The Impact of Water Treatment Plant Processes on Algae and Algal Toxins

Lee H. Odell, PE
CH2M HILL
lee.odell@ch2m.com

Algae causes many issues with water treatment plant operations including: clogging of intake screens, fouling of weirs, disruption of floc settling, production of algal mats, filter clogging from algae or from extracellular organic matter (EOM), increase coagulant demand, increased chlorine demand, increased disinfection by products, pH fluctuations, tastes and odors and release of algal toxins.

What may be lesser known is that water treatment processes also have an effect on algae, and as more and more interest is focused on algal toxins it is important to consider these impacts.

First, algal toxins are produced by cyanobacteria, which is commonly called blue-green algae although it is not really an algae. Second, algal toxins are released from cyanobacteria as a bloom nears the end of its lifecycle, or the cells are lysed (split apart) and the toxins are released.

Regulatory Background

The USEPA has listed three algal toxins on the Candidate Contaminant List 3 (CCL3): Anatoxin–a, Microcystin–LR, and Cylindrospermopsin. The World Health Organization (WHO) has established a health-based drinking water guideline of 1.0 ppb for Microcystin-LR. The Australian standard is 1.3 ppb for total microcystins, while Health Canada has proposed a similar standard of 1.5 ppb for total microcystins.

In addition to the health guidelines listed above, short-term exposure recommendations have been developed by United Kingdom Water Industry Research (UKWIR). They have developed Short-term No Adverse Response Levels (SNARLs) for three algal toxins, which may be more representative of levels of concern for a short-term algal bloom. The 24-hour and 7-day SNARLs are shown in Table 1.

Table 1: Short-Term No Adverse Response Levels (SNARLs) from UKWIR

Algal Toxin	24 hour health-based SNARL	7 day health-based SNARL
Microcystin-LR	**12 ug/L**	**6 ug/L**
Anatoxin-a	**3 ug/L**	**1.5 ug/L**
Cylindrospermopsin	**9 ug/l**	**4.5 ug/L**

Source Water Prevention of Algal Blooms

Prevention of algal blooms in source waters generally falls in one of four categories:

- Limiting Light
- Limiting Nutrients
- Mixing/aeration, and
- Biomanipulation

Limiting light may be limited to water treatment plant intakes and basins within the water treatment plant, but structured coverings, floating covers and even “bird balls” have been used to reduce algae growth.

The ratio of nutrients for algal growth is generally C(42):H(8.5):O(57):N(7):P(1), and while very little phosphorous is needed, it is often the focus of most nutrient control strategies. Phosphorous input is usually easier to control than nitrogen, nitrite, nitrate and ammonia. Anoxic zones in lakes and reservoirs can release phosphorous from sediments and are often part of the control strategy.

In-lake treatments to control phosphorous are manifold. Ferric coagulation has been used, but it is difficult to control in anoxic areas. Alum coagulation is a concern because of aluminum toxicity to aquatic species. Lime may effectively precipitate and control phosphorous and generally not lyse cells and release toxins; however, application of lime over large bodies of water may present permitting and logistical challenges.

Dredging of sediments can be an effective long-term phosphorous control strategy. Mixing and aeration have had mixed results, even carefully designed and operated systems have not been effective in some cases. If sufficient mixing volumes are generated, they may be more effective. Mixing and aeration that destratifies deep lakes and reservoirs may be an effective preventative measure to algal blooms. Lake flushing has been shown to be effective if there is sufficient flow of low phosphorous water available. Rotting barley straw has been successful in some cases at applied doses of 5 to 50 g/m3for green algae & cyanobacteria, however, other types of straw have increased cyanobacteria growth.

Biomanipulation is the removal of fish populations that feed on phytoplankton & benthic feeders, and introduction of predatory fish. This allows zooplankton to consume algae and control blooms. Not all algae is consumed by zooplankton including some cyanobacteria. In some cases zooplankton may cause WTP impacts including filter clogging in a direct filtration plant.

The use of algicides, including copper sulfate, are not recommended because of aquatic species toxicity issues and because they lyse cells and release algal toxins.

Water Treatment Plant Impacts on Algae and Algal Toxins

“Until a bloom collapses or is otherwise affected by some treatment practice, the majority of toxins will be retained within the cells, making removal of intact cells a high treatment priority.”
- **Toxic Cyanobacteria in Water: A guide to their public health consequences, monitoring and management, WHO, 1999**

Physicochemical water treatment processes have been shown to cause cell lysis and toxin release (James and Fawell, 1991). There have been mixed results on the effect of mixing and transport, including pumping. These may or may not contribute to cell lysing (Dickens and Graham, 1995), (WRc, 1996). Changes in pH from 5 to 9 did not cause any release intracellular toxins (WRc, 1996).

In addition to whether or not water treatment processes can lyse cells, there are three major issues that are of concern: how water treatment processes remove algae, how water treatment processes control

taste and odor compounds that are algal by products (geosmin and MIB) and how water treatment processes control algal toxins.

Riverbank Filtration

Riverbank filtration has been demonstrated to be effective for algae removal, providing 4-log removal of algae cells (USEPA IESWTR). It is also effective for removal of cyanotoxins except during massive blooms (CK Schmidt et al, 2003).

Microstrainers

Microstrainers were shown to result in 40-70% removal of cyanobacteria cells in one study, but removed less than 10% of smaller cells (Mouchet & Bonnelye, 1998). Microstrainers can be difficult to install and operate if the algae species changes or cells mat, and can significantly increase headloss.

Preoxidation

A permanganate dose of 1-8 mg/L was effective for algae & cyanobacteria destruction (Fitzgerald, 1966). Maintaining a chlorine residual was effective at controlling algae within WTP basins with 0.25 to 2 mg/L free chlorine residual (Holden, 1970). Lysing of cells is an issue with preoxidation, so downstream processes must be able to remove metabolites (AWWA 2004)

Chlorination

Studies of treatment for algal toxins using chlorine have shown mixed results.

One study showed a 5 mg/L was ineffective for destroying algal toxin extracts (Hoffman, 1976). A second study demonstrated combined treatment processes which included chlorination at 0.5 mg/L were also ineffective (Keijola *et al., 1988; Himberg et al., 1989).* A third study showed chlorination achieved negligible reduction in microcystin levels of 0.3-0.5 µg/L in treated water *(Lambert et al., 1996)*. Two studies showed no discernible removal of anatoxin-a by chlorination (Nicholson *et al., 1994), (Carlile, 1994).* Rositano and Nicholson (1994) also showed that chlorination of anatoxin-a was ineffective with a dose of 15 mg/L at pH 7 for 30 minutes contact time, providing only a 16 per cent removal.

However, chlorination was very effective at destroying microcystin-LR and nodularin with free chlorine residual of 0.5 mg/L after 30 minutes contact time with pH < 8 (Nicholson *et al., 1994)*. Dissolved microcystin-LR and anatoxin-a in the range 5-10 µg/L, using a chlorine residual of 0.7 mg/L showed at pH 5, removal was more than 93 % within 30 minutes but at pH 7 removal reached only 88 per cent after 22 hours (Carlile, 1994), (Croll and Hart, 1996) (Hart *et al., 1997).*

Cylindrospermopsin can be effectively degraded by chlorination. With cylindrospermopsin concentrations of 17-185 mg/l, a residual chlorine concentration of 0.5 mg/l was sufficient to degrade >99% of cylindrospermopsin. Degradation occurred rapidly (within a minute) over the pH range 6 to 9. The presence of other organic substances consumed chlorine, requiring higher chlorine doses for degradation of cylindrospermopsin. A cylindrospermopsin concentration of 20-24 mg/l was effectively destroyed by a chlorine dose of 4 mg/l at pH 7.2-7.4. A concentration of 100 mg/l was reduced to <0.2 mg/l after 30 minutes contact and a residual chlorine concentration of 0.53 mg/l.

Chloramination

Chloramination was completely ineffective at destroying microcystin-LR and nodularin (Nicholson *et al., 1994)*.

Permanganate

Permanganate at a dose of 1 mg/L achieved 95% removal of microcystin-LR in 30 minutes, however, in the presence of live intact cells removal was much poorer (Rositano, 1996). Similar studies with microsistin and anatoxin-a have shown similar results (Hart and Stott, 1993) (Carlile, 1994) (Croll and Hart, 1996) (WRc, 1996). Longer contact times produced some cell lysis (Lam et al.,1995).

Ozone

The most consistently efficient process for destruction of both ultra- and extracellular microcystins appears to be ozonation, which can rapidly achieve essentially complete destruction of microcystins, nodularin and anatoxin-a at low doses and contact times (Keijola *et al., 1988)(Himberg et al.,* 1989)(Rositano and Nicholson, 1994)(Croll and Hart, 1996)(Rositano *et al., 1996)(Hart et al., 1997).* At low pH, an ozone dose of as little as 0.4 mg/L removed 97% of *microcystin-LR (WaterRF, 2010).*

A major operational consideration is the ozone demand of the water. At a DOC level of 8.5 mg/L ozone doses above 1 mg/L were necessary to achieve complete microcystin-LR destruction (Rositano and Nicholson, 1994). At low doses up to 0.6 mg/L, ozone degraded DOC and had little effect on microcystin-LR. Only after the DOC demand was satisfied, did the ozone show an effect on microcystin-LR (Hart *et al., 1997)*. With a dose of 0.6 and 1.3 mg/L, Ozone treatment consisted almost entirely of cellular lysis, and only at 2 mg/L was extracellular toxin subsequently converted(Hart *et al., 1997)*.

A solution of 166 mg/l pure microcystin-LR in water was completely destroyed by 0.2 mg ozone/l in 4 minutes (15). When other organic material was present the required dose rate increased, but 1 mg ozone/l almost completely removed 220 mg microcystins/l from an algal extract in 5 minutes. Ozone became less effective at pH values above 7.5. Ozone plus hydrogen peroxide was even more effective. Studies on four different treated waters spiked with 20 mg microcystin LR/l showed that quite low ozone doses (0.15 to 1.1 mg/l) were required for complete removal (62) – these doses were approximately those required to produce an ozone residual.

UV Disinfection and UV-AOP

UV radiation was capable of degrading both microcystin-LR and anatoxin-a, but at very high doses of about 20,000 mWs/cm2 (Croll and Hart, 1996), (WRc, 1996). UV alone or UV with hydrogen peroxide achieved about a 50% removal of microcystin-LR after 30 minutes (Rositano and Nicholson, 1994). UV advanced oxidation process with hydrogen peroxide resulted in 50% to 90% with hydrogen peroxide doses of 2 to 4 mg/L and UV intensities of 100 to 900 mJ/cm2 (WaterRF, 2010).

Very high concentrations of microcystin-LR (50-200 mg/L) were destroyed after 10 to 40 minutes using UV light in the presence of a titanium dioxide catalyst (Robertson *et al., 1997).*

Coagulation and Clarification

Efficient removal of algae in coagulation and clarification is dependent on optimization of chemical doses and coagulation pH as well as the characteristics of the algae species.

Coagulant dose necessary for algal removal is proportional to the sum of alkalinity and the logarithm of cell number (Mouchet and Bonnélye, 1998). Minimizing turbidity in jar test is not sufficient to remove algae and cyanobacteria. Zeta potential is a better reflection of cell motility. At insufficient coagulant dose, cyanobacteria will be the last phytoplankton cells to be removed. Coagulation of algal cells that are smooth and more or less spherical occurs largely by charge neutralization (Bernhardt and Clasen, 1991). Filamentous algae, large algae or species with bristles on their cell surface can be dealt with effectively only by sweep coagulation (Bernhardt and Clasen,1991)

Alum dosed at 120 mg/L with and without polymer removed about 20 per cent of the toxicity from a neurotoxic bloom of *Anabaena circinalis* (Falconer,1989). For microcystins, coagulation had a negligible capability for removal of any soluble toxins present in water in several studies (WRc, 1996), (Rositano and Nicholson,1994), (Lambert *et al. 1996*). These studies tested three coagulants: ferric sulfate, alum and polyaluminium chloride. In all cases they found essentially no toxin removal.

Coagulation and clarification studies have had mixed results on cell lysis and the subsequent release of algal toxins. Results were generally thought to be related to cell life-cycle stage (Lam *et al., 1995*), (Velzeboer *et al.,*1995) (Chow *et al.,1997a*) (Drikas *et al., 1997*).

Clarifier type may also have an effect on algae removal. Sludge blanket-type clarifiers were demonstrated to be substantially more effective than static settlers, particularly upflow pulsed systems – 90-99% phytoplankton removal in 4 plants (Mouchet and Bonnélye, 1998), however, it should be noted that sludge blanket buoyancy can be negatively affected by improper polymer dose.

Dissolved air flotation (DAF) is also more effective than sedimentation processes, and has the added benefit of consistently removing in-tact whole cells. DAF resulted in *98% Microcystis* cell removal in the presence of other algae (Gregory and Zabel, 1990). DAF also resulted in 40% to 80% removal *of Microcystis, 90% to 100 %* removal of *Anabaena,* and *30%* removal *of Planktothrix (Steffensen and Nicholson, 1994).* Many additional similar results with DAF have been reported (Markham *et al., 1997) (*Bernhardt and Clasen, 1991) (Vlaski *et al., 1997).* However, *DAF* performed poorly during high turbidity periods (Mouchet and Bonnélye, 1998).

Powdered Activated Carbon (PAC)

There is general agreement that to achieve high removal efficiencies, very high doses of PAC are required for toxin removal and that contact time is very important. A dose of 20 mg/L of PAC was able to achieve 90% removal of hepatotoxins following conventional treatment combined with pre-ozonation (Keijola *et al., 1988)*. The most effective PAC tested (wood based) of several types, required doses greater than 20 mg /L to achieve toxin removal of greater than 85% (Hart and Stott, 1993) (Croll and Hart, 1996). For Microcystin-LR at an initial concentration of 50 µg/L, a dose of 25 mg/L with 30 minutes contact time was able to achieve 98% removal with one PAC, while a dose of 50 mg/L only achieved a 60 per cent removal with another. The mesopore volume of the various carbons was the best predictor of

carbon performance (Donati *et al., 1994a*). *Nodularin* was also removed with *PAC* (Donati *et al., 1994b*). A dose of 12 mgl1 of PAC achieved 95% removal of dissolved microcystin-LR from an initial concentration of 50 µg/L (Bernazeau, 1994). Alum coagulation in conjunction with PAC was found to affect adversely toxin removal (Jones *et al., 1993*).

Rapid Sand Filtration

Rapid sand filtration achieved 14-30% removal of *Microcystis aeruginosa* cells (Drikas et al.,1997). Another study showed 14% removal of cyanobacterial cells in rapid sand filtration (Lepisto *et al., 1996)*. A third study demonstrated 42% removal of cyanobacteria cells in rapid sand filtration using GAC media (Lambert *et al., 1996*). Researchers have expressed concerns over cell lysis and toxin release during filtration (Mouchet and Bonnélye, 1998).

Slow Sand Filtration

One evaluation demonstrated 99% removal of algal cells by slow sand filtration (Mouchet and Bonnélye, 1998) . Other studies of slow sand filtration reported over 80 % removal of toxins from *Microcystis, 30-65%* removal of toxins from *Planktothrix* and approximately 70 % removal of *anatoxin-a (*Keijola *et al.,1988).* The use of roughing filters followed by slow sand filters showed that *M. aeruginosa* and some *Planktothrix* cells could be removed by physical means and biological processes (Sherman *et al., 1995)*.

Granular Activated Carbon

Granular activated carbon is effective for removal of toxins, provided the adsorption capacity of the GAC has not been compromised. Pilot scale tests treating microcystins at 30-50 µg/L with 5-6.5 mg/L DOC showed greater than 90% toxin removal for water treatment volumes up to 7,000-10,000 activated carbon bed volumes before efficiency dropped (Bernezeau, 1994). Microcystin concentrations of 5-20 µg/L for EBCTs of 10-15 minutes, resulted in a bed-life of only 30-45 days (Hart and Stott, 1993). A full-scale GAC adsorber achieved 40 and 60 % microcystin removal down to 0.6-1.2 µg/L for raw water DOC levels of 20 mg/L, (Lambert *et al., 1996*).

Biological Filtration

Microcystin-LR has been shown to be biodegradable (Fawell *et al., 1993)*. Pilot scale tests using two GACs, one previously used and one unused GAC with contact times of 7.5 and 15 minutes showed no significant difference between the performance of the unused GAC and the used GAC at both contact times (Carlile, 1994) with greater than 90% removal over 11 weeks.

Membrane Filtration

Flat-sheet studies of UF and MF membranes, in both dead-end and crossflow modes, have shown high efficiency of removal (> 98 per cent) of whole cells of toxic *M. aeruginosa* with minimal cell damage *(Chow et al., 1997b).* Nanofiltration removed of microcystin spiked at concentrations of 5 and 30 µg/L resulted in removal to below 1 µg/L (Hart and Stott, 1993). Reverse osmosis membranes at 25- 35 bar eliminated 96.7% and 99.6% of microcystin-LR and microcystin-RR from tap and salt water. (Neumann and Weckesser, 1998). Toxin passage through RO membranes was higher with waters with high levels of natural organic matter (WaterRF, 2010).

Conclusion

Water treatment plant operators and engineers should be aware of the potential for water treatment processes to lyse algal cells, release algal toxins, remove algal cells, and destroy algal toxins and taste and odor causing compounds.

Lee Odell is CH2M HILL's Water Treatment Global Technology Leader. Odell has 22 years of experience as an engineering consultant and 6 years of experience as a water treatment plant operator and operations supervisor. He has a wide range of experience managing projects in water resources, water quality and treatment, water reuse design, and facilities planning. One of the hallmarks of his career has been helping utilities find innovative and unique ways of addressing their specific problems.

References

1. Baron J., Ionesco, N.M. and Bacquet, G. 1997 Combining flotation and ozonation the Flottazone process. In: *Dissolved Air Flotation.* Proceedings of an International Conference, London, Chartered Institution of Water and Environment Management, London.

2. Bernezeau, F. 1994 Can microcystins enter drinking water distribution systems, In: D.A. Steffensen and B.C. Nicholson [Eds] *Toxic Cyanobacteria, Current Status of Research and Management.* Proceedings of an International Workshop, Adelaide, Australia, American Water Works Association Research Foundation, Australian Centre for Water Quality Research, Centre for Water Research, Belgium, 115-118.

3. Bernhardt, H and Clasen, J. 1991 Flocculation of micro-organisms, *J. Water SRT Aqua.***40**(22), 76-87.

4. Carlile, P.R. 1994 *Further Studies to Investigate Microcystin-LR and Anatoxin-a Removal from Water.* Report No. 0458, Foundation for Water Research, Marlow, UK.

5. Casitas Municipal Water District 1987 *Current Methodology for the Control of Algae in Surface Reservoirs.* American Water Works Association Research Foundation, Denver.

6. Chen, G., Chen, C.W., Yu, S.Z., Ueno, Y. 1998 Evaluation of different water treatment to remove microcystins by using a highly sensitive ELISA. In: M. Miraglia, H. van Egmond,

7. Chorus I., Klein, G., Fastner, J. and Rotard, W. 1993 Off-flavors in surface waters, how efficient is bank filtration for their abatement in drinking water? *Wat. Sci. Technol.,* **25/2**, 251-258.

8. Chow, C.W.K., House, J., Velzeboer, R.M.A., Drikas, M., Burch, M.D. and Steffensen D.A. 1997a The effect of ferric chloride flocculation on cyanobacterial cells. *J. Water SRT Aqua,* **46,** 324-334.

9. Chow, C.W.K., Panglisch, S., Mole, J., Drikas, M., Burch, M.D. and Gimbel, R. 1997b A study of membrane filtration for removal of cyanobacterial cells. *AQUA* (In Press).

10. Collins, M.R. 1998 Experiences introducing "new" technology: slow sand filtration. Lecture and abstract of the NSF International PAHO/WHO first International Symposium on Safe Drinking Water in Small Systems, Technology, Operation and Economics, Washington, DC.

11. Craig, K. and Bailey, D. 1995 Cyanobacterial toxin microcystin 'LR' removal using activated carbon, Hunter Water Corporation experience. In: *Proceedings of the Australian Water and Wastewater Association 16th Federal Convention,* Sydney.

12. Croll, B and Hart, J. 1996 Algal toxins and customers. Paper presented at the UKWIRAWWARF Technology Transfer Conference, Philadelphia.

13. Dickens, C.W.S. and Graham, P.M. 1995 The rupture of algae during abstraction from a reservoir and the effects on water quality. *J. Water SRT,* **44**(1), 29-37.

14. Donati, C.D., Drikas, M., Hayes, R. and Newcombe, G. 1993 Adsorption of microcystin-LR by powdered activated carbon. *Wat. J. AWWA,* **20**(3), 25-28.

15. Donati, C, Drikas, M, Hayes, R and Newcombe, G. 1994a Activated carbon in drinking water treatment: II Adsorption of nodularin. Poster presented at the 8th International Conference on Surface and Colloid Science, Adelaide, February, 1994.

16. Donati, C.D., Drikas, M., Hayes, R. and G. Newcombe. 1994b Microcystin-LR adsorption by powdered activated carbon. *Wat. Res.,* **28,** 1735-1742.

17. Drikas, M. 1994 Session IV: Control and or Removal of Toxic Cyanobacteria. In: D.A., Steffensen and B.C. Nicholson [Eds] *Toxic Cyanobacteria, Current Status of Research and Management.* Proceedings of International Workshop, Adelaide, Australia. American Water Works Association Research Foundation, Australian Centre for Water Quality Research, Centre for Water Research, Belgium.

18. Drikas, M., Chow, C.W.K., House, J. and Burch, M.D. 1997 A pilot study of the removal of intact cyanobacterial cells. *J. AWWA* (In Preparation).

19. Effler, S.W., Linen, S., Field, S.D., Tong-Ngork, T., Hale, F., Meyer, M., and Quirk, M.1980 Whole lake responses to low level copper sulphate treatment. *Wat. Res.* **14,** 1489-1499.

20. Elder, J.F. and Home, A.J. 1978 Copper cycles and CuSO4 algicidal capacity in two California lakes. *Environ. Manage.* 2, 17-30.

21. Falconer, I.R., Runnegar, M., Buckley, T., Huyn, V. and P. Bradshaw, 1989 Using activated carbon to remove toxicity from drinking water containing cyanobacterial blooms. *J. Am. Water Works Assoc.,* **81**(2), 102-105.

22. Fawell, J.K., Hart, J, James, H.A. and Parr. W. 1993 Blue-green algae and their toxins analysis, toxicity, treatment and environmental control. *Wat. Supply,* **11**(3/4), 109-121.

23. Fitzgerald, G.P. 1966 Use of potassium permanganate for control of problem algae. *J.AWWA,* **58,** 609-614.

24. Gregory, R and Zabel, T.F. 1990 Sedimentation and flotation. In: F. W. Pontius [Ed.] *Water Quality and Treatment, A Handbook of Community Water Supplies.* 4th edition. American Water Works Association, McGraw Hill, Inc., New York, 443-445.

25. Grohmann, A., Hahn, H.H., Klute, R. [Eds] 1985 *Chemical Water and WastewaterTreatment.* Gustav Fischer Verlag, Stuttgart, New York, 311 pp.

26. Hamann, C.L., McEwen, J.B. and Myers A.G. 1990 Guide to selection of water treatment processes. In: F. W. Pontius [Ed.] *Water Quality and Treatment - A Handbook of Community Water Supplies.* 4th edition. American Water Works Association, McGraw Hill Inc., New York, 157-187.

27. Hart, J. and Stott, P. 1993 *Microcystin-LR Removal from Water.* Report FR 0367, Foundation for Water Research, Marlow, UK.

28. Hart, J, Fawell, J.K and Croll, B. 1997 The fate of both intra and extracellular toxins during drinking water treatment. Special subject No. 18, SS18-1-6, *IWSA World Congress,* Blackwell Science, Oxford.

29. Himberg, K., Keijola, A.M., Hiisvirta, L., Pyysalo, H. and Sivonen, K. 1989 The effect of water treatment processes on the removal of *Microcystis* and *Oscillatoria* cyanobacteria: a laboratory study. *Wat. Res.,* **23**, 979-984.

30. Hoffman, J.R. 1976 Removal of Microcystis toxins in water purification processes. *Water SA.* **2**(2), 58-60.

31. James, H. and Fawell, J.K. 1991 *Detection and Removal of Cyanobacterial Toxins from Freshwaters.* Report No. FR0211 Foundation for Water Research, Marlow, UK.

32. Jones, G., Minatol, W., Craig, K. and Naylor, R. 1993 Removal of low level cyanobacterial peptide toxins from drinking water using powdered and granular activated carbon and chlorination. Result of laboratory and pilot plant studies. In: *Proceedings of the Australian Water and Wastewater Association 15th Federal Convention,* Gold Coast, Australia.

33. Jones, G. and Orr, P.T. 1994 Release and degradation of microcystin following algicide treatment of a *Microcystis aeruginosa* bloom in a recreational lake, as determined by HPLC and protein phosphatase inhibition assay. *Wat. Res.,* **28**(4), 871-876.

34. Keijola, A.M., Himberg, K., Esala, A.L., Sivonen, K. and L. Hiisvirta, 1988 Removal of cyanobacterial toxins in water treatment processes: laboratory and pilot-scale experiments. *Tox. Assess.,* **3**, 643-656.

35. Kenefick, S.L., Hrudey, S.E., Peterson, H.G. and E.E. Prepas, 1993 Toxin release from Microcystis aeruginosa after chemical treatment. *Wat. Sci. Tech.,* **27**(3-4), 433-440.

36. Lahti, K., Kilponen, J., Kivimäki, A.-L., Erkomaa, K. and Sivonen, K. 1996 Removal of cyanobacteria and their hepatotoxins from raw water in soil and sediment columns. In: A.-L. Kivimäki and T. Suokko [Eds] *Artificial Recharge of Groundwater.* NHP/Report No. 38, Helsinki, 187-195.

37. Lam, A., Prepas, E., Spink, D. and Hrudey, S.E. 1995 Control of hepatotoxic phytoplankton blooms; implications for human health. *Water Res.* **29,** 1845-1854.

38. Lambert, T.W., Holmes, C.F. and Hrudey, S.E. 1996 Adsorption of microcystin-LR by activated carbon in full scale water treatment. *Wat. Res.* **30**,1411-1422.

39. Laszlo, F. 1984 Potential release of pollutants in riverbank filtration systems along the River Danube, Hungary. In: *Proceedings of the 3rd International Symposium on Interactions Between Sediments and Water.* CEP Consultants Ltd., Edinburgh, 264-267.

40. Lawton, L.A., Cornish, B.J.P.A. and MacDonald, A.W.R. 1998 Removal of cyanobacterial toxins (microcystins) and cyanobacterial cells from drinking water using domestic water filters. *Wat. Res.* **32**, 633-638.

41. Lepistö, L., Lahti, K., Niemi, J. and Färdig. M. 1994 Removal of cyanobacteria and other phytoplankton in four Finnish waterworks. *Arch. Hydrobiol. Algological Studies,* **75**, 167-181.

42. Markham. L, Porter, M. and Schofield, T. 1997 Algal and zooplankton removal by dissolved air flotation at Severn Trent Ltd. surface water treatment works. In: *Dissolved Air Flotation.* Proceedings of an International Conference, Charted Institution of Water and Environmental Management, London.

43. McGuire, M.J. and Gaston, J.M. 1988 Overview of technology for controlling off-flavours in drinking water. *Wat. Sci. Tech.,* **20**(8/9), 215-228.

44. Mouchet P. and Bonnélye V. 1998 Solving algae problems: French expertise and worldwide applications. *J. Water SRT, Aqua.*, **47***,* 125-141.

45. Muntisov, M. and Trimboli, P. 1996 Removal of algal toxins using membrane technology. *Water,* **23**(3), 34.

46. Neumann, U. and Weckesser, J. 1998 Elimination of microcystin peptide toxins from water by reverse osmosis. *Environ. Toxicol. Water Qual.,* **13.**

47. Nicholson, B.C., Rositano, J. and Burch, M.D. 1994 Destruction of cyanobacterial peptide hepatotoxins by chlorine and chloramine. *Wat. Res.* **28,**1297-1303.

48. Rositano J. 1996 *The Destruction of Cyanobacterial Peptide Toxins by Oxidants used in Water Treatment.* Report 110, Urban Water Research Association of Australia.

49. Rositano, J. and Nicholson, B.C. 1994 *Water Treatment Techniques for Removal of Cyanobacterial Toxins from Water.* Australian Centre for Water Quality Research. Salisbury, South Australia, 55 pp.

50. Rositano, J., Nicholson, B.C. and Pieronne, P. 1996 Destruction of cyanobacterial toxins by ozone. In: *Proceedings of the First Australasian Conference of the International Ozone Association,* Sydney, Australia.

51. Sanchez, I. and Lee, G.F. 1978 Environmental chemistry of copper in Lake Monona, Wisconsin. *Wat. Res.,* **12,** 899-903.

52. Sawyer, C.N. 1962 Causes, effects and control of aquatic growths. *J. Wat. Pollut. Control Fed.,* **34,** 279-288.

53. Sherman, P., Tully, I. and Gibson, H. 1995 Removal of cyanobacterial cells and toxins from drinking water with biologically active filters. In: *Proceedings of the Australian Water and Wastewater Association 16th Federal Convention,* Sydney.

54. Steffensen, D.A. and Nicholson, B.C. [Eds] 1994 *Toxic Cyanobacteria -Current Status of Research and Management.* Proceedings of an International Workshop, Adelaide, Australia, American Water Works Association Research Foundation, Australian Centre for Water Quality Research, Centre for Water Research, Belgium, 172 pp.

55. UK WIR, 1995 *GAC Tests to Evaluate Algal Toxin Removal.* Report DW-07/C, UK Water Industry Research Ltd., London.

56. Velzeboer, R., Drikas, M., Donati, C., Burch, M. and Steffensen, D. 1995 The removal of cyanobacterial cells by alum flocculation. In: *Proceedings of the Australian Water and Wastewater Association 16th Federal Convention,* Sydney.

57. Vlaski, A., van Breemen, A.N. and Alaerts, G.J. 1997 Algae laden water treatment by dissolved air flotation. In: *Dissolved Air Flotation.* Proceedings of an International Conference, London, Chartered Institution of Water and Environmental Management, London.

58. WaterRF, Water Research Foundation, 2010. Matt Alvarez, CH2M HILL, *Treating Algal Toxins Using Oxidation, Adsorption and Membrane Technologies.*

59. WHO 1996 *Guidelines for Drinking Water Quality. Volume 2, Health Criteria and other Supporting Information.* World Health Organization, Geneva, 973 pp.

60. WRc, 1996 *The Fate of Intracellular Microcystin-LR During Water Treatment.* Report Ref.96/DW/07/4, UK Water Industry Research Ltd., London.

61. WRc, 1997 *Algal Toxins: Occurrence and Treatability of Anatoxin and Microcystins.* Report 97/DW/07/E, UK Water Industry Research Ltd., London.

62. Yoo, R.S., Carmichael, W.W., Hoehn, R.C. and Hrudey, S.E. 1995 *Cyanobacterial (Blue- Green Algal) Toxins: A Resource Guide.* American Water Works Association Research Foundation, Denver, 229 pp.