Cyanobacteria and Cyanotoxins
2009–2010 Review

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2009–2010 Review

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The listing of cyanotoxin/cyanobacteria testing facilities in this report is drawn from a draft of the Ministry for the Environment's *New Zealand Guidelines for Managing Cyanobacteria in Recreational Waters – Interim Guidelines.*

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SUMMARY

This report is the second annual collation of cyanobacterial data from sources throughout New Zealand. Its purpose is to improve our understanding of the hazard to public health presented by cyanobacteria in drinking and recreational waters by review and analysis of data already being collected nationwide. This year, in addition to data from samples taken by public health units (PHUs), the report reviews data provided by regional councils and unitary authorities. It also lists, and provides contact information for scientists in Australia and New Zealand with involvement in cyanobacterial/cyanotoxin work, and lists facilities with cyanobacterial/cyanotoxin analysis capabilities.

Only one sample was taken for cyanobacterial/cyanotoxin analysis by PHUs during the 2009-2010 year. This sample was taken by the Northland District Health Board as a check on testing undertaken by the Far North District Council to manage a bloom in one of Kaitaia's drinking-water sources, Kauri Dam. Cells of three genera were found, but no toxins.

The first stage in the collation, review and analysis of data from regional councils and unitary authorities constitutes most of this report. Data were obtained from nine councils and 103 water bodies to produce a single master spreadsheet consisting of 2404 records (samples) containing, cyanobacteria, cyanotoxin, physico-chemical, bacteriological, metrological and hydrological data.

Key findings:

A) Environmental waters may contain more than one of a range of cyanobacterial genera, many of which can produce toxins.

B) 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.

C) Toxin concentration to cell concentration ratios can vary over four orders of magnitude, making cell counts a potentially misleading indicator of toxin concentrations in water. This variation probably arises because of the variable amounts of toxin released into the water by cells during their life cycle. Cell numbers increase as a bloom develops and with bloom aging an increasing fraction of cells will be older and more likely to release their toxins into the water column.

D) Waters with cell counts that would place a water supply at Alert Level 1 can contain toxin concentrations 60-300 times their PMAV.

E) The concentrations that toxins have been found to reach, coupled with the speed at which cyanobacterial toxin producers multiply, the difficulty in removing toxins from the water, and the severity of the health effects that can be associated with them, make cyanotoxins an extremely dangerous hazard in drinking- and recreational-waters.

Implications for drinking-water supply and recreational water management

The characteristics of water bodies monitored by regional councils and unitary authorities are often different from those of waters used as drinking-water sources. Algal bloom[1] development in drinking-water sources may not be as extensive as that experienced in some environmental water bodies. Consequently, the guidance that can be drawn from this dataset that has direct applicability to the management of drinking-water supplies, and perhaps recreational waters, is limited. The value in reviewing the national cyanobacteria and cyanotoxins datasets is that the findings can assist in developing advice given in such documents as the *Draft Guidelines for Drinking-water Quality Management for New Zealand* (draft DW Guidelines) (MoH, 2005). The following guidance applies to water bodies that experience, or are likely to experience, algal growth.

a) Water supplies need to have treatment barriers available, or more generally, defence strategies in place, that can eliminate a range of toxins.

b) Water suppliers should be watchful for signs of cyanobacterial development from early spring, if they have concerns about possible cyanobacteria growth in their source water. The regional council dataset shows that average cyanobacterial cell counts are highest from January to May with maximum cell counts tending to occur around April. However, local conditions may result in toxin concentrations reaching unsafe levels well before the months when average cell counts are at their highest. 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 draft DW Guidelines, s.9.3).

c) As part of their risk management plans and to assist in meeting the requirements of the *Drinking-water Standards for New Zealand* (s.7.2-1), water suppliers should try to identify the factors that favour cyanobacterial growth in their catchment to help devise measures to mitigate their effect. While a scientific research programme may be required to understand these factors properly, parameters that may prove helpful in identifying the important factors for a particular catchment are listed in the draft DW Guidelines (s.9.4). Water suppliers should also take account of how their system may be affected by projected climate change and variability.

[1] 'There is no definition of "bloom" in terms of number of cyanobacterial cells/mL. The term is used in this report to describe a level of cyanobacterial growth at which we cannot be reasonably certain that toxin concentrations are still at safe levels. This level cannot be ascribed to a fixed number of cells/mL.

Implications (continued)

d) 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). This strategy reduces reliance on treatment processes that may be of limited effectiveness, and provides protection for recreational water users for whom there is no treatment barriers for protection.

e) 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 a water supply at the Vigilance Level and Alert Level 1. One of the aims of the annual collations of cyanobacteria/cyanotoxin data should be the collation and analysis of data that will assist in the review and, if necessary, modification of the Alert Levels Framework.

Major results from the preliminary analysis of the regional council dataset

1) Forty-three cyanobacterial genera were detected and reported, of which 16 contained species that are known toxin producers. The two most widely reported genera were *Anabaena* and *Microcystis*. Although these genera were reported by the greatest number of regional councils, they were not necessarily present in the greatest numbers in samples.

2) The largest range of genera was reported by Environment Canterbury (27), followed by Environment Southland (25) and Environment Waikato (24). Often samples contained more than one cyanobacterial genera.

3) Fourteen cyanobacterial genera predominated in this analysis, based on those genera identified in more than 10% of a council's samples.

4) In four of five regions for which cell count data were available, more than 80% of samples contained total cyanobacterial cell counts that exceeded the Vigilance Level threshold defined in the *Draft Guidelines for Drinking-water Quality Management for New Zealand*, and more than 58% exceeded the Alert Level 1 threshold.

5) Data from the complete dataset showed seasonal variation in cell counts. Data from Environment Canterbury showed a much greater difference between counts in the warm and the cool months than was apparent in the Environment Waikato dataset. This difference can be explained by the different characteristics of the waters being monitored.

Major results (continued)

6) The cyclic patterns in *Nodularia* cell concentrations were consistent with the seasonal changes in water temperature. (*Nodularia* was one of the few genera for which cell count and temperature data were available.)

7) There is a weak trend of increasing average monthly cyanobacterial cell counts over the period from 2004–2009, but it is not significant at the 95% confidence level. The March average cyanobacterial cell counts showed a significant increase at the 90% confidence level.

8) Toxin data were available for only 282 samples, 278 of which were from shallow eutrophic lakes in Canterbury. Homoanatoxin-a and anatoxin-a were reported in these samples, but the dominant toxin was nodularin. *Nodularia* was the source of this toxin (see 10 below), although this cyanobacterium tended not to be the dominant genus.

9) One hundred and fifty-four toxin detections were reported. The PMAV for the toxin was exceeded in 133 (86%) of these detections and, in the case of nodularin, the PMAV was exceeded by more than a factor of 10 in 50 of 109 exceedences (55%).

10) Highly significant positive correlations were found between the nodularin and *Nodularia* concentrations, and the nodularin and total cell concentrations. There was no correlation between the dominant genus (*Merismopedia*) in these samples and the nodularin concentration.

11) No nodularin was detected in samples with a total cell count below the Vigilance Level threshold (22 samples). At the Vigilance Level, one of six samples (17%) contained nodularin in excess of its PMAV, and at Alert Level 1, two of eight samples (25%) contained nodularin in excess of its PMAV. In all these exceedences the PMAV was exceeded by factors ranging from 33–300.

12) The seasonal variation in the nodularin concentration was consistent with the seasonal variation in water temperature.

Conclusion and points for consideration

- Only one sample was received from a PHU during the 2009-2010 year. This may reflect increased monitoring by water suppliers, and a reliance on these data by PHUs rather than collection of their own samples. Some guidance for PHUs on the extent to which they need to obtain samples independently of those collected by water suppliers may be helpful.
- The datasets received from regional council/unitary authority have been valuable in understanding cyanobacteria in the larger context of environmental waters, which can experience much greater levels of cyanobacterial growth than water bodies used as dinking-water supplies.
- A more extensive analysis of the regional council/unitary authority dataset should be undertaken when it has been augmented with the data from the remaining councils.
- To understand the relationships between the cell counts and toxin concentrations, more samples tested for both cyanobacteria and cyanotoxins are needed.

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.

The first of the collation reports (FW09076) was prepared by ESR in 2009 (Podivinsky and Williamson, 2009). FW09076 collected all information about cyanobacteria/cyanotoxins that public health units (PHUs) had amassed between 2004 and 2009.

This report provides a review of the data gathered by PHUs during the 2009-2010 year, and presents the first stage of a collation of cyanobacteria/cyanotoxin data from regional councils. The primary purpose of the regional council 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. An update of expertise in the cyanobacteria/cyanotoxin field is also provided in Appendix 5.

2 REGULATORY BACKGROUND

2.1 Introduction

The bulk of this report is an examination of the data provided by eight[2] 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 assist water suppliers 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 *Draft Guidelines for Drinking-water Quality Management for New Zealand* (the DW Guidelines) (MoH, 2005); 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 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

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.

[2] 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. These results will be included in the second stage of the regional council data collation. The author apologises for this oversight.

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	≥1.8[A]	-
Remain within Alert Level 1	>6500	≥1.8[A]	-
Promotion to Alert Level 2			>MAV

[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

[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.

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.

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

Alert Level	Criteria for action			
	OR	OR	OR	
	Concentration Cell/mL	Biovolume mm^3/L	Total microcystins concentration	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	≥12 μg/L	Consistently present
		≥10[B]		

[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 PUBLIC HEALTH UNIT DATA

From 2009–2010, only one request was received by the Cawthron Institute (ESR's subcontractor) from a PHU for cyanobacterial and cyanotoxin assays. The following outlines the background to the sampling.

On 17 March 2010, the Northland District Health Board (NDHB) received a request from the Far North District Council (FNDC) for an opinion on their proposed management of an algal bloom in the Kauri Dam, one of the sources of the Kaitaia drinking-water supply. FNDC had taken samples from several locations in the supply, including the dam, on 8 March. The sampling had shown the presence of two potentially toxic genera, *Anabaena* and *Aphanizomenon*, in the dam (total cell concentration 62,073 cells/mL, but the concentration of microcystins was less than the limit of detection at 0.0005mg/L, i.e. it was less than 50% of the PMAV). Dosing with powdered activated carbon had started at the treatment plant, and the status of the system was to remain at Alert Level 1.

FNDC's intention was to bring the dam drinking-water source back on line and use it while blending it with river and stream sources provided cell counts were sufficiently low, and toxins could not be detected. Algal monitoring was to continue twice weekly at the dam, and in the water leaving the treated water reservoir. The status of the system was to be regularly reviewed in consultation with the NDHB DWA.

To confirm the FNDC's test results, NDHB took a sample from the dam on 22 March for cyanobacterial and cyanotoxin assays. The cyanobacterial results are given in Table 4. No toxins (cylindrospermopsin, homoanatoxin-a and anatoxin-a, microcystins and nodularin) were detected.

Table 4 Cyanobacterial test results from the Kauri Dam taken in 22 March 2010

Cyanobacterial Species	Cell Count (cell/mL)
Anabaena Planktonica	2700
Aphanizomenon gracile	210
Aphanocapsa sp.	310

ESR advised NDHB regarding interpretation of the results with respect to the DW Guidelines. The advice concluded that regular monitoring was still required, and noted that although the cyanobacteria appeared not to be releasing toxins when the samples were taken, the triggers of toxin release were not understood, and therefore, while the cyanobacteria were still present the possibility of toxin release still existed. Occasional sampling for toxins was suggested.

Further samples were not received, and it is assumed that the situation is being managed to NDHB's satisfaction.

4 REGIONAL COUNCIL DATA

4.1 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 the data they held relating to cyanobacteria (including, cell counts, species identity, toxin, physico-chemical analyses and any other data collected with samples).

Replies were received from 10 regional councils, and of these, nine provided actual datasets or directions to where the data could be found on their websites. As data were not received from all regional councils or unitary authorities, this report is regarded as the first stage of the regional councils' survey, with the remaining councils being approached again next year to complete the dataset.

Table 5 summarises the information received from these councils, including the number of water bodies from which data were obtained. The water bodies are identified in Table A1 in the Appendices.

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 this report's 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 the necessary corrections were made.

Where cyanobacterial data, cyanotoxin data, physico-chemical, or other data groups, as listed in Table 5, 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.

Table 5 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)

4.2 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 species 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 report, identification to genus level only was retained.

Few data related to cyanobacterial toxins. 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 regarded as a significant loss at this stage because of the small number of toxin data and their restriction to a small number of water bodies.

The findings discussed in Section 4.3 are only a preliminary examination of the dataset. A more complete analysis of the data, considering other possible relationships between reported variables is beyond the scope of this project, and may be undertaken in subsequent years of the survey when data have been obtained from other councils.

4.3 Findings from preliminary examination of the data

4.3.1 Cyanobacterial data

4.3.1.1 Genera reported

Table 6 expands on the information in Table 5, 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.

Genera marked with a superscript "T" contain species known to be toxin producers according to the DW Guidelines. The absence of this identification does not mean that the genus does not contain toxin producers, simply that none have been identified to date.

The number of samples in which each genus was detected and the percentage this represents of the total number of cyanobacterial samples taken by each council[4] are tabulated in Table A2 in the Appendix. Table 7 lists this information for the most frequently detected genera. A genus is included in this table if it was detected in more than 10% of samples.

[4] Abbreviations for councils, used in tables or figures in this report, are: ARC – Auckland Regional Council; ECan – Environment Canterbury; ES – Environment Southland; EW – Environment Waikato; GWRC – Greater Wellington Regional Council; HBRC – Hawke's Bay Regional Council; MDC – Marlborough District Council; TRC – Taranaki Regional Council.

Table 6 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		✓	✓	✓		✓		
Planktothrix [T]		✓		✓				

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

[T] Some species in this genus are known toxin producers

Table 7 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.

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.

Key Finding: Environmental waters may contain more than one of a range of cyanobacterial genera, many of which can produce toxins.

Interestingly, the most frequently detected genus reported in samples included in the compilation of samples taken by PHUs between 2004 and 2009 was *Phormidium* (Podivinsky and Williamson, 2009). Podivinsky and Williamson noted that this probably reflected the reasons for the samples being taken. They stated that *Phormidium*, a benthic cyanobacterium, had been a particular problem in some recreational rivers. Samples taken and tested to investigate these events would have favoured the detection of this organism. The importance of benthic cyanobacteria in flowing waters means that the nature of the water body sampled will influence the genera found. Environment Southland reported the greatest number of samples containing *Phormidium*, and all the water bodies it has monitored are rivers, streams or creeks. Lakes have been the predominant water bodies monitored by the other councils that have not found *Phormidium* to be an important cyanobacterium.

From 2009–2010, Environment Waikato, Environmental Southland and Environment Canterbury reported the greatest number of detected genera, 24, 25 and 27, respectively. Among other regions, the highest number of genera reported was seven. This appears to be a consequence of the length of time over which samples were collected or the number of samples collected, rather than the number of water bodies monitored. Table 5 shows that Environment Southland had monitoring results from 53 water bodies, while Environment Waikato and Environment Canterbury monitored only 15 and 16 water bodies, respectively.

4.3.1.2 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)[5] for the predominant genera (those genera contained in Table 7) reported by these councils is presented in Table 8. Complete tabulations of the median and 95th percentile concentrations for all genera reported are given in Table A3 and Table A4, respectively. The statistics presented in all these tables are calculated from samples in which the total cyanobacterial cell count was greater than zero.

[5] 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®.

	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		

Table 8 **Tabulation of 95th percentile concentrations of the most frequently identified cyanobacteria in the regional council datasets**

Table 9 provides another interpretation of the relative importance of the two most frequently reported genera *Anabaena* and *Microcystis*. When interpreted in combination with other information, it shows how the characteristics of the sampled water body influence the statistics. Table 9 presents the average percentage of total cyanobacterial cells in regional council samples constituted by each genus. It shows that while *Anabaena* and *Microcystis* concentrations in Environment Canterbury's samples can be high or very high (Table 8), on average, they constitute only a small percentage of the total cyanobacterial cell count (Table 9). On the other hand, *Anabaena* is overwhelmingly the most important genus in the Wellington Region dataset, in terms of frequency of detection, cell concentrations, and the percentage of the total cyanobacterial cell count. The Canterbury samples were obtained from several water bodies, but *Anabaena* and *Microcystis* were present at high concentrations in only one water body. The Wellington monitoring was restricted to a single source in which *Anabaena* was the dominant genus.

Table 9 **Data showing the relative importance of *Anabaena* and *Microcystis* in each of the regional council datasets for which cell concentration data are available**

	Average % of total cell count constituted by each genus	
Regional Council	***Anabaena***	***Microcystis***
Environment Canterbury	0.7%	1.9%
Environment Waikato	53%	20%
Greater Wellington Regional Council	100%	0%
Hawke's Bay Regional Council	48%	48%

As noted in Section 2, both the DW- and Recreation- Guidelines use total cyanobacterial cell counts in defining alert levels. Table 10 tabulates the number of samples found in each regional 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 10 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 10. 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.

4.3.1.3 Seasonal variation and temporal trends

Seasonal variation in the growth of cyanobacteria is well documented, and is supported by the data from regional councils. Fig. 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.

Each of the three histograms in Fig. 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.

Fig. 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.

Fig. 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 Fig. 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.

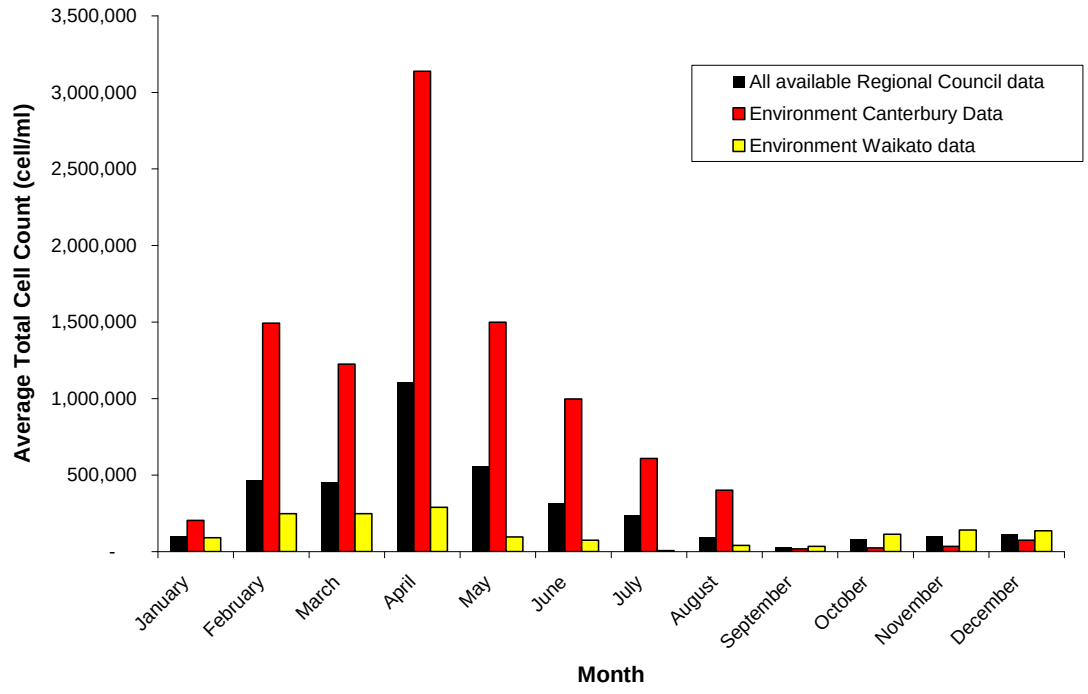

Fig. 1 **Average total cyanobacterial cell counts for each month averaged over the period for which data are available for all regional council datasets, and for the individual Environment Canterbury and Environment Waikato datasets.**

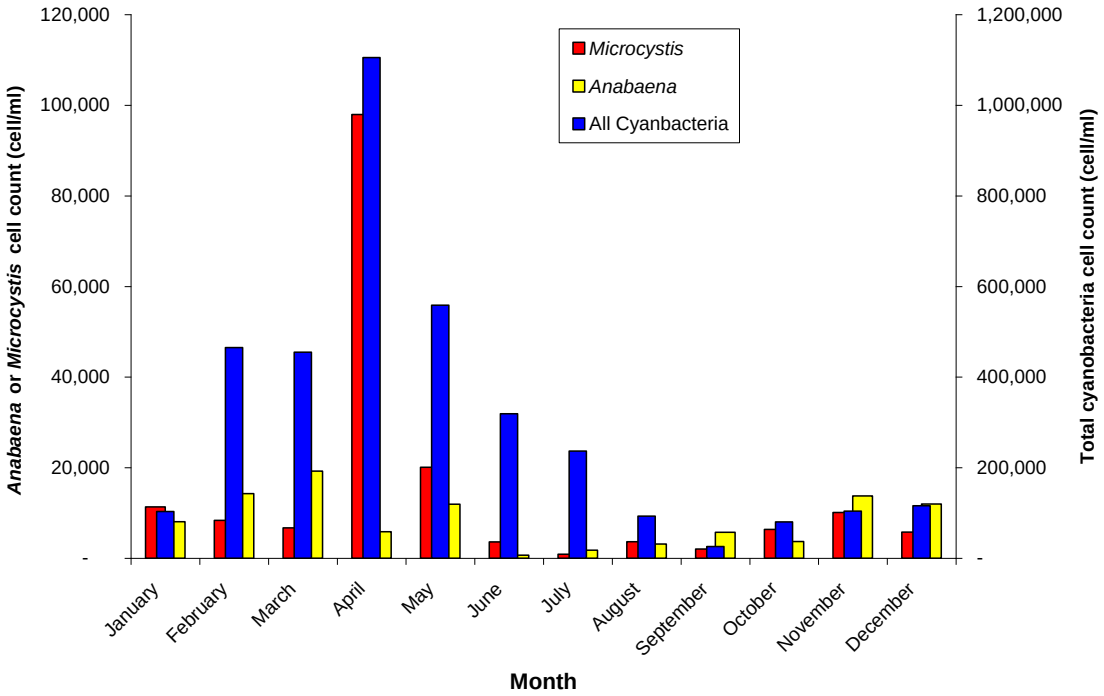

Fig. 2 **Average monthly cell counts for all cyanobacteria, and *Anabaena* and *Microcystis* individually.**

One further figure showing the seasonal dependence of cyanobacterial cell concentrations is given in Fig. 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 is not undertaken, but a match between the two datasets is evident from the figure.

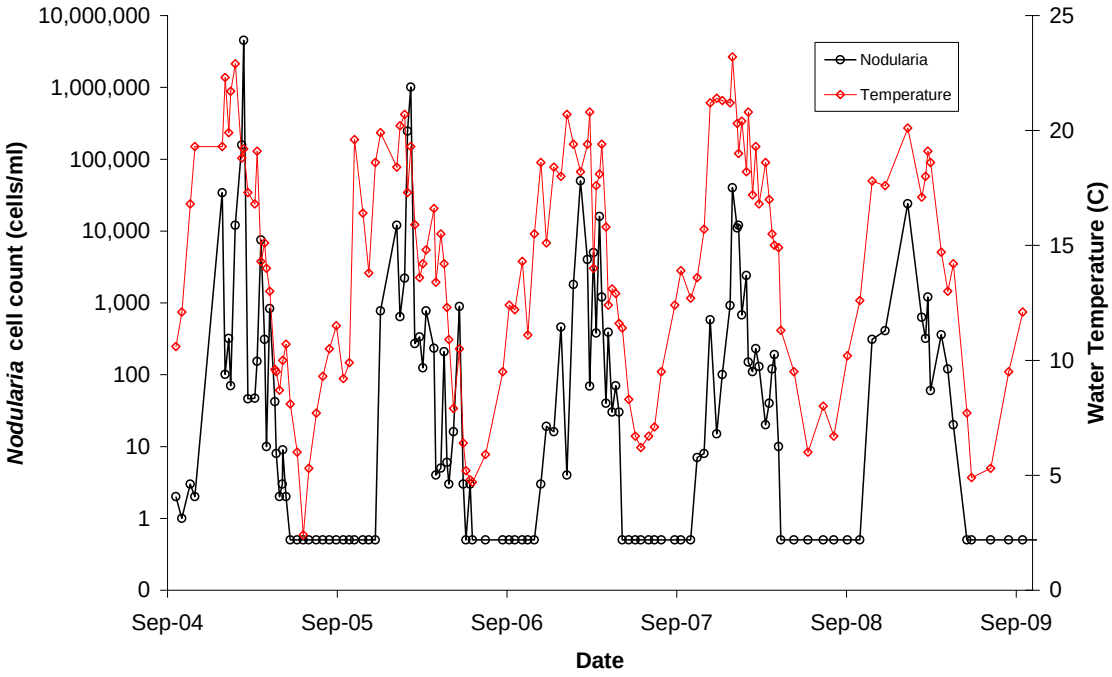

Fig. 3 ***Nodularia*** **cell concentrations and water temperature in Lake Forsyth (ECan) (Non-detected concentrations were arbitrarily out equal to 50% of the limit of detection).**

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. Data were available from 2004–2009. Plots of the monthly data, divided into quarterly groups, and their linear trend-lines (from least squares regressions), are shown in Fig. 4, Fig. 5, Fig. 6, and Fig. 7.

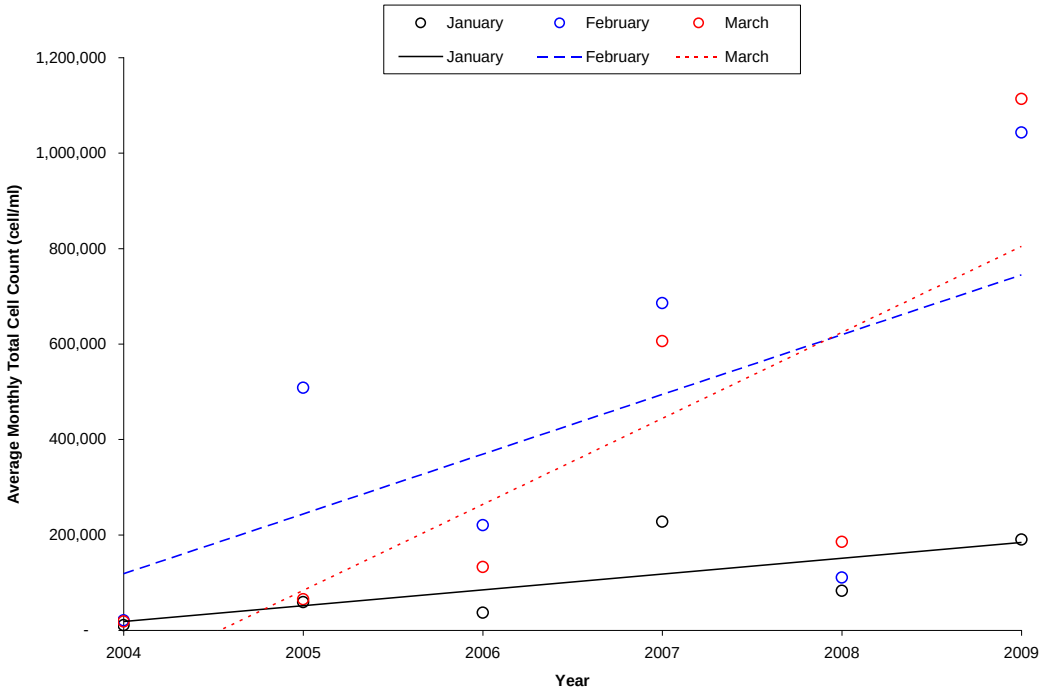

Fig. 4 **Plots of average monthly total cell counts for the first quarter of the year for 2004 to 2009 to show trends with time.**

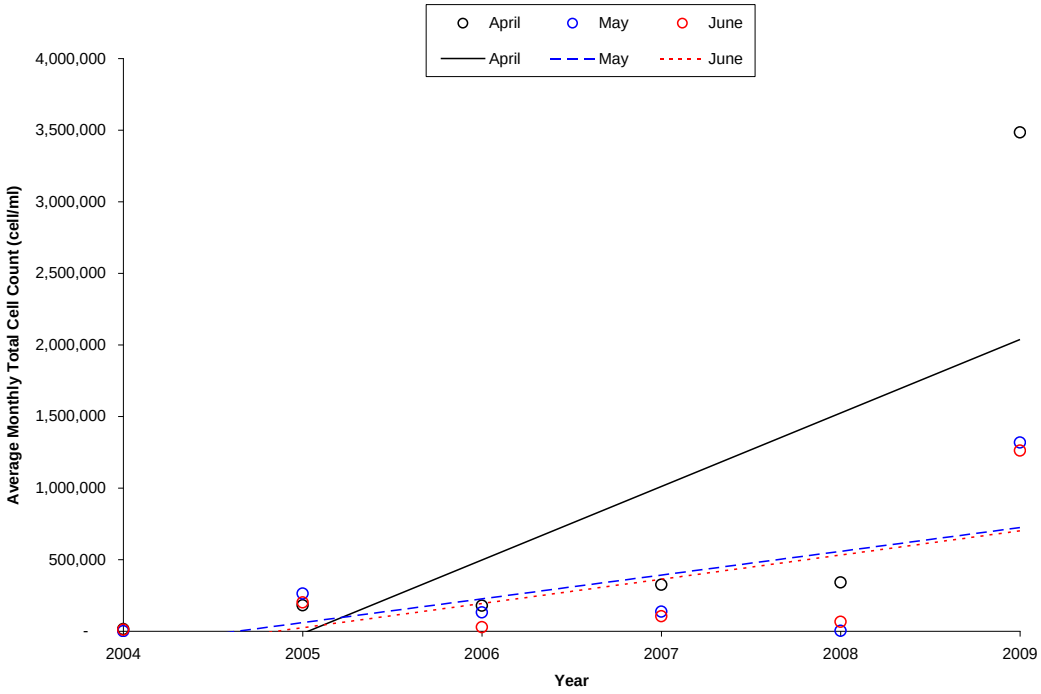

Fig. 5 **Plots of average monthly total cell counts for the second quarter of the year for 2004 to 2009 to show trends with time.**

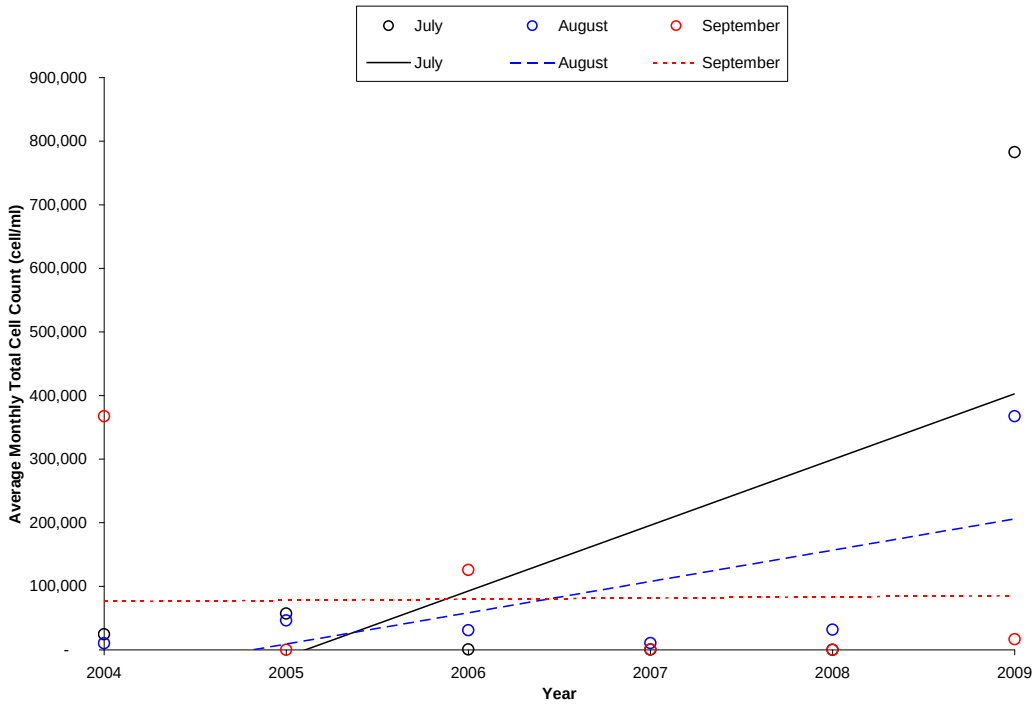

Fig. 6 **Plots of average monthly total cell counts for the third quarter of the year for 2004 to 2009 to show trends with time.**

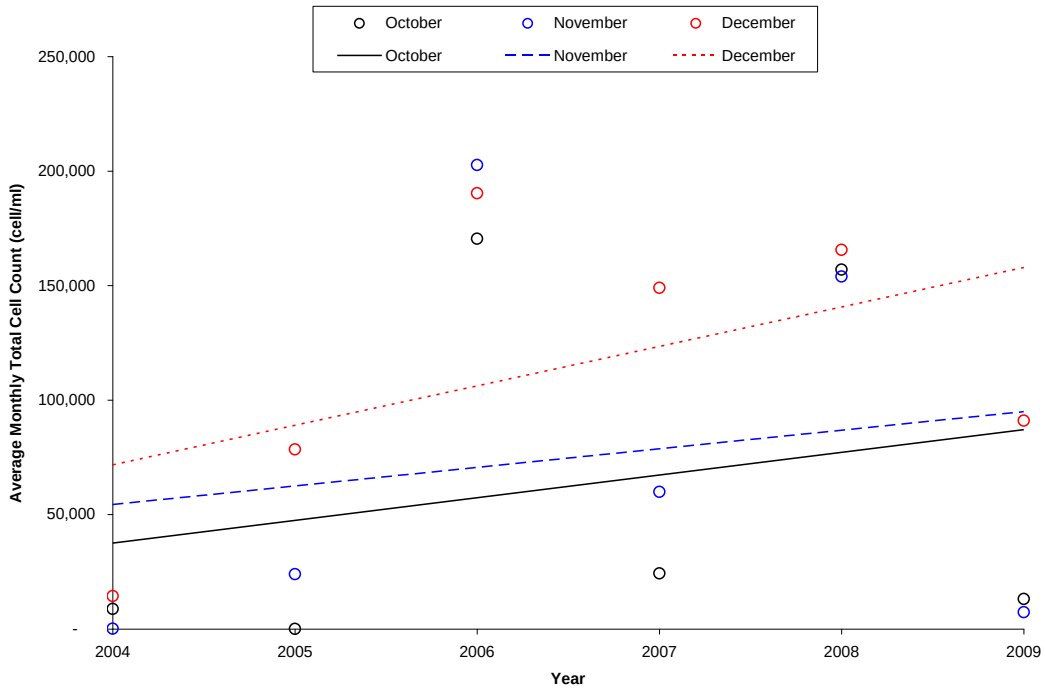

Fig. 7 **Plots of average monthly total cell counts for the fourth quarter of the year for 2004 to 2009 to show trends with time.**

The statistical parameters describing these data fits are given in Table 11. All months except September, show a positive slope. However, the variability in cell counts is such that a relationship between the average monthly cell count and the year cannot be statistically demonstrated at a 95% confidence level (i.e. p values are all greater than 0.05). If there is a trend of increasing counts over the six-year period, it is most apparent in the warmer months. At a 90% confidence level, a trend of increasing cell counts is evident in the March data.

Table 11 Trends in monthly total cyanobacterial cell counts from 2004-2009

Month	Slope (cell/ml/year)	R^2	p value
January	33085	0.501	0.116
February	125246	0.361	0.207
March	180246	0.622	0.062
April	513443	0.512	0.110
May	166086	0.380	0.193
June	169105	0.424	0.162
July	103416	0.381	0.192
August	49167	0.432	0.156
September	-6749	0.066	0.622
October	9901	0.055	0.655
November	8103	0.032	0.733
December	17225	0.242	0.321

4.3.2 Cyanotoxin data

4.3.2.1 Cyanotoxin concentrations

Despite having 2404 records in the dataset, cyanotoxins were monitored in only 282 samples, 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 12. 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 12 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

Key Finding: 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.

The dominance of nodularin in this dataset is a consequence of the particular cyanobacteria in Lake Forsyth, and the statistics in Table 12 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 values of statistical parameters describing the regression fits are given in Table 13. 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 versus *Nodularia* concentration is shown in Fig. 8.

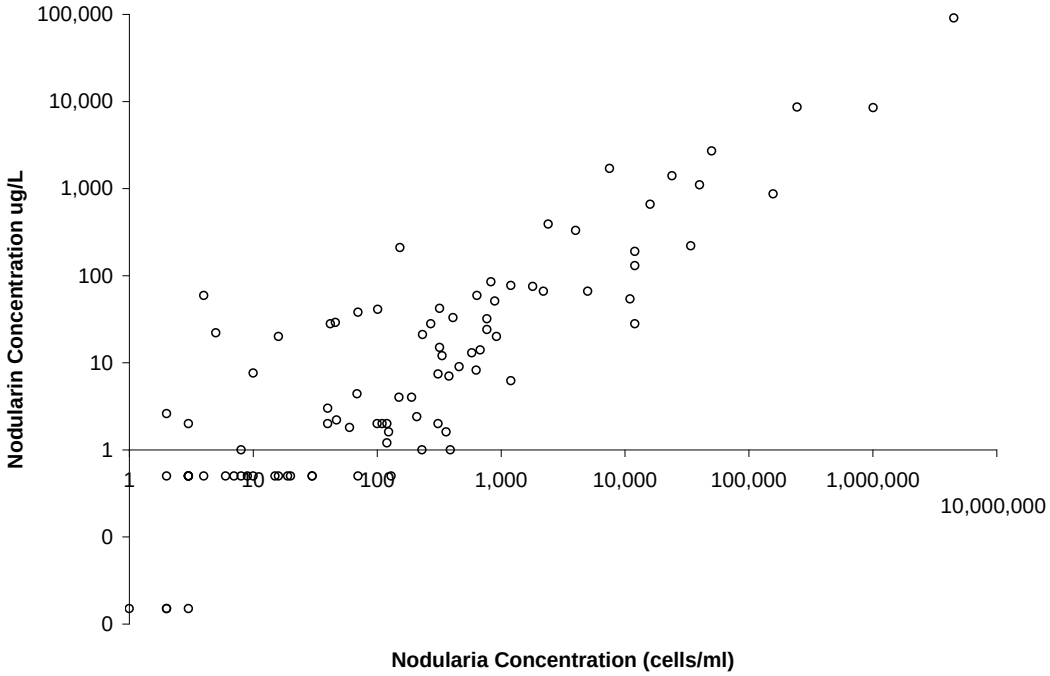

Fig. 8 **Plot showing the correlation between the *Nodularia* and nodularin concentrations**

Table 13 **Summary of statistical parameters describing least squares regression fits to cyanobacterial cell concentration and nodularin concentration data[1]**

Genus	Trend line slope	R^2 value	p value
Nodularia[1]	0.0197	0.981	<0.001
Merismopedia[1]	-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. However, variation in the nodularin concentration is more weakly accounted for by the total cell count than by the *Nodularia* concentration. Thus, despite the significance of the nodularin-total cell count relationship, estimating the toxin concentration from the total cell count will have a substantial associated uncertainty.

Fig. 8 shows that for a given *Nodularia* cell count, a 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 portions 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. Based on these real cell counts, and assuming the amount of nodularin contained in *Nodularia* cells to be similar to microcystins in *Microcystis*, the calculated concentration of nodularin per cell is considerably higher than would be predicted. This is consistent with the accumulation of nodularin in the water from dead cells that have lysed, and explains why cell counts can be misleading indicators of the likely toxin concentration.

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 will 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.

Key Finding: Toxin concentration to cell concentration ratios can vary over four orders of magnitude, making cell counts a potentially misleading indicator of toxin concentrations in water. This variation probably arises because of the variable amounts of toxin released into the water by cells during their life cycle. Cell numbers increase as a bloom develops and with bloom aging an increasing fraction of cells will be older and more likely to release their toxins into the water column.

The *Merismopedia* concentration shows no significant correlation with the nodularin concentration ($p = 0.723$), which is reflected in the other parameters in Table 13. That conditions favouring *Nodularia* growth may also favour *Merismopedia* growth (in most samples *Merismopedia* was the greatest contributor to the total cell count) and that this is in part the reason for the correlation between total cell counts and the nodularin concentration, can be ruled out on the basis of the absence of a correlation between *Merismopedia* itself and the nodularin concentration. The fact that *Nodularia* is part of the total cell count, albeit a minor contributor, appears to result in the correlation between nodularin and the total cell count.

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 imply that the alert levels based on total cell counts provide adequate protection against dangerous toxin

concentrations. The data in Table 14 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 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 14 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%)	-
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

Key Finding: Waters with cell counts that would place a water supply at Alert Level 1 can contain toxin concentrations 60-300 times their PMAV.

Key Finding: The concentrations that toxins have been found to reach, coupled with the speed at which cyanobacterial toxin producers multiply, the difficulty in removing toxins from the water, and the severity of the health effects that can be associated with them, make cyanotoxins an extremely dangerous hazard in drinking- and recreational-waters.

4.3.2.2 Seasonal dependence of cyanotoxin concentrations

The seasonality of the nodularin concentration in Lake Forsyth is shown in Fig. 9. Temperature data are also plotted in this figure to show the correlation (the *Nodularia* concentration correlation with the water temperature is shown in Fig. 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 delay may be related to the age of the bloom with older cells releasing toxins.

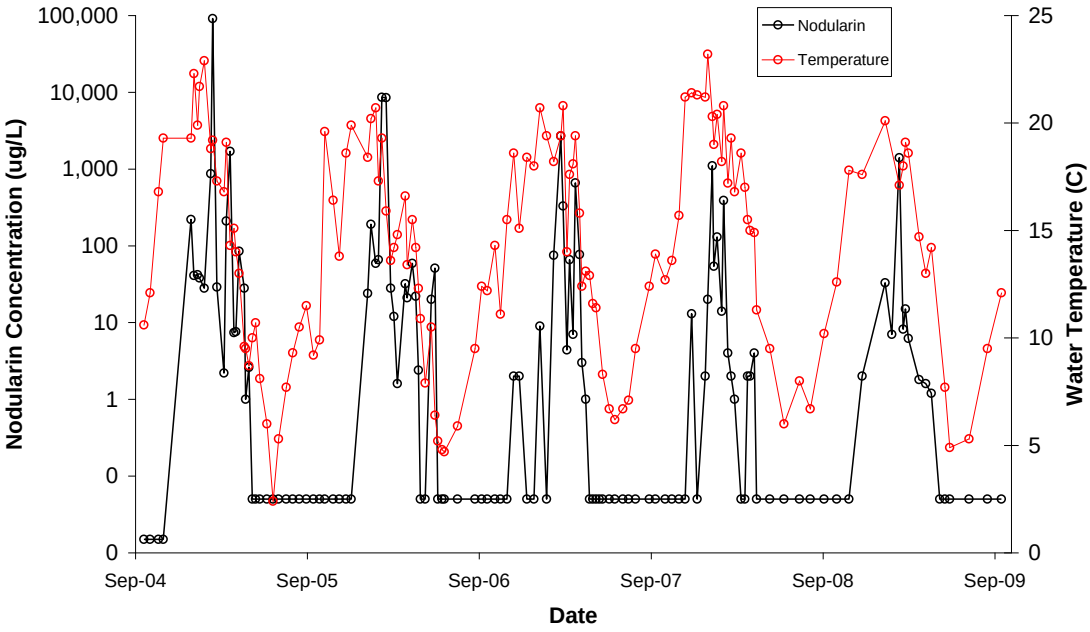

Fig. 9 **Data from Lake Forsyth showing the seasonality of the nodularin concentration and its relationship to the water temperature.**

4.4 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. Defence against toxins by oxidative destruction using chemicals such as chlorine or ozone, may be inadequate because each oxidant is not effective against all toxins. Consequently, a single oxidant may be an inadequate 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) There is a seasonality to cyanobacterial cell counts which shows a maximum about April with a minimum in early spring (approximately September) and concentrations tend to remain low in early summer. This generic 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 draft DW Guidelines, s.9.3).

c) There is evidence, albeit limited, from the regional council data that over the period from 2004–2009, there has been a trend of increasing average cyanobacterial cell concentrations in samples taken during the warmer months.

As part of their risk management planning and to assist in meeting the requirements of the *Drinking-water Standards for New Zealand* (s.7.2-1), water suppliers should try to identify the factors affecting cyanobacterial growth in their catchments and the trends in these factors. Such information will help in mitigating the effects of these factors on source water quality, and provide warning of increasing frequency and size of blooms. While a scientific research programme may be required to understand these factors properly, parameters that may prove helpful in identifying the important factors for a particular catchment are listed in the draft DW Guidelines (s.9.4).

Water suppliers' planning should also take into account projections for climatic changes in their area and what effect these may have on the threat of cyanobacteria in their source water.

d) 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.

e) 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.

   One of the aims of the annual collations of cyanobacterial/cyanotoxin data should be the collection and analysis of data that will assist in the review and, if necessary, modification of the Alert levels Framework.

f) Research organisations and individuals, both in New Zealand and in Australia, have expertise in cyanobacteria and cyanotoxins that could be helpful to PHUs and regional councils. Funding for advice from the Cawthron Institute (accessed in consultation with ESR) for PHUs is provided by the Ministry of Health, and help should be sought from this source before turning elsewhere. Contact information for expertise within Australasia is listed in Appendix 5.

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6 CONCLUSION

Last year's annual collation report showed that while the number of samples taken by PHUs for cyanobacteria or cyanotoxins has fluctuated since 2003, numbers taken in 2007–2008 and 2008-2009 were 38 and 21, respectively. The sole sample taken this year shows a marked reduction in sample numbers. There is no evidence from the data obtained this year that cyanobacterial events are fewer, overall. However, the Ministry of Health has recently strongly encouraged water suppliers to take greater responsibility for monitoring blooms and the Ministry has communicated this approach to PHUs. PHUs have not been canvassed to ascertain whether there are other reasons why sample numbers have declined. With greater monitoring by suppliers, DWAs may be able to rely on data obtained by suppliers when evaluating cyanobacterial blooms. Where regional council also undertake monitoring, discussion with council staff may provide valuable additional context and early warning of bloom development.

The 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 their 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 the range of toxins that may be present), how widely they are found, and their concentration ranges. The limited toxin data have shown the concentrations that can arise when blooms are substantial.

When cyanobacterial-related data are obtained from the remaining councils during the second stage of collating the data from regional/unitary councils, a more thorough analysis of the total dataset should be undertaken to assess relationships not considered in this report. These might include relationships involving nutrient and chlorophyll-a levels, and closer study of data from individual water bodies where sufficient data are available.

The annual data collations have the potential to improve our understanding of how cyanobacteria may impact on public health, and how this is best managed, by reviewing a much larger dataset than is available to individual organisations, and with a different intention from that when the samples were originally taken. This understanding will 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 *Draft 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 gained from cyanobacterial/cyanotoxin sampling.

REFERENCES

Biggs BJ, Kilroy C, 2000, *Stream Periphyton Monitoring Manual*, NIWA, Christchurch.

Chorus I and Bartram J, 1999, *Toxic Cyanobacteria in Water: A guide to their public health consequences, monitoring and management*, E and FN Spon, London.

MfE, 2009, *New Zealand Guidelines for Cyanobacteria in Recreational Fresh Waters – Interim Guidelines*,

MoH, 2005, *Draft Guidelines for Drinking-water Quality Management for New Zealand*,

Podivinsky E, and Williamson W M, 2009, Environmental microbiological risk assessment and management (EMRAM) Cyanobacteria and Cyanotoxins 2008-2009 Review. ESR Client Report FW09076, Christchurch Science Centre.

Wood S A, Holland P T, Stirling D J, Briggs L R, Sprosen J, Ruck J G, Wear R G, 2006, Survey of cyanotoxins in New Zealand water bodies between 2001 and 2004. *New Zealand Journal of Marine and Freshwater Research*, 40, 585–597.

APPENDIX 1 WATER BODIES MONITORED

Table A1 Listing of water bodies monitored for cyanobacteria by each regional council or unitary authority

Auckland Regional Council	Environment Southland
Lake Kawaupaku	Aparima River
Lake Kereta	Brightwater Creek
Lake Kuwakatai	Cascade Creek
Lake Ototoa	Cromel Stream
Lake Pupuke	Dipton Stream
Lake Spectacle	Dunsdale Stream
Lake Tomarata	Eglinton River
Lake Wainamu	Forster Stream
Environment Canterbury	Hamilton Burn
Ashley River	Harries Bay Stream
Cust River	Hedgehope Stream
Hurunui River	Hillpoint Stream
Lake Ellesmere	Home Creek
Lake Forsyth	Irthing Stream
Lake Rotorua	Lill Burn
Okuhu River	Makarewa River
Ophi River	Mararoa River
Opuha River	McKay Creek
Pareora River	Meadow Burn
Selwyn River	Mimihau Stream
Tengawai River	Mokoreta River
Waiau River	Murray Creek
Waimakariri River	North Etal Stream
Waitaki River	Oreti River
Waitohi River	Otamita Stream
Environment Waikato	Otapiri Stream
Lake Hakanoa	Otautau stream
Lake Kainui	Oteramika Stream
Lake Karapiro	Pig Creek
Lake Maraetai	Pourakino River
Lake Ngaroto	Rowallan Burn

Lake Ohakuri	Silver Stream
Lake Rotoaira	Taringatura Creek
Lake Rotongaro	Terrace Creek
Lake Taupo	Thicket Burn
Lake Waahi	Trenders Creek
Lake Waikare	Upukerora River
Lake Waipapa	Waianiwa Creek
Lake Whakaipo	Waiau River
Lake Whangamata	Waihopai River
Lake Whangape	Waihopai Stream
Greater Wellington Regional Council	Waikaia River
Henley Lake	Waikaka Stream
Lake Pounui	Waikawa River
Lake Waitawa	Waikiwi Stream
Whitby Lake	Waikopikopiko Stream
Hawke's Bay Regional Council	Waimatuku Stream
Lake Tutira	Waimea Stream
Marlborough District Council	Waimeamea River
Taylor dam	Waimumu Stream
Taranaki Regional Council	Wairaki River
Lake Opunake	Waituna Creek
Lake Ratapiko	Winton Stream
Lake Rotokare	
Lake Rotomanu	
Waiwhakaiho River	

APPENDIX 2 FREQUENCY OF DETECTION OF EACH GENUS

Table A2 Detailed summary of frequency of detection of each genus

	Number of samples with genus present (percentage of total samples in regional council dataset)							
	ARC	**ES**	**Ecan**	**EW**	**GWRC**	**HBRC**	**MDC**	**TRC**
Acanthoceras	0 (0%)	1 (0.4%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Anabaena	29 (43.3%)	24 (9.6%)	32 (7.3%)	573 (81.3%)	9 (100%)	63 (88.7%)	1 (33.3%)	26 (48.1%)
Aphanizomenon	0 (0%)	2 (0.8%)	0 (0%)	142 (20.1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Anabaenopsis	0 (0%)	4 (1.6%)	0 (0%)	1 (0.1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Aphanocapsa	25 (37.3%)	130 (51.8%)	1 (0.2%)	48 (6.8%)	0 (0%)	0 (0%)	1 (33.3%)	0 (0%)
Aphanothece	0 (0%)	3 (1.2%)	0 (0%)	1 (0.1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Calothrix	0 (0%)	0 (0%)	5 (1.1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Chamaesiphon	0 (0%)	0 (0%)	6 (1.4%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Chroococcus	0 (0%)	9 (3.6%)	0 (0%)	23 (3.3%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Chroodactylon	0 (0%)	0 (0%)	1 (0.2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Coelomoron	0 (0%)	14 (5.6%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Coelosphaerium	0 (0%)	15 (6%)	0 (0%)	12 (1.7%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Coleodesmium	0 (0%)	0 (0%)	10 (2.3%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Cyanodictyon	2 (3%)	1 (0.4%)	1 (0.2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Cylindrospermopsis	0 (0%)	1 (0.4%)	0 (0%)	65 (9.2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Cylindrospermum	0 (0%)	0 (0%)	0 (0%)	6 (0.9%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Dichothrix	0 (0%)	0 (0%)	7 (1.6%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Geitlerinema	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	6 (8.5%)	0 (0%)	0 (0%)
Gloeocapsa	0 (0%)	1 (0.4%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Gomphospheria	0 (0%)	0 (0%)	0 (0%)	5 (0.7%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Hapalosiphon	0 (0%)	0 (0%)	1 (0.2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

	Number of samples with genus present (percentage of total samples in regional council dataset)							
	ARC	**ES**	**Ecan**	**EW**	**GWRC**	**HBRC**	**MDC**	**TRC**
Heteroleibleinia	0 (0%)	1 (0.4%)	87 (19.9%)	2 (0.3%)	0 (0%)	0 (0%)	1 (33.3%)	0 (0%)
Katagnyneme	0 (0%)	1 (0.4%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Leptolyngbya	0 (0%)	0 (0%)	0 (0%)	20 (2.8%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Loefgrenia	0 (0%)	0 (0%)	1 (0.2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Lyngbya	2 (3%)	1 (0.4%)	15 (3.4%)	16 (2.3%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Merismopedia	0 (0%)	188 (74.9%)	14 (3.2%)	3 (0.4%)	0 (0%)	0 (0%)	2 (66.7%)	0 (0%)
Microcystis	30 (44.8%)	8 (3.2%)	3 (0.7%)	273 (38.7%)	4 (44.4%)	49 (69%)	0 (0%)	14 (25.9%)
Nodularia	0 (0%)	162 (64.5%)	0 (0%)	1 (0.1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Nostoc	0 (0%)	0 (0%)	24 (5.5%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Oscillatoria	18 (26.9%)	1 (0.4%)	67 (15.3%)	39 (5.5%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Phormidium	0 (0%)	8 (3.2%)	113 (25.9%)	38 (5.4%)	1 (11.1%)	0 (0%)	0 (0%)	0 (0%)
Picocyanobacteria	0 (0%)	2 (0.8%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Placoma	0 (0%)	0 (0%)	13 (3%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Planktolyngbya	0 (0%)	3 (1.2%)	1 (0.2%)	138 (19.6%)	0 (0%)	8 (11.3%)	1 (33.3%)	0 (0%)
Planktothrix	0 (0%)	1 (0.4%)	0 (0%)	22 (3.1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Pseudanabaena	11 (16.4%)	3 (1.2%)	10 (2.3%)	124 (17.6%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Rhabdoderma	0 (0%)	1 (0.4%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (33.3%)	0 (0%)
Rivularia	0 (0%)	0 (0%)	136 (31.1%)	1 (0.1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Schizothrix	0 (0%)	0 (0%)	3 (0.7%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Snowella	0 (0%)	29 (11.6%)	0 (0%)	8 (1.1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Tapinothrix	0 (0%)	0 (0%)	2 (0.5%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Woronichina	0 (0%)	0 (0%)	0 (0%)	2 (0.3%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Unidentified cyanobacteria	0 (0%)	10 (4%)	17 (3.9%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)

APPENDIX 3 MEDIAN CYANBACTERIA CELL CONCENTRATIONS

Table A3 Median total cyanobacterial cell concentrations

	Median Concentration (cell/ml)			
	ECan	**EW**	**GWRC**	**HBRC**
Acanthoceras	2			
Anabaena	40	193	91,000	750
Aphanizomenon	1575	68		
Anabaenopsis	6	8526		
Aphanocapsa	38 500	50		
Aphanothece	90 000	0		
Calothrix				
Chamaesiphon				
Chroococcus	478	17		
Chroodactylon				
Coelomoron	35			
Coelosphaerium	5	763		
Coleodesmium				
Cyanodictyon	6			
Cylindrospermopsis	2	24 747		
Cylindrospermum		106 599		
Dichothrix				
Geitlerinema				38
Gloeocapsa	1			
Gomphospheria		31		
Hapalosiphon				
Heteroleibleinia	1	1		
Katagnyneme	45			
Leptolyngbya		1		
Loefgrenia				
Lyngbya	3	21		
Merismopedia	43 000	115 006		
Microcystis	95 700	4400	118	3900
Nodularia	200	465		
Nostoc				
Oscillatoria	1	525		
Phormidium	7	1	680	
Picocyanobacteria	9250			
Placoma				
Planktolyngbya	4	27 463		102
Planktothrix	780	295		
Pseudanabaena	60	181		
Rhabdoderma	10			
Rivularia		1		
Schizothrix				
Snowella	350	0		

	Median Concentration (cell/ml)			
	ECan	**EW**	**GWRC**	**HBRC**
Tapinothrix				
Woronichina		1288		
Unidentified cyanobacteria	465			

APPENDIX 4 95TH PERCENTILE CYANBACTERIA CELL CONCENTRATIONS

Table A4 95th percentile total cyanobacterial cell concentrations

	95th Percentile Concentration (cell/ml)			
	Ecan	**EW**	**GWRC**	**HBRC**
Acanthoceras	2			
Anabaena	481,500	32,338	1,593,950	14,240
Aphanizomenon	2,498	132,513		
Anabaenopsis	172	8,526		
Aphanocapsa	8,810,000	40,275		
Aphanothece	117,000	0		
Calothrix				
Chamaesiphon				
Chroococcus	87,200	5,603		
Chroodactylon				
Coelomoron	50			
Coelosphaerium	173	74,743		
Coleodesmium				
Cyanodictyon	6			
Cylindrospermopsis	2	2,628,815		
Cylindrospermum		501,308		
Dichothrix				
Geitlerinema				288
Gloeocapsa	1			
Gomphospheria		120		
Hapalosiphon				
Heteroleibleinia	1	2		
Katagnyneme	45			
Leptolyngbya		25		
Loefgrenia				
Lyngbya	3	60		
Merismopedia	506,900	351,241		
Microcystis	7,605,000	83,954	1,056	156,000
Nodularia	38,750	465		
Nostoc				
Oscillatoria	1	39,587		
Phormidium	1,249	69,857	680	
Picocyanobacteria	10,825			
Placoma				
Planktolyngbya	18	1,912,994		537
Planktothrix	780	11,916		
Pseudanabaena	61	31,232		
Rhabdoderma	10			
Rivularia		1		

	95th Percentile Concentration (cell/ml)			
	Ecan	**EW**	**GWRC**	**HBRC**
Schizothrix				
Snowella	1,380	248		
Tapinothrix				
Woronichina		1,868		
Unidentified cyanobacteria	1,239			

APPENDIX 5 AUSTRALASIAN DATABASE OF FRESHWATER CYANOBACTERIAL AND CYANOTOXIN EXPERTISE

New Zealand's expertise in cyanobacteria and cyanotoxins is limited to a few institutions that maintain one or two people with cyanobacterial expertise. Funding to support on-going research in the cyanobacterial field is limited, which means that most of the researchers are multi-disciplined and do not focus solely on cyanobacteria. To maintain an awareness of what these researchers are doing and what institutions they are working at, it is important to maintain a database summarising this capability. Furthermore, as New Zealand's science community is small, it is prudent to be aware of the cyanobacterial expertise in Australia, which may be drawn on for consultation.

Some of the key New Zealand and Australian people with current publications on cyanobacteria and cyanotoxins in internationally-refereed journals are listed in Table A5 – Table A7. The publications from some of these people indicate that they have a skill-base broader than just cyanobacteria. This diversity in expertise strongly supports confidence that a comprehensive and robust strategic approach can be developed to manage cyanobacteria and their toxins in New Zealand surface waters into the future. The people listed in Table A5 – Table A7 are a subsection of those involved in the science and management of cyanobacteria in New Zealand and Australia, with many local and regional councils having people who hold considerable cyanobacterial expertise.

Table A5 **List of primary New Zealand contacts for drinking-water management of cyanobacteria and cyanotoxins in New Zealand drinking-water sources.**

Name	Institute	Email
Susie Wood	Cawthron Institute 98 Halifax Street East Private Bag 2 **Nelson** 7042	susie.woods@cawthron.org.nz
Wendy Williamson	ESR Ltd, Christchurch Science Centre 27 Creyke Road PO Box 29-181 **Christchurch** 8540	wendy.williamson@esr.cri.nz
David Ogilvie	Ministry of Health 133 Molesworth St PO Box 5013 **Wellington** 6145	David_Ogilvie@moh.govt.nz

Table A6 **List of facilities for freshwater micro-algae/cyanobacterial analysis capabilities, and whether these facilities are accredited through IANZ for these analytical capabilities, in New Zealand (From MfE's Draft (October 2009) *Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas* (Appendix 8)).**

Institution	IANZ accredited	Location	Contact
Cawthron Institute	Yes	Nelson	Stef Naldi Ph: 03 5482319 ext. 266 Email: stef.naldi@cawthron.org.nz Web:www.cawthron.org.nz/analytical-laboratory/natural-toxins.html
Landcare Research	No	Auckland	Stephen Moore Ph: 09 574 4100 Email: MooreS@landcareresearch.co.nz
NIWA	Yes	Hamilton	Karl Safi Ph: 07 856 7026 Email: algalservices@niwa.co.nz Web: www.niwa.cri.nz/ncwr/tools/algae
Ryder Consulting	No	Dunedin	Ben Ludgate Ph: 03 477 2113 Email: b.ludgate@ryderconsulting.co.nz
University of Canterbury	No	Christchurch	Dr Paul Broady, School of Biological Sciences Ph: 03 364 2525 Email: paul.broady@canterbury.ac.nz
University of Waikato	No	Hamilton	Prof. David Hamilton Ph: 07 858 5046 Email: d.hamilton@waikato.ac.nz
Watercare Laboratory Services	Yes	Auckland	Lynette Ronberg Ph: 09-539-7784 Email: clientsupport@water.co.nz

Table A7 **Australasian freshwater cyanobacteria and cyanotoxins researchers and technical experts, with institute and email contact details, for response and planning the long-term management of cyanobacteria and cyanotoxins in New Zealand surface waters, including drinking-water sources.**

New Zealand			
Institute	**Contact**	**Email**	**City**
AgResearch Ltd	Chris Miles	chris.miles@agresearch.co.nz	Hamilton
AgResearch Ltd	Lyn Briggs	lyn.briggs@agresearch.co.nz	Hamilton
Cawthron Institute	Patrick Holland	patrick.holland@cawthron.org.nz	Nelson
Cawthron Institute	Roel van Ginkel	roel.vanginkel@cawthron.org.nz	Nelson
Cawthron Institute	Susie Wood	susie.woods@cawthron.org.nz	Nelson
CPIT	Barbara Dolamore	dolamoreb@cpit.ac.nz	Christchurch
Environment Bay of Plenty	Matthew Bloxham	matthew@envbop.govt.nz	Whakatane
Environment Waikato	Bill Vant	bill.vant@ ew.govt.nz	Hamilton
ESR Ltd	Chris Nokes	chris.nokes@esr.cri.nz	Christchurch
ESR Ltd	Penny Truman	penelope.truman@esr.cri.nz	Porirua
ESR Ltd	Wendy Williamson	wendy.williamson@esr.cri.nz	Christchurch
Landcare Research	Phil Novis	novisp@landcareresearch.co.nz	Lincoln
Massey University Wellington	John Ruck	J.G.Ruck@massey.ac.nz	Wellington
Ministry of Health	David Ogilvie	David_Ogilvie@moh.govt.nz	Wellington
New Zealand Food Safety Authority	Phil Busby	phil.busby@NZFSA.govt.nz	Wellington
NIWA	Ashley Rowden	a.rowden@niwa.co.nz	Wellington
NIWA	Julie Hall	j.hall@niwa.co.nz	Wellington
NIWA	Karl Safi	k.safi@niwa.co.nz	Hamilton
Otago University	Marc Schallenberg	marc.schallenberg@stonebow.otago.ac.nz	Dunedin
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APPENDIX 6 REPORT DISTRIBUTION

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