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Pumping downwards to prevent algal blooms

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Abstract

Blooms of potentially toxic blue-green algae (cyanobacteria) are a major problem in many parts of the world. Copper may kill them in the short term, but it also kills other aquatic species and upsets the ecological balance. Toxins are released into the water when toxic algae are killed. Prevention is needed rather than cure, and this can be done by creating unfavourable conditions for algal growth. Algal blooms occur when there is the right combination of nutrients, light, water column stability, temperature and lack of competition and predation. The main nuisance species in Australia, anabaena and microcystis, are very efficient at utilising available nutrients and cannot usually be controlled by nutrient deprivation. However they are vulnerable to light limitation and may therefore be controlled, at least in deep storages where the volume in the euphotic zone is much less than the total storage volume, by pumping the surface water downwards so algae are continually removed from the light. A large, low-powered surface pump has been used successfully for this purpose in a 1200 ML storage. With design improvements it is expected that much larger storages could be treated.

Keywords

algae, blooms, control, cyanobacteria, light, pumping

INTRODUCTION

Algal blooms, and in particular blooms of potentially toxic blue-green algae or cyanobacteria, are a major problem in many parts of the world. Approximately 50% of all lakes visited in 1991-5 as part of a UK survey has blooms or scum "above warning level" (Environment Agency, UK, 1998). It has been estimated (Chudleigh and Simpson, 2000) that they impose a cost of Aus$200 million per annum on Australian water users alone. According to Burch (1993) they can cause serious health problems including

- hepatoenteritis
- liver damage
- tumor growth promotion
- gastroenteritis
- hepatitis
- renal malfunctioning
- haemorrhaging.

Improved methods of control are needed as alternatives to the traditional practice of dosing with a copper compound. Although copper may kill algae in the short term, it may also kill other aquatic species, upset the ecological balance and exacerbate the algal problem in the long run by killing zooplankton which graze on algae. A further drawback is that the toxins are released into the water when toxic algae are killed. Prevention is needed rather than cure, and this can be done by creating unfavourable conditions for algal growth.

FACTORS INFLUENCING BLOOMS AND POSSIBLE CONTROL MEASURES

Factors influencing algal blooms include nutrient availability, light, mixing conditions, water residence time, temperature, competition and predation. Each of these factors should be assessed for its potential to limit algal blooms.

Nutrients

It is often assumed that nutrient availability is the most important factor influencing algal blooms, and much attention has been given to ways to reduce nutrient concentrations in the water column, including

- aeration, destratification or mixing to maintain an oxidising environment in the water column, which shifts the chemical balance away from soluble phosphorus towards insoluble forms which settle to the bottom, making P less available to floating algae
- improved catchment management to reduce nutrient inflows
- immobilisation of nutrient-rich bottom sediments by means of an impervious layer
- physical removal of bottom sediments by suction dredging.

However these measures may often prove futile on their own. The main nuisance species of blue-green algae in Australia and many other areas are anabaena and microcystis, which are very efficient users of nutrients (Reynolds, 1997), being able to fix nitrogen from the atmosphere and requiring only about $10\ \mu g\ l^{1}$ of phosphorus to form a bloom. In most situations it is impossible to reduce phosphorus to such low levels, so limiting nutrient availability will never prevent blooms, although the extent of blooms may depend largely on nutrient availability.

Mixing, temperature and competition

It has been argued that mixing can control blooms. Various mechanisms have been suggested:

- Mixing can maintain oxidising conditions throughout the water column and thereby reduce phosphorus concentrations, as mentioned above.
- Non-toxic green algae are not able to regulate their buoyancy and depend on some turbulance to keep them suspended in the water column. Mixing provides this turbulence, so they can compete with the potentially toxic blue-green algae for the available nutrients, thereby reducing the likelihood of the blue-greens becoming dominant.
- By bringing cooler hypolimnetic water to the surface, mixing reduces the surface temperature, which may inhibit algal blooms to some extent under some conditions.
- Violent mixing may physically damage algae. It might be assumed that the energy required to inflict significant damage on the total population in a large storage would be excessive. But with suitable circulation design, it may be possible to entrain and adversely affect most of the algae by violent mixing at one or a few points. If the surface layer in which algae photosynthesize is drawn radially inwards to a pump which propels the water and algae downwards, most of the algae will pass through the pump impeller. This concept is discussed below.
- If the storage is mixed randomly so that the euphotic depth is much less than the uniformly mixed depth, algae will be deprived of light most of the time (Lawrence et al, 2000). It is known that anabaena and microcystis are relatively inefficient light harvesters (Reynolds, 1997).

Residence time

A short residence time will generally reduce the likelihood of blooms occurring, but this fact is of little practical value when a reservoir is used for long term storage of scarce water for months or years.

Predation

Blue-green algae are an integral part of the food chain in some aquaculture systems. Although blue green algae are unpalatable to most predators, some species of daphnia and fish such as *Tilapia* and *Haplochromis* may feed on them in some situations (Reynolds, 1997). If edible fish graze them, then this is a highly desirable win-win situation where a nuisance becomes a resource.

Light deprivation

As observed above, random mixing can deprive algae of light where the depth of mixing greatly exceeds the euphotic depth. However mixing is never random in a real situation, and the degree of light deprivation experienced by algae depends very much on the way in which circulation and mixing occurs. The importance of this fact is discussed below.

THE EFECT OF CIRCULATION PATTERN ON LIGHT DEPRIVATION

Mixing using a bubble plume

The most common mixing technique is to pump compressed air through a perforated pipe or a series of diffusers near the bottom of the storage. As the buoyant air bubbles rise they entrain deep, cool, relatively dense water and propel it towards the surface at a velocity in the order of 1 m s^{-1}. This dense water may detrain at a strong thermocline, where it mixes with the warmer, less dense epilimnetic water, forming a layer of intermediate density. More commonly it will reach the surface, where it will spread radially for a short distance then plunge to its neutral buoyancy level near the thermocline. This plunging action will have a local effect on algae in the immediate vicinity of the bubble plume, displacing them downwards from near the surface to the thermocline. If the thermocline is well below the euphotic depth, this will have a light limiting effect on a few algae, but no effect on those in the rest of the storage.

Mixing using an impeller pumping horizontally

This will mix the water in the immediate vicinity of the impeller, carrying a few algae downwards and a few upwards, possibly damaging some. Horizontal pumping has had some success (Cheng, 1999, Smith and Hollands, 1999). But again the light deprivation effect is small, being limited to the random mixing effect mentioned above, and operating only in a small part of the storage.

Mixing using an impeller pumping vertically downwards

An impeller can be oriented so as to pump vertically downwards, thereby continually drawing surface water radially inwards. If sized correctly it will entrain algae near the surface and transport them well below the euphotic zone. They are thereby temporarily deprived of light and may also be damaged by turbulence while passing through the impeller. Anabaena and microcystis become buoyant when deprived of light and rise slowly towards the surface at rates ranging from about 0.5 m d^{-1} up to a maximum of about 2 or 3 m h^{-1} (Brookes, 1997, Reynolds, 1997) to photosynthesize. They will therefore tend to rise closer to the impeller than they would do if neutrally buoyant, and will be quickly re-entrained and pumped downwards again every time they rise into the euphotic zone. Light deprivation can then be expected to limit their growth. At the same time the pumping action mixes and destratifies the water body, achieving all of the benefits of mixing listed above.

PUMP DESIGN

Ridley et al (1966) and Irwin et al (1966) showed that conventional pumps and pipes could be used to circulate and destratify significant sized storages, but the energy costs were high. Garton (1981a, b) pioneered the use of large, economical, low-speed open impellers pumping downwards. There was some anecdotal evidence of effects on algal blooms, but no systematic analysis of causes and effects. Garton concluded that such impellers were suitable for relatively shallow storages, but that deep storages would require a high velocity, high energy jet to provide enough momentum to reach the bottom.

Kirke and Elgezawy (1997) showed that the use of a draft tube can greatly decrease the energy required to displace water (and algae) to any desired depth, since the impeller is then pumping against a very small static pressure head rather than relying on momentum.

Operating experience with large impellers in draft tubes

Elliott (1998) has shown that pumps comprising an impeller and a draft tube up to 5 m diameter are practicable, and flows up to approximately 7 m^3 s^{-1} have been achieved using 4 kW of power. Draft tubes made of flexible plastic tarpaulin material have been used to reduce cost and make installation easier.

As of August 2001, three 2.5 m diameter and four 5 m diameter units had been installed, with a further four 5 m units under construction. A 2.5 m diameter unit with a 1 HP (750 W) motor was installed in the 1200 ML Timor Dam near Coonabarabran in New South Wales in October 1999. Prior to installation, severe blue-green algal blooms occurred every summer. There have been no problems with blue-green algae since the pump was installed. A similar unit installed in Medway Dam, a similar sized storage near Moss Vale appeared initially to have failed to prevent a serious bloom just after it had been installed in October 2000. However it was discovered that an electrical fault had prevented it from re-starting after a power cut, and that it had not been operating at the time the bloom occurred. Since the fault was rectified there have been no further algal problems in that storage.

Data on the performance of three 5 m diameter units installed in two storages in South Australia at the end of 1998 have not yet been made available to the author, and in any case it will be difficult to assess their effectiveness in preventing algal blooms. Two are in Myponga Dam (approximately 30,000 ML), where a bubble plume is also operating, and the third is in Happy Valley Reservoir (approximately 12000 ML), which is fed from the much larger Mount Bold storage. Algae may therefore be transported from Mount Bold to Happy Valley. These storages are dosed with copper sulphate as soon as there is any sign of an algal bloom. The third 5 m unit is in Little Nerang Dam (8200 ML) in Queensland, which does not have an algal problem. It is being used for research into circulation, destratification and effects on dissolved manganese, iron and phosphorus. Thus there have been no cases in which these surface pumps have been shown to be ineffective in preventing algal blooms, but it is still too soon to draw firm conclusions.

Further design developments

No two storages are identical, and it is difficult to assess how many pumps, of what size, at what spacing, are required to prevent blue green algae from blooming in any given storage. Based on the experiences of Ridley et al (1966), Garton (1981a, b) and others, I have tentatively proposed a total flow rate of 4% of the storage volume per day, or approximately 1 m^3 s^{-1} per 2000 ML, to maintain destratified conditions. This does not of course equate with bloom prevention, but it is a starting point. It may be necessary to maintain a minimum radial inflow velocity to ensure that algae are gradually drawn into an impeller and trapped in a closed circulation pattern. Unpublished work in little Nerang Dam showed that drogues placed up to 200 m from the 5 m diameter impeller at depths of 0.5 and 1 m found their way to the pump in still weather. This suggests that a single unit of this size can be used for an area of at least 400 m in diameter. It may be that a single unit placed downwind relative to the prevailing wind may be effective in some situations.

Much scientific work could be done in attempts to assess required numbers and flow rates of pumps as a function of surface area, storage volume and wind. However it is clear from an engineering point of view that the larger the flow rate per unit cost, the more useful this technology will be. Efforts are therefore being made to enhance the cost-effectiveness of the technology.

Experience indicates that it would be difficult to install impellers larger than 5 m in diameter. These have a flow area of about 20 m^2 and can pump about 7 m^3 s^{-1} at a flow velocity of 0.35 m s^{-1}. To double the volumetric flow rate requires that the velocity through the impeller must double, which implies 4 times as much kinetic energy per unit of water pumped, i.e. operating costs rise steeply. Capital costs would also rise steeply since the impeller would have to be stronger and heavier and the torque would increase, requiring a more expensive gearbox and making it more difficult to anchor pontoons, and so on.

One promising concept is a draft tube which expands below the impeller in such a way that it acts as a conical diffuser, recovering some of the kinetic energy as pressure energy. In this way larger volumetric flows can theoretically be achieved without increasing the impeller diameter or the power per unit of water pumped. Conversely a given flow rate can be achieved with a smaller, cheaper impeller running at higher speed with less torque, a smaller gearbox and shaft, and less mooring problems. The higher flow velocity through the impeller is more likely to damage algae, a further bonus. A safety net is provided to ensure that any person accidnetally falling into the water near the pump will not be drawn into the impeller. Model diffuser tests have yielded encouraging results, but more work is needed on the design.

CONCLUSIONS

By pumping surface water containing blue green algae downwards to a level well below the euphotic depth, it is hoped that algae will be starved of light and potentially toxic blooms may be prevented. Apart from possible predation, this appears to be the only technique that will prevent blooms. Results so far in storages of about 1200 ML capacity are encouraging, trials are continuing and work is progressing on design improvements to enable larger storages to be treated economically.

REFERENCES

Brookes, J.D. (1997). *The influences of nutrients and light on the metabolic activity and buoyancy of Microcystis aeruginosa and Anabaena circinalis.* PhD Thesis, University of Adelaide, November.

Burch, M.D. (1993). Cyanobacteria and Water quality: New Problems and Challenges. *Drinking Water Quality: Technical and Management Issues for the 1990's, Seminar, Adelaide, Australia, Oct, pp.18-24.*

Cheng, D. (1999). An ecological approach for the control of blue green algal bloom. *Blue green algae should never be seen.* Wollondilly Phosphorus Action Campaign Forum, Goulburn, NSW, 30 Apr – 1 May, pp. 53-60.

Chudleigh, P. and Simpson, S. (2000). *The National Eutrophication Management Program – a Review.* Land and Water Resources Research and Development Corporation, Australia. Occasional Paper No. 5/00. http://www/lwrddc.gov.au.

Elliott, S.L. (1998). Water Engineering and Research Solutions Pty. Ltd., Burleigh Heads, Queensland, Australia. *Personal communication.*

Environment Agency, UK (1998). *The State of the Environment of England and Wales: Fresh Waters.* London: the Stationery Office, May.

Garton, J. E. (1981a). Jets and Destratification of Reservoirs. In Burns, F.L. and Powling, I.J. (Eds) *Destratification of Lakes and Reservoirs to Improve Water Quality,* Aust. Water Res. Council Conference, Series No 2, Australian Government Publishing Service, pp.187-200.

Garton, J.E. (1981b) Destratification Experiments to Determine Design Factors for the Garton Pump. *Ibid*, pp.354-375.

Garton, J.E. and Rice, C.E. (1976). *Improving the Quality of Water Releases from Large Reservoirs by Means of a Large Diameter Pump*. Oklahoma Water Resources Research Institute, Report OKLA C-5228.

Irwin, H. W., Symons, J. M. and Robeck, G. G. (1966): Impoundment Destratification by Mechanical Pumping. *J. Sanitary Eng. Div., Proc. ASCE,* Dec., 21-40.

Kirke, B.K. and Elgezawy, A.S. (1997). Design and Model Tests for an Efficient Mechanical Circulator/Aerator for Lakes and Reservoirs. *Water Research* **31**(6), 1283-1290.

Lawrence, I., Bormans, M., Oliver, R., Ransom, G., Sheramn, B, Ford, P. and Schofield, N. (2000). *Factors controlling algal growth and composition in reservoirs: Report of reservoir managers' workshops*. National Eutrophication Management Program, CRC for Freshwater Ecology, DLWC, CSIRO and Murray Darling Commission, Australia, Jan.

Reynolds, C.S. (1997). The Control and Management of Cyanobacterial Blooms. *ASL 36th Congress Symposia*, 27-29 Sept., pp.6-22.

Ridley, J.E., Cooley, P. and Steel, J.A. (1966). Control of Thermal Stratification in Thames Valley Reservoir, *Proc. Soc. for Water Treatment and Examination*, **15**(14), 225-244.

Smith, A., and Hollands, M. (1999). The experiences of blue green algae blooms. *Blue green algae should never be seen.* Wollondilly Phosphorus Action Campaign Forum, Goulburn, NSW, 30 Apr – 1 May, pp1-6.