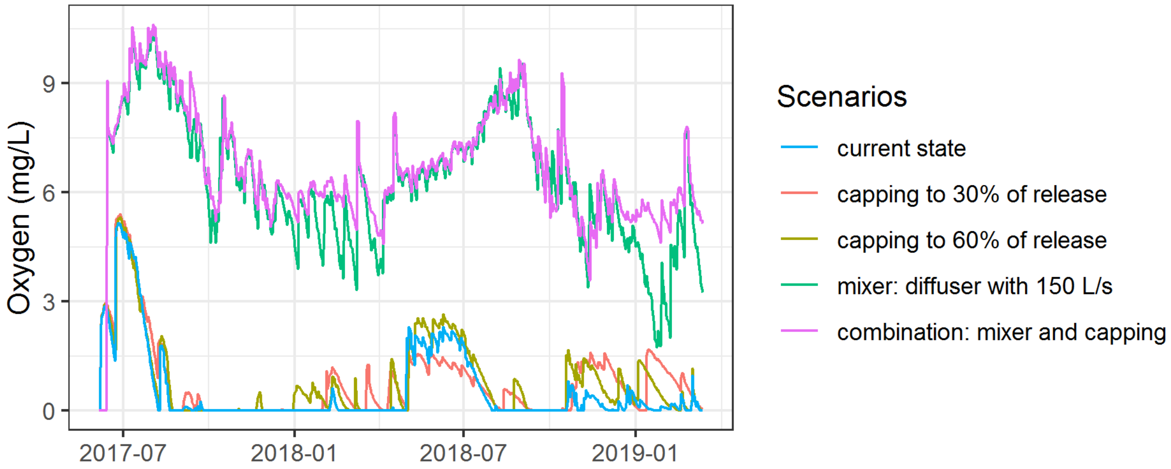

Figure 10: Dissolved oxygen at the bottom (12 m) of LHM from June 2017 to March 2019 for the different lake management scenarios. The blue line is the base case, that is the lake as it is, the capping to 60% of release refers to a Phoslock™ application, capping to 30% of release refers to Phoslock™ plus sand and the green line is a simulation with an aerator installed that mixes the water column. The pink lines simulates all three options in tandem.

In the bottom waters (12 m deep), the management option: 1) aeration, had the greatest effect on increasing dissolved oxygen levels, with the management option: 4) combination of mixer and capping, being no more effective (Figure 10).

Effect on *Chrysosporum*

In the case of the blue-green algae, *Chrysosporum*, the management option 1) aeration scenario differed from the base case at times, with a reduction in *Chrysosporum*, but this was not consistent (Figure 11). The lack of response may be because aeration will mix nutrients in the bottom waters into the surface waters, where they will be more available for algal growth. What is not obvious from Figure 11 is that aeration led to considerably higher concentrations of other non-toxic algal species (e.g., diatoms), so that the water may still appear green although surface blooms may be less prevalent.

The management options 2) Phoslock^{TM}, 3) capping, and 4) combination of aeration and capping, were no more effective than aeration alone early in the study. There was some evidence of a reduction later in the simulation period.

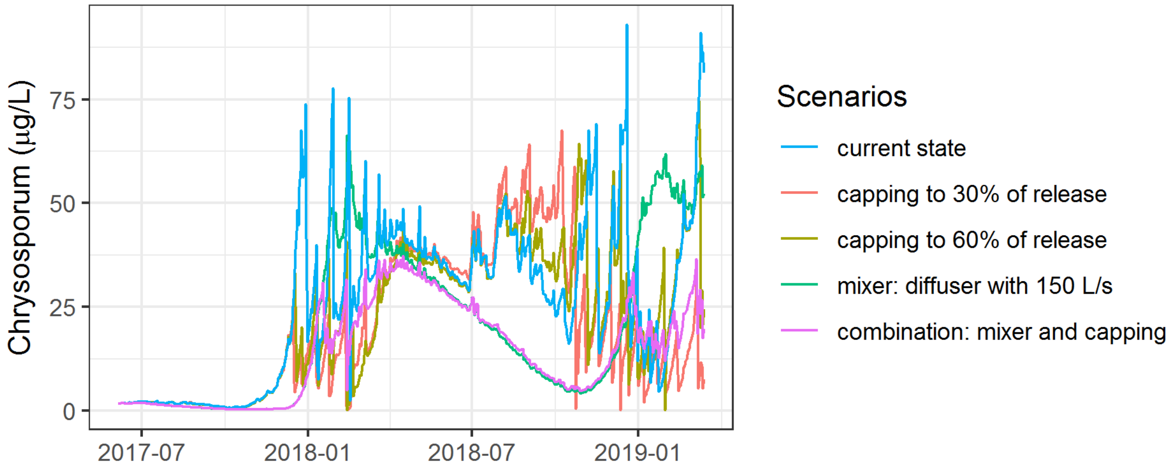

Figure 11: Concentration of the blue-green algae Chrysosporum ovalisporum*, expressed as chlorophyll a (µg/L), at the surface of LHM, June 2017 to March 2019 for the different lake management scenarios. The blue line is the base case, that is the lake as it is, the capping to 60% of release refers to a Phoslock^{TM} application, capping to 30% of release refers to Phoslock^{TM} plus sand and the green line is a simulation with an aerator installed that mixes the water column. The pink lines simulates all three options in tandem.*

Information needed to refine model outputs

There is some evidence from the model simulations that capping plus PhoslockTM may be beneficial in the reducing *Chrysosporum* blooms. However, the model could not be run for longer to substantiate these findings because of a number of data gaps that we believe should be resolved. This information is critical before incurring the additional effort and expense of implementing a full-scale in-lake remediation measure. These data gaps are:

1) Information on effects of salinity on *Chrysosporum*: We have preliminary information from laboratory experiments that increased salinity as a result of mixing would not be sufficient to limit the bloom. This needs to be substantiated. Experimental work needs to be completed as well on the ability of *Chrysosporum* to store phosphorus, and hence how much phosphorus reduction is needed.
2) Experiments with sediment cores to determine the response of the bottom sediments to the sand sedimentation. This is required to ensure that the high density sand does not sink through the existing upper sediment layer.
3) Carry out additional Phoslock™ experiments to ascertain its effectiveness at different salinities, at different dosages, and on *Chrysosporum* filaments.

There are still large uncertainties in the amount of surface and groundwater inputs into the lake and the nutrient concentrations associated with these inputs. In the case of groundwater, this is likely to come from subsurface inputs from the adjacent brackish water canal. Surface water comes primarily from stormwater inputs. To assist with the modelling, the City has installed groundwater monitoring stations to gather information on nutrient concentrations and salinity levels.

Reducing these uncertainties is important to ensure that any strategies to reduce in the catchment nutrients, e.g. reducing garden fertilizer applications, can be assessed for their effectiveness. Additionally, in the short term it is important to know that storm events do not reduce the effectiveness of in-lake restoration efforts, e.g., depositing a nutrient-rich layer over sand-capping layers.

Recommendations

Based on this study, we have a number of recommendations, however the city will need to determine, through a multi criteria analysis, the feasibility and costings of progressing any of these recommendations prior to a whole of lake trial or application.

- The profiler data has contributed substantially to our understanding of the LHM ecosystem and the stability of the water column induced by a saline water layer that is also influenced by tidal exchange with the adjacent canal. Use of profilers in future monitoring would be highly beneficial to improve bloom prediction and knowledge of the effect of management options.
- There was no clear evidence that the Phoslock™ application in late 2018 attenuated the bloom of *Chrysosporum*. But it may have had some impact on lake phosphorus stores such that future blooms may be of a lesser magnitude. Some of the characteristics of this blue-green algal species, i.e. *Chrysosporum*, such as akinete formation under unfavourable conditions and nitrogen fixation, and tolerance of higher salinities, likely play an important role in its success, including the potential to make it resilient to many lake remediation measures.
- Improvements in model predictions can be made through better knowledge of the volume and composition of inflows, i.e., the saline groundwater intrusion and the stormwater inflows. It would be useful to have a strategy to better understand the role of these inputs on the nutrient balance in the lake and therefore the changes in algal bloom frequency.
- Of the scenarios tested with the model, the use of sand capping combined with Phoslock™ gave the greatest reduction in *Chrysosporum* blooms, but only after about 1.5 years.

Therefore, based on the modelling, a trial with sand capping, monitoring its effectiveness, then following up with Phoslock™ seems the most promising management approach. A sand layer may have additional benefits of permanently burying *Chrysosporum* akinetes (= resting spores) but whether this will help control future blooms is unknown. However, we have identified critical knowledge gaps that should be plugged before undertaking a full-scale lake remediation exercise in conjunction with the City’s future multi criteria analysis.

Although our study did not directly examine floating reed beds in LHM, we also believe that given their biomass, they are insufficient to have any significant effects on reducing nutrient levels in the system. The consultants, GHD (as consultants for City) also concluded that removal of FRBs from this system would not reduce water quality.

References

Burford, MA, Hamilton DP, Frassl M, Faggotter S, Chuang A 2018. Study of Management Options to Mitigate Algal Blooms in Lake Hugh Muntz. ARI Report No. 1803 to Gold Coast City Council. Australian Rivers Institute, Griffith University, Brisbane.