Cyanobacteria band testing:

Examining applicability for the National (NZ) Objectives Framework

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Executive Summary

The Ministry for the Environment's 'Freshwater Reform 2013 and Beyond' document suggests an approach of assigning values to attributes for selected waterbodies, with ranges of values presented as 'bands'. The aim of using bands is to assess the long-term likelihood of a water body to present a health risk from cyanobacteria, not to detect short-duration bloom events. These events should be managed following the outline in the New Zealand Guidelines for Managing Cyanobacteria in Recreational Fresh Waters (Ministry for the Environment and Ministry of Health 2009).

In April 2013 a cyanobacteria expert group was convened and it assigned values to bands related to cyanobacteria for; (i) Ecosystem Health and general protection of indigenous species, and (ii) Human Health (secondary contact recreation). Bands were established for planktonic (water column) and benthic (attached to substrate) cyanobacteria for Human Health purposes only.

The University of Waikato and the Cawthron Institute were subsequently tasked by the Ministry of the Environment to test the proposed human health banding system using cyanobacteria data collected by Regional Councils from lakes (planktonic) and rivers (planktonic and benthic).

Planktonic datasets were obtained for the Waikato and Rotorua regions, and benthic datasets from the Canterbury, Wellington and Manawatu-Wanganui regions. Based on the analysis of these datasets the following modifications to the proposed bands are recommended:

1. Recommendations for modifications to the proposed planktonic cyanobacteria bandings

- Include a cell concentration threshold in band A.
- If weekly data are collected, the highest weekly biovolume should be used to determine the band for that month and not a monthly average if more than one sample is taken in a month.

2. Recommendations for modifications to the proposed benthic cyanobacteria bandings

- "Cyanobacteria" should be replaced with "*Phormidium*". There is insufficient data to develop bands for other benthic cyanobacteria.
- Any criteria related to detaching mats should be removed (e.g. from band D).
- If weekly data are collected, the highest weekly percentage coverage from a single transect should be used to determine the band for that month and not a monthly average if more than one sample is taken in a month.

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The authors thank the following scientists and Regional Councils for provision of data, their rapid responses to our requests and enthusiastic support of this project; Bill Vant (Waikato Regional Council), Alastair Suren (Bay of Plenty Regional Council), Juliet Milne (Greater Wellington Regional Council), David Kelly (Environment Canterbury), Logan Brown and Jon Roygard (Horizons Regional Council). We also thank and acknowledge Roger Hodson (Environment Southland) and Paul Fisher (Nelson City Council) who provided datasets. Due to time constraints these data sets were not able to be analysed for inclusion in this report. We thank Brent King and Vera Power (Ministry for the Environment) for their rapid responses in setting up this project.

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1 Introduction

In 2013 the Ministry for the Environment released the discussion document 'Freshwater reform 2013 and beyond'. The discussion document indicates the government's intention to introduce a National Objectives Framework (NOF) to guide council decision-making regarding levels of catchment management and planning to protect human health and maintain or improve water quality.

The 'Freshwater reform 2013 and beyond' document indicates the general approach of assigning values and attributes to selected waterbodies, with those attributes presented as 'bands' and, where appropriate, 'bottom lines'. Bands of A, B C and D are proposed, with the C/D threshold being the 'bottom line'. This effectively makes D the band where the 'value is not met', and the C, B and A bands indicating increasing levels of quality selected by regional communities according to aspirations and considerations for that waterbody.

A number of expert groups were convened to review science and populate attributes for the Framework. A cyanobacteria expert group meet on 18 April 2013 and was tasked with assigning values to bands for two values related to cyanobacteria: (i) Ecosystem Health and general protection of indigenous species, and (ii) Human Health (Secondary Contact). The expert panel agreed that two separate banding frameworks were required: one for planktonic (water column) cyanobacteria and a second for benthic (attached to substrate) cyanobacteria.

The suggested preliminary bandings for protecting human health are given in Table 1. The working group agreed that the criteria for human health were likely to be more stringent than for ecosystem health. Additionally, the working group agreed that there was currently insufficient information to determine the impact of cyanobacterial blooms on ecosystem health, and banding development for this was deferred.

The human health risks associated with benthic cyanobacteria are less well known than the risks associated with their planktonic counterparts. The percentage of areal coverage of bed values given in Table 1 was modified from the New Zealand Guidelines for Managing Cyanobacteria in Recreational Fresh Waters (Ministry for the Environment and Ministry of Health 2009). The most significant change from the guidelines was that the highest percentage coverage in any one of the four transects surveyed should be used rather than the average of the four transects. It was suggested that this would provide a more accurate assessment of the highest health risk posed at each site. The percentage coverage thresholds are based on preliminary observations. For example, Band A with less than 10% coverage, is common in many rivers in New Zealand and does not necessarily indicate that a proliferation event is likely, whereas Band D with >50% would suggest that human contact with mats is highly likely. The presence of detaching mats is considered to be a high risk as it can result in accumulations along shorelines or in vegetation and may become more persistent and accessible to humans. It is acknowledged that the values used to derive the bandings are based on preliminary research and it is anticipated that these will require further refining as knowledge increases and further testing is carried out.

The biovolume thresholds given for planktonic cyanobacteria were taken directly from the New Zealand Guidelines for Managing Cyanobacteria in Recreational Fresh Waters (Ministry for the Environment and Ministry of Health 2009). The threshold values for potentially toxic species have been extrapolated from animal experiments (for the cyanobacterial toxin microcystin) and make various assumptions about exposure, and also include uncertainty factors. It is generally accepted that there is insufficient toxicological data available to calculate quantitative guidelines for cyanotoxins other than microcystins (i.e., not for anatoxins or saxitoxins). A second value for all planktonic cyanobacteria is given based on knowledge that there is an increase in the likelihood of symptoms (e.g., respiratory complaints) reported in recreational users regardless of whether toxins are detected. Full details of how these values were derived are given in Appendix 2 of the New Zealand Guidelines for Managing Cyanobacteria in Recreational Fresh Waters (Ministry for the Environment and Ministry of Health 2009).

Table 1. Proposed preliminary cyanobacteria bandings for protecting human health. Values were developed from the Cyanobacteria Working Group (S. Wood, D. Hamilton, W. Williamson J. Milne, K. Safi).

<table>
<tr><th>Band</th><th>Planktonic</th><th>Benthic</th></tr>
<tr><td>A</td><td>Biovolume equivalent of the combined total of all cyanobacteria does not exceed 0.5 mm^3/L</td><td>All transects have less than 10% cyanobacterial cover</td></tr>
<tr><td>B</td><td rowspan="2">Biovolume equivalent of 0.5 to <1.8 mm^3/L of potentially toxic cyanobacteria OR
0.5 to <10 mm^3/L total biovolume of all cyanobacteria</td><td>All transects have less than 20% cyanobacterial cover</td></tr>
<tr><td>C</td><td>All transects have less than 50% cyanobacterial cover</td></tr>
<tr><td>D</td><td>Biovolume equivalent of ≥1.8 mm^3/L of potentially toxic cyanobacteria OR
≥10 mm^3/L total biovolume of all cyanobacteria</td><td>Any one transect has more than 50% cyanobacterial cover OR
Presence of detaching mats</td></tr>
</table>

The University of Waikato and the Cawthron Institute were tasked by the Ministry of the Environment to test the proposed banding systems using cyanobacterial data collected by Regional Councils from both lakes and rivers (planktonic) and rivers (benthic). Several criteria were tested to determine a suitable exceedance frequency. It was initially proposed that the bands be assessed using an exception-based approach. Using monthly samples, if the biovolume/percentage coverage of one or two monthly samples (or a month's average if more than one sample is taken in a month) in a hydrological year deviate below the designated banding, then the waterbody will not have met its designated objective banding. This method resulted in some waterbodies moving between bands on an annual basis, due to fluctuations in climatic or environmental conditions. A second alternative based on using two-year averages was then assessed; however, we recommend further investigation of exceedance frequency is undertaken that uses longer-time frames for example, the exceedance over a three-year period.

2 Methods

Planktonic datasets were obtained for the Waikato and Rotorua region.

Waikato Regional Council supplied data for eight lakes in the Waikato region (three hydro lakes; Karapiro, Ohakuri, and Maraetai and five shallow peat lakes; Hakanoa, Waahi, Ngaroto, Whangape, and Waikare). Waikato Regional Council collects samples (usually monthly) at the shoreline of each lake for the purpose of assessing human health risk. The available data sets were from 2003, however, prior to 2010 only cell counts were provided. Post 2010 biovolumes for each species were provided and these data (28 months) were used to assess the suggested bands. For each monthly sample biovolumes for each species were summed to give the total cyanobacterial biovolume per sample. Due to time constraints, all cyanobacteria in the samples were considered to be potentially toxic. This assumption was deemed to be reasonable as the dominant species are all known toxin producers, e.g., *Cylindrospermopsis*, *Anabaena* and *Microcystis* species. Each monthly sample was assigned a band based on the preliminary banding provided in Table 1. A yearly band (using a hydrological year) was then assigned. For this dataset we assessed the effect of deriving the yearly band based on either the highest or second highest monthly value within a hydrological year.

Data were provided by the Bay of Plenty Regional Council (BoPRC) for seven lakes (Rotoehu (4 sites), Rotoiti (11 sites), Rotorua (6 sites), Tarawera (2 sites), Okaro (1 site), Okeraka (1 site), and Rotokakahi (1 site)) and the Kaituna River (4 sites). The Kaituna River is a planktonic dataset (not benthic). Sample collection started in 1996, although it was sporadic in the early years. Some sites have long data sets, whilst at others monitoring stops or has only recently been initiated. The provision of data for multiple sites within a water body provided the opportunity to assess how cyanobacteria concentration varied spatially. It is likely that this needs to be considered when assigning a band to a water body (i.e., whether there should be one band for a water body or a site specific band). The BoPRC dataset is an extremely large one and due to time constraints priority was given to selected sites with consistent long-term data (Lake Okaro, Lake Rotoiti – Hinehope and Okawa Bay, Lake Rotoehu – Kennedy and Otautu Bays, Lake Rotorua – Ngongotaha and Ohau Channel and Kaituna River – Maungarangi and Trout Pool). Sampling frequency also varied among years and sites and in recent years samples have been collected weekly. A total biovolume for each sample location was provided by BoPRC. Due to time constraints, all cyanobacteria in the samples were presumed to be potentially toxic. This assumption was deemed to be reasonable as the dominant genera all contain species that have potential to produce toxins, e.g., *Anabaena* and *Microcystis*. When weekly or fortnightly samples were collected an average monthly biovolume was calculated and each sample was assigned a band based on Table 1. For this dataset we assessed the effect of deriving the yearly band based on either the highest or second highest monthly value within a hydrological year.

Benthic datasets were obtained for the Canterbury, Wellington and Manawatu-Wanganui regions. All Regional Councils used the site survey method outlined in the New Zealand Guidelines for Managing Cyanobacteria in Recreational Fresh Waters (Ministry for the Environment and Ministry of Health 2009) which involves assessing percentage coverage of *Phormidium* (a benthic cyanobacterial species that can produce toxins) at five points along four separate transects.

Environment Canterbury provided data for 14 different sites from 8 different rivers (Opihi, Pareora, Otaio, Waipara, Hurunui, Waipara, Ashley, and Selwyn). At many sites surveys were undertaken sporadically and when three or less samples were collected within a hydrological year we considered that there were insufficient data to assign a band. For each site survey the average (average of five views) percentage *Phormidium* cover was calculated for each individual transect. The average percentage *Phormidium* coverage and the maximum percentage coverage across the four transects were then determined. The presence of detaching mats was also noted. For this dataset a yearly band was determined using six different methods: the highest average coverage in one transect without considering detachment, the second highest average coverage in one transect without considering detachment, the highest average coverage in one transect and taking detachment into consideration, the highest average coverage across all four transects without considering detachment, the second-highest average coverage across all four transects without considering detachment, and the highest average coverage across all four transect and taking detachment into consideration.

The Greater Wellington Regional Council supplied data for Waikanae River (2 sites), Waingawa River (2 sites), Wainuiomata River (1 site), Waiohine River (1 site), Ruamahanga River (6 sites), Pakuratahi River (1 site), Otaki River (1 site), Hutt River (6 sites) and Waipoua River. Due to time constraints only the Hutt and Waipoua datasets were analysed. At these sites surveys were undertaken weekly during summer (approx. November to March). Only the average percentage coverage from the four transects from each site survey was available for analysis. Weekly data were averaged to give a monthly average. Yearly bands were assigned based on the highest and second-highest monthly average obtained within a hydrological year. The presence/absence of detaching mats was not considered during analysis of this dataset.

Horizons Regional Council provided two data sets for analysis, one in which samples had been collected weekly and the other monthly. Weekly data were provided for 13 sites of which 6 were selected for analysis (Makakahi at Hamua, Mangatainoka at Putara, Mangatainoka at State Highway 2, Oroua downstream of the Feilding Sewage Treatment Plant, Oroua upstream of the Feilding Sewage Treatment Plant, Tiraumea at Ngaturi, and Tokomaru at Horseshoe Bend). Site surveys were undertaken weekly for most sites over a 14-month period from 2010 to 2012. For each site survey the average and maximum percentage *Phormidium* coverage per transect (5 views) was calculated. The average percentage *Phormidium* coverage and the maximum percentage coverage across the four transects was then determined. The average percentage *Phormidium* coverage and the maximum percentage coverage for each month was then determined. For this dataset a yearly band (based on a hydrological year) was determined using four different methods: the highest monthly average maximum coverage, the second-highest average maximum coverage, the highest average monthly coverage, and the second-highest average monthly coverage. The presence/absence of detaching mats was not considered during analysis of this dataset.

The second dataset set provided by the Horizons Regional Council consisted of 52 different sites sampled monthly from 2010 to 2012. For each site survey the average and maximum percentage of *Phormidium* coverage per transect was calculated. The average percentage *Phormidium* coverage and the maximum percentage coverage across the four transects was then determined. The average percentage *Phormidium* coverage and the maximum percentage coverage across the four transects were then determined. For this dataset a yearly band (based on a hydrological year) was determined using two different methods: the second-highest average coverage in one transect and the second-highest average coverage in all four transects at a site. The presence/absence of detaching mats was not considered during analysis of this dataset.

3 Results

3.1 Planktonic cyanobacteria – Waikato region

The Waikato lakes ranged in band from A to D (Table 2). Whilst the band of some lakes remained reasonably constant, e.g., Waikare and Whangape (band D), others varied markedly, e.g., Hakanoa rated D in 2009-2012 and then A in 2012-2013. Using the highest rather than second highest monthly band to resolve the yearly band resulted in a change in bands in three of the test cases (Table 2).

Table 2. Planktonic cyanobacteria band testing for data from selected hydro-lakes and peat and riverine lakes differentiated by lake, hydrological year and method of banding (data from Waikato Regional Council). * Yearly band was lower when the highest monthly band was used in place of the second highest monthly band.

Lake	Year (based on hydrological year)	Yearly band (based on 2nd highest monthly band)	Yearly band (based on highest monthly band)
Karapiro	2009/2010	A	A
	2010/2011	A	A
	2011/2012	A	A
	2012/2013	A	A
Maraetai	2009/2010	A	A
	2010/2011	B	B
	2011/2012	B	B
	2012/2013	A	A
Ohakuri	2009/2010	A	A
	2010/2011	A	A
	2011/2012	A	B*
	2012/2013	A	A
Hakanoa	2009/2010	D	D
	2010/2011	D	D
	2011/2012	D	D
	2012/2013	A	A
Waahi	2009/2010	B	B
	2010/2011	D	D
	2011/2012	D	D
	2012/2013	A	B*
Ngaroto	2009/2010	D	D
	2010/2011	D	D
	2011/2012	D	D
	2012/2013	B	D*
Whangape	2009/2010	D	D
	2010/2011	D	D
	2011/2012	D	D
	2012/2013	D	D
Waikare	2009/2010	D	D
	2010/2011	D	D
	2011/2012	D	D
	2012/2013	D	D

3.2 Planktonic cyanobacteria – Rotorua region

The Rotorua lakes and Kaituna River ranged in band from A to D (Table 3). Lake Okaro was the only site to remain constant in its banding (D) over the test period. All other sites showed variability ranging between A to D across the test period. Using highest rather than second-highest monthly band to resolve a yearly band resulted in a change in 15% of the bands (Table 3). Variability among banding within a waterbody was observed. For example, within Lake Rotoiti the Okawa Bay site consistently received a lower banding than the Hinehopu site.

Table 3. Planktonic cyanobacteria band testing for data from selected Rotorua lakes and Kaituna River differentiated by lake/river, hydrological year and method of banding (data from Bay of Plenty Regional Council). 2H = Yearly band assigned based on 2nd highest monthly band, H = Yearly band assigned based on highest monthly band. *Yearly band was lower when the highest monthly band was used in place of the second highest monthly band.

	Lake Okaro		Kaituna (Maungarangi)		Kaituna (Trout Pool)		Rotoehu (Kennedy Bay)		Rotoehu (Otautu)	
	H	**2H**	**H**	**2H**	**H**	**2H**	**H**	**2H**	**H**	**2H**
1993/1994							D	D		
1994/1995							D	D	D	D
1995/1996							A	A	A	A
1996/1997							D	A	D*	A
1997/1998							D	D	D	D
1998/1999	D	D					D	B	D	D
1999/2000	D	D					D	D	D	D
2000/2001							D	D	D	D
2001/2002							D	D	D	D
2002/2003							D	B	D	D
2003/2004	D	D			D*	B	A	A	D	A
2004/2005	D	D	A	A	A	A	D	D	D	D
2005/2006	D	D	B	B	B	B	D	D	D	B
2006/2007	D	D	A	A	A	A	D	B	D	D
2007/2008	D	D	A	A	B*	A	D	D	D	D
2008/2009	D	D	D	D	D	D	D	D	D	D
2009/2010			B*	A	B	B	B*	A	D	B
2010/2011	D	D	A	A	A	A	A	A	A	A
2011/2012	D	D			A	A	A	A	A	A
2012/2013	D	D	A	A	A	A	B	A	B	B

Table 3 cont.

	Rotoiti (Hinehopu)		Rotoiti (Okawa Bay)		Rotorua (Ohau Channel)		Rotorua (Ngongota)	
	H	**2H**	**H**	**2H**	**H**	**2H**	**H**	**2H**
1996/1997	A	A	D	D	B*	A	D*	A
1997/1998	D*	A	D	D	D*	A	A	A
1998/1999	A	A	D	D	B*	A	A	A
1999/2000	B*	A	D	D	B	B	D	B
2000/2001	A	A	D	D	A	A	A	A
2001/2002	D	D	D	D	D*	A	A	A
2002/2003	D	D	D	D	D*	B	D*	B
2003/2004	B	A	D	D	D	D	D	D
2004/2005	B	A	D	D	D	B	B	B
2005/2006	A	A	D	B	D*	B	D	D
2006/2007	A	A	A	A	B	B	B*	A
2007/2008	B*	A	A	A	B	B	B*	A
2008/2009	A	A	D*	B	D	D	D	D
2009/2010	A	A	A	A	B	B	B	B
2010/2011	A	A	B*	A	A	A	A	A
2011/2012	A	A	A	A	A	A	A	A
2012/2013	A	A	D*	A	A	A	A	A

3.3 Benthic cyanobacteria – Canterbury region

When mat detachment was considered, all sites across all hydrological years were banded D (Table 4). When mat detachment was not considered, and using the highest average percentage coverage in one transect in each month, the bands were lower in 4 of the 21 hydrological years tested (Table 4).

Table 4. Benthic cyanobacteria band testing for data at weekly or monthly frequency from selected rivers, and comparison of methods of banding differentiated by site, hydrological year and method of banding (data from Environment Canterbury). 1TH = band assigned based on highest average coverage in one transect, 1T2H= band assigned based on second-highest average coverage in one transect, AVET-H = band assigned based on highest average coverage across all four transects, AVET-2H = band assigned based on second-highest average coverage across all four transects. * Yearly band was lower when the highest monthly band was used in place of the second highest monthly band.

Site	Hydrological Year	No. surveys	1T-H	1T-2H	1T-H	1T-2H	AVET-H	AVET-2H
			Mat detachment not considered		Mat detachment considered			
Opihi River at SH1	2009/10	5	C	C	D	D	D	D
	2010/11	4	D	D	D	D	D	D
	2011/12	4	D*	C	D	D	D	D
Opihi River at Saleyards Bridge	2009/10	4	D	C	D	D	D	D
	2010/11	1	C	C	D	D	D	D
Opihi River at Waipopo	2009/10	4	C	C	C	C	C	C
	2010/11	4	C	C	D	D	D	D
Pareora River at Huts	2009/10	6	D	D	D	D	D	D
	2010/11	6	D	D	D	D	D	D
	2011/12	4	D*	C	D	D	D	D
Otaio River at Gorge	2012/13	4	C	C	D	D	D	D
Waipara River at Teviotdale Bridge	2010/11	5	C	C	D	D	D	D
Hurunui at SH1	2012/13	4	C	C	D	D	D	D
Waipara River at Teviotdale	2010/11	5	C	C	D	D	D	D
Waipara River at Stringers	2010/11	3	C	C	D	D	D	D
Ashley River at SH1	2010/11	2	C	C	D	D	D	D
Ashley River above Rangiora	2010/11	6	C	C	D	D	D	D
	2012/13	4	C	C	D	D	D	D
Selwyn River at Glentunnel below	2011/12	7	D*	B	D	D	D	D
Selwyn River at Whitecliffs camp	2012/13	5	D	D	D	D	D	D
Selwyn River at Whitecliffs picnic	2010/11	5	C*	A	D	D	D	D

3.4 Benthic cyanobacteria – Wellington region

The band assigned to each site varied from A to C along the Hutt River (Table 5). Despite having numerous health warnings issue at these sites between 2009 to 2013 none of the sites were banded a D. When the yearly band was assigned use of the second highest monthly band as opposed to the highest, a higher band was resolved in 15 of the 24 cases. This was particularly apparent at the Waipoua Colombo road site where all four years bands were higher when the second highest monthly band was used (Table 5).

Table 5. Benthic cyanobacteria band testing for data based on monthly averages from selected rivers and comparison of methods of banding differentiated by site, hydrological year and method of banding (data from Wellington Regional Council). H = Yearly band assigned based on highest monthly band, 2H = Yearly band assigned based on 2nd highest monthly band. * Yearly band was lower when the highest monthly band was used in place of the second highest monthly band.

	Hutt River at Birchville		Hutt River at Boulcott		Hutt River at Maoribank Corner		Hutt River at Silverstream Bridge	
	H	2H	H	2H	H	2H	H	2H
2009/10	A	A	C	C	A	A	C*	A
2010/11	B	B	C*	A	B*	A	C*	B
2011/12	C*	A			C*	A	C*	B
2012/13	B*	A			B	B	B	B

	Hutt River at Poets Park		Hutt River at Melling Bridge		Waipoua River at Colombo Road	
	H	2H	H	2H	H	2H
2009/10	B*	A			C*	B
2010/11	B	B			B*	A
2011/12	C*	A	B*	A	C*	B
2012/13	A	A	A	A	C*	B

3.5 Benthic cyanobacteria – Manawatu-Wanganui region - weekly data

The Manawatu-Whanganui Rivers assessed in this weekly dataset ranged in band from A to D (Table 6). When the yearly band was assigned using the second highest monthly band as opposed to the highest, a higher band was obtained in 6 of the 13 years when the highest maximum coverage in a single transect was used, and 3 of 13 years when the average coverage across 4 transects was used. Using the maximum percentage coverage in a single transect compared to the average percentage coverage across all four transects resulted in 2 lower bands when the highest monthly values were used and only one difference in band when the second highest monthly band was used to assign the yearly band. In general, when the bands calculated using weekly data were compared with those calculated using monthly data, the bands were lower when the monthly data was used. For example; Mangatainoka at State Highway 2 (using the highest percentage coverage on a single transect) was banded D in both 2010/11 and 2011/12, based on the weekly dataset, and B and C based on monthly data (Table 6 and 7). Makakahi at Hamua (using the highest percentage coverage on a single transect) was banded D and C in 2010/11 and 2011/12, respectively, based on the weekly data, and C and C based on monthly data (Table 6 and 7).

Table 6. Benthic cyanobacteria band testing for data at weekly frequency from selected rivers and comparison of methods of banding differentiated by site, hydrological year and method of banding (data from Horizons Regional Council). H = Yearly band assigned based on highest monthly band, 2H = Yearly band assigned based on second-highest monthly band. * Yearly band was lower when the highest monthly band was used in place of the second highest monthly band. # Yearly band was higher when the average percentage coverage of all four transects was used as opposed to using the single transect with the highest percentage coverage.

Site	YEAR	No. surveys	Max. value one transects	Max. value one transects	Avg. of all transects	Avg. all of transects
			H	2H	H	2H
Makakahi at Hamua	2010/11	15	D*	B	D*	B
	2011/12	39	C*	B	C*	B
Mangatainoka at Putara	2011/12	38	A	A	A	A
Mangatainoka at State Highway 2	2010/11	15	D*	C	C#	C
	2011/12	39	D*	C	C#	C
Oroua downstream of Feilding Sewerage Treatment Plant	2010/11	15	C*	B	C	A#
	2011/12	39	C*	A	C	A
Oroua upstream of Feilding Sewerage Treatment Plant	2010/11	15	A	A	A	A
	2011/12	38	A	A	A	A
Tiraumea at Ngaturi	2010/11	15	C	C	C	C
	2011/12	39	A	A	A	A
Tokomaru at Horseshoe Bend	2010/11	15	B	B	B*	A
	2011/12	39	C	C	C	C

3.5 Benthic cyanobacteria – Manawatu-Wanganui region - monthly data

When the yearly band was assigned using the second highest monthly band as opposed to the highest monthly band, a higher band resulted in 17 of the 103 years (Table 7). In general the bands tended to stay relatively constant among years; however, there were several sites where the band moved from A to C or vice versa between the two years assessed.

Table 7. Benthic cyanobacteria band testing for data at monthly frequency from selected rivers and comparison of methods of banding differentiated by site, hydrological year and method of banding (data from Horizons Regional Council). 1TH= band assigned based on highest average coverage in one transect. 1T2H= band assigned based on second highest average coverage in one transect. * Yearly band was lower when the highest monthly band was used in place of the second highest monthly band.

Site	YEAR	No. surveys	1T-H	1T-2H
Kumeti at Te Rehunga	2010/11	3	A	A
Kumeti at Te Rehunga	2011/12	9	A	A
Makakahi at Hamua	2010/11	5	C	C
Makakahi at Hamua	2011/12	8	C	C
Makotuku at Raetihi	2010/11	4	A	A
Makotuku at Raetihi	2011/12	8	B*	A
Makotuku at SH49	2010/11	5	A	A
Makotuku at SH49	2011/12	9	A	A
Makotuku d/s Raetihi STP	2010/11	8	B*	A
Makotuku d/s Raetihi STP	2011/12	8	C	C
Makotuku u/s Raetihi STP	2010/11	8	B*	A
Makotuku u/s Raetihi STP	2011/12	9	B	B
Makuri at Tuscan Hills	2010/11	5	B*	A
Makuri at Tuscan Hills	2011/12	8	B	B
Manawatu at Hopelands	2010/11	5	A	A
Manawatu at Hopelands	2011/12	8	A	A
Manawatu at Opiki	2010/11	4	A	A
Manawatu at Opiki	2011/12	8	A	A
Manawatu at Teachers College	2010/11	5	A	A
Manawatu at Teachers College	2011/12	8	A	A
Manawatu at Upper Gorge	2010/11	4	A	A
Manawatu at Upper Gorge	2011/12	6	A	A
Manawatu at Weber Road	2010/11	5	A	A
Manawatu at Weber Road	2011/12	9	A	A
Mangaatua Stream Downstream Woodville STP	2010/11	4	C*	B
Mangaatua Stream Downstream Woodville STP	2011/12	4	A	A
Mangapapa at Troup Road	2010/11	5	A	A
Mangapapa at Troup Road	2011/12	9	A	A

Table 7 cont.

Site	YEAR	No. surveys	1T-H	1T-2H
Mangatainoka at Putara	2010/11	5	A	A
Mangatainoka at Putara	2011/12	9	A	A
Mangatainoka at SH2	2010/11	5	B	B
Mangatainoka at SH2	2011/12	8	C	C
Mangatainoka d/s DB Breweries	2010/11	5	C	C
Mangatainoka d/s DB Breweries	2011/12	8	D	D
Mangatainoka d/s Pahiatua STP	2010/11	5	B*	A
Mangatainoka d/s Pahiatua STP	2011/12	8	C	C
Mangatainoka u/s Pahiatua STP	2010/11	5	A	A
Mangatainoka u/s Pahiatua STP	2011/12	8	C*	B
Mangatainoka u/s Tiraumea confluence	2010/11	5	B	B
Mangatainoka u/s Tiraumea confluence	2011/12	8	D*	C
Mangatepopo d/s Genesis Intake	2010/11	5	A	A
Mangatepopo d/s Genesis Intake	2011/12	8	A	A
Mangatera d/s Dannevirke STP	2010/11	5	A	A
Mangatera d/s Dannevirke STP	2011/12	9	A	A
Mangatera u/s Dannevirke STP	2010/11	5	A	A
Mangatera u/s Dannevirke STP	2011/12	9	A	A
Mangawhero at DoC	2010/11	5	A	A
Mangawhero at DoC	2011/12	9	A	A
Mangawhero at Pakihi Rd Bridge	2010/11	8	C	C
Mangawhero at Pakihi Rd Bridge	2011/12	8	C*	B
Mangawhero d/s Ohakune STP	2010/11	3	A	A
Mangawhero d/s Ohakune STP	2011/12	8	B	B
Mangawhero u/s Ohakune STP	2010/11	5	B*	A
Mangawhero u/s Ohakune STP	2011/12	9	B	B
Moawhango at Waiouru	2010/11	5	A	A
Moawhango at Waiouru	2011/12	6	A	A
Ohau at Gladstone Reserve	2010/11	4	A	A
Ohau at Gladstone Reserve	2011/12	9	A	A
Ohau at SH1	2010/11	4	A	A
Ohau at SH1	2011/12	9	C*	B
Oroua at Almadale	2010/11	4	A	A
Oroua at Almadale	2011/12	8	A	A
Oroua at Apiti Gorge	2010/11	4	A	A
Oroua at Apiti Gorge	2011/12	8	A	A
Oroua at Awahuri Bridge	2010/11	4	A	A
Oroua at Awahuri Bridge	2011/12	8	A	A

Table 7 cont.

Site	YEAR	No. surveys	1T-H	1T-2H
Oroua d/s Feilding STP	2010/11	4	A	A
Oroua d/s Feilding STP	2011/12	8	A	A
Oroua u/s Feilding STP	2010/11	4	A	A
Oroua u/s Feilding STP	2011/12	8	A	A
Oruakeretaki at SH2	2010/11	5	A	A
Oruakeretaki at SH2	2011/12	8	B*	A
Pohangina at Mais Reach	2010/11	5	A	A
Pohangina at Mais Reach	2011/12	7	A	A
Pohangina at Piripiri	2010/11	5	A	A
Pohangina at Piripiri	2011/12	9	A	A
Rangitikei at Mangaweka	2010/11	2	B*	A
Rangitikei at Mangaweka	2011/12	8	A	A
Rangitikei at McKelvies	2010/11	2	A	A
Rangitikei at McKelvies	2011/12	8	A	A
Rangitikei at Onepuhi	2010/11	2	A	A
Rangitikei at Onepuhi	2011/12	8	A	A
Rangitikei at Pukeokahu	2010/11	2	A	A
Rangitikei at Pukeokahu	2011/12	8	A	A
Tamaki at Reserve	2010/11	5	A	A
Tamaki at Reserve	2011/12	9	A	A
Tamaki at Stephensons	2010/11	5	A	A
Tamaki at Stephensons	2011/12	9	A	A
Tiraumea at Ngaturi	2010/11	1	A	A
Tiraumea at Ngaturi	2011/12	7	C*	B
Tokiahuru at Karioi	2010/11	5	A	A
Tokiahuru at Karioi	2011/12	9	A	A
Tokomaru at Horseshoe Bend	2010/11	5	B*	A
Tokomaru at Horseshoe Bend	2011/12	8	C	C
Waikawa at North Manakau Road	2010/11	5	A	A
Waikawa at North Manakau Road	2011/12	9	B*	A
Waitangi d/s Waiouru STP	2010/11	5	A	A
Waitangi d/s Waiouru STP	2011/12	9	A	A
Waitangi u/s Waiouru STP	2010/11	5	A	A
Waitangi u/s Waiouru STP	2011/12	9	A	A
Whakapapa d/s Genesis Intake	2010/11	5	B*	A
Whakapapa d/s Genesis Intake	2011/12	8	A	A
Whanganui d/s Genesis Intake	2010/11	5	A	A
Whanganui d/s Genesis Intake	2011/12	8	A	A

4 Discussion and recommendations

4.1. General considerations

The analysis of the datasets highlighted the variability both spatially and temporally among planktonic and benthic cyanobacteria. For example, the extreme dry conditions of 2012/13 resulted in a reduced cyanobacterial biovolume in some Waikato lakes, which in turn led to a marked improvement in their banding. Lakes Hakanoa and Waahi were banded D from 2009-12. In 2012-13 both rated A based on the proposed banding systems. This variability is such that the tested water bodies regularly move between bands when using the suggested single annual exceedance statistic. This rapid and natural movement between bands suggests that the monitoring statistic based on annual data is not suitable for consistently characterising a water body and informing catchment planning over the longer-term.

Planktonic cyanobacteria are well known for extremes in spatial concentrations within a waterbody. Buoyant cyanobacteria can aggregate under specific physical conditions (e.g., calm and still water) and may form surface scums, especially when light winds move the cyanobacteria to one side of a water body. This variability was observed in the Rotorua lakes' datasets. Among the large lakes, e.g., Rotoiti, Rotorua and Rotoehu, there were marked difference in biovolumes between sampling sites. Benthic cyanobacteria also show marked spatial variability as nutrient concentrations and flow change down a river. This was highlighted in the current analysis in the Hutt River sample set. These observations raise important questions about how to best quantify spatial variability in bandings assigned to lakes and rivers when the objective is to have management on a catchment-by-catchment basis rather than a site-specific basis. Further consideration should be given to this as the National Objectives Framework bandings are developed in the future.

Complimentary actions to monitor and manage immediate and short-duration health risks from cyanobacteria blooms remain important. The 'New Zealand Guidelines for Managing Cyanobacteria in Recreational Fresh Waters' provide guidance for such events. This document should be complimentary to and not replaced by any objectives, attributes and monitoring developed for the NOF.

4.2. Recommendations for modifications to the proposed planktonic cyanobacteria bandings

1. Include a cell count threshold in band A as it recognised that many samples may contain very low concentrations of cyanobacteria and it is not necessary (or economically viable) to convert these to a biovolume estimate.

2. Criteria for assessing a band should use a sufficiently long monitoring period and statistic that accounts for natural variability. We tested one alternative methodology with the aim of consistently characterising each water body into a band. This statistic involved using the two-year annual summer average of cyanobacterial biovolumes to assign a banding (Table 8). The method provides some resilience from extreme

fluctuations associated with, for example, the 2013 drought when many of the Waikato lakes had very low levels of cyanobacteria. However, this methodology is not definitive and requires further analysis, especially as it may underestimate the health risks associated with cyanobacteria in a waterbody. We suggest that alternative options are explored further, for example, that the exceedance period be determined over a three-year period, with three exceedances (i.e., one per year, or ca. 8%) determining the banding. We recommend further discussion of these criteria among the cyanobacterial working group.

Table 8. Bands for selected lakes using annual average and 2-year average, 2009 – 2013 (data from Environment Waikato).

Year	Lake Ngaroto		Lake Waahi		Lake Hakanoa	
	Annual average	2-year average	Annual average	2-year average	Annual average	2-year average
2009/10	D		A		D	
2010/11	D	D	B/C	B/C	D	D
2011/12	D	D	B/C	B/C	D	D
2012/13	B/C	D	A	B/C	A	D

3. Due to time constraints we did not distinguish between toxic and non-toxic species during this analysis. As knowledge about toxic species increases this should be possible and will allow water managers to refine their risk assessments. Easy access to an up-to-date list of known toxic species in New Zealand and worldwide would facilitate this. It is also worth noting that genotype composition within some species (e.g., *Microcystis*) can change rapidly (i.e., strains of the same species may have ability to produce toxins and while others do not). Therefore even if no toxins are detected, but the dominant species in the water body is known to produce toxins, it should be considered potentially toxic.

Suggested bands based on above review

Table 9. Suggested modified planktonic cyanobacteria bandings for protecting human health (secondary contact).

Band	Planktonic
A	Biovolume equivalent for the combined total of all cyanobacteria does not exceed 0.5 mm^3/L **OR** The cell concentration of total cyanobacteria does not exceed 500 cells/mL
B/C	Biovolume equivalent of 0.5 to < 1.8 mm^3/L of potentially toxic cyanobacteria **OR** 0.5 to < 10 mm^3/L total biovolume of all cyanobacteria
D	Biovolume equivalent of ≥ 1.8 mm^3/L of potentially toxic cyanobacteria **OR** ≥10 mm^3/L total biovolume of all cyanobacteria

4.3. Recommendations for modifications to the proposed benthic cyanobacteria bandings

1. The wording in the banding should be modified to make it clear that the bands have been developed specifically for *Phormidium*. In New Zealand the mat-forming genus *Phormidium* forms expansive black/brown leathery mats that may cover the entire substrate of a river and stretch for many tens of kilometres. It commonly produces neurotoxins which have been associated with multiple dog deaths. Although other benthic cyanobacteria have been shown to produce toxins in New Zealand, this is the only genus where there are insufficient site surveying methods and data available to develop a band.

2. The reference to detaching mats should be removed from band D. Analysis of the Canterbury dataset (Table 4), and a scan of the Wellington and Manawatu-Wanganui region datasets showed that detaching mats were common even when percentage coverage was low. Analysis of the effect of detachment was not undertaken on the Wellington and Manawatu-Wanganui datasets, as it prevented the influence of other variables on bands been assessed. When detaching mats were included in the initial banding of the Canterbury dataset all sites across all years were banded D. *Phormidium* mats detach naturally during their lifecycle, thus detaching mats can be present even when coverage is very low, and they provide little indication of the extent of a bloom of *Phormidium* in a river. Detaching mats pose the greatest health risk to humans and animals and therefore should remain as a 'trigger' for issuing health warnings in the 'New Zealand Guidelines for Managing Cyanobacteria in Recreational Fresh Waters', but should be removed from the NOF bandings as managing a river or its catchment to remove the presence of detaching *Phormidium* mats is not possible.

3. The use of highest average percentage cover on a single transect (as used in the proposed banding scheme) was compared to the average percentage coverage across all four transects (as recommended in 'New Zealand Guidelines for Managing Cyanobacteria in Recreational Fresh Waters' for the Manawatu-Wanganui region datasets. There was a small effect, with 3 of 13 sites receiving a lower band with this more stringent criterion. *Phormidium* mats can vary markedly in their percentage coverage within a small reach of a river. The objective of these bands is to protect human health, thus the maximum average coverage in a single transect is a 'worst case scenario' approach. We recommend that this remains unchanged in the proposed banding scheme and it be considered for inclusion in the 'New Zealand Guidelines for Managing Cyanobacteria in Recreational Fresh Waters' during their revision.

   A flushing flow in a river can remove or reduce the coverage of *Phormidium*. When sites are surveyed at a monthly frequency it is highly likely that the period of highest health risk will be missed, and by using the second-highest value the health risk of a site is further underestimated. This was particularly notable in the Manawatu-Wanganui region weekly dataset where nearly 50% of sites received a lower banding when the second highest monthly band was used to assess the yearly band. If weekly data are collected the highest weekly percentage coverage from a single transect should be used to determine the band for that month.

4. We recommend that the criteria for assessing a band uses a longer monitoring period and statistic that accounts for natural variability. We have tested one alternative methodology with the aim of consistently characterising each water body into a band. This involves using the two-year annual summer average of *Phormidium* coverage to assign a banding (Table 10).

Table 10. Bands for selected rivers using a two-year summer (November-April) average of the maximum average coverage of any one of the four transects (data from Horizons Regional Council).

Year	Makakahi at Hamua			Mangatainoka at SH2			Tokomaru at Horseshoe Bend		
	Annual average	2-year average	2-summer average	Annual average	2-year average	2-summer average	Annual average	2-year average	2-summer average
2011	B/C			B/C			B/C		
2012	A	B/C	B/C	B/C	B/C	B/C	B/C	B/C	B/C
2013	B/C	B/C	B/C	B/C	B/C	B/C	B/C	B/C	B/C

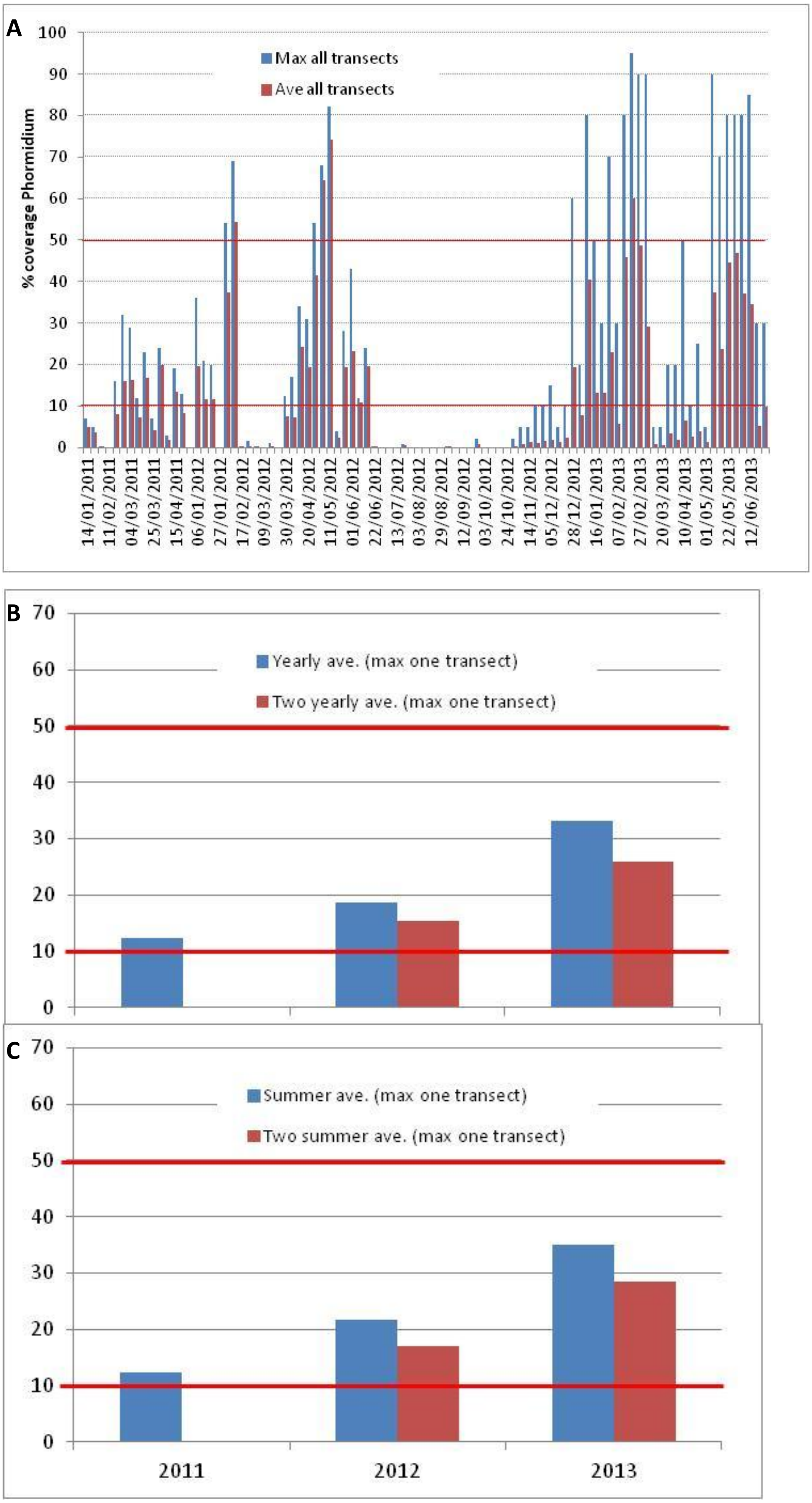
These river monitoring sites showed considerable movement between bands using the previous statistics. Table 10 shows the effect of averaging and how this reduces the influence of extreme seasonal events. However, we believe that the use of an average is not appropriate. This is illustrated in Figure 1, which shows that the weekly data have multiple exceedances during a summer season. We suggest that alternative options are explored, for example, that the exceedance period be determined over a three-year period, with three exceedances (i.e., one per year, or ca. 8%) determining banding. We recommend further discussion of these criteria among the cyanobacterial working group. Where there is considerable inter-annual variability in cyanobacteria abundance due to fluctuations in environmental drivers, e.g. frequency of flushing flows, short-term datasets may be insufficient to determine the banding of specific sites.

<u>Suggested bands based on above review</u>

Table 11. Suggested modified benthic cyanobacteria bandings for protecting human health (secondary contact).

Band	Benthic
A	All transects have less than 10% *Phormidium* cover
B/C	All transects have less than 50% *Phormidium* cover
D	Any one transect has more than 50% *Phormidium* cover

Figure 1. *Phormidium* cover in the Tokomaru River (at Horseshoe Bend; data from Horizons Regional Council). (A) weekly data, (B) average data over one- and two-year periods, and (C) average data over one and two summer periods.



5 References

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