CYANOBACTERIA AND CYANOTOXINS: REVIEW OF REGIONAL COUNCIL DATA

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ABSTRACT

Some genera of cyanobacteria are capable of producing toxins that can have severe hepatic (affecting the liver) or neurological (affecting the nervous system) effects. The development of blooms, which release toxins into the water, make them a potential health hazard in water supply source and recreational waters. This paper reports the collation and review of cyanobacteria and cyanotoxin data collected by regional councils to extract information of public health importance. The study, which reviewed data collected by eight regional councils up to 2009 (inclusive), found that sampling by these councils had identified a total of 43 different genera, 16 of which contain toxin-producing species. Detections of the toxin-producing genera *Anabaena* and *Microcystis* were reported by the greatest number of councils. The data showed that while there was a correlation between toxin and cell concentrations in Lake Forsyth, a wide range of toxin concentrations could be associated with very similar total cell concentrations. This suggests the need for caution when assessing the health risk associated with cyanotoxins based on the cell count in a water. The data also showed that the nodularin (toxin) concentration in Lake Forsyth can exceed its provisional maximum acceptable value by up to a factor of 300.

KEYWORDS

Cyanobacteria, cyanotoxins, blue-green aglae, algal blooms, drinking-water

1 INTRODUCTION

Cyanobacteria are a phylum of bacteria that generate energy through photosynthesis. They may inhabit both fresh and marine waters, and can be a concern because the metabolic pathways of some species generate toxins (cyanotoxins). These toxins are often hepatic (affecting the liver) or neurological (affecting the nervous system), or they are skin irritants. Consequently, cyanobacteria are undesirable in waters used as sources of human or animal drinking-water, or for recreation. Furthermore, some aquatic organisms, such as shellfish, bio-accumulate the toxins and can make the organisms themselves toxic.

When environmental conditions favour the growth of cyanobacteria, their extremely rapid multiplication can result in “algal blooms”. The vast increase in cell numbers can lead to a corresponding increase in toxin levels. Toxins may be contained within the cyanobacterial cells, or be free in the water column, as a result of their release by living cyanobacteria or through cell lysis (rupture). Toxins within the cells remain a threat after they have died because of the possibility of their release into the water through cell lysis.

Of the classes of contaminant that may appear in a drinking-water supply source, cyanotoxins should be regarded as the most dangerous. Their concentrations can increase greatly over a very short period and the consequences of their ingestion can be severe, and possibly fatal, on a time scale much shorter than that of pathogenic microorganisms. The toxins of greatest concern are the cyclic peptides, microcystins and nodularin. Acute exposure to high concentrations causes death through liver failure or liver haemorrhage, and chronic exposure to low doses may lead to tumour development in the liver and at other sites (Chorus and Bartram, 1999).

Cyanotoxins are a problem for water supplies drawing water from sources that experience blooms. Water treatment plants can remove cells through coagulation, sedimentation and filtration processes. However, these physical treatment processes can rupture the cells during their removal releasing toxins into the water. Disinfection is usually the last step in the treatment train. As the most commonly used chemical disinfectants are also oxidants, this provides the opportunity for the toxins to be destroyed before the water passes into the distribution system. However, the ability of a disinfectant to do this depends on the toxin; a given

disinfectant/oxidant may destroy some toxins, but not others. The addition of a highly adsorbent material, such as activated carbon, can provide a barrier to toxins that have slipped through other treatment processes, but it is expensive to use.

The difficulty in removing cyanobacteria and their associated cyanotoxins once they are in the water makes controlling the concentration of cyanobacteria in the source water, to avoid bloom development, the preferred method of managing the threat of cyanotoxins.

For these reasons, regional councils, water suppliers and district health boards pay great attention to signs of algal growth in sources for drinking-water supplies and recreational waters. To understand more about cyanobacterial development, the factors that control it, and correlations between cell numbers and the concentrations of cyanotoxins in the water, the Ministry of Health has funded projects to collect and collate data from national sources.

This paper provides a review of cyanobacteria/cyanotoxin data collected by regional councils. The primary purpose of this data analysis is to determine whether any data have been collected that may be of assistance in managing the risk presented by cyanobacteria and their toxins to drinking-water supplies and recreational users of New Zealand's freshwater bodies.

2 REGULATORY BACKGROUND

2.1 INTRODUCTION

The bulk of this report is an examination of the data provided by eight[1] regional councils from environmental waters they manage. Although the regional councils' data may not have been collected specifically with the intention of assisting water supply operation (as most of the water bodies monitored are not used for community water supply), examination of the data may be helpful in managing cyanobacterial threats.

To help understand the significance of the regional council data for health and the use of guidelines, this section outlines the key cyanobacterial information in three documents: the *Drinking-water Standards for New Zealand 2005 (Rev. 2008)* (DWSNZ) (MoH, 2008); the *Guidelines for Drinking-water Quality Management for New Zealand* (the DW Guidelines) (MoH, 2013); and the *New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters – Interim Guidelines* (the Recreation Guidelines) (MfE, 2009).

2.2 THE DRINKING-WATER STANDARDS FOR NEW ZEALAND

Cyanotoxins are chemical contaminants, albeit derived from a microbiological source, but the DWSNZ handles them differently from other chemical determinands. Compliance with the cyanobacterial section of the DWSNZ requires water suppliers to put in place a number of management protocols if the water has experienced algal blooms previously, or if the drinking-water assessor (DWA) considers there is the likelihood of a bloom.

These protocols are intended to:

a) assist in determining whether cyanobacteria are present in the source and when their concentration is likely to lead to 50% of a toxin's PMAV[2] (provisional maximum acceptable value) being exceeded,

b) determine when a toxin monitoring programme should be put in place,

c) set out the actions that will be taken in the event of a toxin's concentration exceeding 50% of its PMAV, and

[1] Data were received from nine councils, but the data from two samples provided by the Otago Regional Council were overlooked when data were entered into the master datasheet. The author apologises for this oversight.

[2] PMAVs: anatoxin-a – 0.006 mg/L; cylindrospermopsin – 0.001 mg/L; homoanatoxin-a – 0.002 mg/L; microcystins – 0.001 mg/L; nodularin – 0.001 mg/L; saxitoxins – 0.003 mg/L.

d) ensure that the DWA is notified when levels of cyanobacteria or cyanotoxin in the source water indicate that toxin levels are approaching 50% of their PMAV.

These protocols depend on information from the source providing warning of bloom development and the threat of toxins entering the system intake. Hence there is value in examining the regional council information for links between cyanobacteria and cyanotoxin concentrations and other environmental variables. The DWSNZ does not specify which variables, or their levels, should be used in evaluating the threat to a supply; it is left to the water supplier to determine which parameters are best for their situation.

A cyanotoxin can be assigned as a Priority 2 determinand[3] to a water treatment plant or distribution zone if any sample of treated water is found to contain the toxin at a concentration of more than 50% of its PMAV. This assignment requires the water supplier to start monitoring the toxin at a location and frequency stated in the DWSNZ, until there is evidence that the toxin concentration has subsided to a concentration less than 50% of its PMAV and is continuing to drop.

2.3 GUIDELINES FOR DRINKING-WATER QUALITY MANAGEMENT FOR NEW ZEALAND

The DW Guidelines contains an extensive section on cyanobacteria and cyanotoxins. A key part in assisting water suppliers to manage the hazard of cyanobacteria is an "Alert Level" framework. The framework defines the conditions that could be used to establish a particular level of preparedness that a water supplier should maintain in guarding against cyanotoxins.

Three alert levels are defined in the framework. Cyanobacterial concentration (cells/mL) and cyanobacterial biovolume (mm^3/L) are used to determine when the supply should move from one alert level to the next, as given in Table 1.

Table 1 Criteria defining alert levels in the DW Guidelines

Action	**Criteria for action**		
	OR	OR	
	Concentration Cell/mL	Biovolume mm^3/L	Toxin concentration
Promotion to Vigilance Level	>500	>0.5	-
Promotion to Alert Level 1	>2000	$\geq 1.8^A$	-
Remain within Alert Level 1	>6500	$\geq 1.8^A$	-
Promotion to Alert Level 2			>PMAV

[A] Biovolume of potentially toxic cyanobacteria only.

Following these alert levels, or maintaining the cyanobacterial concentration or biovolume below these levels is not required for compliance with the DWSNZ. They are provided as guidance only.

2.4 NEW ZEALAND GUIDELINES FOR CYANOBACTERIA IN RECREATIONAL FRESH WATERS – INTERIM GUIDELINES

Like the DW Guidelines, the Recreation Guidelines provide advice only on how any threat to public health from cyanobacterial blooms might be managed. A framework defining alert levels for planktonic cyanobacteria and benthic cyanobacteria is also introduced in the Recreation Guidelines. The drinking-water alert levels were harmonised as much as possible with the alert levels for planktonic cyanobacteria before the interim Recreation Guidelines were published. The recreational alert levels are defined according to Table 2 and Table 3.

[3] Priority 2 determinands are chemical substances of health significance that have been found to be present in a water at more than 50% of the maximum acceptable value (MAV). When a Priority 2 determinand has been found a water supply, the water supplier is required to monitor the determinand for as long as its concentration exceeds 50% of its MAV.

Table 2 Criteria defining alert levels for planktonic cyanobacteria in the Recreation Guidelines

Alert Level	Criteria for action			
	Concentration Cell/mL	OR Biovolume mm^3/L	OR Total microcystins concentration	OR Scum
Surveillance Level (Green mode)	≤500	≤0.5	-	
Alert Level (Amber mode)	-	0.5–< 1.8[A] OR 0.5– <10[B]	-	
Action Level (Red mode)	-	≥1.8[A] OR ≥10[B]	≥12 µg/L	Consistently present

[A] Biovolume of potentially toxic cyanobacteria only.

[B] Biovolume of all cyanobacteria.

Table 3 Criteria defining Alert Levels for benthic cyanobacteria in the Recreation Guidelines

Alert Level	Criteria for action	
	Coverage of substrate by potentially toxic cyanobacteria	Scum
Surveillance Level (Green mode)	<20%	-
Alert Level (Amber mode)	20–50%	-
Action Level (Red mode)	>50% OR ≤50%	where scum is detaching and accumulating on surface or exposed river edge

3 REGIONAL COUNCIL DATA

3.1 DATA COLLECTION

Sixteen regional and unitary authorities were contacted by email in October 2009, with a note explaining the background to the request that followed and asking for cyanobacteria data (including, cell counts, species identity, toxin, physico-chemical analyses and any other data collected with samples) they held. Replies were received from 10 councils, and of these, nine provided actual datasets or directions to where the data could be found on their websites. Datasets from only eight councils were analysed, as the accidental omission of the dataset from one was not noted until after completion of the study. Table A1 (Appendix A) summarises the

information received from these councils, including the number of water bodies from which data were obtained.

The nature of the information gathered varied widely, presumably because of the differing reasons for the monitoring being undertaken and the resources available. The format in which the data were recorded also varied widely; formats differed among councils, and sometimes among datasets from the same council. The data from all councils were compiled into a single master datasheet (Excel®) to facilitate data analysis.

The data received were assumed to have been correctly entered into the spreadsheets by the councils, and no further quality checks were undertaken. Cross-checks were undertaken between the data held in the master datasheet and the data provided by the councils to identify systematic errors arising from the transfer of data, and any necessary corrections were made.

Where cyanobacterial data, cyanotoxin data, physico-chemical, or other data groups, as listed in Appendix A

were obtained from the same location on the same date, they were assigned to the same record (row) in the master datasheet. Biovolumes (mm^3/mL) as well as cell counts (cells/mL) were often recorded in the council results. As one can be calculated from the other, only the cell counts were transferred into the master dataset.

3.2 LIMITATIONS OF THE DATA COLLATION

The collated dataset is an incomplete compilation of regional council data.

Most of the data received related to cyanobacterial cells, and included presence/absence records or concentrations (qualitative or quantitative). The level of identification was mixed. In some samples, identification was to genus level and in others to species level. Moreover, species identification was sometimes uncertain. For this paper, identification to genus level only was retained.

Few cyanobacterial toxin data were available. As the toxigenicity of species within the same genus can vary, identification to genus level does not allow the identification of linkages between species and toxins. This is not a significant loss because of the small number of toxin data and their restriction to a small number of water bodies.

4 CYANOBACTERIA DATA

4.1 GENERA REPORTED

Table A2 (Appendix B) expands on the information in Appendix A, indicating the genera identified in each region's dataset. A genus appears in this table if:

- a sample was reported as having a cell count greater than 0 for that genus
- it was listed as "present" when only presence/absence was reported
- when a qualitative code was provided, the entry was not blank.

Table 4 lists information for the most frequently detected genera in Table A2. A genus is included in this table if it was detected in more than 10% of samples.

Of the 43 genera reported by the eight councils, 16 contain species that are toxigenic (toxin producers). Those genera reported by the greatest number of councils were *Anabaena* (eight of eight councils) and *Microcystis* (seven of eight councils). Species within the *Anabaena* and *Microcystis* genera produce a range of toxins, which includes: cylindrospermopsin, anatoxin-a, anatoxin-a(S), saxitoxins and microcystins (DW Guidelines).

The next most frequently reported genera were reported in only four of the eight regions. Differences in the number of genera found in regions are likely to result from: the reasons for the monitoring; the mix of lakes and rivers/streams sampled; the period over which monitoring was undertaken; and the number of samples taken. For example, fewer genera are likely to be reported by a region where samples were obtained from few

locations, only one type of water body (flowing or static) was monitored (favouring either planktonic or benthic species), or few samples were taken overall.

Table 4 Summary table showing, for each council, the percentage of samples containing cyanobacteria in which each of the predominant[1] genera were reported

	Percentage of samples in which most commonly occurring genera were reported							
	ARC	**ECan**	**ES**	**EW**	**GWRC**	**HBRC**	**MDC**	**TRC**
Numbers of samples with cyanobacteria reported	67	251	437	705	9	71	3	54
Genus								
Anabaena	43%			81%	100%	89%	33%	48%
Aphanizomenon				20%				
Aphanocapsa	37%	52%					33%	
Heteroleibleinia			20%				33%	
Merismopedia		75%					67%	
Microcystis	45%			39%	44%	69%		26%
Nodularia		65%						
Oscillatoria	27%		15%					
Phormidium			26%		11%			
Planktolyngbya				20%		11%	33%	
Pseudanabaena	16%			18%				
Rhabdoderma							33%	
Rivularia			31%					
Snowella		12%						

[1] Arbitrarily defined as those identified in more than 10% of a council's samples containing cyanobacteria.

4.2 GENERA CONCENTRATIONS

Information about the cell concentrations of each genus (expressed as cells/mL) was available from four regional council datasets. A summary of the 95th percentile concentrations (cells/mL)[4] for the predominant genera (those genera contained in Table 4) reported by these councils is presented in Table 5. The statistics presented in Tables 4 and 5 are calculated from samples in which the total cyanobacterial cell count was greater than zero.

[4] Ninety-five percent of the concentrations reported are equal to or less than the 95th percentile concentration, The statistical analyses in this report were undertaken using Excel®.

Table 5 Tabulation of 95th percentile concentrations of the most frequently identified cyanobacteria in the regional council datasets

	95th Percentile Concentration (cell/mL)			
	ECan	**EW**	**GWRC**	**HBRC**
Anabaena	481 500	32 338	1 593 950	14 240
Aphanizomenon	2498	132 513		
Aphanocapsa	8 810 000	40 275		
Heteroleibleinia	1	2		
Merismopedia	506 900	351 241		
Microcystis	7 605 000	83 954	1056	156 000
Nodularia	38 750	465		
Oscillatoria	1	39 587		
Phormidium	1249	69 857	680	
Planktolyngbya	18	1 912 994		537
Pseudanabaena	61	31 232		
Rhabdoderma	10			
Rivularia		1		
Snowella	1380	248		

As noted in Section 2, both the DW- and Recreation- Guidelines use total cyanobacterial cell counts in defining alert levels. Table 6 tabulates the number of samples found in each council's dataset with total cyanobacterial cell counts that exceed each of the criteria used in the DW Guidelines for defining alert levels. These numbers are also expressed as percentages of the number of samples for which cell counts are available. The percentage values show how readily these concentrations are exceeded in each dataset once cyanobacterial development begins.

In four of the five regional datasets, the threshold of 500 cells/mL (the Vigilance Level set in the DW Guidelines and the Surveillance Level in the Recreation Guidelines), is exceeded in 80% or more of samples with detectable cyanobacterial concentrations. The cell concentrations leading to Alert Level 1 (2000 cells/mL) and staying in Alert Level 1 (6500 cells/mL) are reached in a moderate-to-high percentage of samples in all five datasets. High percentages are likely to occur where the focus of monitoring is on water bodies in which blooms are a concern. Lower percentages might be expected when monitoring targets water bodies in which cyanobacteria have been found, but in which their growth may not develop into large blooms.

Table 6 Summary of the number of samples with total cyanobacterial cell counts exceeding the various cell count criteria used in the DW Guidelines for defining alert levels

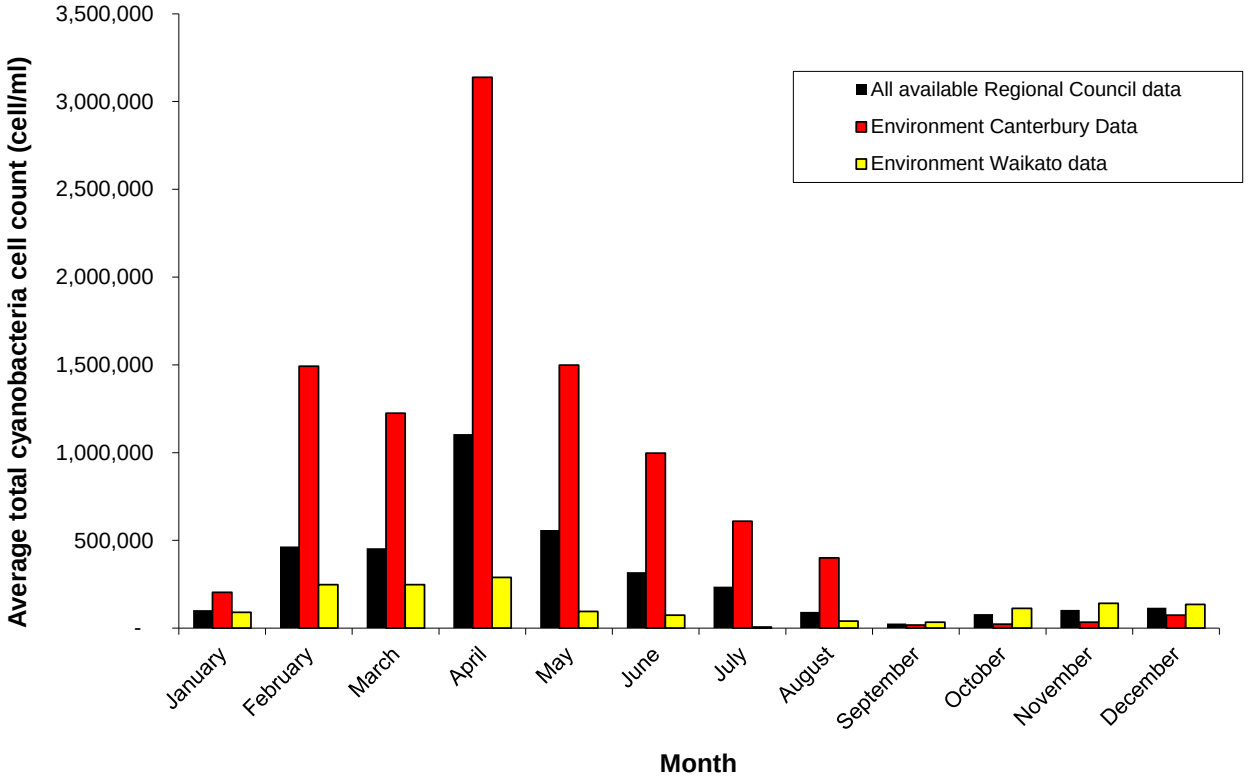
	Samples with cell counts greater than				Expressed as percentages of total number of samples in which cell counts were reported			
Regional Council	**0**	**500**	**2000**	**6500**	**0**	**500**	**2000**	**6500**
Environment Canterbury	251	222	212	198	100%	88%	84%	79%
Environment Waikato	705	387	308	248	100%	55%	44%	35%
Greater Wellington Regional Council	9	9	9	8	100%	100%	100%	89%
Hawke's Bay Regional Council	71	59	41	30	100%	83%	58%	42%
Taranaki Regional Council	54	43	40	34	100%	80%	74%	63%

Care is needed in drawing valid conclusions with respect to the threat of cyanobacteria faced by water supplies, from the results in Table 6. To best meet their resource management responsibilities while conserving water quality monitoring resources, regional councils focus their monitoring on water bodies at greatest risk of blooms. As such, the regional council dataset will produce statistics that show the appearance of high cyanobacterial cell counts to be a more frequent occurrence than in many water bodies in New Zealand.

4.3 SEASONAL VARIATION AND TEMPORAL TRENDS

Seasonal variation in the growth of cyanobacteria is well documented, and is evident in the data from regional councils. Figure 1 is a histogram of monthly cell count data averaged over the years for which numeric data are available. Plots of all regional council data and data from Environment Canterbury and Environment Waikato specifically, are presented. The two regional datasets are included as they are the most complete and most geographically separate of the available numeric datasets. Any regional differences were expected to be most evident from these datasets.

Figure 1 Average total cyanobacterial cell counts for each month averaged over the period for which data are available for all regional council datasets, and for the individual Environment Canterbury and Environment Waikato datasets.

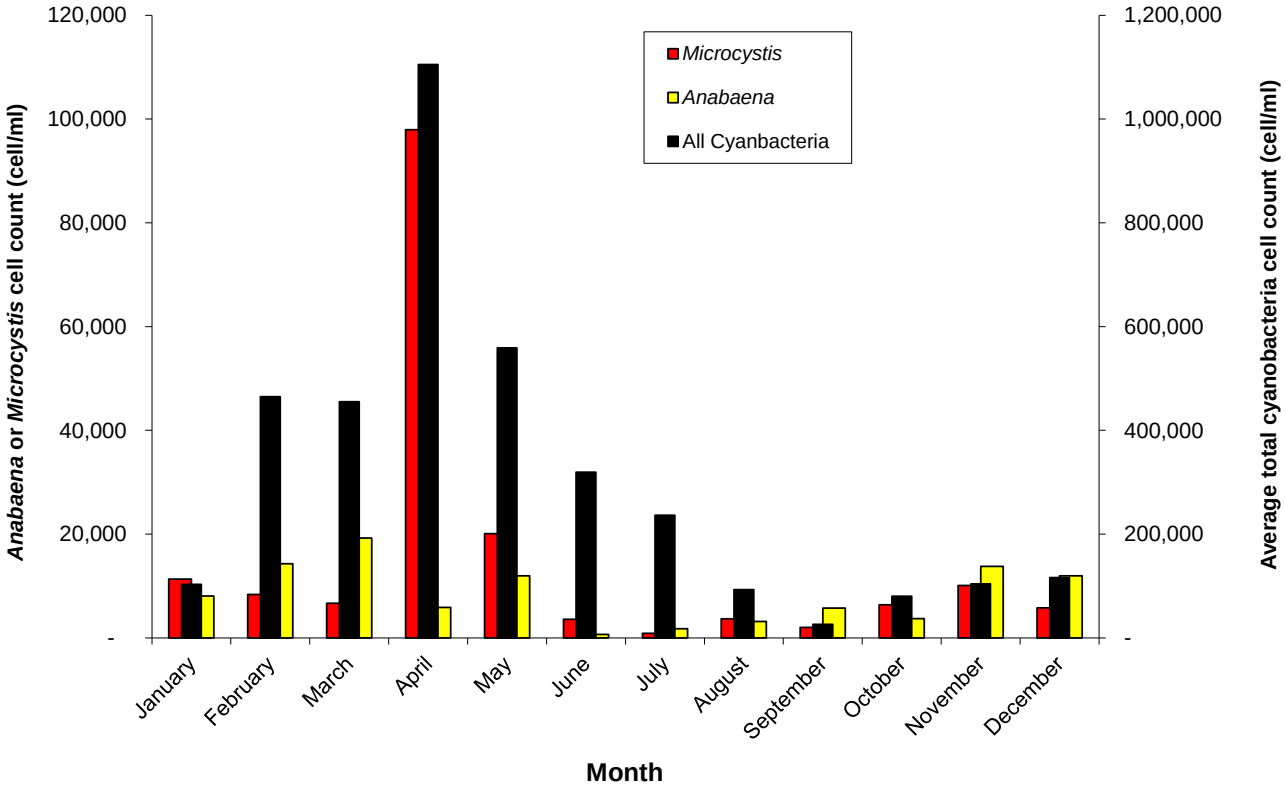


Each of the three histograms in Figure 1 shows essentially the same thing – total cell counts are at their lowest in spring to early summer and reach their maxima during autumn before dropping again during winter. Although the seasonality is apparent in the histograms, the monthly averages cannot be distinguished statistically because of the large standard deviations on each average value.

Figure 1 also shows that the average total cell counts in the Canterbury dataset were greater than those in the Waikato or overall datasets when cell counts are at their highest. There is also a much greater difference in the maximum and minimum cell counts in the Canterbury dataset. Differences in the types of water bodies monitored provide a possible explanation for this. All the samples in which cyanobacterial concentrations were measured in Canterbury were collected from shallow, eutrophic lakes. During the warmer months these conditions are very favourable for cyanobacterial growth and the maintenance of high cell concentrations. The lakes monitored by Environment Waikato were hydrolakes formed on the Waikato River, or small lakes in the region. The flow of water through the hydrolakes minimises nutrient concentrations and is likely to reduce the extent of cyanobacterial growth.

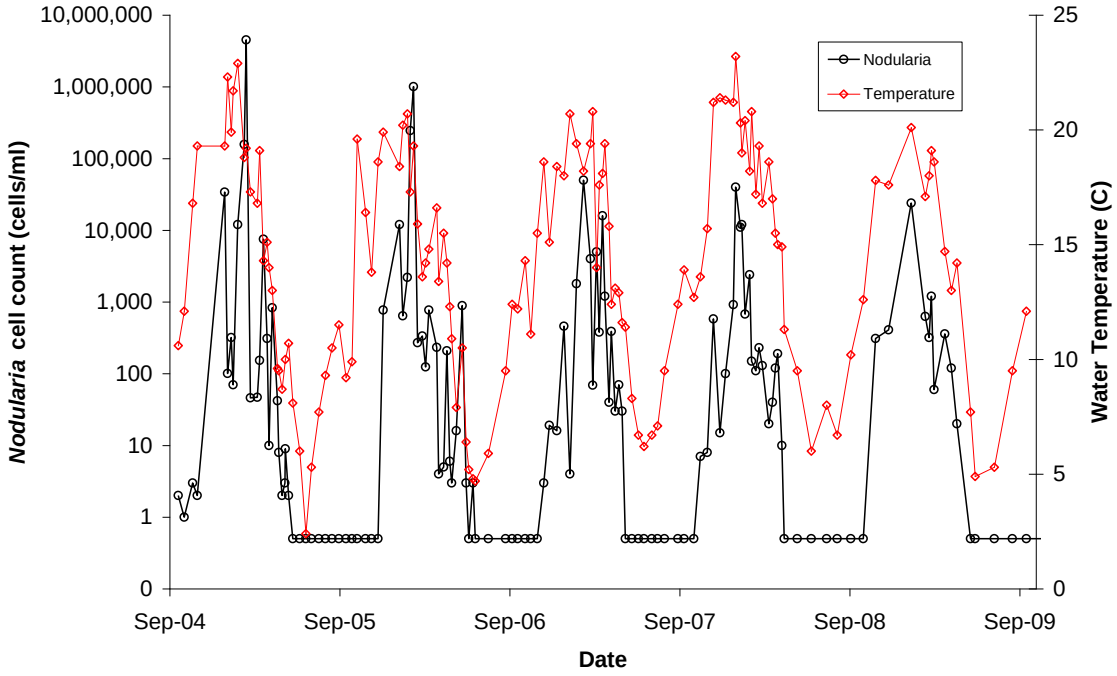
Figure 2 presents histograms of monthly cell concentrations of *Anabaena* and *Microcystis*, with the histogram for all species provided for comparison (plotted against the scale on the right-hand vertical axis). Understanding the seasonal cycle of *Anabaena* and *Microcystis* growth and decay is important because of their widespread occurrence and the toxigenic nature of species contained in the genera. From Figure 2, the seasonal behaviour of these two genera is broadly the same as that seen in the total cyanobacterial cell count. The average concentrations of the two genera are similar except for the April averages. The much greater average value for *Microcystis* in this month is due to an extreme single result in the Canterbury dataset for a sample from Lake Rotorua.

Figure 2 *Average monthly cell counts for all cyanobacteria, and* Anabaena *and* Microcystis *individually.*



One further figure showing the seasonal dependence of cyanobacterial cell concentrations is given in Figure 3, which shows the *Nodularia* cell concentration in Lake Forsyth (Environment Canterbury) from 2004–2009. Also plotted are the water temperature data for the lake. Statistical analysis to show a correlation was not undertaken, but a match between the two datasets is evident from the figure.

Figure 3 Nodularia *cell concentrations and water temperature in Lake Forsyth (ECan) (Non-detected concentrations were arbitrarily put equal to 50% of the limit of detection).*



With intensification of farming in some regions, and the associated increase in nutrient run-off, there is a concern that algal blooms may be increasing in frequency and magnitude. To assess whether any trend can be identified from the regional council data set, the total cyanobacterial cell count data were separated into monthly blocks and trends for each month assessed separately. A relationship between the average monthly cell count and the year could not be statistically demonstrated at a 95% confidence level.

5 CYANOTOXIN DATA

5.1 CYANOTOXIN CONCENTRATIONS

Of 2404 records in the dataset, only 282 contained cyanotoxin concentration data, 278 of which were from Environment Canterbury. One hundred and ninety-eight of Environment Canterbury's toxin-monitoring samples came from extended surveillance (September 2004–September 2009) of a well-documented cyanotoxin problem associated with Lake Forsyth. Consequently, any conclusions drawn from this dataset may be of limited applicability.

While the lakes from which these results were obtained are prone to much greater cyanobacterial concentrations than water bodies used as drinking-water sources, the results show that extremely high toxin concentrations can arise during blooms. The cyanotoxins for which analytical results are available in the collated database, and statistics about the concentrations reported are presented in Table 7. Of 154 toxin detections (anatoxin-a, homoanatoxin and nodularin), the PMAV was exceeded in 133 (86%) cases. For homoanatoxin-a, the PMAV was exceeded by a factor of 10 in 11 of the 14 (79%) samples in which the PMAV was exceeded, and in the case of nodularin, 60 of the 109 (55%) PMAV exceedences were by more than a factor of 10.

Table 7 Cyanotoxins for which analytical results are available in the collated data from regional councils

Cyanotoxin	Number of samples with test results	Number of detections	Concentration range reported (μg/L)[1]	Median concentration (μg/L)	95th Percentile concentration (μg/L)	Number of PMAV exceedences
Anatoxin-a	33	13	2–130	8	68.8	8
Cylindrospermopsin	32	0				
Deoxycylindrospermopsin	30	0				
Homo-anatoxin-a	32	17	2–1500	33	1500	14
Microcystin LR	254	1	4	4	4	1
Microcystin RR	254	1	5	5	5	
Microcystin YR	254	0				
Nodularin	254	122	1–91 000	9.3	1495	109
Saxitoxin	1	0				

[1] One result reported as μg/kg

The dominance of nodularin in this dataset is a consequence of the particular cyanobacteria in Lake Forsyth, and the statistics in Table 7 are not necessarily a guide to the dominant toxins occurring throughout New Zealand. The high concentrations of this toxin and the number of PMAV exceedences recorded for it do not signify a potential threat to health through drinking-water as no water supply draws from this lake. Stock or dog deaths have been the primary consequences of the high concentrations of cyanotoxins in the lake.

The two other toxins reported in multiple samples were anatoxin-a and homoanatoxin-a. Cyanobacterial assays were not carried out in conjunction with the toxin analysis, and consequently the organisms giving rise to the toxin cannot be identified. However, all samples were obtained from rivers indicating that benthic cyanobacteria were likely to be responsible.

The alert levels used in the DW Guidelines, and to a degree those in the Recreation Guidelines, are based on the premise that total cell counts can be used as an indicator of the risk arising from cyanotoxins. This dataset provides an opportunity to test the validity of this hypothesis, at least in terms of the Lake Forsyth circumstances.

Nodularin is the focus of this examination because there is no cell count information accompanying the anatoxin-a and homoanatoxin-a data. Of the 122 samples in which nodularin was detected, 99 have accompanying cyanobacterial data. Cells of up to four cyanobacterial genera were found in these 99 samples, namely, *Aphanocapsa*, *Chroococcus*, *Merismopedia* and *Nodularia*.

Least squares regressions between the nodularin concentration in samples, and the total cyanobacterial cell concentration, *Merismopedia* concentration and *Nodularia* concentration were examined. The total cell concentration was included in these analyses because of its use in defining alert levels in the DW Guidelines. A plot of the nodularin concentration (log scale) versus *Nodularia* concentration is shown in Figure 4. The values of statistical parameters describing the regression fits are given in Table 8.

Figure 4 Plot showing the correlation between the Nodularia *and nodularin concentrations*

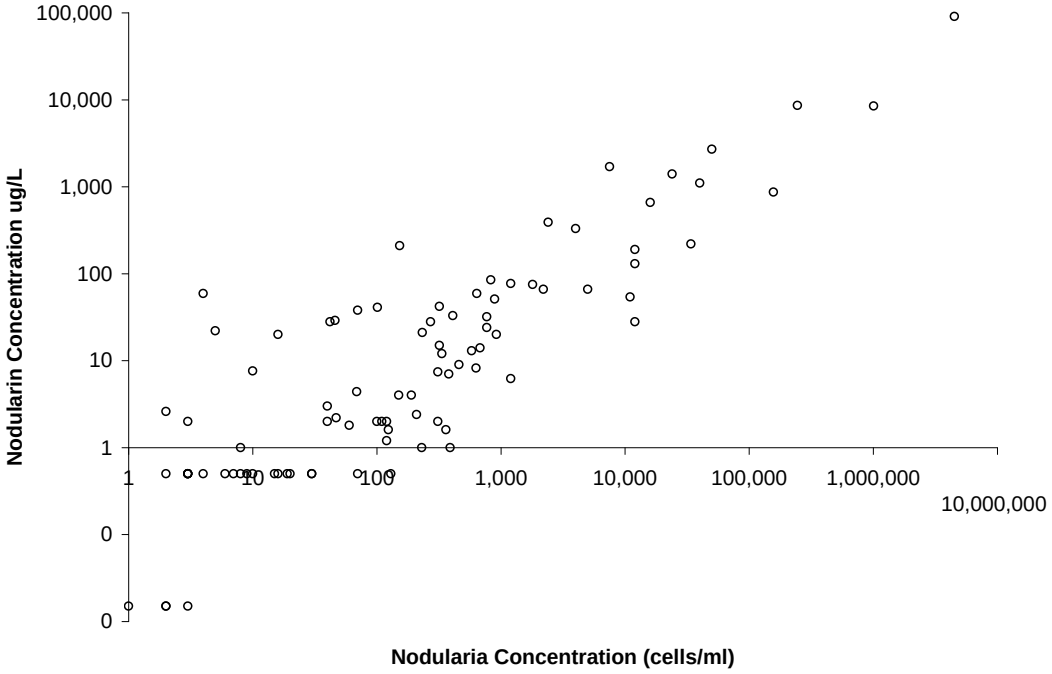


Table 8 Summary of statistical parameters describing least squares regression fits to cyanobacterial cell concentration and nodularin concentration data[1]

Genus	Trend line slope	R^2value	p value
Nodularia	0.0197	0.981	<0.001
Merismopedia	-0.001	<0.001	0.723
All genera	0.0165	0.805	<0.001

[1] Only samples in which cells of at least one cyanobacterial genus had been detected were included in the regression analysis.

A highly significant relationship between the *Nodularia* and nodularin concentrations is apparent from the p value, and ca. 98% of the variation in the toxin concentration is accounted for through variation in the *Nodularia* concentration (R^2 value). A significant relationship is also found between the total cell counts for all genera and the nodularin concentration. The regression statistics are also provided for *Merismopedia* because in most samples it made the greatest contribution to the total cell count.

The data in Figure 4 show that for a given *Nodularia* cell count, a wide range of nodularin concentrations can be found. Variations in the amount of toxin released by the cell may in part be responsible for this variation in toxin levels. The age of cyanobacterial cells and their growth rate influences the relative proportions of toxin retained within the cell and released into the water. Chorus and Bartram (1999) provide data for the release of microcystins from cells of *Microcystis aeruginosa* that show 100% of the toxins being retained within young, slowly growing cells, to 60–70% of the toxins being released into the water by old decaying cells. This percentage increases still further on the death and total decomposition of the cell.

Chorus and Bartram give a figure of 2×10^{-7} µg of microcystins/*Microcystis* cell. From the regional council data on nodularin and *Nodularia*, the median amount of toxin per cell is 3.5×10^{-5}µg, and ranges from 2.3×10^{-6} –1.5×10^{-2}µg. These calculations indicate that estimating the amount of nodularin in the water assuming that *Nodularia* cells hold a similar quantity of toxin to *Microcystis* cells would result in an estimated toxin concentration substantially lower than the measured concentration. This is consistent with nodularin from dead cells that have lysed accumulating in the water, and provides evidence for cell counts being a potentially misleading indicator of likely toxin concentrations.

During early bloom development, when cell counts are low and the biomass is young, toxins are likely to be contained within the cells and their concentration may be too low to detect in the water column. As the bloom develops and ages, there will be more cells present and a larger fraction of these will be older and more likely to release their toxins into the water column.

Although, for the case of nodularin in Lake Forsyth, there is a correlation between the total cyanobacterial cell concentration and the nodularin concentration, this does not show that the alert levels based on total cell counts provide adequate protection against dangerous toxin concentrations. The data in Table 9 are provided to show the extent to which nodularin appears in samples that give rise to different alert levels.

For Lake Forsyth, nodularin was not present in the water column at potentially unsafe levels prior to the Vigilance Level (≤500 cells/ml). Within the Vigilance Level, but before Alert Level 1, one sample contained nodularin at a concentration approximately 30-times greater than the PMAV. Within Alert Level 1, two samples with toxin concentrations 60-times and 300-times the PMAV were collected.

Table 9 Statistics of nodularin PMAV exceedences in total cyanobacterial cell concentration brackets defined in the Alert Level framework of the DW Guidelines – Lake Forsyth data

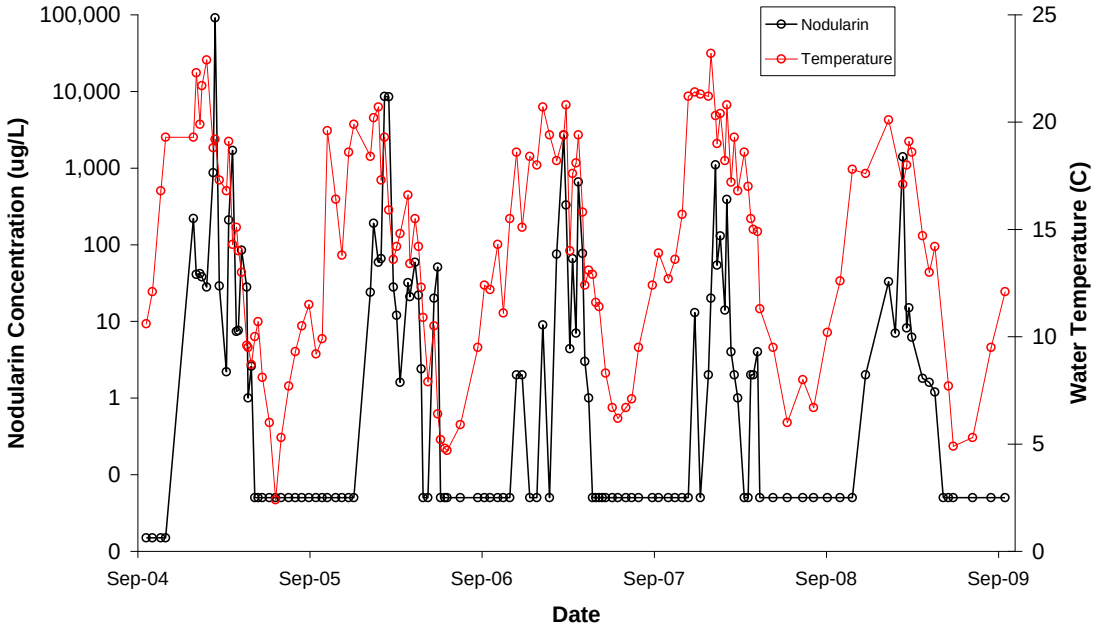
Status	Total Cell concentration bracket	Number of samples in bracket	Number of samples with nodularin PMAV exceedence	Nodularin concentration in exceedences (mg/L)
Vigilance Level not reached	≤500	22	0 (0%)[1]	-
Vigilance Level	>500– ≤2000	6	1 (17%)	0.033mg/L
Alert Level 1	>2000– ≤6,500	8	2 (25%)	0.059mg/L, 0.30 mg/L

[1] Expressed as a percentage of the number of samples in the bracket.

5.2 SEASONAL DEPENDENCE OF CYANOTOXIN CONCENTRATIONS

The seasonality of the nodularin concentration in Lake Forsyth is shown in Figure 5. Temperature data are also plotted in this figure to show the correlation (the *Nodularia* concentration correlation with the water temperature is shown in Figure 3). A statistical analysis of the correlation between nodularin and temperature has not been undertaken. In some years, there appears to be a lag between rising temperature and rising nodularin concentration. This is consistent with factors other than temperature influencing the nodularin concentration in the water column, for example, the bloom not aging as rapidly with a subsequent delay in the release of toxins by cell lysis. The plot also shows that rises in toxin concentrations can be rapid.

Figure 5 *Data from Lake Forsyth showing the seasonality of the nodularin concentration and its relationship to the water temperature.*



6 IMPLICATIONS FOR DRINKING-WATER SUPPLY AND RECREATIONAL WATER MANAGEMENT

This section summarises what can be learnt from the data with respect to drinking-water supply and recreational water management in the context of national and international experience. Few of the points made are new, most are restatements of what is already known or assumed. However, the data obtained from the freshwater management activities of regional and unitary councils support the applicability of the statements to the New Zealand setting.

a) A large number of cyanobacterial genera can be found in New Zealand's freshwater bodies, consistent with trends previously noted (Wood *et al.*, 2006). Many samples contain one or more toxigenic species giving rise to the possibility of a "cocktail" of toxins. The effectiveness of oxidants, such as chlorine and ozone, against toxins, depends on the toxin. Consequently, a single oxidant may prove to be poor defence barrier against a mix of toxins.

   Where a water supply's source is known to be, or suspected of being, subject to algal blooms, the supplier needs to have a barrier available, such as activated carbon adsorption, that is effective against a range of toxins. Alternatively, a strategy of stopping the growth of cyanobacteria before bloom development will also provide an effective barrier against multiple toxins. (see Chorus and Bartram (1999), chapter 8, for discussion of measures to prevent bloom development).

b) Based on the regional council dataset, there is a seasonality to cyanobacterial cell counts which shows a maximum about April with a minimum in early spring (approximately September). Concentrations tend to remain low in early summer. This general pattern provides only a rough guide to when cell counts may be at their highest. Local conditions can give rise to toxin concentrations well in excess of their PMAV well before the period when cell counts are generally at their highest.

   Water suppliers need to be watchful for the presence and growth of cyanobacteria from early spring. Simple observations that may provide warning of bloom development include checks for: poor water transparency or discolouration; the development of scums, clumps of algae or detached algal mats; increase in water temperature above 18°C and persistent stratification of the water column (see DW Guidelines, s.9.3).

c) The DWSNZ contains a separate chapter concerning compliance with respect to cyanotoxins because, despite being chemical contaminants, their behaviour is quite unlike that of other chemical contaminants. The regional council dataset confirms that toxin concentrations can change rapidly, and that in the event of a substantial bloom, toxin concentrations readily exceed their PMAV by one order of magnitude and in many instances, several orders of magnitude. Further, the satisfactory removal of toxins from water may not be achieved by conventional treatment processes. Given the acute and chronic health consequences of ingestion of elevated toxin concentrations, the growth of cyanobacteria in waters can present an extreme hazard to water supplies and recreational water users.

   Where possible, the threat of cyanotoxins to public health should be addressed by preventing bloom development in preference to attempting to remove the toxins by treatment processes (see Chorus and Bartram (1999), chapter 8, for discussion of measures to prevent bloom development). As a backup to this, water supplies need to have treatment processes available that can be brought on line and are capable of achieving at least a 3 log reduction in toxin concentration (and preferably more). Thought also needs to have been given to an alternative source of drinking-water for the community should treatment barriers prove inadequate.

d) Total cell counts readily exceed the lower thresholds in the Alert Levels framework. Further, toxin concentrations well in excess of their PMAV have been found in samples with total cell concentrations that would place them at the Vigilance Level or Alert Level 1. More samples in which **both** cell counts and toxin concentrations are determined are needed to provide a better understanding of the relationships between cell and toxin concentrations from which can be evaluated the robustness of the cell count thresholds used to define the alert levels and the actions recommended at each level.

7 CONCLUSIONS

The cyanobacteria/cyanotoxin datasets provided by regional councils and unitary authorities consisted predominantly of information about cyanobacteria: genus/species identification and measures of the numbers of the organisms. This is expected given the councils' environmental management responsibilities. The data have been helpful in understanding cyanobacteria in the larger context of general environmental waters, which can experience much greater levels of cyanobacterial growth than water bodies used for drinking-water supplies. In particular, the datasets have shown the range of genera that can be found in New Zealand's freshwaters, (and therefore which toxins could be present), how widely cyanobacteria are found, and their concentration ranges. The limited toxin data have shown the concentrations that can arise when blooms are substantial.

Collating and review of a cyanobacteria/cyanotoxin dataset aggregated from several regions has the potential to improve our understanding of how cyanobacteria may impact on public health, and how this is best managed. Such reviews may assist regional councils in managing recreational waters, and the Ministry of Health in helping water suppliers by reviewing, and revising when necessary, the cyanobacteria section of the *Guidelines for Drinking-water Quality Management for New Zealand*.

The shortage of samples analysed for both cyanobacteria and cyanotoxins is one of the barriers to understanding how the concentrations of the two are related. Knowledge of this relationship, and how it is affected, is necessary for assessing the advice given in the *Guidelines for Drinking-water Quality Management*

for New Zealand, and the Alert Levels framework the document contains. As both regional councils/unitary authorities and public health units will often have an interest in obtaining both analyses, collaboration to pool resources, if not already being done, would be a step forward in improving the value of cyanobacterial/cyanotoxin sampling.

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APPENDIX A

Table A1 Summary of the data received from regional and unitary councils

Regional or Unitary Council	Period over which data were collected	Number of samples[1]	Number of water bodies monitored[2]	Cyanobacteria			Cyanotoxin concentrations	Physico-chemical data	*E. coli*	Meteorological Data
				Presence/absence	Cell/ count	Qualitative				
Auckland Regional Council	Jan 07–Nov 08	67	8	✓						
Environment Canterbury	Sep 04–Dec 09	639	16		✓		✓	✓	✓	✓
Environment Southland	1999–Apr 09	718	53	✓		✓[3]				
Environment Waikato	Dec 03–Aug 09	743	15		✓					
Greater Wellington Regional Council	Feb 07–Oct 09	14	4	✓	✓		✓		✓	
Hawke's Bay Regional Council	Dec 05–Nov 09	108	1		✓		✓	✓	✓	
Marlborough District Council	Mar 09–Apr 09	3	1	✓	✓					
Taranaki Regional Council	Nov 07–Apr 09	112	5		✓					

[1] Total samples, including those for cyanobacteria. cyanotoxins, and physico-chemical data

[2] Samples may be taken from more than one location in each water body.

[3] The older data sets indicate relative cyanobacterial concentrations by one, two or three crosses for increasing concentrations, respectively. Later datasets employed the standardised descriptors used by MfE (Biggs and Kilroy, 2000). These provided a scale of relative abundance from 1 (Rare) to 8 (Dominant)

APPENDIX B

Table A2 Cyanobacteria reported as detected by each regional council

	Regional Council							
	ARC	ECan	ES	EW	GWRC	HBRC	MDC	TRC
Acanthoceras		✓						
Anabaena [T]	✓	✓	✓	✓	✓	✓	✓	✓
Anabaenopsis [T]		✓		✓				
Aphanizomenon [T]		✓		✓				
Aphanocapsa [T]	✓	✓	✓	✓				
Aphanothece		✓		✓				
Calothrix			✓					
Chamaesiphon			✓					
Chroococcus		✓		✓				
Chroodactylon			✓					
Coelomoron		✓						
Coelosphaerium		✓		✓				
Coleodesmium			✓					
Cyanodictyon	✓	✓	✓					
Cylindrospermopsis [T]		✓		✓				
Cylindrospermum [T]				✓				
Dichothrix			✓					
Geitlerinema						✓		
Gloeocapsa		✓						
Gomphospheria				✓				
Hapalosiphon [T]			✓					
Heteroleibleinia		✓	✓	✓				
Katagnyneme		✓						
Leptolyngbya				✓				
Loefgrenia			✓					
Lyngbya [T]	✓	✓	✓	✓				
Merismopedia		✓	✓	✓			✓	
Microcystis [T]	✓	✓	✓	✓	✓	✓		✓
Nodularia [T]		✓		✓				
Nostoc [T]			✓					
Oscillatoria [T]	✓	✓	✓	✓				
Phormidium [T]		✓	✓	✓	✓			
Picocyanobacteria		✓						
Placoma			✓					
Planktolyngbya		✓	✓	✓		✓		

	Regional Council							
	ARC	ECan	ES	EW	GWRC	HBRC	MDC	TRC
Planktothrix [T]		✓		✓				
Pseudanabaena [T]	✓	✓	✓	✓				
Rhabdoderma		✓					✓	
Rivularia			✓	✓				
Schizothrix			✓					
Snowella [T]		✓		✓				
Tapinothrix			✓					
Woronichina				✓				
Unidentified Cyanobacteria	.	✓	✓					

[T] Some species in this genus are known toxin producers. The absence of this identification does not mean that the genus does not contain toxin producers, simply that none have been identified to date.