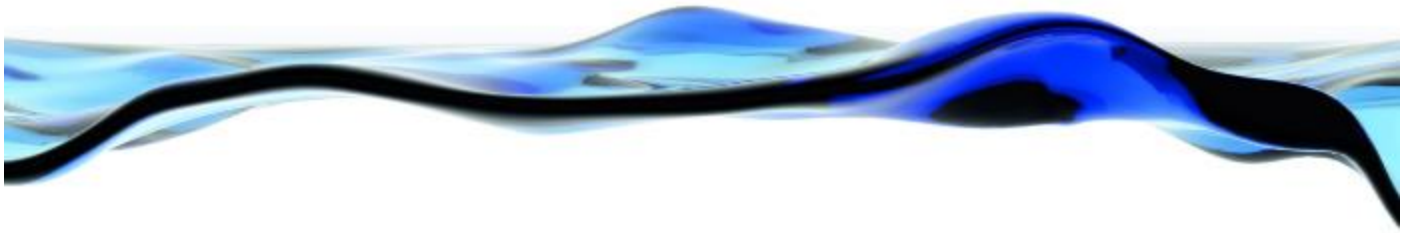
River Torrens Water Quality Improvement Trial
Summer 2013–14

Brookes, JD and Daly, R



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Executive Summary

In the Torrens Lake cyanobacteria have caused summer blooms for more than a decade, which have often resulted in restrictions to recreation activities. Various efforts to control these algal blooms include bubble plume and venturi aerators, physical removal with surface pumps extracting the scum, the application of activated clays and more recently flow releases from upstream to dilute the standing biomass of cyanobacteria in the lake.

Flow releases from upstream reservoirs were delivered over the previous two summers (2011-12 and 2012-13) to determine how effective these were at diluting the cyanobacterial biomass. The diluting amenity flows in 2011-12 and 2012-13 had a maximum daily flow of 40 ML/day. This effectively diluted the lake by 10 % per day, as the lake volume is about 400 ML. Modelling of cyanobacteria population growth and dilution showed that flow rates of 40ML/day could maintain the population below 100,000 cells/mL for approximately 20 days but large flows from rainfall events would be required to flush out the lake populations.

In 2013-14 the objective was to use larger flow volumes to enable greater and more refreshment of the lake water during warm periods and to pre-emptively strike before cyanobacteria populations established. The flow releases were managed by the Adelaide and Mt Lofty Ranges NRM Board in collaboration with Adelaide City Council and SA Water, and were based on regular water quality monitoring and the short term weather forecast. This report documents the outcomes of the 2013-14 flow trial.

Water was released from Kangaroo Creek Reservoir at a rate of up to 150 ML/d for periods of up to five days at a time. If cyanobacteria counts in Torrens Lake were low and stable and the weather forecast was for mild conditions, no flow releases were required. However if hot dry weather was forecast and cyanobacteria was growing in the lake then flow was released. At this flow rate the full volume of the lake was refreshed in a relatively short period of time.

Strings of thermistors were deployed at three sites and sampling for determination of cyanobacterial abundance occurred at eight sites within the lake. Sampling was also undertaken upstream and downstream of the lake to quantify cyanobacterial abundance, enterococci and several other water quality parameters. Three-dimensional hydrodynamic modelling within the lake assisted in evaluating the success of the trial and enabled a comparison with different flow volumes.

Population abundance data for *Microcystis flos-aquae* and *Anabaena circinalis* demonstrate the transitions between populations growing and then being reduced with controlled flow releases. The populations show an increase in growth and greater distribution across the lake and then the populations are reset to zero as the flow dilutes the population. The cycle is repeated for each flow release. The resetting of the population to zero is evidence that the larger flow volumes are able to remove the cyanobacteria from the lake, which the flow strategies in the previous two years were unable to achieve. The higher flow volumes delivered during the 2013-14 trial effectively diluted the cyanobacteria so at no time did they breach the threshold.

The pre-emptive flow releases in response to warm weather and heightened risk of cyanobacterial growth proved to be an effective strategy. There are two lines of evidence to support this conclusion: first, the flow maintained the populations well below the thresholds for lake closure and reset the populations to zero and second, the hydrodynamic modelling shows replacement of the ambient lake water with inflow water.

If controlled amenity flow releases are considered for future control of cyanobacteria then the higher flow volumes should be considered. The pre-emptive delivery of water in response to weather forecasts of hot weather proved successful and has proved to be the only reliable strategy for control of cyanobacteria in the lake thus far.

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1. Introduction

Cyanobacteria are a notorious group of organisms that contaminate water bodies and cause concern because they produce toxins and taste and odour compounds. In the Torrens Lake cyanobacteria have caused unsightly summer blooms for more than a decade, which have often resulted in the lake being closed to recreation activities. Various efforts to control these algal blooms include bubble plume and venturi aerators, physical removal with surface pumps extracting the scum, the application of activated clays and more recently flow releases from upstream to dilute the standing biomass of cyanobacteria in the lake. These flow releases are often referred to as amenity flows or dilution flows.

Flow releases from upstream reservoirs were delivered over the previous two summers (2011-12 and 2012-13) to determine how effective these were at diluting the cyanobacterial biomass. The aim of the amenity flow trial was to use flow from an upstream storage to dilute the cyanobacterial populations in the Torrens Lake before they reach large numbers. The premise is that rather than controlling growth, which is proving difficult, the population size could be controlled by continual dilution. The lake is used predominantly for recreational activities such as fishing, rowing and paddle boating, and so maintaining the lake 'open' for these activities is a priority. Furthermore the lake is a focal point for summer events in the city of Adelaide, such as the Tour Down Under, The fringe Festival and Womadelaide, and so an aesthetically pleasing lake is preferred.

Cyanobacteria population showed explosive growth between 24 Dec and 31 Dec 2012. The rate of growth was 1.33 doublings/day, which is a rate four times higher than the long-term average. Flows were released in response to visual observations that cyanobacteria were present but these were unable to significantly reduce the rapid accumulation of biomass. Consequently it was concluded that the amenity flow released from Hope valley was ineffective at reducing the cyanobacterial abundance during the highest growth period. Furthermore, commencing flows at the first detection of *Microcystis aeruginosa* would not have prevented lake closure because growth rate was too rapid and population increases could not be offset by dilution. The amenity flow alone was insufficient to prevent lake closure.

The diluting amenity flows in 2011-12 and 2012-13 had a maximum daily flow of 40 ML/day. This effectively diluted the lake by 10 % per day. Modelling of cyanobacteria population growth and dilution showed that flow rates of 40ML/day could maintain the population below 100,000 cells/mL for approximately 20 days but large flows from rainfall events would be required to flush out the lake populations (Brookes et al., 2012). The lack of rain to achieve a major dilution meant that the strategy of releasing low dilution flows was not able to control the cyanobacterial populations below the level required to prevent lake closure. Larger flows of approximately 150ML/dy were used pre-emptively in this trial to flush the cyanobacteria from the large before the populations can take hold and rapidly increase concentrations with exponential growth.

Brookes et al. (2013) reported on the second amenity flow release trial and concluded that the amenity flows (of the magnitude used on 2011-12 and 2012-13) are insufficient on their own to provide relief against high cyanobacterial growth, however, if coupled with algicidal technology such as hydrogen peroxide they may attain the upstream and downstream benefits and cyanobacterial control in-lake. A larger flow volume released from Hope Valley Reservoir would have greater dilution effects however it was not practical without significant modification of the reservoir and downstream channel. In the absence of rain events to reset the cyanobacterial populations in the lake large water releases from upstream reservoirs could fulfil a similar role.

The ongoing public concerns about cyanobacteria and lake closure, the development of the Riverbank Precinct and a desire from the South Australian State Government to have a lake free of cyanobacteria blooms and lake closures prompted a third flow trial. The first two trials released a maximum of 40ML/day to dilute the cyanobacterial population by 10% per day. This trial fundamentally differed from the previous trials; this trial used a much higher flow rate for releases and permitted these flows to discharge to sea. In 2013-14 the objective was to use larger flow volumes to enable greater and more refreshment of the lake water during warm periods and to pre-emptively strike before cyanobacteria populations established. The flow releases were managed by the Adelaide and Mt Lofty Ranges NRM Board in collaboration with Adelaide City Council and SA Water, and were based on regular water quality monitoring and the short term weather forecast. This report documents the outcomes of the 2013-14 flow trial.

For the rational of using flow for cyanobacterial biomass control see Brookes et al. (2012) and refer to Brookes et al. (2012) and Brookes et al. (2013) for reports on the two previous amenity flow trials.

The aim of this amenity flow trial was to use larger flow volumes released from an upstream reservoir to dilute the cyanobacterial populations in the Torrens Lake and maintain low numbers over the summer period. The premise is that rather than controlling growth, which is proving difficult, the population size could be controlled by more refreshment of the lake water. The lake is used predominantly for recreational activities such as fishing, rowing and paddle boating, but is also the backdrop for several high profile national and international events hosted by Adelaide, and so maintaining the lake 'open' for these activities is a priority. The NHMRC (2008) recreational guideline for cyanobacteria is a biovolume equivalent of 10 mm^3/L. There is an interspecies difference in the number of cells per millilitre to achieve the biovolume threshold (Table 1). The Adelaide City Council has reviewed its trigger levels for lake closure based on toxicity and has incorporated separate triggers for primary and secondary activities, which are higher than the NHMRC guideline.

Table 1 Cyanobacteria cell concentrations that reach the recreational guideline for cyanobacteria in the Torrens Lake historical, derived from the NHMRC biovolume guideline of 10 mm^3/L, and revised by Adelaide City Council in consultation with the Department of Health.

Cyanobacteria	NHMRC guideline equivalent cell count (cells/mL)	Revised cell count by Adelaide City Council (cells/mL)	Biovolume equivalent (mm^3/L)
Anabaena circinalis	40,000	1,000,000	10
Microcystis aeruginosa	115,000	250,000	10.005
Microcystis flos-aquae	455,000	910,000	10.01
Planktothrix mougeotti	156,500	313,000	10.016

2. Methods

Logistics of releasing flow from upstream

Water was released from Kangaroo Creek Reservoir at a rate of up to 150 ML/d for periods of up to five days at a time. If cyanobacteria counts in Torrens Lake were low and stable and the weather forecast was for mild conditions, no flow releases were required. However if hot dry weather was forecast and cyanobacteria was growing in the lake then flow was released. At this flow rate the full volume of the lake (400 ML) was delivered in a relatively short period of time to dilute water in the lake.

Flows released from Kangaroo Creek Reservoir flowed downstream, through Torrens Lake, over the city weir, through Breakout Creek (the lower River Torrens) and out to sea at West Beach.

Torrens Lake site description and sampling sites

The main site of interest was the Torrens Lake, which spans the reach of river from Hackney Road to the city weir, has a volume of approximately 400 ML and an average depth of 2m. The lake forms the northern boundary of the City of Adelaide and has high recreational and cultural significance for the city. The sampling sites used in this monitoring program (Figure 1) included the same sites as those used in the regular monitoring program for algal counts by the City of Adelaide. This was done to ensure consistent datasets, enable comparison with historical records and achieve representative coverage of the lake. An additional monitoring site was added at the start of the 2013-14 season to better monitor the section of the lake between Frome and Hackney Roads.

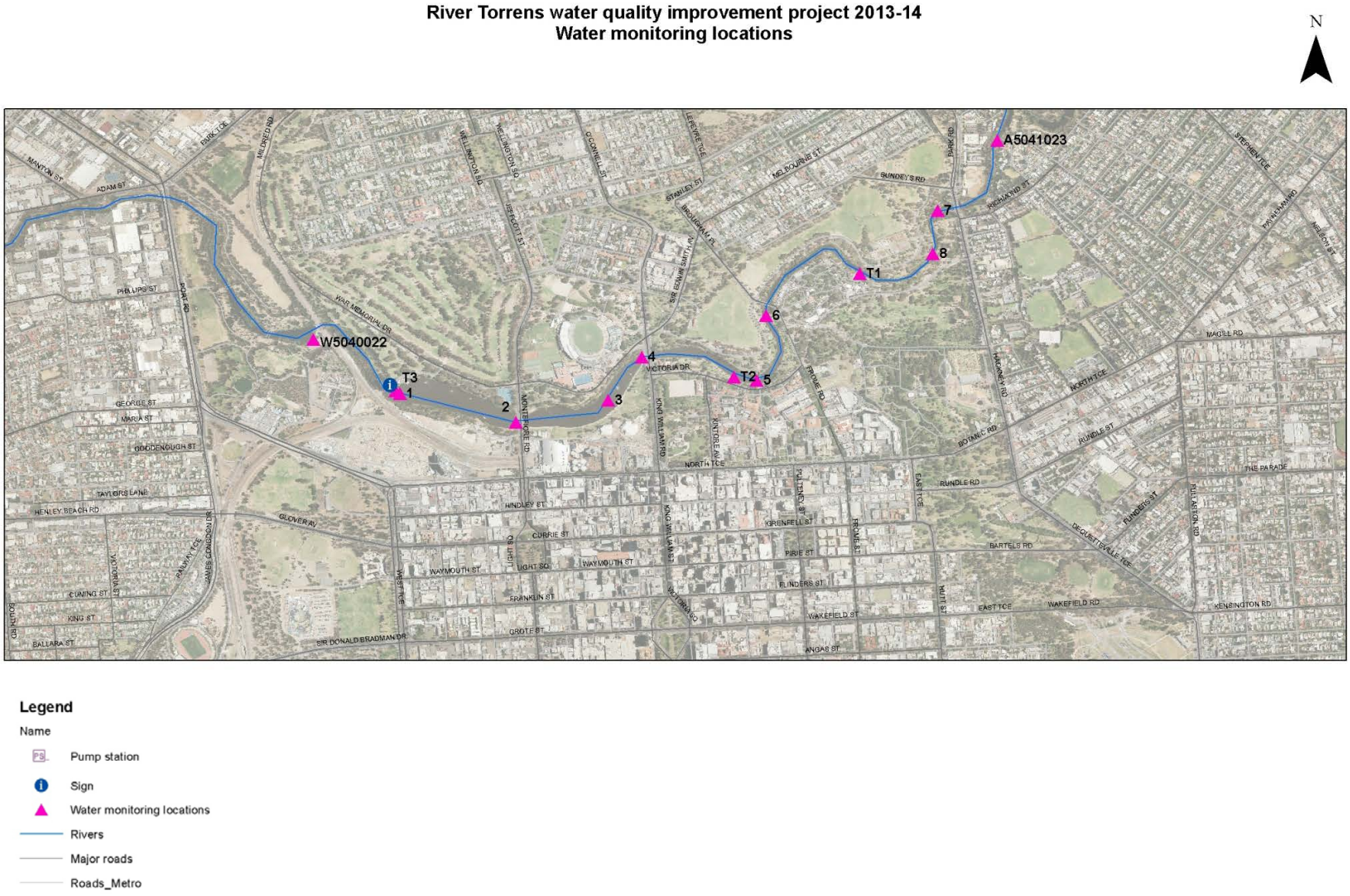

Figure 1 Location of monitoring sites 1-8 and T1-T3 on the Torrens Lake, Adelaide

Lake hydrodynamics

The premise of using controlled upstream water releases to control cyanobacteria in the Torrens Lake is that with the introduction of 'new' water and mixing of the water column there is sufficient dilution and loss of cells downstream to overcome growth and biomass expansion in the lake. Thermistor chains were deployed at three locations (Figure 1) and maintained by Water Data Services.

T1. Torrens Lake DS Hackney Road (at Adelaide Zoo Pump Shed)

T2. Torrens Lake DS Adelaide University Footbridge (Opposite Barr Smith Boat Club)

T3. Torrens Lake at City Weir (W5040030 – Torrens Lake Weather Station)

These provided temperature and salinity data at various depths through the water column at each location to enable understanding of how the flow release water mixed within the lake. Thermistors at the weir site (T3) were deployed at 0.3, 0.7, 1.0, 1.3, 1.6, 1.9, 2.4, 2.9, 3.4, 3.9, 4.4 and 4.9m. At the University footbridge thermistors (T2) were at depths 0.1, 0.5, 0.9, 1.3, 1.7, 2.1, 2.5, 2.9 and 3.3m. At the Hackney Road site (T1) thermistors were deployed at 0.2, 0.6, 1.0, 1.4, 1.8, 2.2m.

Phytoplankton and nutrients

Phytoplankton were sampled twice weekly at sites 1-8 in the lake (Table 2). Sampling was undertaken as integrated water column samples. Cell counts were performed by the Australian Water Quality Centre (AWQC), a NATA accredited laboratory. In previous years integrated samples were collected from a boat, however, in 2013/14 samplers utilised a ball valve integrated sampler to facilitate sampling from bridges. The sampling at the city weir differed from the other sites as it occurred within the boat exclusion zone where algal scums may accumulate.

Samples for nutrient analysis were collected once every two - four weeks at all eight sites in the lake and were stored on ice prior to analysis. Analyses included: Total Phosphorus (TP); Total Kjeldahl Nitrogen (TKN); Filterable Reactive Phosphorus (FRP); Ammonia; and nitrate and nitrite. All chemical analysis was undertaken by the AWQC.

Table 2 Description of the monitoring sites and a summary of the monitoring program.

Site #	Site Description	Temperature & salinity	Cell counts	Nutrients
1	Torrens Lake city weir		Twice Weekly	Fortnightly
T3	Torrens Lake city weir	Thermistor chain		
2	Morphett Street Bridge		Twice Weekly	Fortnightly
3	Elder Park		Twice Weekly	Fortnightly
4	King William Road Bridge		Twice Weekly	Fortnightly
T2	Downstream University Footbridge	Thermistor chain		
5	University Footbridge		Twice Weekly	Fortnightly
6	Frome Road Bridge		Twice Weekly	Fortnightly
T1	Adelaide Zoo pump shed	Thermistor chain		
7	Hackney Road Bridge		Twice Weekly	Monthly
8	Footbridge downstream of Hackney Road		Twice weekly	Fortnightly
Additional sites upstream and downstream of Torrens Lake				
Site #	**Site Description**	**Type**		
A5040501	Torrens River at Gorge Weir	Flow and water quality	Twice weekly	
A5040529	Torrens River at Holbrooks Road	Flow and water quality	Twice weekly	
A5041014	Torrens River Outlet – Henley South	Flow and water quality	Twice weekly	
A5041023	Torrens River downstream Second Creek	Flow and water quality	Twice weekly	
W5040022	Downstream of Torrens Lake Weir	Water quality	Twice weekly	
W5040029	Torrens River Outlet on the beach -Sea	Water quality	Twice weekly	

Rapid detection of cyanobacteria

A possible limitation of the amenity flow for control of cyanobacteria is that it takes some time to sample, count cyanobacteria, report the result and then instigate a flow release from upstream reservoirs, and then further time for the flow to travel downstream to the lake. There was considerable discussion whether the installation of a blue-green-algae probe might enable early detection of cyanobacteria and so facilitate a more rapid response and release of water from the upstream storage. Phycocyanin is an accessory pigment specific to the cyanobacteria and phycocyanin fluorescence is measured by a "blue-green-algae probe" to estimate relative cyanobacterial abundance.

A Hydrolab Sonde containing a phycocyanin sensor was deployed 0.5m below the water surface at the meteorological station at the city weir at the western end of Torrens Lake. The sensor recorded phycocyanin fluorescence every 10 minutes. It is reported here as cells/mL based on factory calibration.

River water quality considerations upstream and downstream of Torrens Lake

The aim of the amenity flow trial was to improve lake water quality without having any adverse impacts on water quality upstream and downstream of the lake. An additional monitoring program was instigated to determine: the presence of cyanobacteria in the river; and the environmental and health risks to the downstream river and marine environment. The faecal indicator Enterococci was used to determine if there were any health risks associated with the transfer of water from the Lake to the coast. Turbidity was used as an indicator of risks for the marine environment and for beach swimmers (Figure 3). The sampling site was slected to be in the outflow from the River Torrens so the exact location varied slightly (See Figure 3)

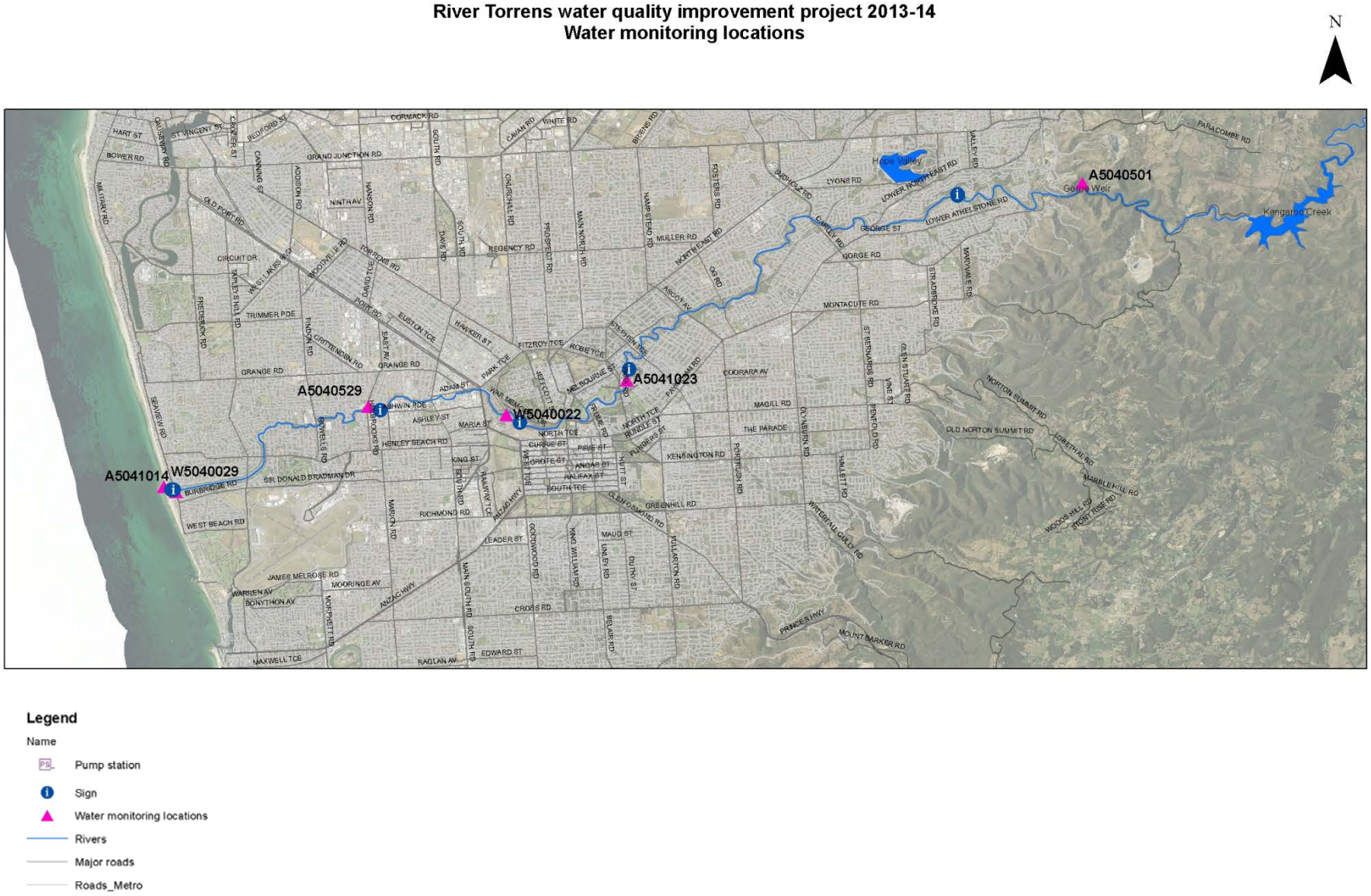

Figure 2 Sampling sites upstream and downstream of the Torrens Lake

Figure 3 Sea sampling sites at the Torrens outlet

Reporting and communication

Cyanobacterial cell counts were reported within three days of sampling. This data was used to inform decisions on the appropriate flow to be released from Kangaroo Creek Reservoir. The results were collated along with river flow data and packaged into a report prepared by the Adelaide & Mt Lofty Ranges NRM Board titled, River Torrens Water Quality Improvement Trial Summer 2013-14 update. These updates were sent directly to key stakeholders in state and local government and the community. General project information was communicated on the Adelaide & Mt Lofty Ranges NRM Board's website and on project signs installed at strategic locations along the river (refer Figure 2).

Flow and Pumping logistics

Flow in 2013-14 was delivered directly down the Torrens River from Kangaroo Creek Reservoir. This differs from previous years when water was delivered from Hope Valley Reservoir. Flow through the lake during the amenity flow trial exceeded the capacity of the pumps and sewer connection previously used (20 ML/d) to extract water from the river and discharge it to the Bolivar WWTP sewer system. Flows also exceeded the capacity of the pumps previously used (20 ML/d) to divert water to West Lakes (via the Grange stormwater system). Consequently considerably more water was delivered downstream to the River Torrens outlet at West Beach than in previous years.

Lake modelling

Three dimensional modelling of the hydrodynamics within the lake assisted in evaluating the success of the trial. Several data inputs were required for the modelling:

- Due to the lack of Torrens Lake meteorological data alternative sources of data were used.
    - Net and Shortwave solar radiation data from an SA Water monitoring station located at Myponga was used. Calculated longwave radiation was adjusted to account for the difference in surface temperature between Myponga and the Torrens Lake.

    - All other meteorological data used was sourced from the Bureau of Meteorology weather station at Kent Town.
    - A scaling of Kent Town wind velocity was needed to correct poor correlation between modelled and observed water temperatures. This was achieved by using 2010/2011 Torrens wind data (which was available) and comparing it to Kent Town data from the same period. The result was that Kent Town was 'windier' – so a correction factor was applied to the data to use it for the Torrens Lake.
- The gauged flow downstream of Second Creek (A5041023) was used as the inflow to the lake.
- The inflow water temperature was based on measured values from A5041023 - Torrens River d/s Second Creek.
- Outflows from the lake were estimated based on inflows, calculated evaporation rate and the assumption that the lake level remained constant.

Modelling scenarios included inserting a tracer into the inflow to determine whether the inflow was mixing with the lake water and what amount of dilution might be expected. The actual flow during each of the flow release events was modelled with tracers to determine what dilution occurred. This scenario was expanded to include a growth parameter that enabled cyanobacteria to grow at a rate of 0.3/day but also be diluted by the flow.

3. Results

Flow and Hydrodynamics

In Adelaide summer 2013-14 was typically dry but punctuated with a record rainfall event of 75.2mm on 14 February, followed by an additional 17.6mm on 15 February, resulting in a daily flow of greater than 2000 ML/day (Figure 4). Rainfall for December, January and February was 16.2 mm, 10.2 mm and 98.2 mm respectively. Three controlled flow releases preceded the high rainfall event in response to warm conditions and detection of cyanobacteria.

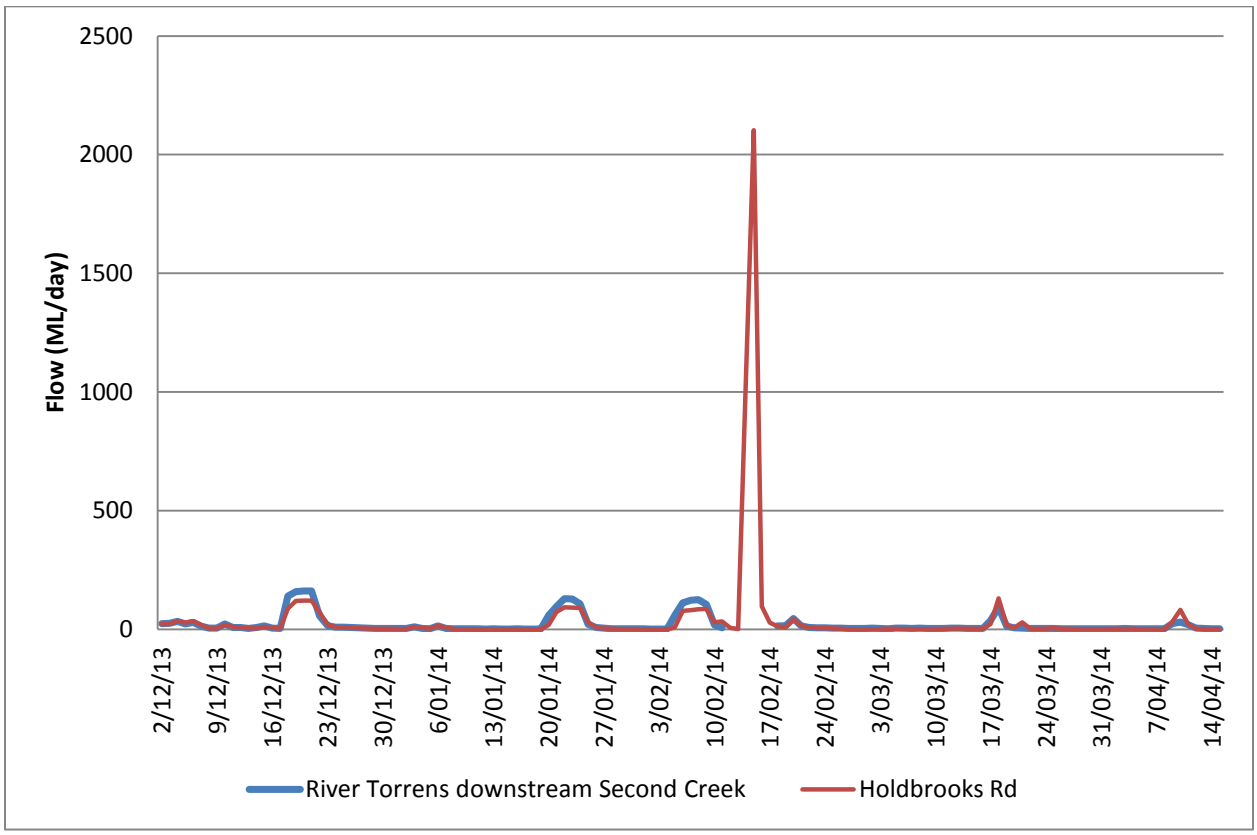

Figure 4 River Torrens Flow measured upstream of the Torrens Lake (downstream Second Creek) and downstream of the Lake (Holbrooks Rd). Base flow was minimal and small rises in flow are due to amenity flow releases. The large flow on 14 February was a 75 mm rainfall event.

Although the Torrens Lake is only shallow it does exhibit periods of intense temperature stratification (Figure 5). Temperatures exceeded 30°C in the surface layer in early January and a 10°C temperature gradient was evident over the five metre water column. Periods of stratification and mixing continued throughout summer. The periods of persistent temperature stratification indicate there is typically very little mixing, and under these conditions the buoyant bloom-forming cyanobacteria have a competitive advantage over other phytoplankton groups which rely upon mixing to keep them entrained in the water column.

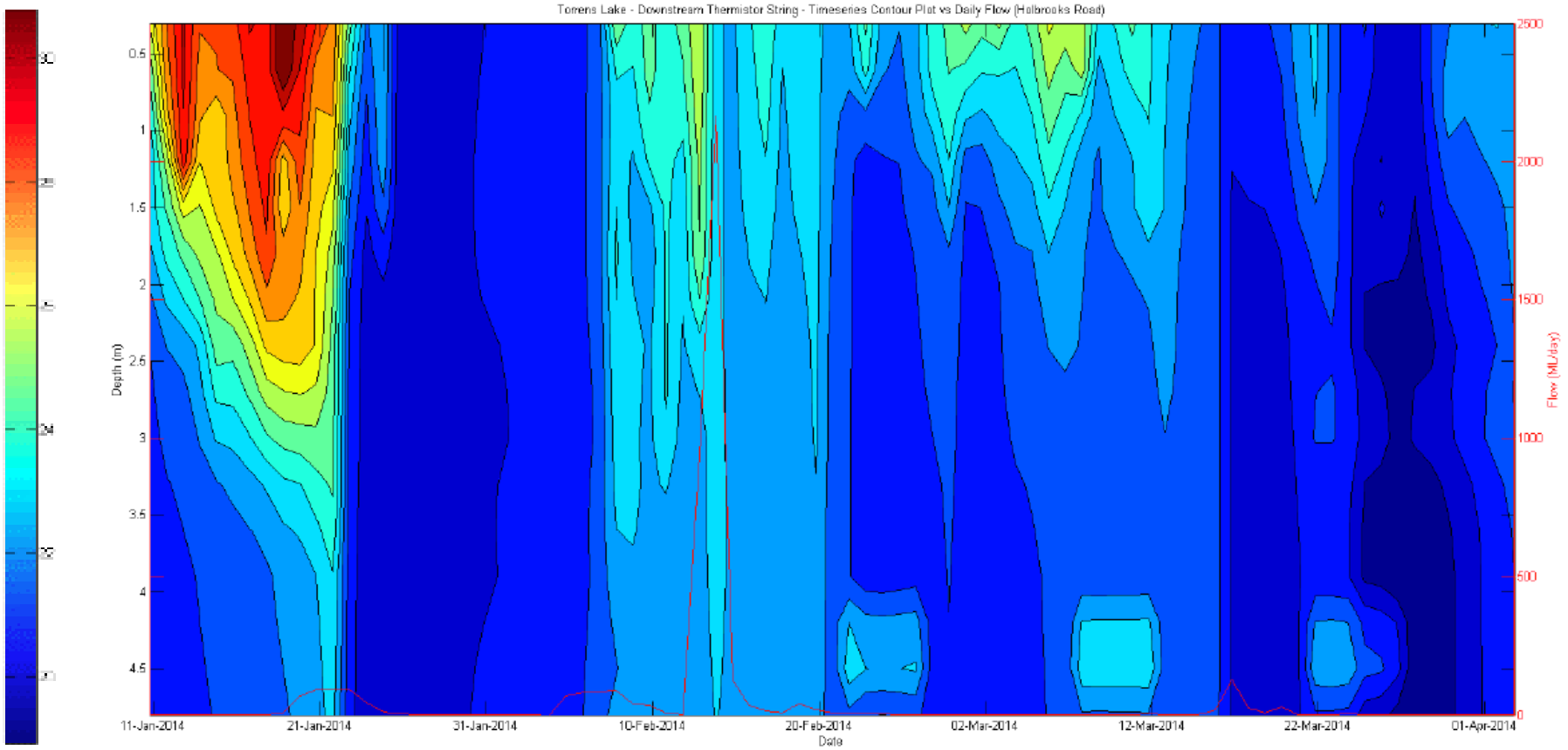

Figure 5 Temperature profile measured at the Torrens Lake Weir. The Flow at Holbrooks gauging station downstream of the Torrens Lake is shown in faint red line corresponding to the YY axis

Phytoplankton

Phytoplankton counts discussed in this report are restricted to the cyanobacteria. Total cyanobacteria counts were derived from the sum of all observed cyanobacteria including *Microcystis aeruginosa*, *Microcystis flos-aquae*, *Anabaena circinalis* and *Planktothrix sp*. There are several outstanding features in plots of the total cyanobacteria counts (Figure 6); the community increases in mid-January coinciding with intense heating, the community is washed out during the large rains of 14-15 February, and there is considerable spatial heterogeneity in the concentration of cyanobacteria across the lake. The species of most concern in previous years, *Microcystis aeruginosa* did not reach concentrations exceeding 1000 cells/mL (Figure 7).

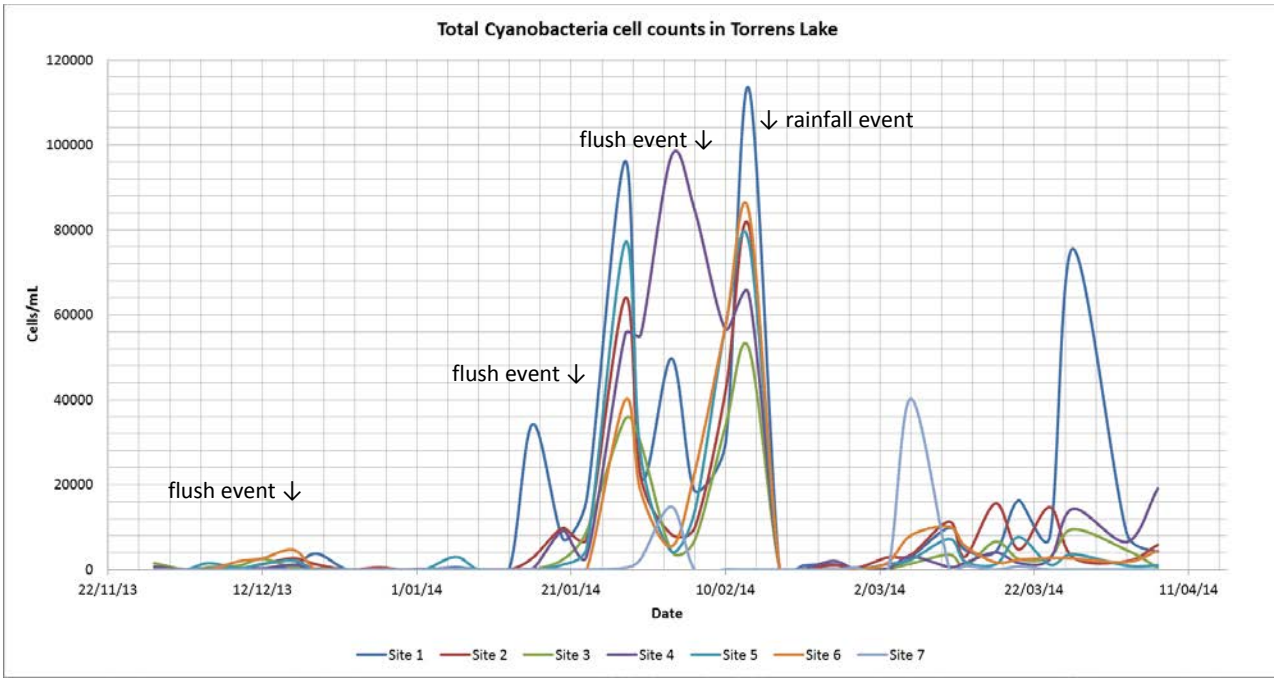

Figure 6 Total cyanobacteria at seven sites in the Torrens Lake, expressed as cells/mL. Site 8 was not included as cell counts were close to zero.

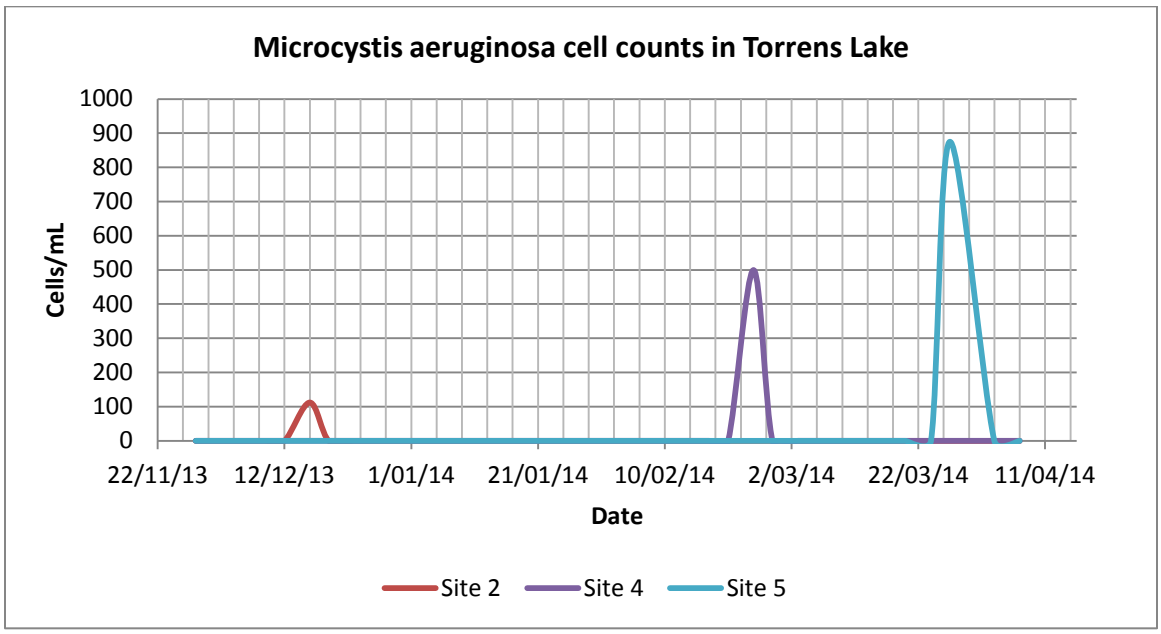

Figure 7 *Microcystis aeruginosa* cell counts in the Torrens Lake. Sites where *Microystis aeruginosa* were not observed have been excluded.

Tabulating the cell count data allows visualisation of the spatial distribution and abundance of the various cyanobacterial species. In early December the total cyanobacterial count remained fairly low (Fig. 6; Table A.1). A pre-emptive flow release in mid-December, as temperatures began to increase, virtually removed the cyanobacteria from the lake. There was only very low abundance of cyanobacteria from mid-December to mid-January (Fig. 6; Table A.1). Total cyanobacterial abundance began to increase again in mid-January but this was comprised of *Microcystis flos-aquae* (Table A.2) and *Anabaena circinalis* (Table A.3). *Microcystis flos-aquae* cells are approximately four times smaller than *Microcystis aeruginosa* cells, by biovolume, and so a much higher concentration is tolerable (Table 1).

Both the *Microcystis flos-aquae* (Table A.2) abundance data and the *Anabaena circinalis* (Table A.3) abundance data demonstrate the transitions between populations growing and then being reduced with controlled flow releases. The populations show an increase in growth and greater distribution across the lake and then the populations are reset to zero as the flow dilutes the population. The cycle is repeated for each flow release. The resetting of the population to zero is evidence that the larger flow volumes are able to remove the cyanobacteria from the lake, which the flow strategies in the previous two years were unable to achieve.

Rapid detection of cyanobacteria

Early detection of cyanobacteria is key to the dilution amenity flow concept working. Diluting flows have a proportionally bigger impact when the cell concentrations are low and so releasing flow early is optimal for maintaining low population numbers. Manual sampling and counting is time consuming and costly which dictates the periodicity of sampling and how many samples can be taken. Counts taken twice weekly gives a good chance of detecting cyanobacteria early enough but populations can grow rapidly between samplings which becomes problematic when public holidays etc. interrupt the normal sampling frequency. To try and overcome this problem a probe was trialled again in the 2013-14 summer which offered the possibility of rapid online detection. The blue-green-algae probe recorded phycocyanin concentrations every 10 minutes. The probe was factory calibrated to a 'standard cyanobacterial cell concentration' but no further calibration was undertaken.

A concern with using a fluorescence probe is that the signal may become quenched with exposure to light. This occurs with chlorophyll fluorescence as cells become photoinhibited. To

test whether this occurs with phycocyanin fluorescence a comparison was made with phycocyanin fluorescence measured at 6am (ie no significant light exposure), 12:00 pm and 6:00pm (following light exposure). The phycocyanin fluorescence did not vary significantly during the course of a single day (Figure 8) and so we can be confident that the signal is not impacted greatly by light exposure of the cyanobacteria.

A comparison between the microscopically counted cell count and the 'blue-green algae probe' derived count revealed a poor correlation (r^2= 0.05; Figure 9). If the correlation was better but the relationship between the two was not 1:1 cell count: cell count we could assume that any discrepancy may just be due to a calibration issue. However, the poor correlation and lack of linearity suggest the phycocyanin is not effective or accurate at detecting cyanobacteria.

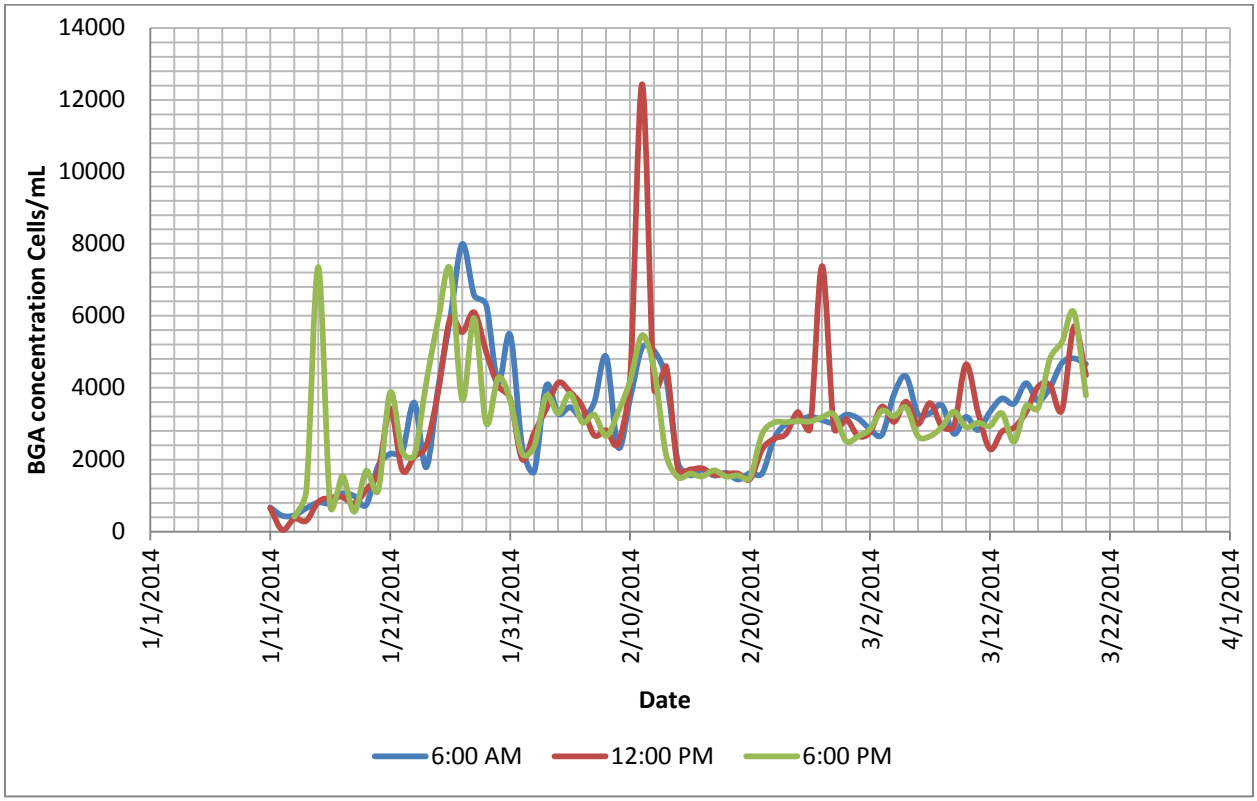

Figure 8 Phycocyanin measured with the "blue-green-algae" probe measured at 6am, midday or 6pm.

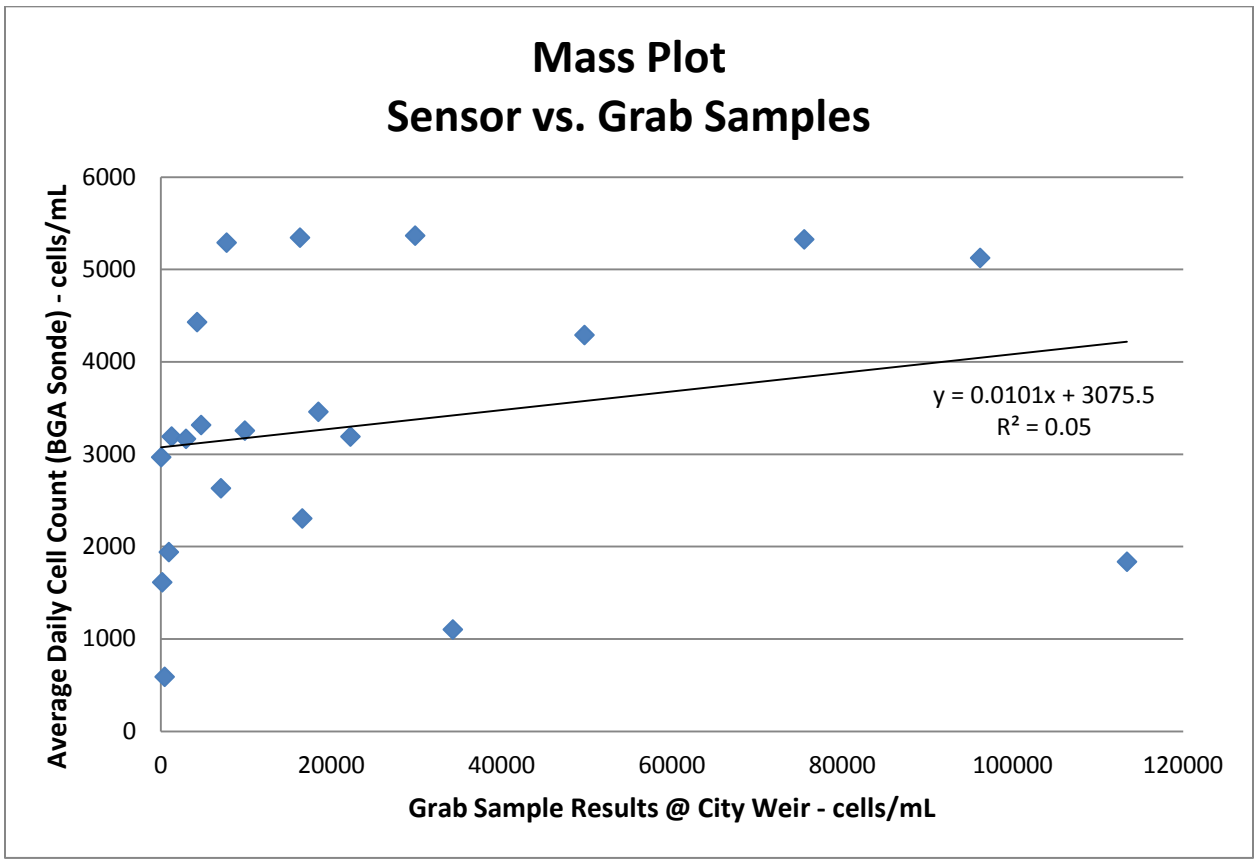

Figure 9 Comparison of cyanobacterial abundance determined by grab sample counted manually and a cell count derived from a phycocyanin probe deployed permanently in the Torrens Lake.

Downstream Water Quality

Enterococci are used as an indicator of bacterial or faecal contamination but have no health significance themselves. Enterococci are used in this study to assess whether there are detrimental impacts from flow releases moving lake water and possibly contaminants downstream. Concentrations of Enterococci were always higher at the Holbrooks Road and Henley South sites as compared to the Torrens River Outlet (Figure 10). Concentrations peaked on 20 January 2014, which coincided with a controlled flow release of 90 ML/day, but typically Enterococci concentrations attenuated as they moved downstream (Figure 10; Table 3) and over the course of each flow release. Cyanobacteria concentrations in the downstream water were also relatively low and concentrations attenuated with downstream travel (Table 4).

The NHMRC Guidelines for Managing Risks in Recreational Waters (NHWRC, 2008) state that adverse health effects can be associated with hazards and risks such as ingestion or inhalation of pathogenic bacteria, viruses and parasites. Risk reduction measures are avoiding contact, control, licensing and treatment of sewage effluents and personal awareness. The general public have no contact with the river or lake water and more extreme exposure like ingestion or inhalation is extremely unlikely. Risks to beach users were managed through increasing public awareness using staff to patrol the beach, signage, fact sheets and website alerts.

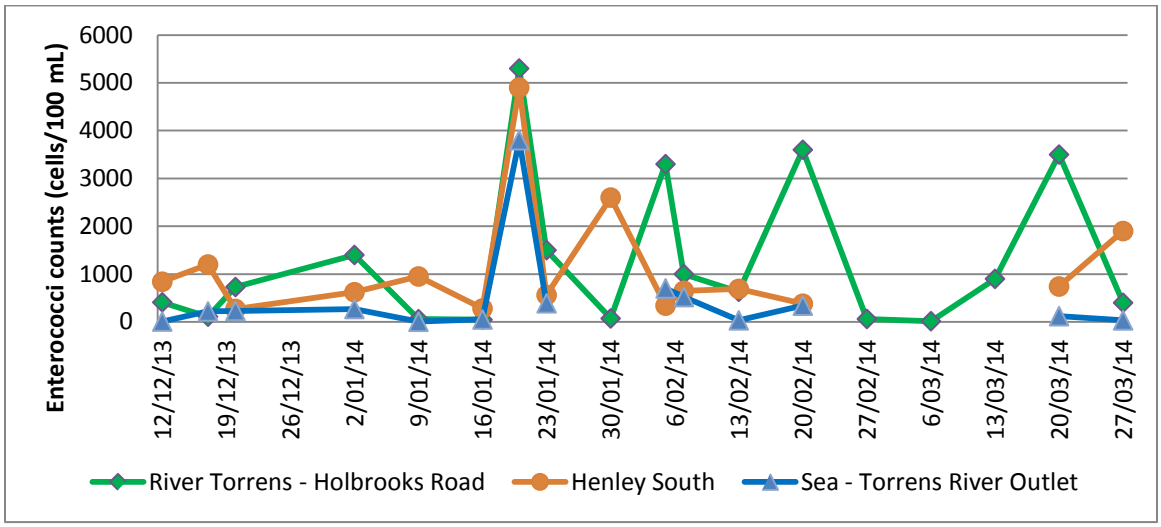

Figure 10 Enterococci counts at River Torrens- Holbrooks Road, Henley South and Sea when available.

Table 3 Enterococci concentrations upstream and downstream of the Torrens Lake during summer 2013-14

Enterococci (cells/100mL)							
location	Torrens River at Gorge Weir	River Torrens downstream Second Creek	River Torrens downstream of Torrens Lake Weir	River Torrens at Holbrooks Road	Torrens Outlet Weir	Torrens River Outlet - Henley South	Sea (approx 1m water depth) Torrens River outlet
Date							
12/12/2013	73	450	45	410	360	840	8
17/12/2013	200	2000	94	110	530	1200	220
20/12/2013	350	2700	170	730	690	270	230
2/01/2014	360	35000	440	1400	450	620	270
9/01/2014	86	1300	270	57	390	950	4
16/01/2014	210	880	290	46	330	280	51
20/01/2014	200	1000	690	5300	6900	4900	3800
23/01/2014	120	2400	4600	1500	620	560	390
30/01/2014	50	920	160	72	110	2600	
5/02/2014	240	3100	240	3300	4500	340	700
7/02/2014	1500	2800	120	1000	2700	650	520
13/02/2014	130	720	1800	630	480	690	33
20/02/2014	80	1700	1200	3600	410	380	340
27/02/2014	73	230	77	62	180		
6/03/2014	23	280	270	15	260		
13/03/2014	310	400	200	900	250		
20/03/2014	120	2200	480	3500	460	740	120
27/03/2014	37	470	73	400	500	1900	32

Table 4 Total cyanobacteria at downstream sites (cells/mL)

Date	Torrens River at Holbrooks Road	Torrens River Outlet on the beach	Torrens River Outlet - Henley South
12/12/2013	0	0	0
17/12/2013	0	0	0
20/12/2013	0	104	0
24/12/2013	0	0	0
02/01/2014	0	0	0
09/01/2014	0	0	0
16/01/2014	0	0	308
20/01/2014	2520	0	94
23/01/2014	1470	3990	2690
30/01/2014	1910	4130	560
05/02/2014	1880	597	62700
07/02/2014	1330	2370	2460
13/02/2014	6750	11100	2150
20/02/2014	0	600	0
27/02/2014	620	0	
06/03/2014	0	96	
13/03/2014	0	260	
20/03/2014	616	460	1340
27/03/2014	594	0	0

Modelling of flow scenarios

The three dimensional hydrodynamic model Elcom was used to simulate stratification and flow in the Torrens Lake. To have confidence that the model was able to adequately simulate a range of scenarios it was first calibrated against existing data. Calibration to obtain similar vertical temperature structure in ELCOM to the deployed thermistors successfully recreated the temperature structure (Figure 11, Figure 12). Overall there is a good agreement between the model outputs and thermistors and major features are well simulated: the warming and cooling cycles and the depth of stratification (Figure 11, Figure 12).

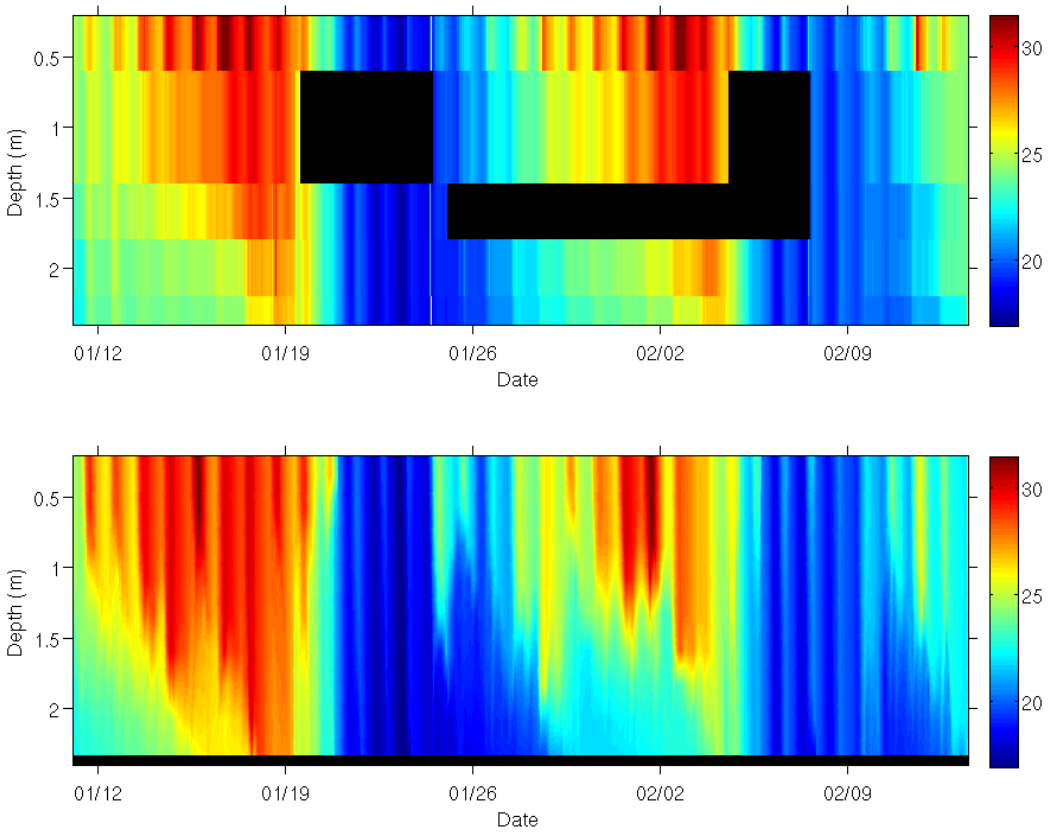

Figure 11 Temperature measured with thermistors at the upstream monitoring site (top panel) and temperature structure derived from the three-dimensional hydrodynamic model, Elcom. The black region indicates time periods where the thermistors failed.

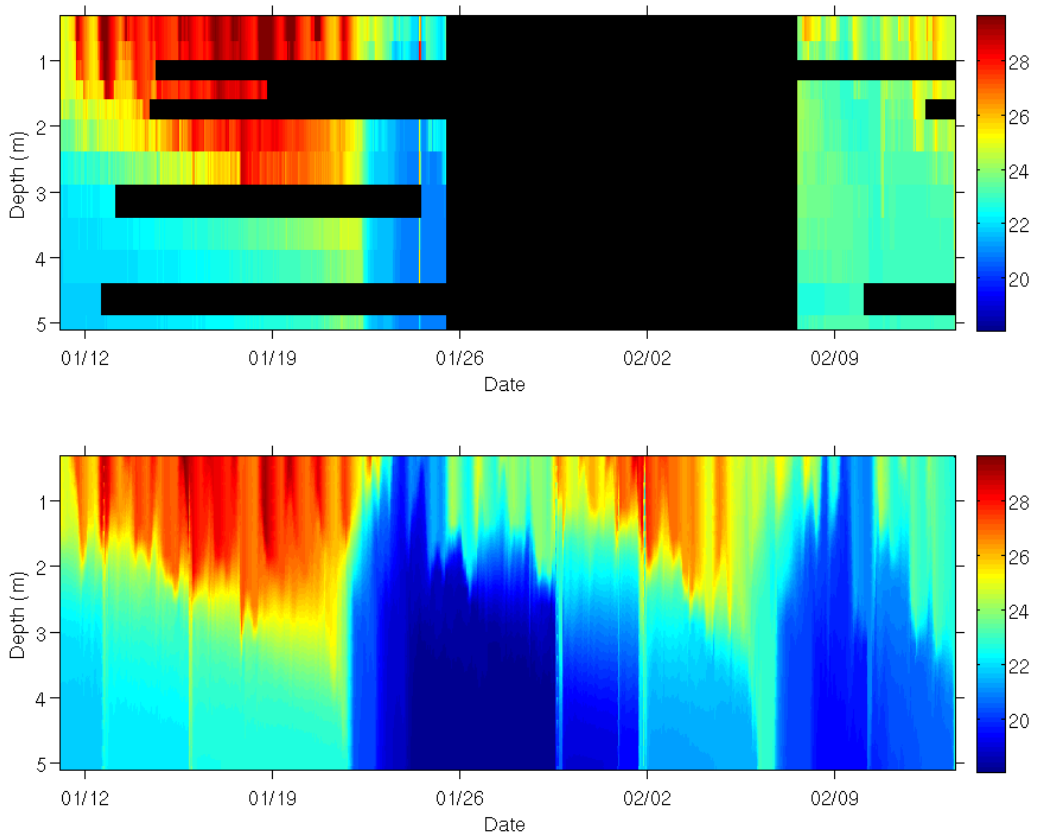

Figure 12 Temperature measured with thermistors at the city weir (top panel) and temperature structure derived from the three-dimensional hydrodynamic model, Elcom. The black region indicates time periods where the thermistors failed.

The aim of the amenity flow is to dilute the cyanobacteria populations in the lake with water released from an upstream reservoir. To determine how successful the flows in the 2013-14 trial were diluting the lake water, a model simulation was performed with a 'tracer' in the inflow to determine the rate of mixing and dilution. The third flow release was modelled for the period between 5-9 February 2014 (Figure 13). The results are presented as a southward looking transect through the lake with the concentration of the tracer shown as a proportion between 0-1 where 1 is the maximum tracer concentration in the inflow (red) and the ambient lake water at the beginning of the simulation is 0 (blue). The inflowing water entered the lake as a shallow plug flow for the first 600m but was cooler than the ambient lake water so inserted as an underflow reaching the weir after approximately 24 hours (Figure 13). The inflow water continued to flood the lake basin replacing the surface water, which over-topped the weir. After 3.5 days (12:00 pm 8 February) most of the lake water was from the inflow and the

remnant original lake water only occurred at the surface towards the weir although this was also >75% from the upstream flow release.

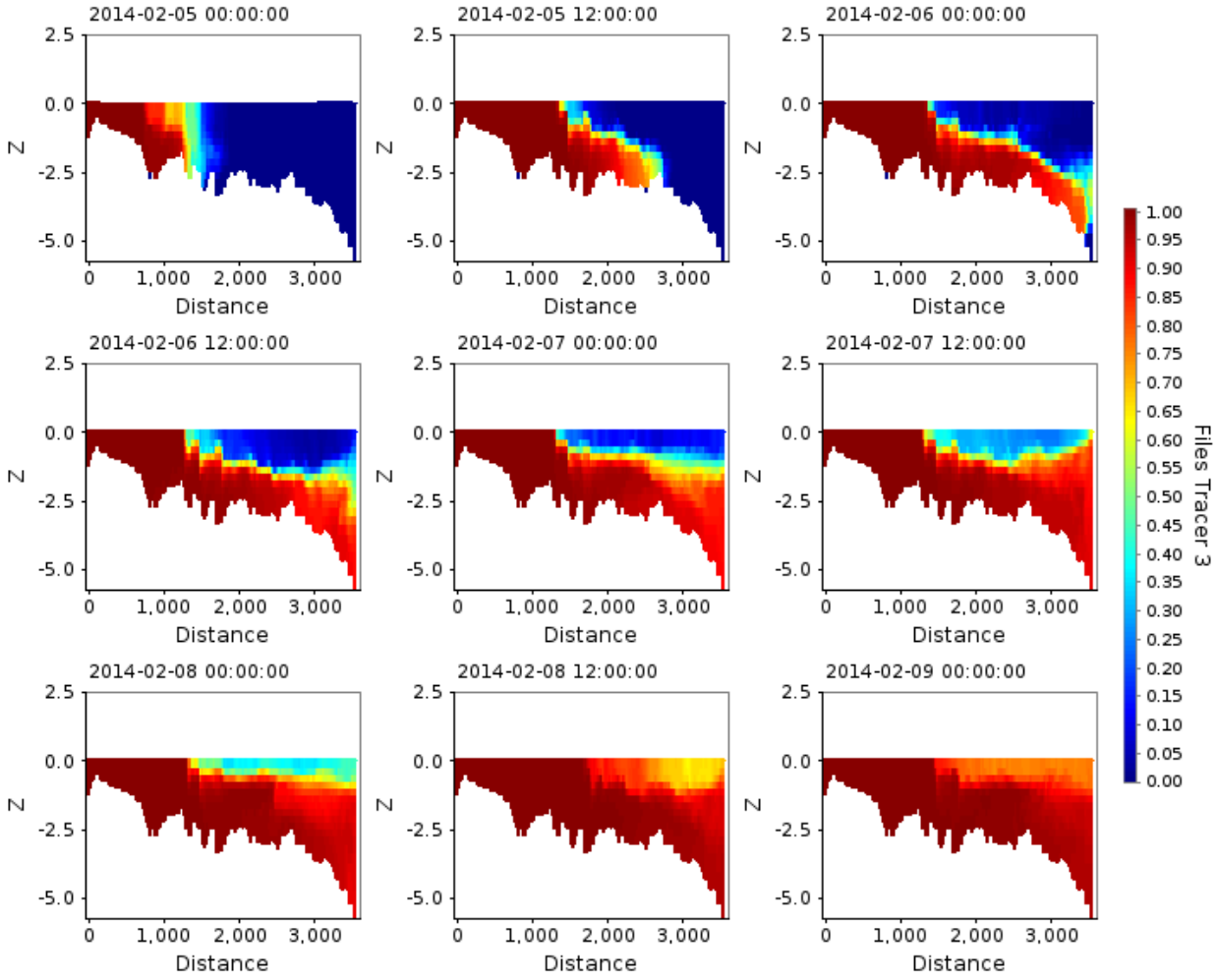

Figure 13 Simulation of the third controlled flow release. Each figure is a south-ward looking transect of the lake depicting the concentration of a tracer inserted in the inflow. The tracer has a concentration of 1 and the lake water with no tracer is 0.

The tracer experiment using Elcom (Figure 13) and the cyanobacterial cell counts from the routine monitoring (Figure 6) both demonstrate very effective dilution of the lake water using the larger flows in the 2013-14 trial. In previous flow trials (2011-12 and 2012-13) the flow was capped at 40ML/day. To compare the dilution achieved using the two different flow volumes a scenario was modelled with a tracer in the inflow where the flow rate was either 130 ML/day or 40 ML/day. The tracer in this scenario is set at 1 in the inflow and the proportion of the tracer at each location depicts how much dilution has occurred at each of five sites: University

footbridge; King William Road; Elder Park; Morphett Street bridge; and the city weir (Figure 14). The tracer concentration at the University footbridge is > 0.95 indicating that with a flow of 130ML/day most of the water at this site originates from the controlled flow release within 2 days. In contrast tracer concentrations at the footbridge with 40ML/day are approximately 0.25. It takes longer for the tracers to reach the other sites as the flow travels through the lake but the tracer concentration and hence dilution is consistently lower in the 40ML/day scenario than the 130ML/day scenario. The lake average tracer concentration shows that the inflows have diluted most of the lake within six days but the 40ML/day flows managed to only dilute 40% of the lake (Figure 14).

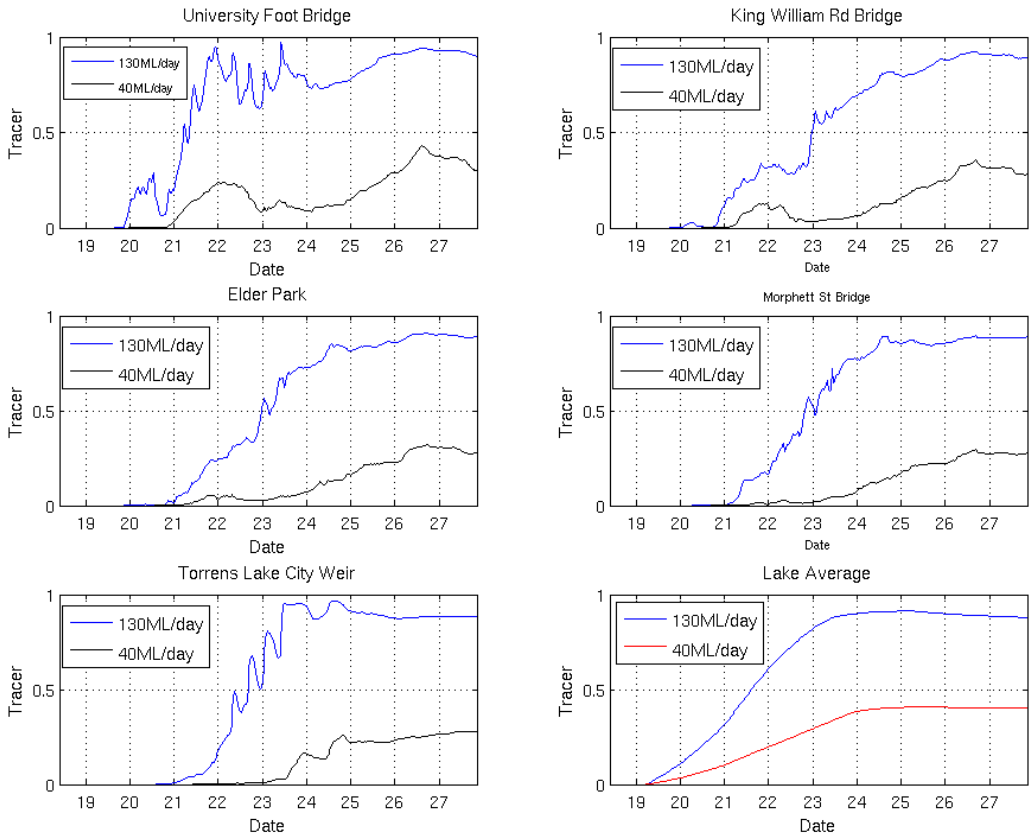

Figure 14 Tracer experiment comparing the magnitude of lake dilution that occurs with a 40 ML/day flow and a 130 ML/day flow– the inflow has a concentration of 1 and the lake =0. The plot is for the concentration at 0.5 m depth at five locations in the lake

The comparison of the two flow scenarios was expanded to include cyanobacterial growth. The growth of cyanobacteria was set at a constant growth rate of 0.3 /day and the two different

flow volumes were imposed; 130 ML/day and 40 ML/day. The 40 ML/day flow was unable to control the expansion of the cyanobacterial population (Figure 15), whereas the 130 ML/day flow maintained or decreased the size of the cyanobacterial population as soon as the flow was instigated.

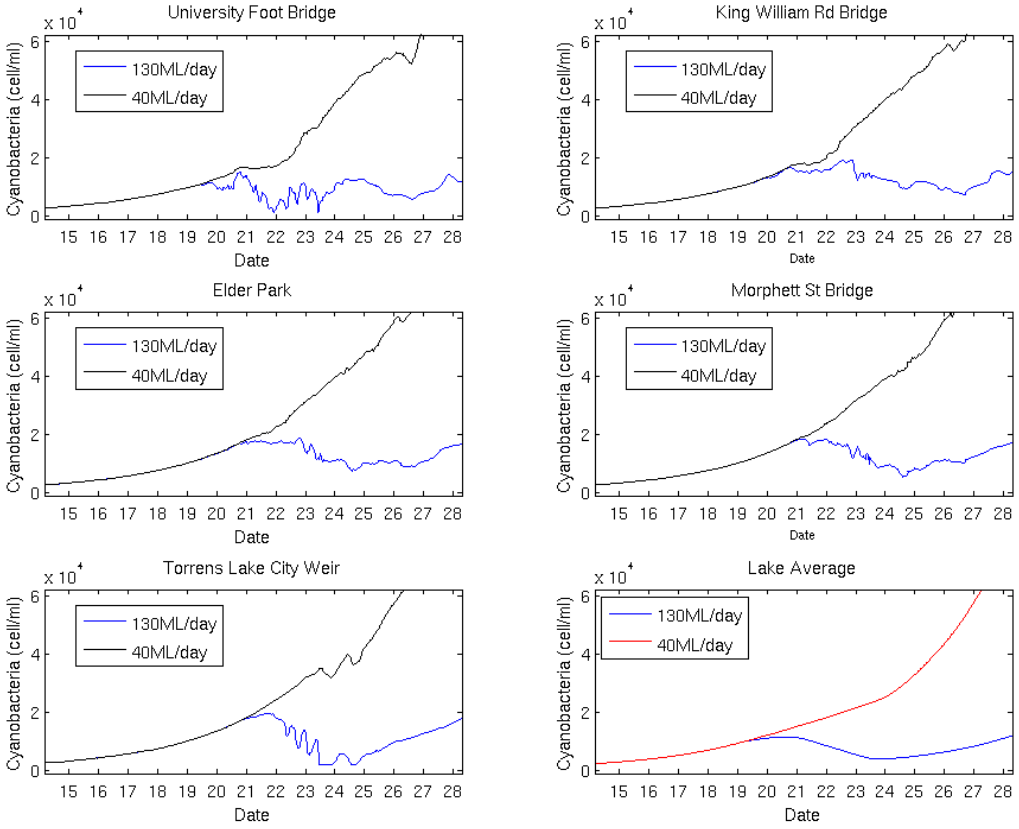

Figure 15 Relative cyanobacterial abundance modeled with Elcom for two flow rates, 130 ML/day and 40 ML/day. The growth rate of cyanobacteria was set at a constant doubling rate of 0.3/day.

The temperature of the inflowing water may also affect the dilution rate. Inflows that are colder, and hence denser, than the ambient lake water will tend to insert as underflows. We hypothesised that inflow water that has a temperature closer to the lake water will have greater mixing and result in greater dilution of cyanobacteria than cooler water which will insert as an underflow so not dilute the cyanobacteria at the surface to the same degree.

The inflow temperature may vary as a function of the source water used for the diluting amenity flows. The inflow temperatures for three different water sources were used to explore

dilution: ambient (inflow similar to the lake surface water temperature); Hope Valley Reservoir slightly cooler than the lake temperature and Kangaroo Creek Reservoir water which is the actual observed inflow temperature. Initially the three different source waters had different rates of dilution but this was most apparent near the upstream end of the Torrens Lake. After several days of controlled flow releases the differences in the concentration of the tracer were less apparent and the lake average reveals very little difference between the water sources. However, there were differences in the cyanobacterial populations with the three different inflows (Figure 17). The cooler water from Kangaroo Creek Reservoir would tend to insert as an underflow and so buoyant cyanobacteria in the surface waters would not be diluted as much as water of similar temperature to the lake water which would show greater mixing.

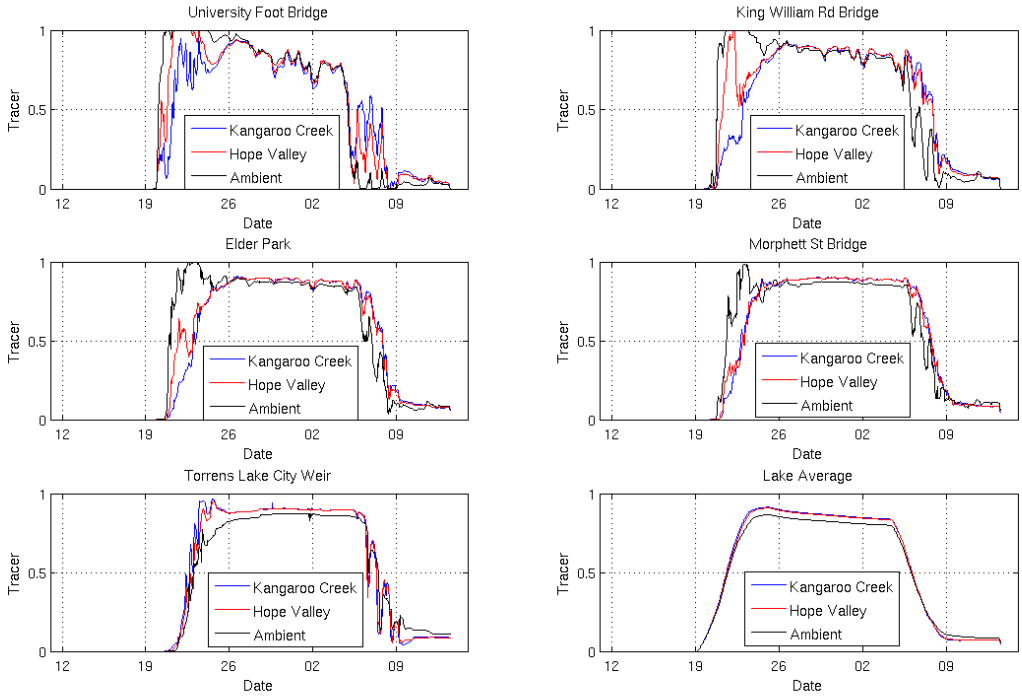

Figure 16 Tracer experiments in Elcom testing the effect of different water sources on dilution. The sources were Ambient, which is water of equivalent temperature to the lake surface, Hope Valley Reservoir slightly cooler than the lake surface and Kangaroo Creek Reservoir water, which was the observed water inflow temperature.

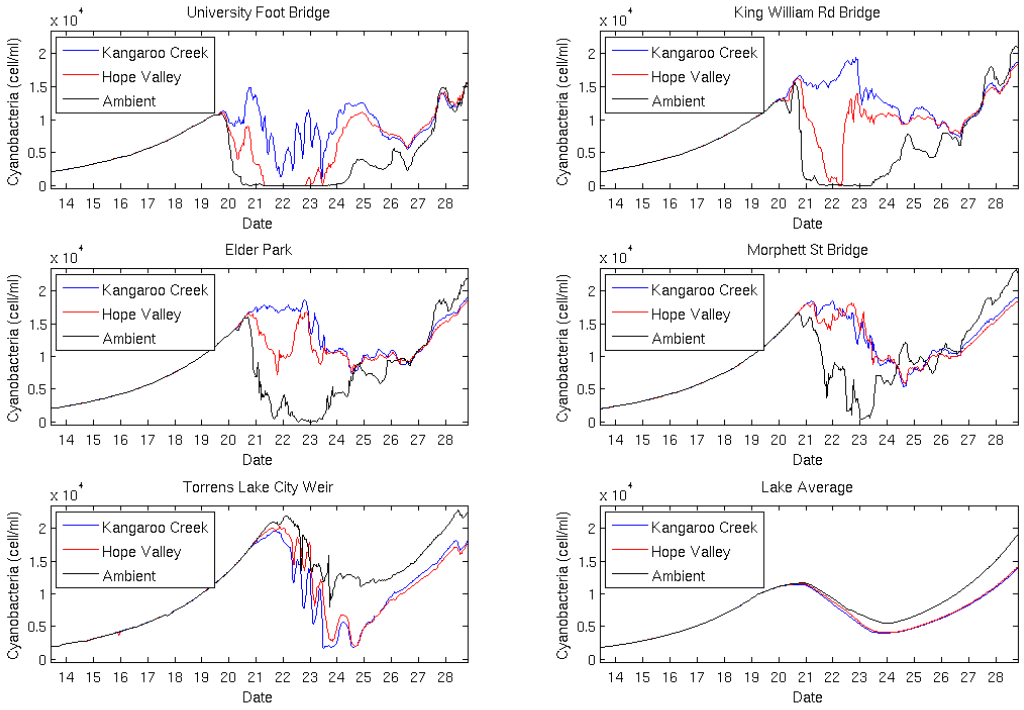

Figure 17 Predicted cyanobacterial abundance simulated in Elcom testing the effect of different water sources on dilution of the cyanobacterial population with a fixed doubling rate of 0.3 /day. The sources were Ambient, which is water of equivalent temperature to the lake surface, Hope Valley Reservoir slightly cooler than the lake surface and Kangaroo Creek Reservoir water which was the observed water inflow temperature.

4. Discussion

Critical evaluation of the trial

The aim of delivering flows from the upstream storages to the lake is to dilute the cyanobacterial populations and maintain the lake below the critical thresholds that trigger lake closure. In consultation with SA Health these threshold concentrations have been increased to account for primary and secondary contact, with the revised concentrations presented in Table 1. The higher flow volumes delivered during the 2013-14 trial effectively diluted the cyanobacteria so at no time did they breach the threshold. On only one occasion (28 January 2014) did Anabaena exceed the old guideline value (Table A.4) with populations controlled well below concentrations triggering lake closure.

Brookes et al. (2013) reporting on the second amenity flow release trial concluded that on balance the amenity flows are insufficient on their own to provide relief against high cyanobacterial growth. The amenity flow was designed to work in combination with rainfall events which would reset the populations in the lake. Brookes et al. (2013) suggested that in the absence of rain events to reset the cyanobacterial populations in the lake large water releases from upstream reservoirs could fulfil a similar role. A larger flow volume released from Hope Valley Reservoir would have greater dilution effects and so slow the increase in population expansion in the lake.

The pre-emptive flow releases in response to warm weather and heightened risk of cyanobacterial growth proved to be an effective strategy. There are two lines of evidence to support this conclusion: first, the flow maintained the populations well below the thresholds for lake closure and reset the populations to zero; and second, the hydrodynamic modelling shows replacement of the ambient lake water with inflow water (Figure 13).

Comparison of dilution flows with previous trials

The amenity flow releases in the previous two trials failed to maintain cyanobacteria concentrations below the threshold for lake closure. The flow was simply not large enough to dilute the lake water (Figure 14) and counteract the exponential growth of cyanobacteria (Figure 15).

The higher magnitude flows used in the 2013-14 trial effectively controlled the cyanobacteria in the lake by providing flows that diluted the cyanobacteria at a much higher rate than it could grow.

Considerations for long term sustainability of flow releases to control cyanobacteria

The long-term sustainability of controlled flow releases from upstream to control cyanobacteria in the lake must consider a number of other factors. Having a lake free of cyanobacterial blooms has tourism, recreational and aesthetic benefits. The value that the community places on these benefits in the lake needs to be weighed up against operational costs, water availability, upstream and downstream water quality and downstream environment and health risks.

The cost of the water is perhaps the greatest challenge for the sustainability of the amenity flow program. The 2013-14 trial used approximately 2000 ML of water with a pumping costsa of pproximately $250 / ML.

The water quality factors that need consideration are the downstream faecal and cyanobacterial counts. Enterococci are used as an indicator of faecal contamination but they did not show any risk higher than what would be expected under a typical rainfall event. The cyanobacterial counts never approached critical levels in the lake and so the downstream concentrations were similarly low and cells may have suffered damage during downstream passage. The upstream water quality was satisfactory and anecdotal evidence suggests that the community appreciated the elevated flow in summer and it increased the amenity value of Linear Park.

The low flow scenarios (40 ML/day) are inadequate but the higher flow volumes used in this trial (130 - 150 ML/day) controlled cyanobacterial populations. The timing of delivery of these flows mean they are not an environmental flow for the native fish species but they do have environmental benefit by ensuring cyanobacteria do not dominate, as cyanobacteria are a poor food source and are generally detrimental to water quality. Surveys of fish in the

lower River Torrens were undertaken as a separate exercise this year and information of this can be sought from the Adelaide and Mt Lofty Ranges NRM Board.

Future monitoring

The monitoring program executed in the 2013-14 flow trial differed from the previous years as samples in the lake were integrated samples from bridges rather than integrated watercolumn samples from a boat. The manually collected and counted samples proved adequate to provide the information necessary to order flows and manage cyanobacterial concentrations in the lake. It is recommended that a more targeted investigation is performed on the phycocyanin probe to prove or disprove its accuracy as measure of relative cyanobacterial abundance, if it is to be used in future summers.

Future use of dilution amenity flows

If controlled amenity flow releases are considered for future control of cyanobacteria then the higher flow volumes should be considered. The pre-emptive delivery of water in response to weather forecasts of hot weather proved successful and has proved to be the only reliable strategy for control of cyanobacteria in the lake thus far. Water allocation planning could factor amenity flows for maintenance of water quality in the Torrens Lake.

As with the conclusions of previous reports, if an amenity flow is coupled with algicidal technology, such as hydrogen peroxide, then the upstream and downstream benefits as well as cyanobacterial control in-lake should be achieved. Hydrogen peroxide is still untested in the Torrens Lake and this would need to be tested before lake-wide application is undertaken.

5. References

Brookes JD (ed) (2012) *River Torrens Water Quality Improvement Trial - Summer 2011-12,* Goyder Institute for Water Research Technical Report Series No. 12/4

Brookes JD (ed) (2013) *River Torrens Water Quality Improvement Trial - Summer 2012-13,* Goyder Institute for Water Research Technical Report Series No. 13/16

NHMRC (2008) Guidelines for Managing Risks in recreational Water. National Health and Medical Research Council, Commonwealth of Australia, Canberra http://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/eh38.pdf

NHMRC/NRMMC (2011) Australian Drinking Water Guidelines 6 version 2 Updated December 2013 National Water Quality Management Strategy. National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra https://www.nhmrc.gov.au/_files_nhmrc/publications/attachments/eh52_aust_drinking_water_guidelines_update_131216.pdf

6. Appendix

Table A.1 Total Cyanobacteria cell counts (cells/mL).

Sample date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Average
28/11/2013	218	634	1510	715	0	0	0		385
2/12/2013	18	76	0	0	0	0	0	0	12
5/12/2013	0	127	532	165	1510	0	0	0	292
9/12/2013	182	190	960	0	360	1980	0	0	459
12/12/2013	325	1260	2522	268	1320	2630	0	0	1041
16/12/2013	938	2692	485	1130	2110	4650	0	0	1501
19/12/2013	3770	1200	258	0	0	0	0	0	654
23/12/2013	0	0	0	0	0	0	0	0	0
27/12/2013	375	495	10	0	0	0	0	24	113
30/12/2013	0	0	0	0	0	0	0	0	0
2/01/2014	0	22	0	150	0	0	0	0	212
6/01/2014	500	0	0	0	3000	0	177	0	460
9/01/2014	80	0	0	0	0	0	0	1000	135
13/01/2014	434	0	0	0	0	0	0	0	54
16/01/2014	34265	2772	0	225	0	105	98	1750	4902
20/01/2014	7040	9870	2475	9175	1232	0	0	0	3724
23/01/2014	16590	7310	9052	3188	5067	0	0	0	5151
28/01/2014	96171	63985	35485	55480	77035	39965	435	0	46070
30/01/2014	22245	21888	29770	55268	26869	18410	2500	2850	22475
3/02/2014	49722	8258	4282	97460	4230	5480	14820	3990	23530
6/02/2014	18482	9862	6925	84670	13728	22900	0	229	19600
10/02/2014	29842	42080	33928	56572	57430	57500	42	0	34674
13/02/2014	113410	81030	52180	64850	77280	84452	0	3720	59615
17/02/2014	150	0	325	365	290	338	0	0	184
20/02/2014	925	122	140	120	0	88	0	1250	331
24/02/2014	1250	1040	0	2030	90	0	0	55	558
27/02/2014	28	400	0	0	0	0	505	30	120
3/03/2014	0	2900	245	270	1300	1620	0	105	805
6/03/2014	2940	3450	1410	3090	2300	8050	40300	5120	8333
11/03/2014	9850	11302	3500	602	7220	10162	298	20400	7917
13/03/2014	4715	3020	767	1560	1940	5605	930	9126	3458
17/03/2014	4242	15600	6590	4006	1238	1697	0	0	4172
20/03/2014	16322	4722	2500	1568	7662	2360	722	695	4569
24/03/2014	7710	14702	2920	2402	1152	2690	0	1050	4078
27/03/2014	75520	2870	9510	14320	3600	2615	0	3250	13961
3/04/2014	8490	1978	4558	6544	920	1792	0	1090	3172
7/04/2014	4172	5818	480	19060	990	4428	0	0	4369

Table A.2 *Microcystis aeruginosa* cell counts (cells/mL).

Sample date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Average
28/11/2013	0	0	0	0	0	0	0	0	0
2/12/2013	0	0	0	0	0	0	0	0	0
5/12/2013	0	0	0	0	0	0	0	0	0
9/12/2013	0	0	0	0	0	0	0	0	0
12/12/2013	0	0	0	0	0	0	0	0	0
16/12/2013	0	112	0	0	0	0	0	0	14
19/12/2013	0	0	0	0	0	0	0	0	0
23/12/2013	0	0	0	0	0	0	0	0	0
27/12/2013	0	0	0	0	0	0	0	0	0
30/12/2013	0	0	0	0	0	0	0	0	0
2/01/2014	0	0	0	0	0	0	0	0	0
6/01/2014	0	0	0	0	0	0	0	0	0
9/01/2014	0	0	0	0	0	0	0	0	0
13/01/2014	0	0	0	0	0	0	0	0	0
16/01/2014	0	0	0	0	0	0	0	0	0
20/01/2014	0	0	0	0	0	0	0	0	0
23/01/2014	0	0	0	0	0	0	0	0	0
28/01/2014	0	0	0	0	0	0	0	0	0
30/01/2014	0	0	0	0	0	0	0	0	0
3/02/2014	0	0	0	0	0	0	0	0	0
6/02/2014	0	0	0	0	0	0	0	0	0
10/02/2014	0	0	0	0	0	0	0	0	0
13/02/2014	0	0	0	0	0	0	0	0	0
17/02/2014	0	0	0	0	0	0	0	0	0
20/02/2014	0	0	0	0	0	0	0	0	0
24/02/2014	0	0	0	500	0	0	0	0	63
27/02/2014	0	0	0	0	0	0	0	0	0
3/03/2014	0	0	0	0	0	0	0	0	0
6/03/2014	0	0	0	0	0	0	0	0	0
11/03/2014	0	0	0	0	0	0	0	0	0
13/03/2014	0	0	0	0	0	0	0	0	0
17/03/2014	0	0	0	0	0	0	0	0	0
20/03/2014	0	0	0	0	0	0	0	0	0
24/03/2014	0	0	0	0	0	0	0	0	0
27/03/2014	0	0	0	0	875	0	0	0	109
3/04/2014	0	0	0	0	0	0	0	0	0
7/04/2014	0	0	0	0	0	0	0	0	0

Table A.3 *Microcystis flos-aquae* cell counts (cells/mL).

Sample date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Average
28/11/2013	0	362	50	0	0	0	0	0	52
2/12/2013	18	76	0	0	0	0	0	0	12
5/12/2013	0	0	0	0	0	0	0	0	0
9/12/2013	0	0	0	0	0	0	0	0	0
12/12/2013	0	0	422	0	0	0	0	0	53
16/12/2013	0	0	0	0	0	0	0	0	0
19/12/2013	0	0	0	0	0	0	0	0	0
23/12/2013	0	0	0	0	0	0	0	0	0
27/12/2013	375	495	10	0	0	0	0	0	110
30/12/2013	0	0	0	0	0	0	0	0	0
2/01/2014	0	0	0	150	0	0	0	0	19
6/01/2014	500	0	0	0	3000	0	177	177	460
9/01/2014	80	0	0	0	0	0	0	0	135
13/01/2014	337	0	0	0	0	0	0	0	42
16/01/2014	30800	2480	0	0	0	105	98	98	4404
20/01/2014	1000	1620	500	7250	875	0	0	0	1406
23/01/2014	10400	2750	4780	488	3250	0	0	0	2709
28/01/2014	32200	20100	12200	36700	52400	20200	0	0	21725
30/01/2014	16800	16570	21800	49500	19200	8830	1630	1630	16791
3/02/2014	49200	7770	3710	95200	3820	4160	11700	11700	22316
6/02/2014	18400	9000	6400	82300	13200	20800	0	0	18763
10/02/2014	29400	40600	33600	56400	56800	57500	0	0	34288
13/02/2014	112000	79200	51800	63400	74400	83600	0	0	58050
17/02/2014	150	0	325	365	290	338	0	0	184
20/02/2014	925	122	140	120	0	88	0	0	331
24/02/2014	1250	1040	0	1530	90	0	0	0	496
27/02/2014	28	400	0	0	0	0	505	505	120
3/03/2014	0	2900	245	270	1300	1620	0	0	805
6/03/2014	2940	3450	1410	3090	2300	8050	40300	40300	8333
11/03/2014	9630	11200	3500	560	7200	10100	298	298	7861
13/03/2014	4600	3020	725	960	1940	5440	930	930	3337
17/03/2014	3920	15500	6150	3430	1120	1530	0	0	3956
20/03/2014	15700	4430	2500	1250	7380	2360	722	722	4380
24/03/2014	6500	14500	1880	2180	792	2690	0	0	3699
27/03/2014	67200	1280	7340	12800	1880	2070	0	0	11978
3/04/2014	6250	978	3720	5670	600	860	0	0	0
7/04/2014	2920	4900	440	18000	0	4300	0	0	0

Table A.4 *Anabaena circinalis* cell counts (cells/mL).

Sample date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Average
28/11/2013	218	272	1460	715	0	0	0	0	333
2/12/2013	0	0	0	0	0	0	0	0	0
5/12/2013	0	127	532	165	1510	0	0	0	292
9/12/2013	182	190	960	0	360	1980	0	0	459
12/12/2013	325	1260	2100	268	1320	2630	0	0	988
16/12/2013	938	2580	485	1130	2110	4650	0	0	1487
19/12/2013	3770	1200	258	0	0	0	0	0	654
23/12/2013	0	0	0	0	0	0	0	0	0
27/12/2013	0	0	0	0	0	0	0	24	3
30/12/2013	0	0	0	0	0	0	0	0	0
2/01/2014	0	22	0	0	0	0	0	0	3
6/01/2014	0	0	0	0	0	0	0	0	0
9/01/2014	0	0	0	0	0	0	0	0	0
13/01/2014	97	0	0	0	0	0	0	0	12
16/01/2014	755	0	0	225	0	0	0	0	123
20/01/2014	3860	6860	1850	950	357	0	0	0	1735
23/01/2014	4330	2240	3880	2000	1760	0	0	0	1776
28/01/2014	63900	43800	22400	17200	23900	19700	435	0	23917
30/01/2014	4630	4390	7830	5620	7240	8890	770	2850	5278
3/02/2014	522	488	572	2260	410	1320	3120	1020	1214
6/02/2014	82	862	525	2370	528	2100	0	0	808
10/02/2014	442	1480	328	172	630	0	42	0	387
13/02/2014	1410	1830	380	1450	2880	852	0	0	1100
17/02/2014	0	0	0	0	0	0	0	0	0
20/02/2014	0	0	0	0	0	0	0	0	0
24/02/2014	0	0	0	0	0	0	0	0	0
27/02/2014	0	0	0	0	0	0	0	0	0
3/03/2014	0	0	0	0	0	0	0	0	0
6/03/2014	0	0	0	0	0	0	0	0	0
11/03/2014	0	102	0	0	20	0	0	0	15
13/03/2014	115	0	42	192	0	165	0	0	64
17/03/2014	322	100	298	58	0	0	0	0	97
20/03/2014	622	292	0	318	282	0	0	0	189
24/03/2014	1210	202	1040	222	360	0	0	0	379
27/03/2014	8320	1590	2170	1520	765	545	0	0	1864
3/04/2014	2240	1000	838	874	320	932	0	80	786
7/04/2014	1252	918	40	1060	990	128	0	0	549

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