Chapter 9: Cyanobacterial compliance

Contents

9.1 Introduction

9.1.1 Algal bloom development

9.1.2 Health significance of cyanotoxins

9.1.3 Taste and odour caused by cyanobacteria

9.1.4 Occurrence of toxic cyanobacteria internationally and in New Zealand

9.2 Risk management

9.2.1 Assessment of risk

9.3 Monitoring

9.4 Compliance

9.5 Sampling and testing

9.5.1 Sample testing

9.5.2 Sample collection

9.6 Transgressions

9.7 Risk reduction

9.7.1 Alert levels

9.7.2 Preventive and remedial measures

References

List of tables

Table 9.1. Example assessment of the potential for high biomass of cyanobacteria based on environmental conditions [a]

Table 9.2: Toxic cyanobacteria species and their geographical distribution

Table 9.3: Cyanobacteria genera known to occur in New Zealand fresh waters and the toxins they are known to produce

Table 9.4: Information that may help in situation assessment and management

Table 9.5: Summary of performance of water treatment processes capable of removing cell-bound microcystins by removing whole cells

Table 9.6: Efficiency of dissolved toxin removal by oxidants/disinfectants and activated carbons

List of figures

Figure 9.1: Rapid assessment of the level of risk posed by toxic cyanobacteria in a drinking water source

Figure 9.2: Procedure for use of the integrated hose-pipe sampler for planktonic cyanobacteria and cyanotoxins

Figure 9.3: Benthic cyanobacteria monitoring and sampling schematic of layout of transects and survey areas

Figure 9.4: Benthic cyanobacteria monitoring and sampling schematic of transect cross-section showing arrangement of sampling points

Figure 9.5: Alert levels framework for the management of cyanobacteria in water supplies

9.1 Introduction

This chapter provides a large amount of information on cyanobacteria and cyanotoxins because of the increasing number of supplies that encounter difficulties with these micro-organisms, and because many water suppliers may have little understanding of how to manage them. Although prepared primarily for use in relation to drinking-water supplies, the information should also be of use to those managing recreational waters.

The Ministry for the Environment and the Ministry of Health published in 2009 the *New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters – Interim Guidelines*. This document contains material that is also relevant to managing and sampling drinking-water sources and is recommended to be consulted for additional scope.

In addition, Water Quality Research Australian (formally CRC for Water Quality) produces many reports and technical notes relevant to managing cyanobacteria in both recreational waters and drinking-water sources and is recommended to be consulted for additional scope. These reports can be found at: http://www.wqra.com.au. A readable fact sheet produced for the public was produced by the CRC (2008).

Lopez et al (2008) produced one of the technical reports for the US Congress required by the Harmful Algal Bloom and Hypoxia Amendments Act of 2004, acknowledging that harmful algal blooms are one of the most scientifically complex and economically damaging issues challenging our ability to safeguard the health of the Nation's aquatic and marine ecosystems.

A most thorough Guidance Manual was published in 2009 for the Global Water Research Coalition (GWRC) by Water Quality Research Australia and SA Water – see references. This is recommended reading.

WHO (2015) published a report on the management of cyanobacteria in -water supplies. Also in 2015 the AWWA/WRF published *A Water Utility Manager's Guide to Cyanotoxins*.

For those who do not wish to read the full text in this chapter, but are concerned with information to support the requirements of the DWSNZ, the following sections are those of greatest importance:

- Compliance with the DWSNZ: see section 9.4
- Sampling: see section 9.5
- Transgressions: see section 9.6
- Risk management: see section 9.7
- Refer also to the datasheets for cyanobacteria and for the cyanotoxins, in Volume 3.

Over recent years, water supplies in some parts of New Zealand have experienced an increase in the number of cyanobacterial blooms affecting their water sources. These events have the potential to introduce into the water toxins that can have acute and, if their concentrations are high enough, fatal consequences for consumers. Experience of such events in New Zealand is still relatively limited, and consequently this section provides substantial detail to assist water suppliers in dealing with cyanobacteria. In preparing this section, extensive use has been made of *Toxic Cyanobacteria in Water: A guide to their public health consequences, monitoring and management* Chorus and Bartram (editors), published on behalf of the World Health Organization 1999. Cyanobacteria may also be referred to as blue-green algae, or harmful algal blooms (HAB) and a publication in 2008 provides holistic coverage of cyanobacteria (Hudnell 2008), with a chapter on cyanotoxin removal during drinking-water treatment (Westrick 2008).

Cyanobacteria are primarily aquatic organisms with many characteristics of bacteria. As their metabolism is based on photosynthesis, they have also been termed blue-green algae. They may grow as filaments or colonies readily visible and identified (to the genus level) under a microscope.

Cyanobacteria are not, of themselves, a health hazard, but the toxins they produce (called cyanotoxins) are. For this reason Chorus and Bartram (1999) recommended that public health management be focussed on the cyanotoxins, and that cyanobacteria in drinking-water be managed as a chemical problem. The presence of cyanobacteria can be regarded as a trigger for monitoring for cyanotoxins.

Cyanobacteria inhabit all natural waters and become a problem only when they increase to excessive numbers (water blooms). Why population densities reach bloom proportions is a subject for much discussion and research. For example, Smith and Lester (2006) discuss the balance between cyanobacteria, zooplankton and fish in the Karori Reservoir in Wellington.

Concern about the effects of cyanobacteria on human health has grown in many countries in recent years for a variety of reasons. These include cases of poisoning attributed to toxic cyanobacteria and awareness of contamination of water sources (especially lakes) resulting in increased cyanobacterial growth. Cyanobacteria also continue to attract attention in part because of well-publicised incidents of animal poisoning.

Outbreaks of human poisoning attributed to toxic cyanobacteria have been reported in several countries including Australia, following exposure of individuals to contaminated drinking water, and the UK, where army recruits were exposed while swimming and canoeing. However, the only proven human fatalities associated with cyanobacteria and their toxins have occurred in Brazil (see section 9.1.2).

A diagram to rapidly assess the level of risk to health presented by a cyanobacterial bloom, by considering the treatment processes in place, is given in Figure 9.1, which assumes that treatment processes are working properly, and that they are capable of treating the levels of toxin or cell concentrations in the raw water. If either of these assumptions is invalid, the absolute levels of risk may be markedly different.

The purpose of this chapter is to provide:

- general information on cyanobacteria, the factors that control bloom formation, and their toxins and health significance
- advice on how the risk they present to consumers can be evaluated
- discussion on meeting the cyanotoxin compliance requirements of the DWSNZ

- guidance on how the public health risk associated with cyanotoxins can be managed.

9.1.1 Algal bloom development

Cyanobacteria are members of the community of phytoplankton (which means small free floating plants; however cyanobacteria are actually bacteria, have no defined nucleus, rather than plants, which do have a defined nucleus) and the bottom-dwelling organisms living on the surface of the sediments and stones in most water-bodies. The right combination of environmental conditions, particularly high nutrient levels, may cause their excessive growth (bloom formation), leading to blue, brown or greenish discolouration of water through the high population density of suspended cells, and to the formation of surface scums. Such accumulations of cells may lead to high toxin concentrations.

Some key factors affecting bloom development are:

a) Eutrophication

High levels of nutrients, usually phosphorus and nitrogen, can cause increases in natural biological production in rivers, lakes and reservoirs. These conditions can result in visible cyanobacterial or algal blooms, surface scums, floating plant mats and aggregations of plants attached to underwater surfaces. The levels of phosphorus in the water often limit the growth of cyanobacteria, but in a substantial number of lakes in New Zealand, the dissolved nitrogen concentrations are said to be the limiting factor despite cyanobacteria being able to fix nitrogen.

Some lakes are naturally eutrophic, but in most the excess nutrient input is of anthropogenic origin, resulting from wastewater discharges or run-off from fertilisers and manure spread on agricultural areas. Where nutrient concentrations in water bodies are naturally low, or have been lowered by remedial actions to limit nutrient run-off, high cyanobacterial populations may still develop where species that are able to fix atmospheric nitrogen are present. The relationship between nutrient levels and the predominance of different micro-organisms can be quite complex; for example, cyanobacteria grow in Antarctica.

Understanding the conditions that promote the growth of cyanobacteria in water bodies is useful for predicting whether cyanobacterial problems are likely to occur. A fundamental basis for cyanobacterial growth is the concentration of total phosphorus, as the total amount of phosphorus in the system limits the total amount of biomass that can occur. Water temperature is also an important factor for assessing the potential for cyanobacterial growth, as shown in Table 9.1. Data on additional factors, such as chlorophyll *a*, thermal stratification, local weather conditions influencing stratification and concentrations of nitrogen, can improve the assessment.

Table 9.1. Example assessment of the potential for high biomass of cyanobacteria based on environmental conditions [a]

Indicator	Very low	Potential for high biomass of cyanobacteria (blooms)			Very high
Total phosphorus (µg/L)	<10	12 – 25	>25 – 50	>50 – 100	>100
Water residence time	River, visible current	<1 month	<1 month	<1 month	≥1 month
pH	<5 - 6	<6 – 7	<6 – 7	<6 – 7	>7
Temperature (°C)	<10	10 – <15	15 – <20	20 – <25	≥25
Secchi disc during cyanobacteria season	≥2	<2 – 1	<1 – 0.5	<1 – 0.5	<0.5

[a] The higher the number of these conditions that are fulfilled, the greater the potential for high biomass This table has been taken from WHO (2015), which was adapted from Umweltbundesamt (2014).

In a Manawatu catchment study, *Phormidium* growth seemed more likely to occur when the dissolved reactive phosphorus concentration was <0.01 mg/L and dissolved inorganic nitrogen was >0.2 mg/L. Successful removal by flushing tended to be site specific. There was no correlation between anatoxin production and any of the physicochemical variants measured. Wood et al (2014).

b) Temperature

Provided nutrient and light levels do not limit cyanobacterial growth, blooms will persist in waters with temperatures between 15 and 30°C (and pH levels between 6 and 9), with maximum growth rates occurring at temperatures in excess of 25°C. There have been instances where blooms have occurred only during "a long hot summer". During "long hot summers", there may be fewer occasions of higher flow flushing away any build-up of benthic micro-organisms; eg. as discussed in Heath and Wood (2010).

c) Light

The intensity of daylight needed to optimise growth depends on the cyanobacterial species. Extended exposure to moderate to high light intensities is lethal for many species, although species that form surface blooms are tolerant of these conditions. Maximum growth results from intermittent exposure to high light intensities.

Cyanobacteria require little energy to function. As a consequence, they are able to grow at faster rates than other phytoplanktonic organisms at low light intensities.

d) Alkalinity and pH

Alkalinity and pH determine the chemical speciation of inorganic carbon, such as carbonate, bicarbonate and carbon dioxide. Low carbon dioxide concentrations favour the growth of several cyanobacterial species. Hence, water conditions such as low alkalinity and hardness and the consumption of carbon dioxide during photosynthesis by algae, increasing the pH, give cyanobacteria a competitive advantage. Health Canada (2000, edited 2002).

e) Gas vesicles

Many planktonic cyanobacteria contain gas vacuoles. These can be used to control buoyancy through the production of carbohydrates from photosynthesis. Buoyancy control allows movement to optimum depths in the water column for growth. For example, filling the vacuoles with carbohydrate allows the organism to sink down through thermal gradients to reach nutrients in the cooler layers.

f) Growth rates

Cyanobacteria have slow growth rates compared with other phytoplankton, which means they require long retention times in still water bodies for blooms to form. Turbulence and high flows are unfavourable to the growth of cyanobacteria, as they interfere with their ability to maintain optimum depths in the water column.

g) Population stability

Cyanobacteria have few natural enemies, which in combination with their ability to avoid sedimentation through buoyancy control, results in a low loss rate in their population. This compensates for their slow growth rates, once they have become established.

Blooms of benthic (attached or mat-forming) cyanobacteria can occur in rivers and at the edges of lakes. In rivers, benthic cyanobacterial mats are usually observed during periods of stable (but not necessarily) low flow. Benthic cyanobacteria are widespread throughout New Zealand rivers and are found in a wide range of water quality conditions, including oligotrophic waters (waters with low nutrients). The potential for these cyanobacteria to develop in waters with low nutrients requires vigilance from drinking-water operators using river water. The most common mat-forming benthic cyanobacterial genus in New Zealand is *Phormidium*. During stable flow conditions *Phormidium* mats can proliferate, at times forming expansive black/brown leathery mats across large expanses of river substrate. Flow conditions, substrate, water chemistry and species composition can influence the macroscopic appearance of benthic cyanobacterial mats and at times they may be confused easily with other algal groups, eg, diatoms, green algae. Microscopic confirmation should be undertaken to confirm whether cyanobacteria are the dominant component of attached communities. These mats also commonly detach from river/ lake substrates and float on the water surface, forming floating rafts in rivers, lakes and reservoirs. This is because under certain environmental conditions, or as mats become thicker (and bubbles of oxygen gas become entrapped within them), they will detach from the substrate and may accumulate along river edges. During these events the risk to human and animal health is higher due to accessibility of toxins to river users and bankside abstractions. Additionally, during these periods the cells are likely to be lysing and releasing toxins.

9.1.2 Health significance of cyanotoxins

Cyanobacteria do not multiply within the human body and are therefore not infectious. Many cyanobacteria, however, produce potent toxins. Exposure to these toxins, either in the cells or the water, through ingestion, inhalation or through contact with the skin, is therefore the primary health concern associated with cyanobacteria.

Generally, toxicity is not a trait specific for certain species; rather, most species comprise toxic and nontoxic strains. For microcystins, it has been shown that toxicity of a strain depends on whether or not it contains the gene for microcystin production (Rouhiainen et al 1995; Dittmann et al 1996) and that field populations are a mixture of both genotypes with and without this gene (Kurmayer et al 2002). Experience with cyanobacterial cultures also shows that microcystin production is a fairly constant trait of a given strain or genotype, only somewhat modified by environmental conditions (see various contributions in Chorus 2001). While conditions leading to cyanobacterial proliferation are well understood (the physiological or biochemical function of toxins for the cyanobacteria is the subject of many hypotheses: Chorus and Bartram 1999), the factors leading to the dominance of toxic strains over non-toxic ones are not. See WHO (2003) for reference details.

Cyanotoxins belong to a diverse group of chemical substances, each of which shows specific toxic mechanisms in vertebrates. Some cyanotoxins are strong neurotoxins (anatoxin-a, anatoxin-a(S), saxitoxins), others are primarily toxic to the liver (microcystins, nodularin and cylindrospermopsin) and yet others (such as the endotoxins) appear to cause health impairments (such as gastroenteritis), which are poorly understood. Assignment of health effects to specific species or toxins is often difficult because several cyanobacterial species may co-exist in a water body. Global data show that hepatoxins (those causing liver damage) occur most frequently, although there have been blooms producing neurotoxins that have led to animal deaths.

Table 2.3 of the DWSNZ lists provisional maximum acceptable values (PMAVs) for some cyanotoxins. Refer to Chapter 1: Introduction, section 1.6.2 for information about MAVs. Chorus (2012) collated cyanotoxin standards and regulations from several countries around the world.

The effects of cyanotoxins can be both acute and chronic, and protection against both long-term exposure, and short-term exposure, is required. While some short-term exposure can lead to health effects from which recovery is complete, it can also result in long-term damage to target organs:

Acute effects:

- dermal exposure, particularly if cells are accumulated under swimsuits and wet suits, may lead to skin irritations and allergic reactions (Pilotto et al 1997)
- symptoms involving irritation of internal and external mucous membranes, ie, gastro-intestinal or respiratory organs, eyes, ears, mouth and throat are also reported
- exposure to cell material of any cyanobacteria can cause illness such as fever, probably evoked by lipopolysaccharides contained in the cell wall of cyanobacteria (Keleti et al 1979; Lippy and Erb 1976)
- neurotoxins administered in mouse studies led to rapid respiratory arrest
- extensive kidney and liver damage following exposure to cyanotoxins has been reported (eg, Hawkins et al 1985)
- severe acute effects on human health appear to be rare, the only fatalities associated with cyanobacteria or their toxins having been reported in Brazil. In 1988 a new impoundment in Brazil developed an immense cyanobacterial bloom and there followed approximately 2000 gastroenteritis cases, 88 of which resulted in death. Cyanobacterial toxins were the likely cause (Teixera et al 1993), with contamination by heavy metals and pathogens ruled out. In 1996 (Jochimsen et al 1998; Carmichael et al 2001; Azavedo et al 2002), over 100 kidney patients developed liver disease and over 50 deaths were attributed to dialysis with water containing cyanobacterial toxins (Jochimsen et al).

Chronic effects:

- the key concerns of chronic effects associated with cyanotoxins are liver and kidney damage as well as tumour promotion, but there is a lack of clinical studies relating to chronic exposure (such as tumour promotion, eg, Ueno et al 1996, and liver damage), and this hinders the determination of safe levels for long-term exposure
- animal experiments have shown chronic liver injury from continuing oral exposure to cyanotoxins.

Members of the population at greatest risk when exposed to cyanotoxins are children (because their water intake:bodyweight ratio is higher than that of adults), and those who already have damaged organs that may be the target of the toxins. Recreational exposure is the most probable pathway for ingestion of a high dose of microcystins or nodularins. Any water sport that involves immersion of the head invariably leads to some oral uptake or aspiration. IARC (2010).

The health risks associated with cyanotoxins are greatest when cyanobacterial cell concentrations are high due to excessive growth (ie, bloom events). The highest cyanotoxin levels are usually contained within the cells (intracellular), and toxin concentrations dissolved in the water (extracellular toxins) are rarely reported above a few μg/L (Chorus and Bartram 1999). While the risks associated with cyanobacteria may rise and fall with the development and decay of bloom events, in some countries cyanobacteria may be present in water bodies over extended periods of time which results in continued exposure to subacute concentrations (Ressom et al 1994; Hitzfeld et al 2000), and the possibility of chronic health effects.

When a cyanobacterial bloom develops in a water body, exposure of those using the water for recreational purposes to hazardously high cyanotoxin concentrations will be most likely where cell densities are high, particularly in surface scums. Wind-driven accumulations of surface scums can result in toxin concentrations increasing by a factor of 1000 or more. Such situations can change within very short time periods, ie, hours. Children playing in shallow zones along the shore where scums accumulate are particularly at a risk.

The death of cyanobacterial cells, through the organism reaching the end of its lifecycle or through measures taken to control blooms, can result in higher than normal concentrations of extracellular toxin. Episodes of acute sickness have been reported after treatment of cyanobacterial blooms with copper sulphate to control the bloom, which then resulted in release of cyanotoxins into the water and breakthrough of dissolved toxins into drinking-water supplies.

It is preferable to control the health hazards associated with cyanotoxins by reducing the likelihood of bloom formation, rather than having to remove the cyanobacteria and any extracellular toxin present from the water. Monitoring of source water for evidence of the start of bloom development, or the potential for bloom formation, overcomes difficulties such as inadequate analytical methods associated with the measurement of cyanotoxins themselves.

Several regions in the world, e.g. Mexico, northern Africa and China, have a documented history of use of blue-green algae (*Spirulina* and *Nostoc* spp.) as a food source. In the twentieth century, blue-green algae supplements, which were primarily products that consisted entirely or partially of *Aphanizomenon flos-aquae* and *Spirulina* spp., represented an important economic activity, and were sold mainly in industrialised countries. Although producers and retailers of blue-green algae supplements maintain that batches that contain levels of microcystins above 1 μg/g dry weight are not marketed, independent investigations of microcystin contamination in these publicly available products have demonstrated toxin concentrations of up to 35 μg microcystin-LR equivalents/g dry weight. Although samples with toxin contamination greater than 10 μg microcystin-LR equivalents/g dry weight are the exception, several independent analyses detected more than 1 μg microcystin-LR equivalents/g dry weight in 50–100% of the blue-green algae products tested. From IARC (2010).

9.1.3 Taste and odour caused by cyanobacteria

Cyanobacteria have, for a long time, been recognised as a nuisance in the drinking-water industry because of the ability of several taxa to produce earthy and musty smelling compounds, notably geosmin and 2-methyl isoborneol (2-MIB), for which the odour detection thresholds of less than 10 ng/L are remarkably low amongst sensitive individuals.

The cyanobacterial genera that are known to produce geosmin are *Anabaena, Aphanizomenon, Lyngbya, Microcystis, Oscillatoria, Phormidium, Schizothrix* and *Symploca* (Perrson 1983, cited in Chorus and Bartram 1999). All of these (except *Symploca*) are also known to include toxin-forming species and strains. Because of this, the possibility of using odour compounds as an early warning for the development of toxin-producing cyanobacterial blooms has been considered. However, there is no evidence of a correlation between toxin production and the production of taste- and odour- producing compounds that would provide a warning of toxicity. It is very unlikely that the production of taste and odour compounds is biochemically connected to the production of cyanotoxins (Chorus and Bartram 1999).

9.1.4 Occurrence of toxic cyanobacteria internationally and in New Zealand

Not all cyanobacteria that have been found to produce toxins have been identified in New Zealand. Table 9.2 lists, in alphabetical order some of the species found internationally to produce toxins, the nature of the toxin produced and where the species was found. This list is continually increasing, and should not be regarded as definitive. It is provided as a guide to those trying to determine whether a cyanobacterial species found in a water may be a toxin producer.

Table 9.2: Toxic cyanobacteria species and their geographical distribution

Toxic species	Cyanotoxin	Location with toxin identified
Anabaena bergii	cylindrospermopsin	Australia[1]
Anabaena blooms	anatoxin-a	Germany
Anabaena circinalis	microcystins	France
Anabaena circinalis	saxitoxins	Australia
Anabaena flos-aquae	microcystins	Canada, Norway
Anabaena flos-aquae	anatoxin-a	Canada
Anabaena flos-aquae	anatoxin-a(S)	Canada
Anabaena plantonica	anatoxin-a	Italy
Anabaena spp.	microcystins	Egypt
Anabaena spp.	anatoxin-a	Finland, Ireland
Anabaena spp.	anatoxin-a (minor amounts)	Japan
Anabaena spp. (*flos-aquae, lemmermannii, circinalis*)	microcystins	Finland
Anabaena lemmermannii	anatoxin-a(S)	Denmark
Anabaena?	microcystins	Denmark
Anabaenopsis millenii	microcystins	Greece
Aphanizomenon	anatoxin-a	Germany
Aphanizomenon flos-aquae	saxitoxins	USA
Aphanizomenon ovalisporum	cylindrospermopsin	Israel, Australia[2]
Aphanizomenon sp.	anatoxin-a	Finland
Aphanocapsa cumulus	microcystins	Brazil[3]
Arthrospira	microcystins	New Zealand – see Table 9.3
Cylindrospermopsis raciborskii	cylindrospermopsin	Australia, Hungary, New Zealand[4]
Cylindrospermopsis raciborskii	saxitoxins	Brazil
Cylindrospermum sp.	anatoxin-a	Finland
Haphalosiphon hibernicus (soil isolate)	microcystins	USA
Lyngbya wollei	saxitoxins	USA
Microcystis aeruginosa	microcystins	Worldwide
Microcystis flos-aquae	microcystins	Australia[2]
Microcystis sp.	anatoxin-a (minor amounts)	Japan
Microcystis viridis	microcystins	Japan
Microcystis wesenbergii	microcystins	Japan[5]
Microcystis botrys	microcystins	Denmark
Nodularia spumigena	nodularins	Australia, Baltic Sea, New Zealand

Toxic species	Cyanotoxin	Location with toxin identified
Nostoc spp.	microcystins	Finland, England
Oscillatoria limosa	microcystins	Switzerland
Oscillatoria sp. (benthic)	anatoxin-a	Scotland
Oscillatoria sp.?	anatoxin-a	Ireland, New Zealand[6]
Phormidium (benthic)	microcystins, anatoxin-a, homoanatoxin-a	New Zealand – see Table 9.3
Planktothrix agardhii	microcystins	China, Denmark, Finland, Norway
Planktothrix formosa	homoanatoxin-a	Norway
Planktothrix sp.	anatoxin-a	Finland
Planktothrix sp.	saxitoxins	Italy[7]
Planktothrix mougeotii	microcystins	Denmark
Pseudanabaena sp.	microcystins	Morocco[8]
Raphidiopsis curvata	cylindrospermopsin	China[9]
Synechocystis sp.	microcystins	Morocco[8]
Umezakia natans	cylindrospermopsin	Japan

Modified from Chorus and Bartram (1999)

1 Schembri et al 2001 2 Queensland Government 2004 3 Domingos et al 1999
4 Wood and Stirling 2003 5 Namikoshi et al 1992 6 Hamill 2001
7 Pomati et al 2000 8 Oudra et al 2002 9 Li et al 2001

Table 9.3 is more specific to New Zealand, and provides more detail about toxic cyanobacterial genera that have been found in New Zealand and the range of toxins they produce worldwide. Cyanotoxins shown in bold face are known to be produced by species from the associated genera in New Zealand.

Table 9.3: Cyanobacteria genera known to occur in New Zealand fresh waters and the toxins they are known to produce

Genera	Cyanotoxins known to be produced
Anabaena	anatoxin-a*, anatoxin-a(S), LPS, microcystins*, saxitoxins, cylindrospermopsin
Anabaenopsis	microcystins
Aphanocapsa	microcystins
Aphanizomenon	anatoxin-a, cylindrospermopsin, LPS, saxitoxins, microcystins
Arthrospira	microcystins
Cylindrospermum	cylindrospermopsin[1], LPS
Cylindrospermopsis	cylindrospermopsin[2], saxitoxins
Lyngbya	aplysiatoxins, antillatoxins, kalkitoxin, lyngbyatoxin-a, saxitoxins
Microcystis	anatoxin-a, cylindrospermopsin, microcystins, LPS, saxitoxins
Nodularia	nodularin
Nostoc	microcystins*, BMAA (beta-methylamino-L-alanine)[3]
Oscillatoria	anatoxin-a[4], aplysiatoxins, LPS, microcystins*, anatoxin-a(S)
Phormidium	microcystin*, homoanatoxin –a[5], anatoxin-a and other toxin(s) have yet to be defined
Planktothrix	microcystins*, homoanatoxin-a, anatoxin-a, aplysiatoxins, saxitoxins, homoanatoxin-a
Pseudanabaena	microcystins
Raphidiopsis	cylindrospermopsin, anatoxin-a* homoanatoxin-a, microcystins*
Snowella	microcystins
Synechocystis	microcystins

Woronichinia	microcystins

Data source: Kouzminov 2001, Wood 2005

1 Stirling and Quilliam 2001. Rigorous identification of the causative species not carried out. This taxon is likely to have been *Cylindrospermopsis* given the habitat sampled.

2 Wood and Stirling 2003.

3 Cox et al 2003.

4 Hamill 2001.

5 Wood et al 2007.

* The results of cyanotoxin testing on environmental samples indicate this toxin is produced by species from the associated genera in New Zealand Wood 2005.

There have been two reports of cyanobacterial data collected from waters throughout New Zealand, Podivinsky and Williamson (2009); Nokes (2010). A key finding (Nokes 2010) was:

> Where substantial blooms develop, toxin concentrations readily exceed provisional maximum acceptable values (PMAV) by a factor of 10, and in some instances by four-to-five orders of magnitude. Cyanobacteria are an extremely dangerous hazard in drinking and recreational waters because of the speed at which cyanobacterial toxin producers multiply, the concentrations toxins can reach, the difficulty in removing toxins from the water, and the severity of the health effects that can be associated with them. The most effective strategy for defence against them is to take measures to stop blooms developing.

9.2 Risk management

9.2.1 Assessment of risk

Assessing the risk posed by cyanobacterial toxins, or the potential for development of cyanobacterial blooms, and linking this to effective measures for the protection of public health within available resources, is complex. Situation assessment may be proactive (ie, carried out with the intention of preventing the bloom from developing), to determine whether contingency planning is required or to initiate long-term action, such as pollution control to minimise bloom formation, for example; or it may be reactive (ie, carried out as a response to the development of the bloom), such as assisting in interpretation of specific local events or conditions to provide information on which to base emergency or incident responses.

The type of information that could be used to assess the risk due to cyanobacteria is summarised in Table 9.4.

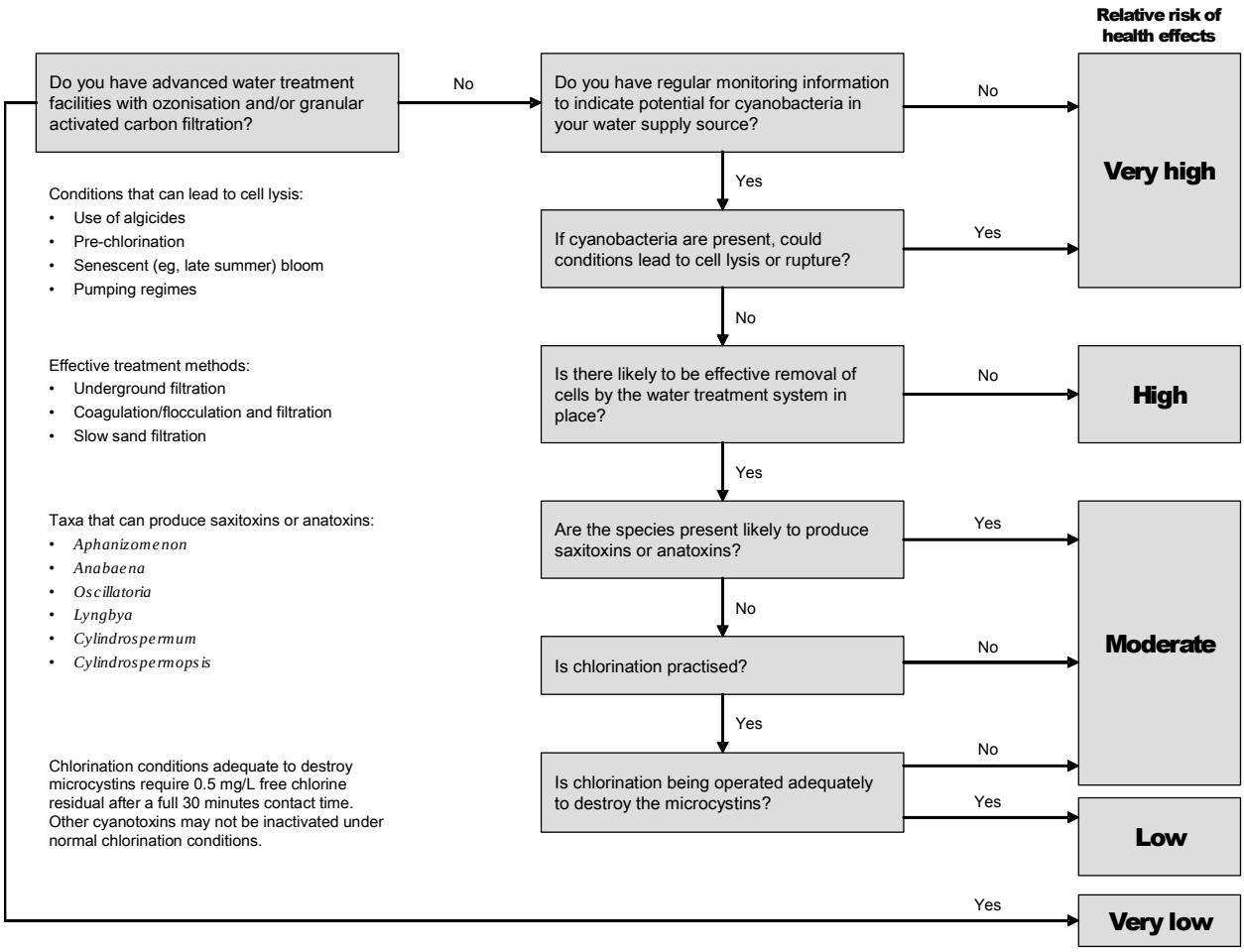
Table 9.4: Information that may help in situation assessment and management

Observation	Sources of information	Management options
Potential for bloom formation	Water quality monitoring data (nutrients, temperature, etc)	Basis for proactive management (ie, actions to stop conditions developing that will allow bloom formation)
History of bloom formation	Cyanobacterial blooms may follow marked seasonal and annual patterns	Can inform proactive management
Monitoring of cyanobacteria and/or cyanotoxins	Turbidity, discolouration, odour, cell microscopic identification, cell counts and toxin analysis provide increasingly reliable information	Possible basis for proactive management provided cell counts are monitored regularly
Scum scouting	In areas of high public interest the general public and untrained agency staff may play a role in identifying and reporting obvious hazards such as scums	Possible only during event and enables only reactive management (ie, taking actions after the bloom has developed)
Reporting of animal deaths and human illness	Requires both the willingness of the community to assist in providing the data and a mechanism for data collection which may not exist	Possible only during event and informs only reactive management
Epidemiological detection of disease patterns in the human population	Requires both effective reporting and large-scale effects before detection likely	Normally well after an event; can inform future management strategies

From Chorus and Bartram 1999.

A diagram to rapidly assess the level of risk to health presented by a cyanobacterial bloom, by considering the treatment processes in place, is given in Figure 9.1, which assumes that treatment processes are working properly, and that they are capable of treating the levels of toxin or cell concentrations in the raw water. If either of these assumptions is invalid, the absolute levels of risk may be markedly different.

Figure 9.1: Rapid assessment of the level of risk posed by toxic cyanobacteria in a drinking water source



Modified from WHO 1997, and Chorus and Bartram 1999.

Chorus (2005) and Burch (2008) have summarised current approaches to cyanotoxin risk assessment, risk management and regulations in different countries. The approach taken by different countries varies from informal arrangements where information is gathered by different organisations and collated by one group for non-specific publication, to formal guidelines and regulations. Most countries with specified values use the WHO tolerable daily intake (TDI) for microcystin-LR with slight variation (from 0.84 to 1.5 μg per L). Monitoring and trigger points for cyanotoxin testing (rather than cyanobacteria testing) and for actions to neutralise cyanotoxins varies considerably between countries. For example, Brazil has an upper tolerance of 10,000 cells per mL or 1.0 mm^3 biovolume, whereas Australia has an upper limit of 6500 cells per mL, with cyanotoxin testing coming in below these levels.

An attempt to predict the vulnerability of reservoirs in Australia to cyanobacterial blooms has resulted in a vulnerability index (Leigh 2010). The analysis suggests that strong links exist between the physical environmental of dammed river systems, their physicochemical characteristics and algal ecology. The vulnerability index used parameters which satisfied the following four conditions:

1 correlation with water quality was well established in the literature

2 parameters were easily calculated from readily available data on reservoir or catchment characteristics

3 parameters were not strongly correlated with each other

4 parameters were relatively static or predictable though time so that the index was unaffected by substantial spatial and temporal variation.

9.3 Monitoring

The design of monitoring programmes for cyanobacteria and their toxins is more challenging than programmes for other pathogens or chemical determinands. Factors that contribute to the added complexity are their ability to grow in open waters, not necessarily near a particular source; scums of cyanobacteria may be shifted and concentrated by wind; toxins may be contained in their cells, or dissolved in the water, be absent, or develop very quickly.

Monitoring programmes for these organisms need to be tailored to the characteristics of each body of water. They also need to be flexible to take account of changes in the risk the toxins present with time and location. Collection of historical information regarding blooms and growth conditions, and identification of patterns of cyanobacterial growth can be used to help focus the monitoring programme on critical periods and locations in the water body of interest.

Operational monitoring (monitoring to assist in the operation of a supply) includes both regular inspections and testing. In small and remote systems, great attention should be given to inspections of systems, to check that the preventive measures used to protect water supplies are functioning.

The frequency of catchment assessments will depend on the characteristics of each site, the source of raw water, the time the water remains in storage, and the subsequent treatment that is provided. As well as regular inspections in the immediate vicinity of the intake area, every catchment where there is habitation or free public access should be comprehensively inspected at least once a year for potential sources of pollution.

To make monitoring programmes as efficient as possible a structured strategy is recommended.

Level 1 Visual inspection for transparency, discolouration:

- move to Level 2 if poor transparency and discolouration are observed.

Visual inspection for scums, detached, accumulated cyanobacterial and mats:

- move to Level 3, if visual inspection indicates that cyanobacteria are present.

Measurement of temperature and assessment of structure of the water column:

- move to Level 3, if the temperature is more than 18°C, or there is persistent stratification of the water body.

These inspections should be made weekly or fortnightly.

Level 2 Measurement of nutrient concentrations:

- dissolved nitrogen and total phosphorus should be measured. Phosphorus can be the nutrient that limits cyanobacterial growth, but in a substantial number of New Zealand lakes, growth is nitrogen-limited.

Measurement of hydrological characteristics, which should include:

- retention times of water in lakes
- the persistence of thermal stratification of lakes
- the accrual period in rivers. The accrual period is the amount of time available for growth of periphyton (attached algae) in rivers, ie, the amount of time between flood events.

Measurement of light penetration:

- penetration of light below the warm upper mixed layer in a stratified water body will favour cyanobacterial growth.

Inspection of the catchment to identify the source of the nutrients:

Information about factors in this level, which are likely to influence bloom formation, together with cell counts, will help to develop the ability to predict bloom formation. Monthly measurement is satisfactory, at least or the first two years; more frequently if there are rapid changes in the nutrient concentrations.

Level 3 Determination of biomass of cyanobacteria (at least two weekly; weekly or more frequently if Alert Level 1 (see section 9.7.1 and Figure 9.5) is exceeded):

- identification of cyanobacterial taxa and population densities is a good basis for assessing risk
- use the Alert Levels framework (see section 9.7.1 and Figure 9.5) to determine what action should be taken
- move to Level 4 if Alert Level 1 is exceeded.

Level 4 Determination of toxicity of the water or toxin concentrations (fortnightly is sufficient, unless there is reason to believe toxin concentrations are changing rapidly and are close to 50 percent of a MAV):

- this level of monitoring allows more accurate assessment of the levels of toxins present in the water
- use the Alert Levels framework (see section 9.7.1 and Figure 9.5) to determine what action should be taken.

The collation of monitoring information gathered during one bloom event, (water appearance, water temperature, preceding weather conditions, hydrology (water levels and flows), nutrient levels, cell counts, cyanobacterial taxa, and toxin levels) will provide a valuable basis for predicting when future blooms may occur and the levels of risk associated with the bloom as it develops.

Cyanotoxin levels change with environmental and hydrological conditions, and toxin concentrations may be very low. Current sampling practices (e.g. grab samples) provide only a snapshot of cyanotoxins present at one point in time and may miss areas or times of highest risk, and fail to give early warning. These are particular issues when sampling rivers where continuous flows transport toxins rapidly. A passive *in situ* methodology known as solid phase adsorption toxin tracking technology (SPATT) has been shown to be a simple and sensitive means of warning of toxic micro-algal bloom development and associated shellfish contamination in the marine environment. Wood et al (2010) describe trials using SPATT in rivers. SPATT does not measure toxin levels within cyanobacterial cells; it measures that fraction of a toxin that has been released from cells into water. Although it is not possible to relate the levels of anatoxins in the SPATT to concentrations in the river water, this technique should provide a very useful management tool.

9.4 Compliance

Cyanotoxins are chemical determinands, and like other chemical determinands can be given Priority 2 classification. However, the way this assignment is made, and the consequent compliance requirements, is different from those of other chemical determinands.

The factors leading to these differences are:

- cyanobacteria may appear irregularly, or annually
- cyanotoxins may be present at potentially health-significant concentrations for only short periods, so monitoring throughout the whole year is unnecessary
- cyanobacterial numbers, and, hence, cyanotoxin concentrations, can increase rapidly, therefore higher monitoring frequencies than for other chemical determinands are required to ensure that the water supplier is aware of toxin levels reaching health significant concentrations
- unlike most chemical determinands, the health effects of cyanotoxins are acute at low concentrations and potentially fatal, although there may also be long-term effects.

Some compliance requirements for cyanotoxins result from a toxin being assigned as a Priority 2 determinand (DWSNZ section 7.3). Other compliance requirements have also to be met to ensure that the water supplier has systems in place to determine when cyanotoxins reach potentially health significant concentrations, and to manage the risk to their consumers. These requirements are contained in section 7.2 of the DWSNZ.

Section 7.2 (DWSNZ) lists four sets of requirements, two of which specify objectives that have to be met for compliance.

1 Collect information about the source that will assist in determining:

   a) whether cyanobacteria are present in the source water

   b) when cyanotoxin concentrations (in the source water) reach or exceed potentially health-significant concentrations (greater than 50 percent of MAV).

2 Develop a protocol, approved by the drinking water assessor, that:

   a) identifies which determinands or observations are to be monitored for assessing the development of cyanobacteria

   b) specifies the actions that will be taken in the event of any cyanotoxins reaching a potentially health-significant concentration

   c) initiates a cyanotoxin monitoring programme in the source water when the protocol indicates that the risk of cyanotoxins being present has reached a predetermined level based on evidence from 7.2(1)(b).

The ways in which these objectives are to be met are undefined. Risk management protocols that best suit supply circumstances can therefore be developed. This approach has been taken because of the variable relationship that exists between cyanotoxin concentrations in a water and surrogate parameters, such as cell count. These should be developed as a section of the Water Safety Plan (WSP) for the water supply. Consequently, although the Alert levels framework based on overseas experience is presented in section 9.7.1, the cell counts used to define the Alert levels should be considered as guides only. Some references about the conditions that alter cyanobacteria growth and distribution include: Ahern et al 2008; Baldwin et al 2008; Bayer et al 2008; Burger et al 2008; Downs et al 2008; Kobayashi et al 2008; Redden and Rukminasari 2008; Ryan et al 2008; Shaw et al 2008.

Experience of managing cyanobacterial blooms in New Zealand waters is limited. The first set of requirements in section 7.2 (DWSNZ) therefore obliges the water supplier to gather information to provide a scientifically defensible basis for the protocol that has to be prepared in the second set of objectives. Measurements or observations that could be monitored to meet the first set of requirements include:

- source appearance
- water temperature
- pH
- nitrogen and phosphorus concentrations
- water level or flow (cyanobacteria bloom events normally have happened in low flow waters)
- taste and odour complaints
- cell counts of cyanobacteria
- determination of the presence of stratification in the water column (lakes and reservoirs)
- direct toxin measurement.

Experience may show that other parameters correlate well with the development of cyanobacteria in source waters. Sharing information between water suppliers in the same area or drawing from the same source, will assist in making best use of what has been learnt from past algal bloom events.

The protocol required for compliance requirement 7.2(2) is developed from the information collected as a result of meeting requirement 7.2(1). Completion of this protocol is not required for compliance, if its development is waiting for the data collection of requirement 7.2(1), and this collection is underway. As part of this protocol the water supplier must specify what actions will be taken to manage the health risk when a cyanotoxin reaches a potentially health-significant (greater than 50 percent of its PMAV) concentration. Section 9.7 of this chapter provides information that will assist in identifying the actions needed in these circumstances. These actions must be incorporated in the water safety plan (WSP – formerly known as a public health risk management plan, PHRMP).

The fourth compliance requirement of section 7.2 (DWSNZ) is:

4 notify the DWA when the protocol shows the development of cyanobacteria and cyanotoxins in the source water has reached a stage where source water cyanotoxins are approaching 50 percent of the PMAV.

It is important to keep the DWA regularly informed of the outcome of monitoring results so that, should the results indicate greater than 50 percent PMAV, the DWA can assign Priority 2b in a timely manner to protect public health. After Priority 2b has been assigned, it necessary for the supplier to monitor the source water, raw water and the treated water for cyanotoxins (section 7.3.2).

The completion of requirements 7.2(1) and (2) is needed to meet this requirement. Priority 2 determinands are usually identified through the Priority 2 Chemical Determinands Identification Programme. This is not possible for cyanotoxins because of the large and rapid variability in their concentration. The Priority 2 classification of cyanotoxins is therefore made by the DWA using monitoring information provided by the water supplier, requirement 7.2(4).

After a cyanotoxin has been classified as a Priority 2 determinand, the requirements of section 7.3 (DWSNZ) must be met. See section 9.5.2 of this chapter for information about recognised laboratories.

Samples for cyanotoxin testing must be taken twice-weekly from the water leaving the treatment plant. Either through the success of the actions set out in the WSP, or because of a subsidence in the size of the bloom causing the high cyanotoxin levels, the toxin concentration will eventually drop. Once the cyanotoxin concentration in three successive samples (taken at the required frequency of twice weekly) has been found to be less than 50 percent of its MAV, and the concentration in each sample is less than the previous, the classification of the cyanotoxin is returned to Priority 3.

For other chemical determinands, monitoring of Priority 3 determinands is generally not required. This is because sufficient evidence should have been collected to establish that there is only a low likelihood of the determinand appearing in the water again at concentrations exceeding 50 percent of its MAV. This assumption cannot be made for cyanotoxins because of the possibility of the redevelopment of a bloom. Therefore, although a cyanotoxin may be reclassified as Priority 3 and monitoring of the toxin itself may cease, the monitoring requirements of the protocol developed in section 7.2 of the DWSNZ must continue.

9.5 Sampling and testing

9.5.1 Sample testing

As with other testing required for demonstration of compliance with the DWSNZ, a Ministry of Health recognised laboratory must be used. Methods for analysis of the cyanotoxins are given in the datasheets (Volume 3, Part 2.4). A discussion on cyanotoxin analyses appears in a publication by the Cawthron Institute (2005).

Some laboratories have IANZ accreditation for the identification and enumeration of cyanobacteria. Further, because of the intermittent need for these tests, the instrumental analyses are not routine so can be expensive.

A list of the New Zealand laboratories recognised by the Ministry of Health to conduct analyses for cyanobacteria and related toxins may be found on the Ministry of Health website www.health.govt.nz/water, 'Publications'. See the latest edition of the *Register of Recognised Laboratories: Drinking water supplies* (updated annually).

Whichever laboratory is used for testing, advice should be obtained from the laboratory about sampling containers for the particular determinand in question, before collecting the samples, because there is some evidence that common additives in plastics could contaminate water samples and co-elute with microcystins to give erroneously high readings (van Apeldoorn et al 2007).

9.5.2 Sample collection

Sampling to obtain information to help in the management of cyanobacteria may be undertaken for three reasons:

- determination of nutrient concentrations
- assessment of the cyanobacterial population for both number and species
- determination of cyanobacterial toxin concentrations.

The design of monitoring programmes for cyanobacteria is challenging due to factors such as:

- their ability to grow in open waters
- the ability of some species to regulate their buoyancy
- their ability to form scums that may be shifted and concentrated by wind
- the interactions of buoyant cells with the surface drift currents created by wind
- the ability of some species to produce toxins that may be contained in their cells or dissolved in water.

The heterogeneous (mixed) and dynamic nature of many cyanobacterial populations can make sampling site selection difficult. A flexible response to the current situation when choosing the sampling sites may, at times, be more appropriate than following a rigid programme. Alternatively, fixed sites may always be sampled within a broader monitoring programme, to provide linear time series, and supplemented with sampling of sites currently harbouring cyanobacterial scums.

The selection of sampling sites is a key factor in collecting representative samples. The following should be considered:

- the history, if available, of cyanobacterial population development and occurrence of toxins in the water body, or similar water bodies nearby. This information may indicate sites most likely to harbour scums/mats
- specific incidents, such as animal deaths or human illness, may provide indications of 'high risk' sites
- morphometric and hydrophysical characteristics of the water body (eg, exposure to wind or thermal stratification) may help identify sites which are prone to scum accumulation
- prevailing weather conditions, particularly wind direction, which can lead to scum accumulation along certain shorelines
- local logistical resources, accessibility and safety factors.

The nature of the information required should determine where samples are taken and how.

Two types of sample can be taken: grab samples and composite samples. Grab samples are single samples used to provide information about a particular site at a particular time. Where there may be uneven distribution of a determinand, either in space (geographical location, water depth) or time, a composite sample may be necessary. This type of sample is designed to gather representative information about the determinand that cannot be provided by a single sample. A number of grab samples at different locations or times may be taken then mixed together, or the water may be sampled continuously while changing the location of sampler intake. The latter approach may be used in sampling at different depths, for example.

Concentrations of nutrients, cyanobacteria and cyanotoxins are unlikely to be the same throughout a water body because of stratification within it, and other factors such as wind and currents that may shift cyanobacterial masses. Unless the factors that may affect the concentration of a determinand within the water body are understood, interpretation of the data from a single grab sample is likely to be difficult.

Single grab samples are valuable when a water supplier wishes to know the cyanotoxin concentration entering the treatment plant at a particular time, or, the greatest cyanotoxin concentration that may challenge the treatment plant. When identifying the sampling location to gather worst case information, consideration needs to be given to such factors, as the ability of some species to be blown by the wind on the surface of the water, or to accumulate at different depths in the water.

Samples should also be included from points where previous samples have revealed unsatisfactory water quality. When assessing the risk associated with cyanotoxins entering the reticulated water, water suppliers should collect samples at locations and times likely to reveal the highest concentrations of cyanobacteria and their toxins.

Site inspection should be carried out at the time samples are taken. From this the following should be recorded:

- weather conditions, including the wind direction and velocity
- whether the bottom of the lake/reservoir is visible at a depth of about 30 cm along the shore line
- any distinct green, blue-green, or brown colouration of the water
- a distinctive odour
- signs of cyanobacteria as blue-green streaks on the surface or scum.

This information may assist in interpretation of sample analysis.

River intakes should also be inspected for benthic (attached) cyanobacterial mats. These appear as expansive, thick black or dark-brown slimy mats on the riverbed or growing on intake structures. The mats commonly detach from the substrate and float on the water surface, accumulating behind obstructions in the river channel or in lakes / reservoirs.

An underwater viewer is generally required to assess the extent of benthic cyanobacteria. For example a Nuova Rade underwater viewer (which is available from http://www.marisafe.com/store/viewItem.asp?ID=506050907). These viewers allow a clear view of the stream bed with no interference from surface turbulence and reflection. They also enable definition of a more-or-less standard area of the stream bed at each survey point (ie, equivalent to a quadrat in terrestrial ecology).

Samples can be collected for identification or analysis for toxins by scraping mats from stones / intake structures, or collecting samples of the buoyant scums. Water samples taken from intakes will allow estimates of cells per mL in the raw water to be determined, but may underestimate risk from extracellular toxins or from sporadic inputs of cyanobacterial mats as they detach from the riverbed and enter intakes. The *New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters – Interim Guidelines* (2009) includes excellent methodological information and diagrams for monitoring and sampling of benthic cyanobacteria. See in particular sections 3.5, 3.6, 3.7 (pp 17–19), and Decision Charts 2 and 3.

Appropriate and careful handling of samples both prior to and during analysis is extremely important to ensure an accurate determination of toxin concentration. Some cyanotoxins are readily degraded both photochemically (ie, in light) and microbiologically. Samples should be kept refrigerated and in the dark prior to analysis, and should not be exposed to strong light during the preparation and analytical procedures.

The following provides detailed guidance for sample collection and handling, and is based on the Queensland Harmful Algal Bloom Response Plan, 2002 (developed by the Department of Natural Resources and Mines, Environmental Protection Agency, Queensland Health, Department of Primary Industries, Local Governments and water storage operators, Australia). It is recommended that advice from the laboratory carrying out the testing, or other local experts, be sought to determine whether the procedures given here need to be modified to suit the requirements of the laboratory or the conditions of the water source. Details for benthic monitoring and sampling have been adapted from the *New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters* – Interim Guidelines (2009). See also Biggs and Kilroy (2000).

Procedures for sample collection and sample handling

a) Method for sample collection

i) *Water samples for phytoplankton identification and enumeration*

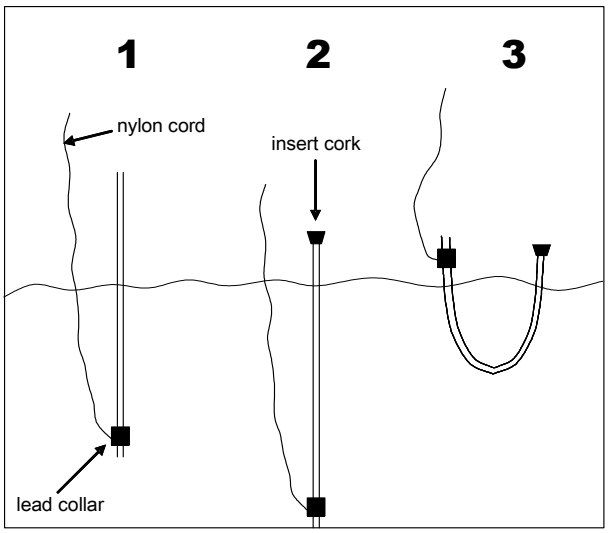
Ideally sampling should be conducted from a boat. Depth integrated samples are recommended for open water sampling where a representative sample of the water column is desired. The samples should be collected using a flexible hose-pipe sampler. A rigid pipe can be fitted with a one-way valve, which tends to simplify the operation of withdrawing the pipe and sample from the water. The length of the sample pipe should reflect the appropriate depth to which the cells are likely to be mixed. This may vary from approximately 2–10 metres depending on the degree of stratification and exposure of the water body to the influence of wind. When the mixing status is unknown, a five-metre long pipe is recommended, however a two-metre long pipe may be more appropriate in shallower areas.

The inner diameter of the pipe should be at least 2.5 cm and flexible pipes are generally more practical than rigid pipes for pipe lengths greater than two metres. The recommended method for the use of the hose-pipe sampler is show below.

The following equipment is needed in order to take samples:

- integrated hose-pipe sampler: 5 m length of 2.5 cm diameter plastic piping with a weighted collar at one end (see Figure 9.2)
- a cord attached to the hose and boat
- a rubber cork to fit one end of the hose
- a bucket
- a sample bottle and lid (minimum 200 mL capacity).

Figure 9.2: Procedure for use of the integrated hose-pipe sampler for planktonic cyanobacteria and cyanotoxins



The procedure for collecting the sample is as follows:

1 Attach a cord to one end of the hose and the boat to prevent accidental loss of the hose.

2 Holding the hose at the top end, rapidly drop the weighted end of the hose-pipe into the water to a depth of about 5 m.

3 Return hose to the boat without inserting the rubber cork.

4 Rinse the hose.

5 Repeat the procedure, but this time insert the cork into top end of the hose (so that the end is held in the hand).

6 Pull the bottom end of the hose to surface using the cord, so that the tube is in a U-shape (see Figure 9.2).

7 Lower the weighted end of the hose into a bucket and remove the cork. Ensure that the entire contents of the hose are emptied into the bucket.

8 Mix the contents of the bucket and then transfer part of the contents into a sample bottle, leaving a 25 mm gap at the top of the bottle. Discard the rest of the contents of the bucket.

NOTE: Some species of phytoplankton can cause skin irritation. If sampling from an area that has a high level of phytoplankton, minimise contact with the water during sampling by wearing appropriate protective clothing, in particular gloves. Normal hygiene precautions such as washing off any splashes and washing hands before eating or drinking should be observed at all times. When not in use, the hosepipe sampler and bucket should be kept clean and stored in a dark shed or cupboard.

Where sampling from a boat is not practicable, eg, a river, bank, shoreline, bridge or valve tower sampling should be assisted by the use of a pole-type sampler. The bottle is placed in a cradle at the end of an extendable pole to avoid contamination of shoreline-accumulated scums.

For monitoring and sampling benthic cyanobacteria, upon arriving at a survey area, spend approximately five minutes looking along a 30–60 m section of river bed for the presence of cyanobacterial mats. Ensure that this section includes some runs and riffles. Mark out four transects in the selected area by placing marker rocks along the water's edge, approximately 10–15 m apart. Record details, including site, date, time, etc, and note the general presence/ absence of cyanobacterial mat and the presence of any detached mat along the shoreline.

Assemble the underwater viewer and, starting at the downstream end, wade into the stream at right angles to the water's edge. Go out to a depth of approximately 0.6 m (Figures 9.3 and 9.4). A standard maximum depth of 0.6 m should be used at all sites, where possible. In shallow rivers, the transects may span the entire width. Record the maximum distance and depth for transect 1. Hold the underwater viewer about 20 cm under the water more or less on the transect line. The area of view should not be one that has just been walked over. Holding the viewer steady and as vertical as possible, estimate to the nearest 5 percent the proportion of the area you see which is occupied by the cyanobacterial mat. Coverage should only be recorded if mats are greater than 1 mm thick. It is useful to record the presence of thin mats as well.

Figure 9.3: Benthic cyanobacteria monitoring and sampling schematic of layout of transects and survey areas

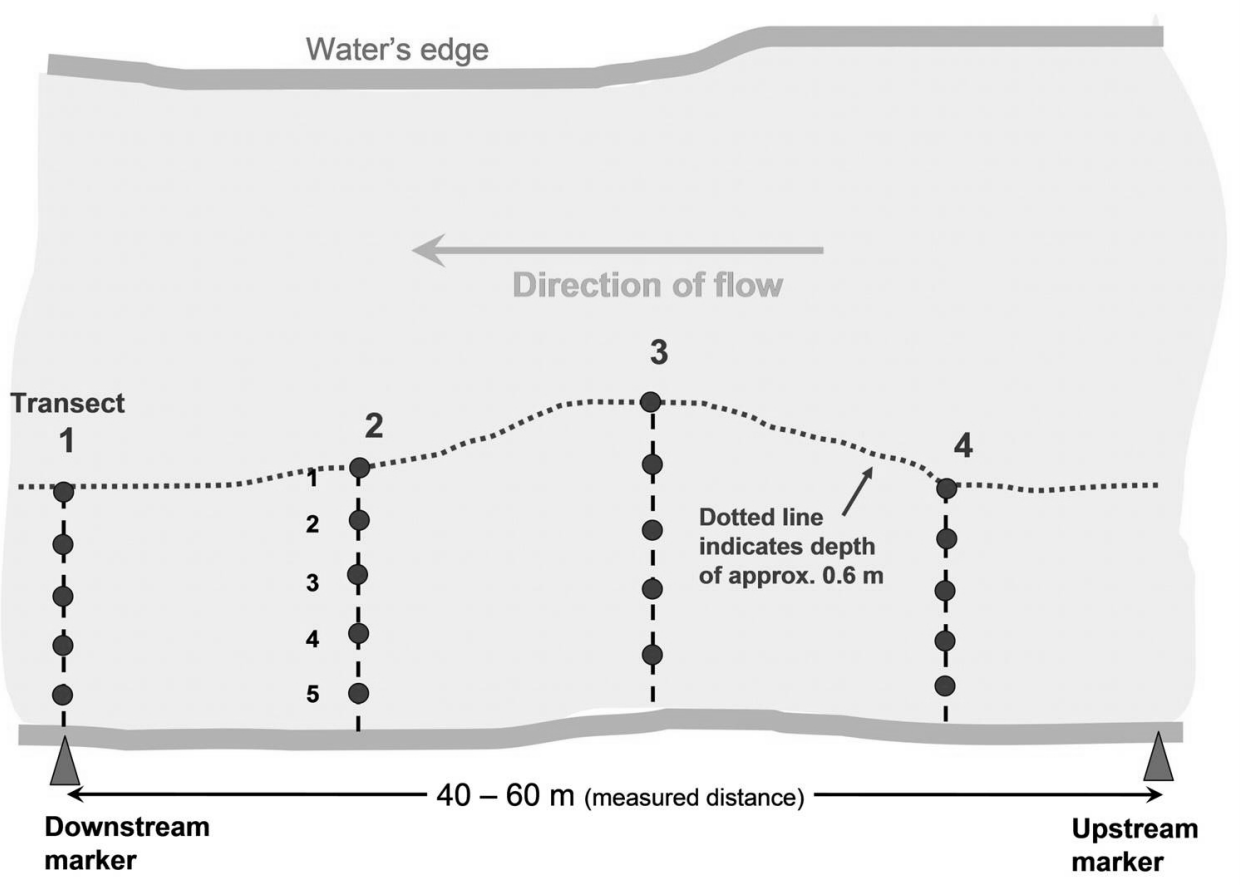
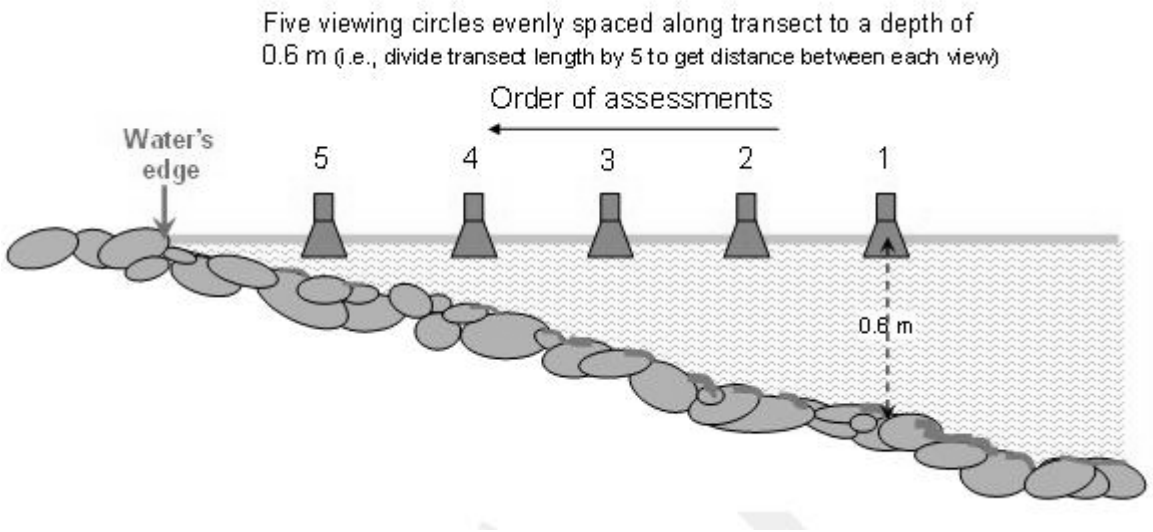


Figure 9.3 illustrates a benthic cyanobacteria monitoring and sampling schematic of layout of transects (numbered in red) and survey areas (red circles, numbered in black) at a site (not to scale). The numbering indicates the order in which assessment are made. The transects are spaced evenly along the survey reach. It may not always be possible to have five viewer results (ie, steep sided rivers). In these circumstances take as many views as practical per transect (Source: C Kilroy, NIWA).

Figure 9.4 illustrates a benthic cyanobacteria monitoring and sampling schematic of transect cross-section showing arrangement of sampling points (not to scale). Assessment 1 will cover a greater area than assessment 5 because of the greater water depth. However, this will be the case at all sites. Therefore assessments should be comparable (from *New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters – Interim Guidelines*, source: C Kilroy, NIWA).

Figure 9.4: Benthic cyanobacteria monitoring and sampling schematic of transect cross-section showing arrangement of sampling points



ii) *Samples for toxin analysis*

- **Qualitative:** Qualitative toxin analysis is generally performed by bioassay, and is performed when either more sophisticated techniques are unavailable, or the identity of the toxin is initially unknown. Samples for qualitative analysis may be collected from concentrated scums or by trailing a phytoplankton net (10–50 μm mesh) from a boat or casting the net from the shoreline. The volume of sample required is dependent upon the concentration of the cells. Up to 2 litres may be required if cell concentrations are low. Advice should be sought from the analytical laboratory before collecting and submitting a sample for qualitative toxin analysis.
- **Quantitative:** Quantitative toxin analysis is performed using a variety of methods suited to the type of sample and the toxin present. Samples are collected in the same manner as those taken for phytoplankton identification and enumeration and the volume of sample required is dependent on the type of analysis to be used. In general, at least 500 mL of water should be collected.

iii) *Samples for benthic cyanobacterial identification and quantification*

Under certain circumstances samples for benthic cyanobacteria may be required (eg, *Phormidium* and *Lyngbya wollei*). In most cases benthic samples are collected for qualitative analysis. Samples can be collected using a benthic sampler such as an Eckman grab or a rigid plastic corer (eg, PVC or polycarbonate pipe). Duplicate samples at varying depths are collected by either grab or hosepipe and emptied into a container with a fitted lid. If large quantities of sediment/sample are collected, a sub-sample can be taken and stored in a smaller specimen jar.

b) Preservation, transport and storage of samples

- **Samples for identification and enumeration:** To ensure the sample remains in a condition suitable for identification and enumeration, Lugol's iodine preservative solution should be added to the sample as soon as possible after collection. See APHA (2005) for recipe). Sufficient Lugol's iodine solution should be added to render the sample a colour resembling weak tea (ie, 0.5 mL Lugol's iodine per 100 mL of sample). It is sometimes useful to retain a portion of sample in a live (unpreserved) state, as some species of phytoplankton may be easier to identify in this way.

  The analytical laboratory can advise on whether unpreserved samples are required.

Preserved samples are reasonably stable as long as they are stored in the dark. If samples are unlikely to be examined for some time, they should be stored in amber glass bottles or PET plastic bottles with an airtight seal. Polyethylene bottles tend to absorb iodine very quickly into the plastic and should not be used for long-term storage. Live samples will begin to degrade quickly especially if there are high concentrations of cells present. These samples should be refrigerated and examined as soon as possible after collection.

- **Samples for toxin analysis:** Careful handling of samples is extremely important to ensure an accurate determination of toxin concentration. Some toxins are readily degraded both photochemically (ie, in light) and microbially. Samples should be transported in dark cold conditions and kept refrigerated and in the dark prior to analysis.

c) Training and quality

It is essential that staff involved in the collection of field samples be trained in all facets of collecting, transporting and delivering samples. Samplers should be aware of sample requirements including sample sites, types and numbers at each water body.

They should also be fully trained in the process of visual inspections and the need to collect samples of cyanobacterial scum if present. Samplers should undergo continual training to ensure new procedures are learned and existing skills are refreshed. Any queries relating to training in drinking water quality management should be referred to:

Water Industry Training
PO Box 10383
Wellington

9.6 Transgressions

The exceedence of a cyanotoxin PMAV results in a transgression. This requires remedial actions to reduce the risk to consumers. Section 9.7 provides guidance material that can be used for planning the remedial actions to be taken following a transgression.

Remedial actions should not be left until a transgression has occurred. When the routine monitoring undertaken as a requirement of section 7.2 of the DWSNZ shows the likelihood of algal bloom development, or the growth of cyanobacteria to a level at which toxin concentrations may be a concern, remedial actions should be taken to reduce the likelihood of a transgression occurring.

Section 7.3.3 of the DWSNZ lists actions that must be taken in the event of a cyanotoxin transgressing its MAV. These must be incorporated into the WSP when it is prepared. The WSP should also include any other actions the water supplier considers important for their particular supply. These may have become apparent during the collection of information undertaken to meet the requirements of section 7.2.

9.7 Risk reduction

9.7.1 Alert levels

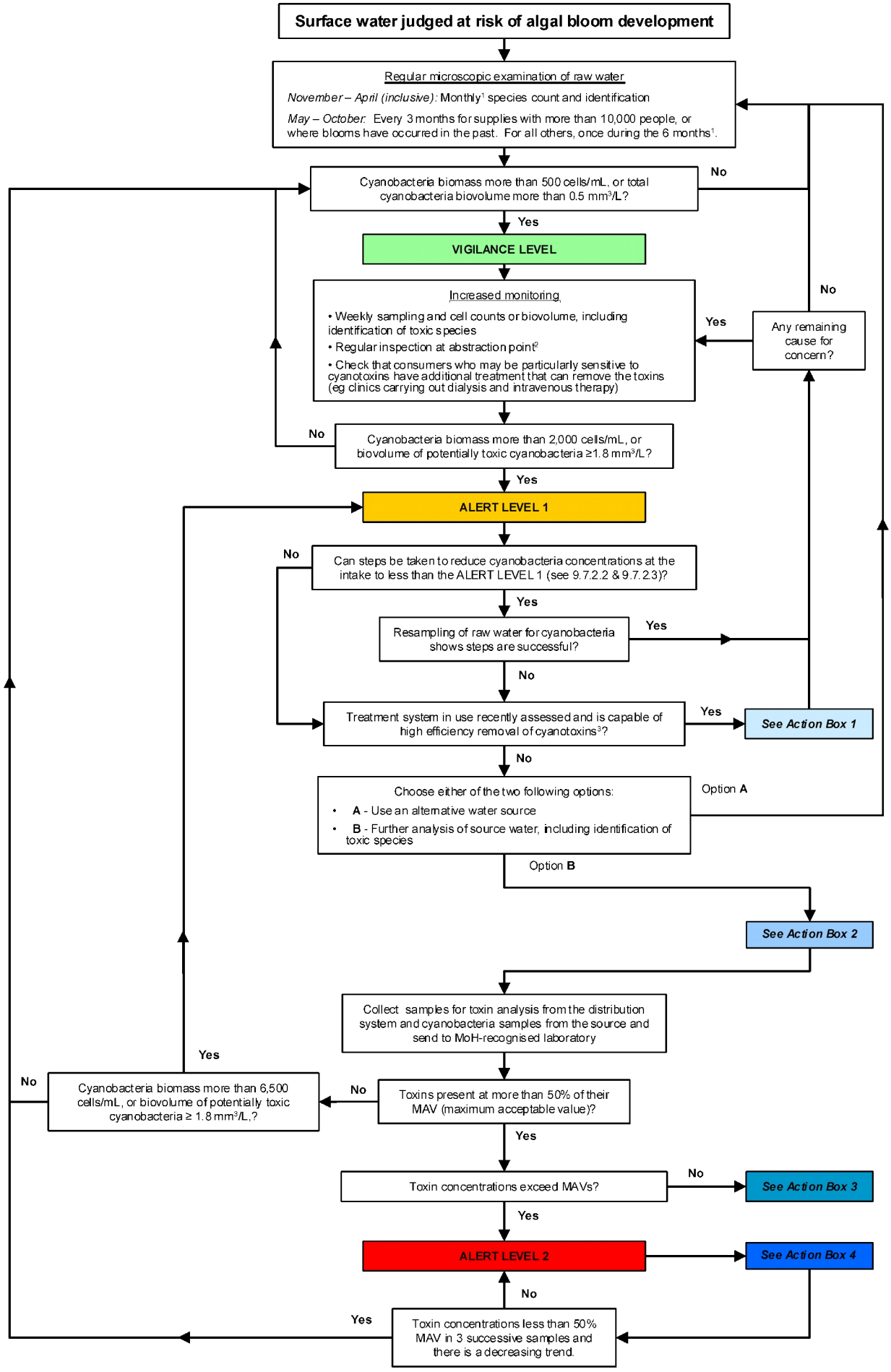
An Alert Levels framework is a monitoring and management action sequence that water treatment plant operators and managers can use to provide a graduated response to the onset and progress of a cyanobacterial bloom. The decision tree (Figure 9.5) should be seen as a general framework, which is based on overseas experience, and that may require adaptation of specific alert levels and actions to suit local conditions. Individual water suppliers may wish to augment the minimum monitoring requirements set out in Figure 9.5, making use of their knowledge and experience, which should be documented in the WSP. Where possible, they should gather information about cyanobacteria cell concentrations and their relationship with cyanotoxin concentrations in their source waters. These may be different from cell/toxin relationships used to establish the alert levels in Figure 9.5.

Note that there are difficulties in identifying the risk arising from benthic cyanobacteria attached to riverbeds or supply intakes by the microscopic examination of the raw water required in Figure 9.5. Section 9.5.2 provides advice on sampling in these situations.

Monitoring of the type noted in Level 1 of section 9.3 could be used before the Vigilance Level in Figure 9.5 is reached to supplement the low frequency microscopic examination of the water.

Cyanotoxins are currently measured in three suites: the microcystin / nodularin, the anataoxin / cylindrospermopsin, and the PSP (saxitoxin) suite, with each suite costing $200–300. Because the cost of analysing cyanotoxins is high, water suppliers with source waters that have a history of cyanobacterial blooms will have a real incentive to manage their catchment and raw water quality. They will need to develop a contingency plan that can be implemented at short notice, see section 9.7.2.3.

Figure 9.5: Alert levels framework for the management of cyanobacteria in water supplies



Notes:

1 Treatment plant staff must be able to recognise cyanobacterial blooms and know what action to take, if they develop between samplings.

2 Make sure intakes are not located where scum may be blown by the prevailing winds.

3 Treatment capable of removing more than 99 percent of cells without their lysis, or removing more than 90 percent of extracellular toxins (see Tables 9.5 and 9.6).

4 LC-FLD (liquid chromatography with fluorescence detection) will be needed to quantify saxitoxins.
LC-MS (liquid chromatography – mass spectrometry) is suitable for all other toxins in the DWSNZ.
ELISA (enzyme linked immunosorbent assay) is a research tool for saxitoxin analysis with potential for routine use.
Where a calibration standard for a toxin is unavailable, bioassay should be undertaken to determine whether toxins present are a potential risk to health.

Source: Modified from Chorus and Bartram 1999. Cell counts based on Australian Drinking-water Guideline 6 (2004). Other data sources: Jones et al 1993, NHMRC/ARMCANZ 1996.

Action Box notes

Action Box 1

- Continue regular monitoring of raw water (and treated water if necessary) to ensure adequate system performance, particularly if the cyanobacterial biomass remains above 2000 cells/mL or the biovolume remains equal to or greater than 1.8 mm^3/L.
- Consider analysis of the treated water to confirm the absence of toxins.

Action Box 2

- Consult with health authorities and other appropriate agencies.
- Investigate options for reducing the nutrient load.
- Ensure that the local authority places signs at the water source, warning people not to swim, fish or practise any other sport within the contaminated areas.
- Prepare to:
  - implement water supply contingency plan
  - use an alternative source of water, or
  - use water treatment processes capable of removing cells or toxins (see section 9.7.2.3 and Tables 9.5 and 9.6), or
  - provide drinking-water by tanker or bottles.

Action Box 3

- Continue monitoring as required by section 7.3.2 (DWSNZ). Ideally, samples of raw water should be composite collected over 24 hours.
- If possible, use an intake that has not been affected.
- Assess level of health risk using Figure 9.1.

Action Box 4

- Continue monitoring as required by section 7.3.2 (DWSNZ), but preferably increase the monitoring frequency to daily, if toxin levels are near, or exceed their MAV.
- Close the water body temporarily.
- Assess level of health risk using Figure 9.1.
- If not already done, have water analyses carried out to determine which toxin is present, and its concentration.
- Activate contingency plan (which should include):

  – use of alternative water source, OR
  – provision of drinking water by tanker or in bottles, OR
  – use of advanced treatment processes (powdered activated carbon and/or DAF (dissolved air flotation) and/or ozonation)
  – provision of safe water from an alternative source (eg, tanker) to consumers particularly sensitive to toxins (eg, clinics carrying out dialysis or intravenous therapy)
  – increase sampling for cell counts (or biovolume) to assess bloom growth/decay, and help in management of raw water abstraction
  – use of aeration of the reservoir to reduce cell growth.

- Contact dialysis clinic staff directly to discuss the problem and technical solutions.
- Routine supervision of dialysis clinic water treatment system.
- Consider whether there is a need to replace the water treatment plant sedimentation step with a DAF system.
- Do not use water source for drinking again until four weeks after cell counts have returned to less than 500 cells per mL, less than 0.4 mm^3/L where the known toxin producer is dominant, or until testing shows that the toxin levels are less than 50 percent of their MAV.

9.7.2 Preventive and remedial measures

Providing safe drinking-water from cyanobacteria-infested surface waters requires consideration of the system as a whole, and the use of different combinations of resource

management and treatment tailored to the specific locality. There also needs to be local assessment of performance and local optimisation of resource management and treatment strategies.

A drinking-water safe from cyanotoxins will either draw from a resource that does not harbour cyanotoxins (eg, groundwater or surface water that does not support cyanobacterial growth), or have treatment in place that is likely to remove cyanobacterial cells (without causing their rupture) as well as removing cyanotoxins. When cyanobacterial blooms occur in New Zealand, alternative water sources are often unavailable, and water treatment plants may not have the capacity to remove all cyanobacterial cells or related toxins that are the prime health hazard. However, in many circumstances a potential cyanotoxin hazard can be managed effectively without the necessity of advanced treatment processes, through good water resource management.

There are three levels of management, consisting of preventive and remedial measures that can be used to control cyanobacteria and their toxins. In decreasing order of preference, these are:

- measures to reduce nutrient inputs into the water
- management of the source water or reservoir
- treatment to remove cyanobacteria or their toxins.

An important aspect of managing cyanotoxins, as with any risk management planning, is to ensure an emergency incident plan has been developed in advance in the WSP to deal with situations in which preventive measures have failed and rapid cyanobacterial growth has led to acutely dangerous toxin levels. These plans need to take into consideration, as far as possible, the capacity of water supply and laboratory personnel to react to emergency situations.

9.7.2.1 Measures to reduce nutrient inputs

Cyanobacterial bloom formation can be avoided by reducing the factors allowing the cyanobacteria to grow, ie, nutrients and light.

A water supply's WSP should identify activities and situations within the catchment that may adversely affect water quality. Activities leading to the direct input of human or animal waste into water or indirect input through processes such as run-off from pastures, or fertiliser use, should be identified as a concern. To reduce the effects of these activities on the nutrient levels in the water, steps need to be taken to limit animal access to water sources, and to encourage agricultural practices that minimise the loss of nutrients in manure and fertiliser into water sources through run-off. Treatment of sewage to reduce its nutrient content, before disposal into water or on to land, may also be needed.

Land use and land practices are often outside the direct control of water suppliers. In these circumstances, assistance from the regional council should be sought to work with the affected community to determine what actions to reduce nutrient input are practicable.

There may be a substantial delay (many years) between the introduction of steps to reduce nutrient input and nutrient concentrations dropping below levels expected to sustain an algal bloom. This is because feedback mechanisms within the ecosystem, such as the release of nutrients that have been stored in sediments, will continue to release nutrients into the water. Nutrient concentrations should be monitored regularly so that trends in these concentrations can be identified.

9.7.2.2 Management of the source water or reservoir

Management of the source water or reservoir to reduce the levels of cyanobacteria and their toxins being taken into the water supply include:

- engineering techniques to alter the hydrophysical conditions to reduce cyanobacterial growth
- positioning of abstraction points
- selection of intake depth
- abstraction through an infiltration gallery
- barriers to restrict scum movement
- use of algicides, which should be used with extreme caution because of their ability to cause cell lysis and the release of toxins into the water.

Natural microbial populations in water bodies can degrade cyanotoxins.

Measures addressing light availability directly (eg, artificial mixing) or controlling nutrients by manipulating the types and numbers of organisms (eg, aquatic plants that compete for nutrients with the cyanobacteria) is an area that has been used successfully, chiefly in less eutrophic situations. For highly eutrophic waters under restoration by a reduction of nutrient loading, such measures may accelerate and enhance success.

A commercial product, Phoslock™, has been developed in Australia that is designed to remove phosphorus from water. Phoslock™ is a reaction product of bentonite clay and lanthanum chloride in which the proportion of exchangeable cations (mainly sodium) is replaced by lanthanum cations through electrostatic binding. Phoslock™ is designed to adsorb oxyanions, predominantly phosphate, from a variety of natural aquatic environments notably in order to reduce the incidence of algal blooms. The recommended dosage is 100:1 Phoslock™ to filterable reactive phosphorus (FRP). NICNAS (2014) has assessed the use of Phoslock™.

Prevention by riparian strips and control of land use etc is more effective than using algicides such as copper sulphate. Algicides have difficulty in removing a bloom; they are more effective at preventing a bloom if dosed early enough. Risk management issues relating to algicides are discussed in the MoH Public Health Risk Management Plan Guide PHRMP Ref. P4.1: Pretreatment Processes – Algicide Application. See also CRCWQT (2002).

The use of copper sulphate to control cyanobacterial growth can release toxins through cell lysis, and either destroy the natural micro-organisms that degrade toxins, or inhibit the action of the enzymes that carry out the degradation (Heresztyn and Nicholson 1997). Copper sulphate may prevent formation of phytoplankton blooms if dosed early enough, preferably in the morning when cyanobacteria are likely to be close to the surface and water calm, but algicides are unlikely to eliminate a bloom, once underway.

A study by Water Quality Research Australia (WQRA 2012) assessed the performance of copper sulphate, chelated copper sulphate, stabilised hydrogen peroxide, sediment capping, surface mixing, and ultrasound treatment for control of algae and cyanobacteria. Performance of the algicides depended on water quality and the type of organism; all needed a higher dose than claimed by the supplier. Ultrasonics were not effective. Sediment capping only deals with the current load of phosphorus.

9.7.2.3 Treatment options

The final step in controlling cyanobacteria and their toxins is the water treatment process. The water treatment train needs to be able to remove suspended material (bacterial cells) as well as

water soluble toxins (eg, microcystins, nodularins and anatoxins), which are the primary health hazard. The effectiveness of a water treatment system in doing this is determined by many factors. The brief analysis below, based on a comparative assessment of experiments in countries affected by cyanobacterial contamination, identifies the main factors and also the capacity of established and novel treatment processes for the removal of cells and dissolved toxins. As a general observation, conventional surface water treatment plants using coagulation, clarification and filtration are effective in removing cyanobacterial cells, but they are only partially successful in removing cyanobacterial toxins.

Much of the work on cyanotoxin removal has focused on single treatment steps, but a multi-barrier approach is more effective.

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. Cylindrospermopsin and deoxycylindrospermopsin may be exceptions, as these toxins can be released by actively growing cells into the surrounding water. Under bloom conditions, a substantial proportion of toxin may be released to the water column, making removal of soluble toxin an unavoidable concern.

Table 9.5 summarises the toxin-removal performance of treatment processes capable of removing of cell-bound microcystins by removing whole cells. The effectiveness of processes that can remove extra-cellular toxins, ie, oxidation/disinfection processes and activated carbon processes, are presented separately in Table 9.6. Table 9.6 sets out removal data for a range of toxin groups.

A number of factors concerning good practice and the effective design and operation of treatment plants should be considered in conjunction with the information in Tables 9.5 and 9.6. These include:

<u>General</u>

- Chemical preparation and dosing facilities must be of adequate size, have appropriate retention times, and chemical doses and treatment conditions (eg, pH level) should be optimised.
- Frequent monitoring of treatment performance is crucial to ensure safety, particularly with respect to cyanotoxin removal. The performance of different treatment steps is variable, for reasons that are not understood, and there is no suitable surrogate that can be used to assess cyanotoxin removal. Variable and often high loads of dissolved organic carbon (DOC) during cyanobacterial blooms may rapidly compromise treatment procedures that were initially successful. This is because non-toxic natural organic matter, which is present at much higher levels than the cyanotoxins, may saturate the capacity of the treatment process.
- Best results are achieved by combinations of treatment steps, and by the separate evaluation of cell removal and the removal of dissolved toxin (eg, combinations of pre-oxidation to enhance cell removal with effective post-oxidation to ensure destruction of liberated toxin, or combinations of cell removal and slow sand filtration).
- The complexity of managing cyanobacterial contamination necessitates consultation with the relevant health authority.

<u>Raw water treatment and pre-oxidation</u>

- Raw water sources and abstraction should be managed to minimise the cyanobacterial concentrations in the raw water delivered for treatment, but such steps as adjusting the abstraction depth.

- Pre-oxidation should be avoided because it often results in cell lysis and resulting release of cyanotoxins into the water. Physical removal of cells should be undertaken before high levels of pre-oxidant are added to the water. Separation of steps into a low pre-oxidation dose to enhance flocculation, and a higher dose after cell removal to oxidise dissolved toxins is a safer approach. Pre-oxidation should not be used, if it cannot be shown that the process results in an overall improvement in the removal of cyanotoxins.
- Pre-ozonation is preferable to pre-chlorination, especially in conjunction with primary disinfection by ozone further down the treatment line, eg, between clarification and filtration (usually dosed at a minimum of 1 mg/L).
- Algicides, such as copper sulphate, as well as pre-oxidants, can cause cell lysis and the release of cyanotoxins.

Coagulation/flocculation/clarification

- Conventional treatment plants without ozone or granular activated carbon (GAC) might satisfactorily remove cyanobacterial cells and dissolved toxins if coagulation, clarification, filtration and superchlorination – dechlorination (with a C.t value of more than 15 mg.min/L) or ozonation are carried out effectively.
- At optimum turbidity and UV absorbance removal rates, coagulants such as aluminium sulphate, PAC and ferric chloride are able to remove most cyanobacterial cells without physical damage and the release of toxins, eg, *Microcystis aeruginosa* and *Anabaena circinalis* cells (Drikas et al 2001). Lysis will be more predominant if coagulation occurs at pH <6.
- However, under normal bloom conditions it is highly likely that the cells are in various stages of their growth cycle, with some already dying and releasing toxins. A further treatment step may therefore be required to remove extracellular toxins.
- Under normal operating conditions, very little additional toxin is released from settled cells if sludge is rapidly removed from sedimentation basins. However, cells that are held up in the sludge blanket can remain viable and multiply for at least 2-3 weeks, so increasing the sludge blanket discharge volumes or frequency will probably be required.
- Recycling to the head of the plant of supernatant from sludge thickening or drying should not be done until the bloom is over or all toxins in the sludge have degraded.
- Dissolved air flotation (DAF), in which the clarification (sedimentation) process is replaced by the release of compressed air into the water to float flocs to the surface, has often been found more effective than clarification in removing cells from cyanobacteria-rich waters.

Some other observations reported by Newcombe et al (2015) are:

- Do not use prechlorination.
- While turbidity cannot be used as an indicator of the presence of cyanobacteria or cell concentration, use the decrease in settled water turbidity with coagulant dose as a surrogate for, or indicator of, cell removal if the initial turbidity is ≈10 NTU or above.
- If the presence of cyanobacteria results in increased coagulant demand to achieve improved settled water turbidity, the application of a particulate settling aid, or even powdered activated carbon, may lead to improvements.
- In most conditions, *Cylindrospermopsis raciborskii* was the least readily removed cyanobacterium by coagulation, maybe <90%.
- Although removal of cyanobacteria through conventional coagulation can be very effective, 100% cell removal is unlikely in normal full scale operations; in general 90–95% removal was the optimum. In the event of high cell numbers entering the plant, monitor for cell carryover and accumulation in clarifiers. This can lead to serious water quality problems if not rectified.

Sand filtration

- Slow sand filter plants remove phytoplankton cells effectively, although pre-treatment steps are generally applied to maximise filter runs and efficiency. Because of the biological activity in slow sand filters and long contact times, some removal of dissolved toxin should be expected, but this capability is unclear. Slow sand filter plants with pre-ozonation and/or sand-GAC sandwiching would be expected to be effective for dissolved toxin removal (but this has not been confirmed). Slow sand filtration is not a common treatment process in New Zealand.

Membrane filtration

- Cells can be removed by membrane filtration systems. However, care is needed when selecting microfiltration membranes because the characteristics of the membrane will affect the extent to which cells trapped in the membrane cannot be removed during backwash. Death and lysis of these cells will them result in toxin release into the water.
- Care is needed in the use of direct filtration, as long filter runs will trap more cells in the filter bed than short runs, leading to release of greater amounts of cyanotoxins following cell death and lysis.
- Recent studies by Water Research Australia indicate that an NF membrane as the final stage of an integrated membrane system (IMS) may be the best method for maximising removal of extracellular cyanobacterial metabolites. Selection of the correct NF membrane was essential. The most efficient removal of cyanobacterial metabolites was achieved with a polyamide NF membrane with MWCO of about 100Da. This membrane should also be hydrophilic for the best retention of flux. A UF membrane incorporating coagulation and powdered activated carbon addition is also a practical treatment. Aluminium chlorohydrate (ACH) is the best readily available coagulant for removal of intracellular cyanobacterial metabolites. ACH may also be a better coagulant for UFIMS in remote locations as lower doses are required for flux retention. WRA (2012).

AWWA/WRF (2015) states that RO effectively removes extracellular cyanotoxins. Typically, NF has a molecular weight cut off of 200 to 2,000 Daltons, which is larger than some cyanotoxins. Individual membranes must be piloted to verify toxin removal.

Activated carbon

- Granular activated carbon plants with a high empty bed contact time (EBCT) and ozone-GAC facilities can remove toxins effectively, especially if the GAC supports substantial biological activity.
- The effectiveness of treatment plants without ozone, but with GAC, will depend on the GAC EBCT value, on the degree of biological activity on the GAC, on the extent of exhaustion of the GAC and of the magnitude and duration of toxin occurrence.

Water treatment plants with rare or occasional cyanobacterial blooms are not likely to have GAC filters. Without these, powdered activated carbon (PAC) will be needed. Water supplies likely to experience cyanobacterial problems should make provisions for dealing with them. It will be necessary to find out how to purchase activated carbon for prompt delivery, and there needs to be a process in place for dosing it; these should be noted in the section of the WSP dealing with cyanobacteria and cyanotoxins.

Generally, a conventional treatment train, including the combinations of coagulation, flocculation, settling or flotation, and filtration, is preferred to treat cyanobacteria-rich waters.

Picoplanktonic cyanobacteria (cyanobacteria less than 2 μm in diameter), however, are not easily removed by most filtration systems.

Boiling water typically does not destroy toxins, and cell destruction can lead to the release of greater amounts of toxin into the water. If boiling of water is used as a means of destroying other micro-organisms, further water treatment must be undertaken to deal with the cyanotoxins.

In addition to the possible natural degradation of toxins by other microbes in the water, sunlight has been found to reduce the toxicity of anatoxin-a (Stevens and Krieger 1991).

Alternative source of drinking water

If contingency treatment options are unrealistic, water suppliers may need to consider treating an alternative raw water, or delivering safe drinking-water while the normal supply remains suspect.

Table 9.5: Summary of performance of water treatment processes capable of removing cell-bound microcystins by removing whole cells

Treatment process	Expected removal[1]		Comments
	Cell bound	Extra-cellular	
Copper sulphate dosing of impounded water	Very high	Causes lysis and release of dissolved metabolites	Usual effective dose 1–2 mg/L, but has been found toxic to some cyanobacterial species at concentrations less than 1 mg/L. Limited significance to human health at the doses commonly used. Accumulation in sediment can cause environmental problems, and fish find it toxic at concentrations well below the doses effective for cyanobacterial control. Toxins in the water column must be removed by some other treatment method.
Pre-ozonation	Very effective in enhancing coagulation	Potential increase	Useful in low doses to assist coagulation of cells; risk of toxin release requires careful monitoring and possibly subsequent treatment steps.
Pre-chlorination	Effective in enhancing coagulation	Causes lysis and release of dissolved metabolites	Useful to assist coagulation of cells but applicable for toxic cyanobacteria only if subsequent treatment steps will remove dissolved toxins and other released metabolites.
Combined coagulation/ sedimentation/ filtration	High	Low	Removal only achievable for toxins in cells, provided cells are not damaged. Cells of some species may be more susceptible to damage than others.
Coagulation/ dissolved air flotation	High	Not assessed, probably low	Removal only achievable for toxins in cells, provided cells are not damaged. Cells of some species may be more susceptible to damage than others.
Precipitation (for hardness reduction)/ sedimentation	High	Low	Removal only achievable for toxins in cells, provided cells are not damaged. Cells of some species may be more susceptible to damage than others.
Direct filtration	Moderate	Low	Removal only achievable for toxins in cells, provided cells are not damaged.
Slow sand filtration	Very high	Probably significant	Removal effective for toxins in cells; efficiency for dissolved microcystin is likely to depend on biofilm formation and thus on filter run length.
Membrane processes	Likely to be very high	Uncertain	Depends on membrane type, further research required to characterise performance. Some UF membranes are able to remove dissolved microcystins, and nanofiltration and RO membranes are also expected to be able to achieve this.

Based on data from Chorus and Bartram 1999 and Drikas et al 2001.

1 Likely efficiency of removal when continuously applied at optimal doses and pH and under proper operating conditions.

The processes in Table 9.6 are ineffective at removing whole cells, although some oxidants are able to lyse cells and destroy the intracellular toxins they contain.

Table 9.6: Efficiency of dissolved toxin removal by oxidants/disinfectants and activated carbons

Oxidant/ disinfectant or activated carbon	Dissolved toxin removal					Comments
	Microcystins	Nodularin	Anatoxin –a	Saxitoxin	Cylindrospermopsin	
Chloramine	Ineffective	Ineffective	–	–	–	Free chlorine application will yield ineffective chloramines in waters enriched with nitrogenous compounds.
Chlorine	High (pH < 8)	Very high (pH < 8)	Low (pH 6-7)	High (pH ≈ 9)	Very high (pH 6 –9)	Toxin destruction is pH-dependent, and pH control is necessary. Conditions for removals noted are for free chlorine >0.5 mg/L and contact time > 30 minutes. Effectiveness reduced with increased DOC. The cells of some cyanobacteria can be lysed and the toxins they contain destroyed by chlorine.
Chlorine dioxide	Ineffective	–	–	–	–	Ineffective for the doses used in drinking-water treatment. Limited data.
Hydrogen peroxide	Ineffective	–	–	–	–	Ineffective on its own. Limited data.
Ozone	High	High	High	Low – moderate Variable effectiveness – dependent on toxin variant	May be effective – limited data	Level of removal influenced by water chemistry (ozone demand). Cell lysis followed by intracellular toxin destruction has been observed for microcystins. In general, the ozone dose should be sufficient to provide an ozone residual after five minutes contact time. Effectiveness reduced at lower temperatures.
Potassium permanganate	High	–	–	–	–	Contact time 30 minutes. Effective on soluble toxin but only in absence of whole cells.
UV irradiation	Ineffective	–	Ineffective	–	Ineffective	Toxins can be destroyed by UV light, but not at the doses used in water treatment. Titanium dioxide has been found to catalyse the destruction of some toxins.
Powdered activated carbon (PAC)	High	Some removal, limited data	Some removal, limited data	Poor to very high Depends on carbon and toxin variant	Moderate More data required for reliable evaluation	Effectiveness depends on the type of activated carbon, and water quality conditions. Carbons with a large number of large pores provide best removal. Wood-based carbons usually provide best removal. Large differences in levels of removal are seen between different microcystin variants. Doses of effective PACs are generally greater than 20 mg/L.
Granular activated carbon (GAC)	High	–	Removal probable, more data required	Moderate removal of toxicity in saxitoxin equivalents Depends on toxin variant, carbon, and period in use	Removal probable, more data required	Carbons with a large number of large pores provide best removal. Biodegradation influences the extent of toxin removal. Removal efficiency decreases with time. Natural organic matter will reduce effectiveness by occupying adsorption sites.

Oxidant/ disinfectant or activated carbon	Dissolved toxin removal					Comments
	Microcystins	Nodularin	Anatoxin –a	Saxitoxin	Cylindrospermopsin	
Biological granular activated carbon	High					See GAC, biological activity enhances removal efficiency and bed life.

DOC Dissolved organic carbon

9.7.2.4 Drinking-water treatment for households and small communities

Domestic treatment of drinking-water has been a recent issue of concern in New Zealand. Many reticulated supplies provide excellent quality drinking-water and additional household treatment may actually cause deterioration rather than improvement. However, domestic treatment may have a role in regions supplied with poor quality drinking-water. Such treatment, using filtration, activated carbon and oxidation has shown a good removal of health hazards associated with cyanobacteria.

New (previously unused) point-of-use filter cartridges can achieve a removal of microcystin variants in the range 30–60 percent, and this degree of removal could be increased to about 90 percent by the passage of the water through three such filters. The removal may drop to 15 percent, however, by the time the filter is halfway through its expected life. The form of the cyanobacteria also has an influence on the efficiency of removal. A filter consisting of activated carbon and ion exchange resins may remove about 60 percent of the filamentous cyanobacteria, while up to 90 percent of the single cells pass through (eg, *Microcystis*). As with other filter systems, the death and lysis of cells retained on the filter creates a potential concern.

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