A brief review of recent cyanobacteria monitoring results in the Waikato River

CBER Contract Report 77

Prepared for Mighty River Power

By David P. Hamilton

Centre for Biodiversity and Ecology Research
Department of Biological Sciences
School of Science and Engineering
The University of Waikato
Private Bag 3105
Hamilton, 3240
New Zealand

30 April 2008

Email: d.hamilton@waikato.ac.nz

Table of contents

Figures

Reviewed by:

Kevin Collier

University of Waikato
Affiliation

Approved for release by:

Brendan Hicks

University of Waikato
Affiliation

Executive Summary

Herewith is a report on possible reasons for low concentrations of cyanobacteria (blue-green algae) cells in the Waikato River in summer 2007-08 compared with previous records from 2003 to 2007. Because of time constraints, this report is a cursory consideration and does not provide the level of detail and analysis required to more fully evaluate phytoplankton succession as it relates to the complex interplay amongst physical, chemical and biological variables.

This report was requested by Mighty River Power following a summer when, as a result of drought conditions, the hydro system was operated in a manner similar to 2003, when cyanobacteria blooms (> 15,000 cells mL^{-1}) occurred in the upper river and water temperatures were elevated. These operating conditions were characterised by maintenance of high water levels in the hydro dams and low inflows into the system, resulting in relatively long water residence times.

Four possible explanations for variations in cyanobacteria concentrations are given. First, the summer of early 2003 appeared to be exceptional in that a species that is considered to be invasive (*Anabaena planktonica*) was first recorded, and formed blooms in the upper hydro storages as opposed to the lower Waikato River where there are higher nutrient concentrations to support algal productivity. It is suggested that the 2003 bloom was caused by exceptional buoyancy of *A. planktonica* and that for reasons not well understood, this species has been less dominant in subsequent years compared with 2002-03. Routine sampling has recently changed from shoreline samples to tailrace samples from lakes Ohakuri, Maraetai and Karapiro. Tailrace samples will be more representative of the surface layer of the lake as a whole and may decrease recordings of bloom events compared with shoreline samples, which tend to be more variable when there are high concentrations of cyanobacteria.

Second, invasive zooplankton may have also influenced cyanobacteria concentrations based on regional observations of the recent proliferation of the North American zooplankton *Daphnia dentifera*, which has possibly co-occurred with higher proportions of small cyanobacteria cells that are less likely to be grazed or to form blooms.

Third, the past 2-3 years of phytoplankton sampling in the Waikato River have been characterised by relatively high densities of small-celled, non-colonial species (e.g., *Planktolyngbya* sp. and *Pseudoanabaena* sp.) as opposed to larger filamentous species (e.g., *Anabaena* sp.). For similar cell counts, biomass may be reduced by an order of magnitude or more in smaller species compared with the larger bloom-forming species.

The final reason considered for lower concentrations of cyanobacteria cells in 2007-08, however, may be widespread incidence of very low rainfall across catchments contributing to Lake Taupo and the Waikato River. Under these conditions the proportion of non-point source contributions of nutrients to the Waikato River is likely to have decreased relative to contributions from Lake Taupo. Nutrient loads from Lake Taupo are likely to have remained at more constant levels due to necessity for Mighty River Power to comply with minimum flow requirements of their resource consent condition. The combination of medium-term (e.g., several month) rainfall patterns and the way in which these patterns influence non-point sources of nutrients to the Waikato River may have an important influence on cyanobacteria concentrations through the hydro system and the river itself.

Introduction

This report is in response to a request by Mighty River Power for the Centre for Biodiversity and Ecology Research at the University of Waikato to provide a brief review of recent cyanobacteria monitoring results for the Waikato River. The specific focus is on elucidating why cyanobacteria cell concentrations were low over the 2007-8 summer.

Mighty River Power holds Resource Consents (105226, 105227 and 105228) under the Resource Management Act (1991) for the on-going and future operation of the Waikato hydro system over 35 years commencing 2006. The Resource Consent is subject to a number of monitoring and reporting conditions (Environment Waikato, 2003), including routine surveillance for blue-green algal species so the public can be advised by Environment Waikato and the Medical Officer of Health if a bloom occurs. For the purpose of this report the monitoring and reporting requirements that are most relevant are given below:

> "Routine surveillance for the existence of blue-green algal species in the hydro reservoirs. This shall comprise as a minimum, monthly monitoring of the tailrace water from Ohakuri, Maraetai B, and Karapiro, between the months of November-April inclusive. Results from this monitoring shall be provided to Waikato Regional Council as soon as available, but at least within one week of sampling. If counts at any one site exceed 5,000 cells/ mL^{-1}, then the monitoring frequency and associated reporting at all sites shall increase to weekly until all sites show results less than 5,000 cells/ mL^{-1}, or as otherwise agreed with Waikato Regional Council.
>
> Should monitoring results demonstrate that it would be in the public interest to do so, Waikato Regional Council may require an increase in monitoring frequency for a temporary period. This requirement must be made in writing to the consent holder" (Environment Waikato, 2003).

It should be noted that the data collated for this report are from several agencies and extend beyond data specific to the Resource Consent conditions prescribed for Mighty River Power. Any inference in this report about changes in phytoplankton dynamics in the Waikato River should be interpreted with caution for several reasons. First, monitoring is selectively biased towards warmer periods of the year and tends to be opportunistic, when cyanobacteria are more likely to be prevalent and could potentially cause health-related risks in the Waikato River. Second, other algal taxa or species besides cyanobacteria are not reviewed. A more complete long-term analysis dating back to the 1970s is provided by Faithfull and Hamilton, (2007). Their review considers changes in proportions and abundance of cyanobacteria and other algal taxa but does not include more recent data, i.e., the summer of 2007-8. Last, the monitoring programme is essentially observational and does not include an associated array of physico-chemical factors (e.g. water temperature, nutrient concentrations, light climate) that could provide a more comprehensive assessment of *why* abundances and successions of different phytoplankton taxa occur in the Waikato River. The physico-chemical and biological drivers of phytoplankton succession are complex and the scope of the present report allows for only a cursory examination of some of their effects on cyanobacteria concentrations in the Waikato River.

The factors that may allow some prescription of reasons for change in cyanobacteria abundance include meteorologically-driven factors (e.g., rainfall), water level changes (e.g., Lake Taupo water level) and changes in species composition. These factors form the basis for the analysis used in the present report.

Methods

The cyanobacteria concentration data used in this report were obtained from Environment Waikato via Mighty River Power. They comprise data taken from a several different locations and by several different agencies. No attempt was made to cross-validate methodologies. The data included:

- Lake Taupo comprising an average of sampling sites at Lake Terrace and Acacia Bay stations, taken by Taupo District Council;
- Lake Ohakuri, both at the lake boat ramp and from the tailrace, taken by Environment Waikato/Mighty River Power
- Lake Maraetai, both at Mangakino and from the tailrace, taken by Environment Waikato/Mighty River Power;
- Lake Karapiro, from both a mid-lake site and from the tailrace, taken by Environment Waikato/Mighty River Power, and also from a beach site, taken by Waipa District Council;
- Hamilton City, taken by Hamilton City Council;
- Ngaruawahia, taken by Waikato District Council;
- Hopuhopu, taken by Waikato District Council;
- Huntly, taken by Waikato District Council;
- Te Kauwhata, taken by Waikato District Council;
- Tuakau, taken by Watercare.

Sampling from the tailrace of Ohakuri, Maraetai and Karapiro has been in place for only just over one year. Results are reported as cells mL^{-1} and no consideration is made of phytoplankton other than cyanobacteria. Figures 1 to 4 present the results from these sites. Note the different scales that have been used in different figure panels, as well as the different frequencies of sampling between sites and seasons.

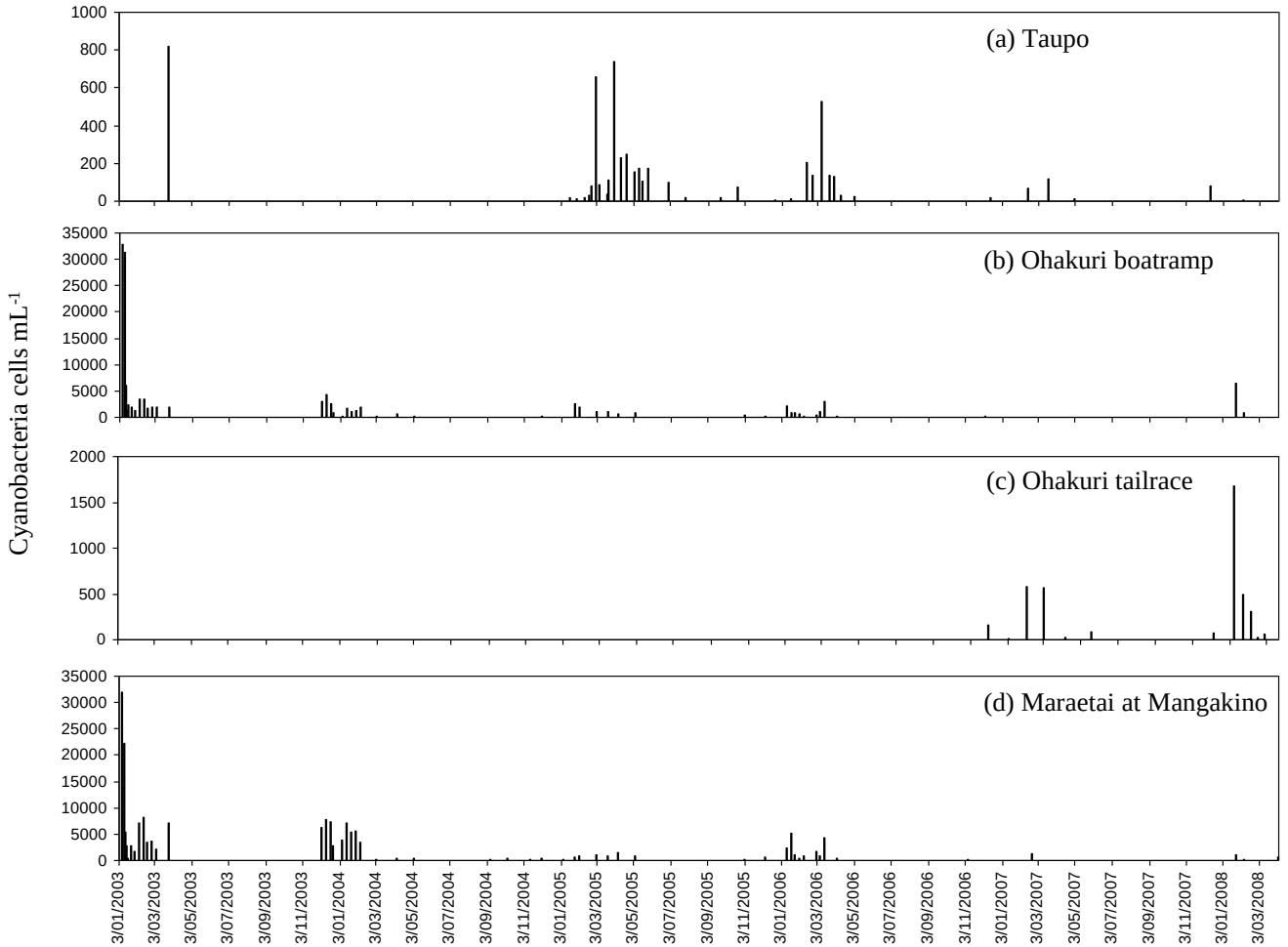

Figure 1. Cyanobacterial cell counts, 2003-2008, for four stations on the Waikato River: (a) Lake Taupo (average of Lake Terrace and Acacia Bay stations) (Taupo District Council), (b) Lake Ohakuri boat ramp (Environment Waikato/Mighty River Power), (c) Lake Ohakuri tailrace (Environment Waikato/Mighty River Power) and (d) Lake Maraetai at Mangakino (Environment Waikato/Mighty River Power). Note different scales for cyanobacterial cell counts.

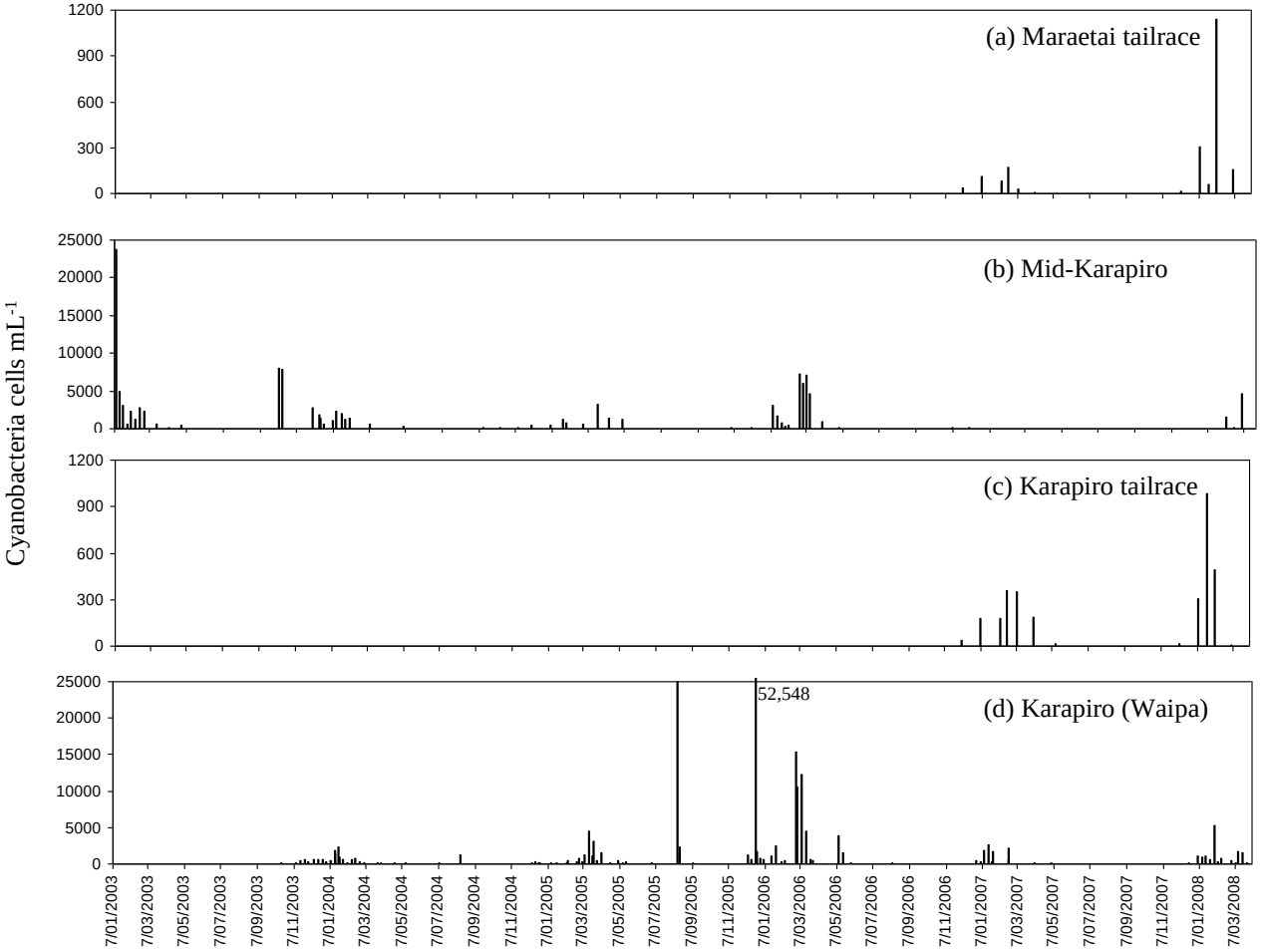

Figure 2. Cyanobacterial cell counts, 2003-2008, for four stations on the Waikato River: (a) Lake Maraetai tailrace (Environment Waikato/Mighty River Power), (b) mid-Lake Karapiro (Environment Waikato/Mighty River Power), (c) Lake Karapiro tailrace (Environment Waikato/Mighty River Power) and (d) Lake Karapiro beach (Waipa District Council). Note different scales for cyanobacterial cell counts.

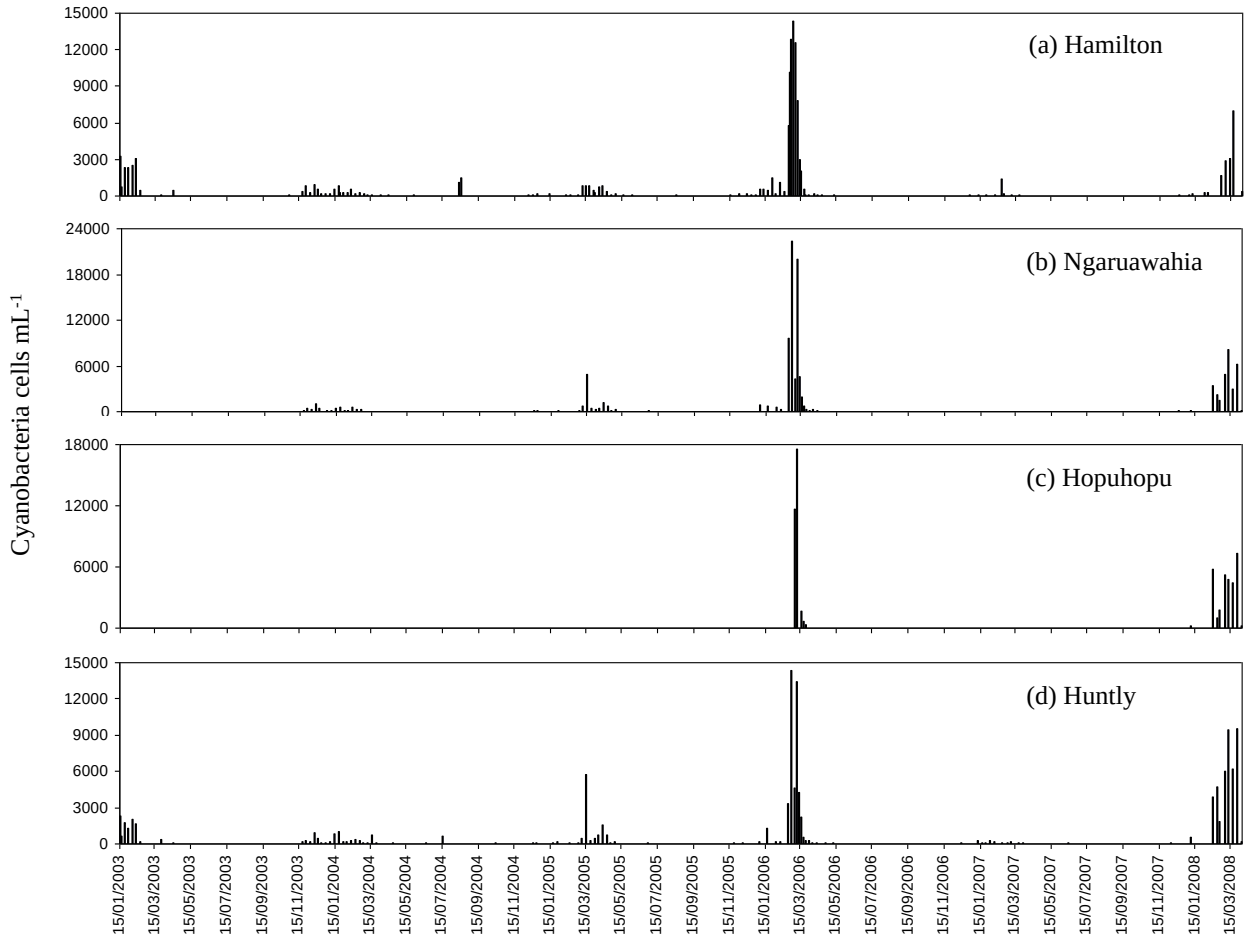

Figure 3. Cyanobacterial cell counts, 2003-2008, for four stations on the Waikato River: (a) Hamilton (Hamilton City Council), (b) Ngaruawahia (Waikato District Council), (c) Hopuhopu (Waikato District Council) and (d) Huntly (Waikato District Council).
Note different scales for cyanobacterial cell counts.

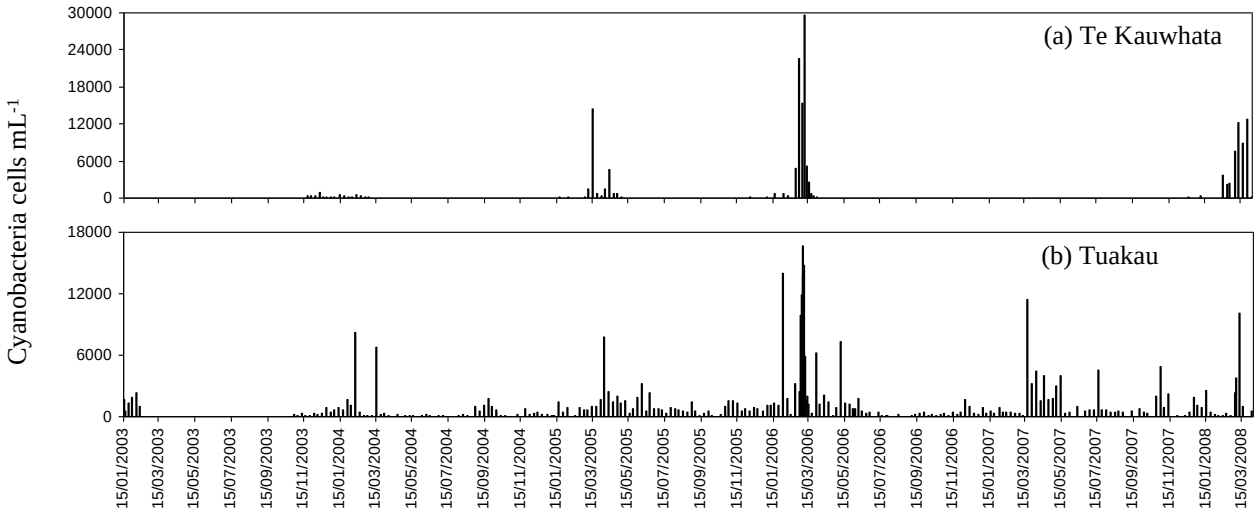

Figure 4. Cyanobacterial cell counts, 2003-2008, for two stations on the Waikato River: (a) Te Kauwhata (Waikato District Council) and (b) Tuakau (Watercare). Note different scales for cyanobacterial cell counts.

Results

Concentrations of cyanobacteria in Lake Taupo do not exceed 1,000 cells mL^{-1} for the period 2003-8. With two notable exceptions there is a general increase in cyanobacteria concentrations with distance downstream from Lake Taupo. The first exception is the tailrace sites at Ohakuri, Maraetai and Karapiro which, although sampled only since the beginning of 2007, clearly have lower concentrations than the respective lake sampling sites. The other exception is at the start of the observation period, at the beginning of 2003. Cyanobacteria cell concentrations at this time show an almost reverse trend, with some values greater than 30,000 cells mL^{-1} at the upstream sites of Ohakuri and Maraetai, and then progressively decreasing through Lake Karapiro and into the lower Waikato River sampling sites of Ngaruawahia, Hopuhopu and Te Kauwhata.

Aside from the relatively consistent changes described above, there are two other samples for Lake Karapiro that are not readily explained (Fig. 2d). The first of these, with c. 25,000 cells mL^{-1} in August 2005, is somewhat anomalous though it is comprised of genera such as *Phormidium* and *Oscillatoria*, which are not normally major contributors to summer assemblages of cyanobacteria. The second, when concentrations exceeded 50,000 cells mL^{-1} in December 2005, is possibly a wind-driven and localized accumulation of cyanobacteria. I regard each of these samples as anomalous and do not consider them further for considerations of trends in cyanobacteria concentrations in the Waikato River.

Overall, the early period of 2003 was notable for having very high concentrations of cyanobacteria at the upstream impoundments, while the early period of 2006 was notable for having high concentrations in the lower Waikato River samples.

Discussion

Anabaena planktonica bloom, 2003

A feature of the early period of monitoring in 2003 was a bloom of *Anabaena planktonica*. This species had not been recorded in New Zealand prior to c. 2000 (S. Wood, Cawthron Institute, pers. comm.). Concentrations of *A. planktonica* were low in Lake Taupo in early 2003, though blooms of cyanobacteria (comprised of both *A. circinalis* and *A. planktonica*) were independently recorded in bays of Lake Taupo. The blooms in the Waikato River were most prominent in upstream lake samples, particularly Ohakuri and Maraetai and, to a lesser extent, Karapiro. It is my contention that tailrace samples in these lakes would not have recorded blooms, defined for convenience as cell concentrations > 15,000 cells mL^{-1}, as peaks in *A. planktonica* concentrations were predominantly due to surface accumulations ('telescoping' and wind accumulations). Tailrace samples integrate concentrations over a greater depth within the surface water layer. For the case of Lake Maraetai there is likely to be even greater disparity between shore-based samples ('Maraetai at Mangakino') and the tailrace samples due to capacity to alter offtake heights at this dam.

Anabaena planktonica formed blooms in many North Island lakes early in 2003. Examples of lakes where the blooms occurred include Rotorua, Rotoiti and Rotoehu, Karori Sanctuary Lower Reservoir, as well as some hydro dams on the Waikato River. With the exception of Karori Sanctuary Lower Reservoir, cell concentrations of *A. planktonica* in most lakes have not reached levels as high as in 2003, and *A. planktonica* appears to have become progressively less dominant. In the case of Karori Sanctuary, *A. planktonica* has remained highly dominant since 2003 and this dominance has provided an opportunity for quantification of some of its physiological features. Prentice (2008) found that *A. planktonica* in Karori Sanctuary is highly buoyant in daylight hours and therefore forms diurnal blooms even when depth-integrated concentrations are at moderate levels. Similarly, in Lake Rotoiti in 2003, when there was a major bloom of *A. planktonica*, there was a strong tendency for increasing chlorophyll fluorescence values near the water surface compared with 2004 and 2005 (Figure 5) when blooms were less prevalent and tended to be dominated by other species.

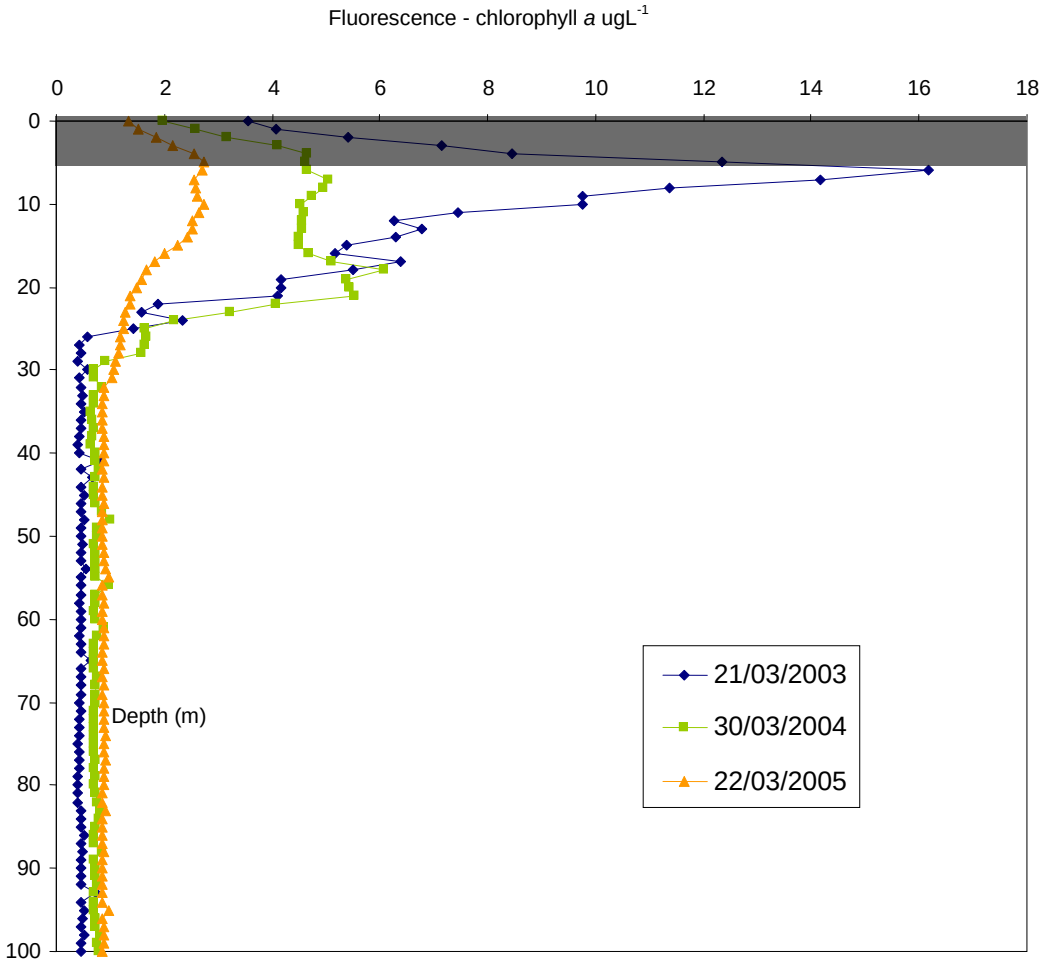

Figure 5. Chlorophyll fluorescence profiles in Lake Rotoiti taken in March in three different years. The shaded band from 0 to 5 m depth is a depth range in which it is best to disregard fluorescence values due to solar quenching; a process in which phytoplankton reduce their fluorescence output in the presence of bright light. The remainder of the profile otherwise represents a proxy for chlorophyll a concentration.

As a rough approximation, 1,500 to 2,000 cells mL^{-1} of *Anabaena* equates to 1 μg L^{-1} of chlorophyll *a*. A further approximation is that 1 μg L^{-1} of chlorophyll *a* can be supported by about the same level of phosphorus; 1 μg L^{-1} of total phosphorus. Thus, based on cell concentrations in Lake Ohakuri, the 2003 bloom approximated to around 15 μg L^{-1} of chlorophyll *a* and 15 μg L^{-1} of total phosphorus. Five-year median levels of total phosphorus in Lake Ohakuri are around 22 μg L^{-1}, considerable elevated over Lake Taupo (Vant, 2001; Beard, 2007). The dendritic shape of Lake Ohakuri and the relatively

large size of this lake may also provide an opportunity for considerable spatial variation to occur within the lake, particularly when there are strongly buoyant cyanobacteria such as *A. planktonica.* Support for my hypothesis is also provided by the observations of substantially lower levels of cyanobacteria in the lower Waikato River (Hamilton City and Huntly) compared with the hydro storages when the 2003 bloom occurred.

The primary reason for a more detailed assessment of the 2003 bloom event is to demonstrate the potential for 'invasive' cyanobacteria to form surface blooms, particularly when the species concerned is highly buoyant. Ryan *et al*. (2003) indicated the potential for the invasive *Cylindrospermopsis raciborskii* to form blooms as it extended its range following an invasion into lower Waikato lakes in 2003. *C. raciborskii* is less buoyant than *A. planktonica*, however, and is therefore less likely to be a problem in the Waikato hydro lakes. The change in monitoring to focus on tailrace samples from lakes Ohakuri, Maraetai and Karapiro will likely decrease measurements of cyanobacteria compared with surface samples taken within these respective lakes; the result will be reflected in a decrease in the probability of exceedance of the consent limits for cyanobacteria based on tailrace samples. To be prepared for 'chance' events from invasive species, note should be made of any new cyanobacteria species recorded in Waikato hydro lakes and river samples and, when a new species is observed, a risk assessment should be made (i.e., a probability of bloom formation) based on what is known about this species. No similarly invasive 'new' cyanobacteria have been noted in the Waikato River system since 2003.

Zooplankton grazing

Zooplankton grazers can strongly regulate biomass of phytoplankton populations. It is generally acknowledged that most cyanobacteria are not a preferred food source for zooplankton, though counter examples exist. Burger *et al*. (2005) found that rotifers dominate the zooplankton fauna in the lower Waikato River, while cladocerans become increasingly important in the hydro lakes. Cladocerans are more likely than rotifers to regulate phytoplankton biomass, particularly by grazing on larger phytoplankton. Their influence on phytoplankton populations in the hydro lakes is likely to be small, but it

should be noted that the invasive crustacean *Daphnia dentifera*, from North America, has colonised a number of North Island lakes in large numbers, most likely in recent years (Duggan *et al*. 2006) and was probably the species first identified in the Waikato River in 1999 as *Daphnia* sp. by Burger *et al*. (2003). I suspect that this species may be influencing phytoplankton dynamics in some North Island lakes where blooms have commonly occurred, e.g., Lake Rotoiti. The cyanobacteria population in Lake Rotoiti has typically been dominated by *Anabaena* species but in the past 2-3 years very small-celled genera (e.g. *Aphanocapsa*) have tended to be dominant. This change may be related to the occurrence of *D. dentifera* in this lake, resulting in larger cyanobacteria being preferentially grazed. A recent trial of river health assessment methods overseen by Dr Kevin Collier (Environment Waikato) may update some information on presence and abundance of *D. dentifera* in the lower Waikato River. Further, an assessment of whether there has recently been a greater proportion small-celled cyanobacteria, while beyond the scope of the present study, may also provide indirect evidence of an increasing role of zooplankton grazing in influencing cyanobacteria populations in the Waikato River.

Species composition

The cyanobacteria assemblage of the more recent period (post c. 2005) has included a substantial proportion of smaller cyanobacteria such as *Lyngbya* sp. and *Pseudoanabaena* sp., as opposed to the larger colonial (e.g., *Microcystis*) or filamentous forms (e.g., *Anabaena* sp.). I regard increasing prevalence of these smaller cells in the lower river as the norm as they are not reliant on calm conditions, and can probably grow and proliferate in the turbulent riverine conditions. These smaller cyanobacteria are likely to be distributed through the water column in the lower river and have limited capacity for buoyancy control, unlike the colonial and filamentous forms that form substantial surface blooms. While the smaller cells can increase to concentrations that may be classed as blooms as the basis of cell counts, their biomass is generally very low, as opposed to the case of *Anabaena* sp. in the upper hydro storages in 2003. An analogous situation is in Lake Rotoiti, where the small cyanobacterium *Aphanocapsa* sp. has occurred in higher

concentrations than during the 2003 bloom of *Anabaena planktonica*, yet there has been relatively high clarity in Lake Rotoiti in latter years.

For circumstances such as this, reporting of biomass may better reflect the human health risks of large numbers of small cyanobacterial cells. It is for this reason that Ministry for the Environment is giving consideration to a change in national guidelines to include biomass as an indicator for cyanobacterial blooms rather than cell counts alone.

The 2007-8 drought and Southern Oscillation Index

One of the distinguishing features of the 2007-8 summer was very low rainfall compared with the previous years considered in the analysis period of this report. Both rainfall and soil moisture levels in the Taupo and lower Waikato regions were the lowest on record or at least much lower than long-term records, and streamflows were categorised as 'extremely low' through central North Island (NIWA, 2008). This occurrence has been attributed to a well developed La Niña phase of the Southern Oscillation system (Figure 6), which is generally considered to bring higher than average summer rainfall to Northland and lower than average rainfall to the south and west of the South Island. Our knowledge of the impacts of these systems is still evolving, however, and not all El Niño or La Niña systems are identical, but the inference is that the La Niña in summer 2007-8 had a major impact of reduced rainfall in central North Island. By contrast, El Niño systems result in higher than average rainfall in the south-west of South Island and lower rainfall in the northeastern North Island.

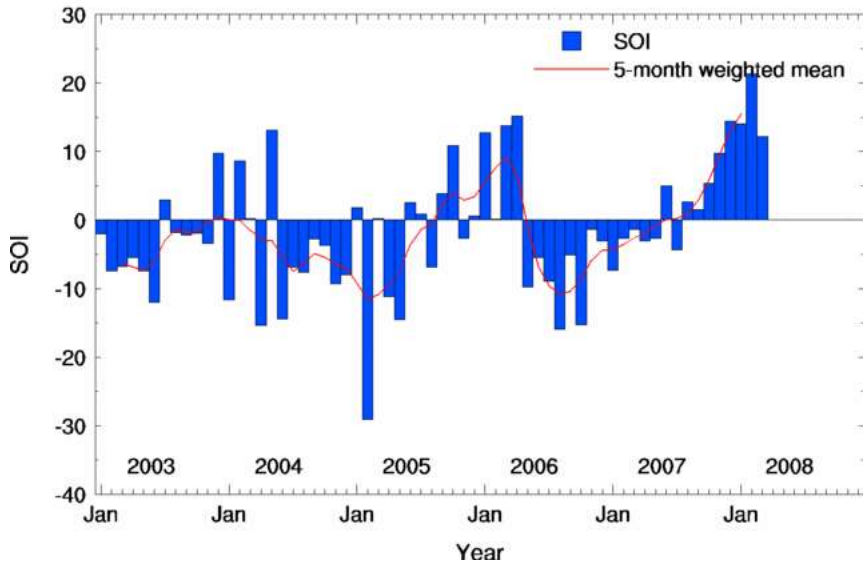

Figure 6. Southern Oscillation Index values (5-month weighted mean) for the study period. Source: http://www.bom.gov.au. Strongly negative values are indicative of an El Niño phase and strongly positive values of a La Niña phase.

Discharge from Lake Taupo was reduced to minimum or near-minimum levels required to meet consent conditions in summer 2007-8, but the lake level nevertheless continued to decrease up until early April of 2008 (Figure 7). Through this period it is likely that a greater proportion of water in the Waikato River was sourced from Lake Taupo, as opposed to contributions below the Taupo Gates. Lake Taupo has low nutrient concentrations, with total phosphorus concentrations in the lake usually substantially less than 5 μg L^{-1}, and this input will therefore have limited capacity to stimulate algal growth. By contrast sources of water below the Taupo Gates have substantially elevated levels of nutrients. Some of the point sources (e.g., Kinleith pulp mill and the Wairakei geothermal discharges) would assume a proportionately greater influence on nutrient concentrations in the Waikato River under the prevailing low-flow regime of 2007-8, while other, mostly non-point sources, are likely to have had substantially reduced influence in terms of their discharges and nutrient loads to the Waikato River. By the time the Waikato River reaches Lake Karapiro, the average volumetric contribution of sources other than Lake Taupo is c. 93 m^3 s^{-1}, which compares with c. 140 m^3 s^{-1} from Lake Taupo, i.e., these other sources are usually a very important overall contribution to flow. A more detailed analysis of river flows through the Waikato River system could

help to ascertain the relative changes in contributions from Lake Taupo and from the wider catchment below Lake Taupo resulting from the 2007-8 drought, though this is beyond the scope of the present study.

I consider that the small contribution from non-point sources below the Waikato River was likely the most important influence leading to low concentrations of cyanobacteria and phytoplankton cells in the Waikato River through summer 2007-8. I also consider that this influence superceded any effect of elevated water temperatures that was likely to have resulted from this relatively warm summer. It is well known that cyanobacteria are favoured over other algal taxa by higher water temperatures (Reynolds, 1997). However, observations in the Rotorua lakes indicated an increase of water temperature of only around 1 ^{o}C over the 2007-8 summer compared with mean summer temperatures, so any stimulation of algal growth by warmer water temperature is likely to have been relatively small. A more detailed analysis of water temperature is beyond the scope of the present study but could be undertaken from continuous measurements of water temperature at several locations along the Waikato River (see http://www.environmentwaikato.govt.nz/enviroinfo/water/temperature).

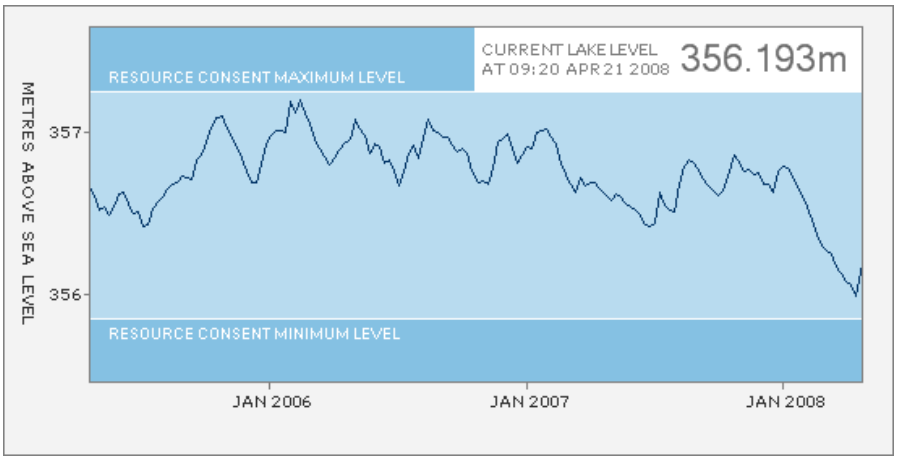

Figure 7. Water level at Lake Taupo, 2005 to mid-April 2008. Source: http://www.mightyriverpower.co.nz/Generation/EnvironmentalReporting/LakeLevels.

In the long-term, these results point to a need to assess future risks to river health from 1) changes in non-point loads of nutrients to the Waikato River, whether they be climate-related or landuse induced, and 2) climate change, particularly whether there could be changes to the frequencies of El Ninõ and La Ninã events, and how these may interact with nutrient loading to the Waikato River.

Acknowledgments

This study was funded by Mighty River Power. I thank Bill Vant (Environment Waikato) for provision of data and both Bill and Dr Susie Wood (Cawthron Institute) for discussions that formulated some of the hypotheses put forward in this report.

References

Beard, S., 2007: Waikato River Water Quality Monitoring Programme: Data Report 2006. Environment Waikato Technical Report 2007/18, ISSN 1172-4005.

Burger, D. F., Hogg, I. D. and Green, J. D., 2002. Distribution and abundance of zooplankton in the Waikato River, New Zealand. *Hydrobiologia* 479(1-3): 31-38.

Duggan, I. C., Green, J. D. and Burger, D. F., 2006. First New Zealand records of three non-indigenous zooplankton species: *Skistodiaptomus pallidus, Sinodiaptomus valkanovi*, and *Daphnia dentifera*. *New Zealand Journal of Marine and Freshwater Research* 40: 561–569

Environment Waikato, 2003. Mighty River Power Taupo-Waikato Consents Decision Report. Environment Waikato Document 852012, 114 pp.

Faithfull, C. L. and Hamilton, D. P., 2007. Comparisons of densities of phytoplankton, cyanobacteria and *Aulacoseira* in the Waikato, 1973-2006. Report to Environment Waikato. Centre for Biodiversity and Ecology Research, University of Waikato.

NIWA, 2008. The Climate Update No. 108. National Institute of Water and Atmosphere Ltd, 15 March 2008.

Prentice, M., 2008. Temporal and spatial variations of cyanobacteria in Karori Reservoir, Wellington. M.Sc. thesis, Department of Biological Sciences, University of Waikato.

Reynolds, C. S., 1997. Vegetation processes in the pelagic: A model for ecosystem *theory*. In: *Excellence in Ecology* Vol. 9, Ecology Institute Publ., Oldendorf.

Ryan, E. F., Hamilton D. P., and Barnes G., 2003: Recent occurrence of *Cylindrospermopsis raciborskii* in Waikato lakes, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 37(4): 829-836.

Vant, W. N., 2001: New challenges for the management of plant nutrients and pathogens in the Waikato River, New Zealand. *Water Science and Technology* 43: 137-144.