River Torrens Water Quality Improvement Trial – Summer 2012–13

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Executive Summary

Ongoing cyanobacterial blooms in the Torrens Lake have prompted exploration into numerous management techniques to control the blooms. Catchment management is ongoing but it may take decades for the full benefits of this to be realised in lake water quality. An assessment of various in-lake techniques revealed that it would be challenging to control the growth of cyanobacteria but dilution of the population with flow released from upstream may slow the population expansion until rain event inflows can flush out the lake.

A second Torrens flow amenity trial was conducted in the summer of 2012–13 to determine how effective a flow release management strategy is at controlling cyanobacteria in the Torrens Lake to below the threshold necessary to avoid lake closure. It was noted that even below this concentration the cyanobacteria can accumulate at the surface and form unsightly surface scums. Because there was uncertainty of how well the inflows will mix the lake water and dilute the population it was necessary to monitor the inflows and their impact upon lake hydrodynamics and cyanobacterial abundance. The criteria for the monitoring is to confidently know that the flow dilution releases are stopping algal blooms and poor water quality episodes.

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 can be 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.

There have been some concerns that the flow releases are having a detrimental impact on water quality downstream of the Torrens Lake. Sampling for cyanobacteria and Enterococci was initiated at a number of sites downstream and at West Lakes where some of the water was discharged. Cyanobacteria and Enterococci were transported downstream from the lake as a result of the amenity flow releases however, the abundance decreased significantly during river passage resulting in a two log removal (100 times dilution).

In consultation with the Department of Health a revision of the recreational guideline was undertaken. This resulted in an increase in the recreational guideline to a biovolume of 40 mm^3/L effectively doubling the tolerable concentrations of cyanobacteria before the lake is closed based on health and exposure risk (biovolume = cell/mL multiplied by voume of cells). This effectively increases the length of time the lake can remain open. Depending on the criteria used to determine the whole lake concentration, the lake could remain open even with a dense bloom. For example if the mean cell

concentration in the main lake site (sites 1-6) is used then a mean concentration of 230,000 cells/mL of *Microcystis aeruginosa* would be permissible and the lake would have remained open all summer. A cautionary note is that at these concentrations dense surface blooms would be present which would be unsightly and may be odorous. It is recommended that the concentration of cyanobacteria at the most upstream site (site 7) be excluded from whole lake determination of mean cell concentration. Cells often accumulate at the upstream site but persist there until they are washed downstream during storm events. The persistent upstream biomass presents a very low risk to lake users and so may unnecessarily bias the value used to determine lake closure.

The amenity flows achieve environmental benefits other than dilution. They serve to maintain water in a river that would have had base flow during summer which has been largely lost by river regulation and catchment development; they provide habitat for native fish; and the water is used to provide water to the Barker Inlet wetlands during long dry summer and there is freshening of water in the entire reach from Hope Valley reservoir to the coast. Amenity flow releases appear to have had a positive effect on native fish communities in the lower Torrens. This translated to increased endemic fish abundance and diversity and a decrease in alien and translocated fish abundance. No immediate negative effects resulting from changes in water quality due to summer flow releases were apparent and, although spawning was stimulated in the alien common carp (*Cyprinus carpio*), idiosyncrasies in the Torrens morphology meant that these events were of little consequence to fish diversity downstream of the Torrens weir.

On balance the amenity flows 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 would have greater dilution effects and so slow the increase in population expansion in the lake. 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.

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1. Introduction

Ongoing cyanobacterial blooms in the Torrens Lake have prompted exploration into numerous management techniques to control the blooms. Catchment management is ongoing but it may take decades for the full benefits of this to be realised in lake water quality. The assessment of the various in-lake techniques also revealed that it would be challenging to control the growth of cyanobacteria; artificial destratification is challenging in shallow environments where phytoplankton can still access adequate light, nutrient control is challenging when there is continuous renewal from the catchment.

One strategy that has been instigated is the use of controlled releases from upstream catchment or from reuse water. This strategy relies upon the diluting flows flushing the cyanobacteria from the system and thereby limiting the accumulation of high biomass. There are several challenges with this strategy, not least of which is achieving the desired dilution given the likely density difference between the inflow and lake water.

The Goyder Institute report on amenity flows in 2011/12 considered the feasibility of dilution flows for cyanobacteria management in the Torrens Lake (Brookes et al., 2012). The authors concluded that for a growth rate of 0.4 /day, a diluting flow of at least 10% per day would be required to have noticeable impact on the cyanobacteria population. With a starting cell concentration of 100 cells/mL, a growth rate of 0.4 /day and a diluting flow of 10% the cell concentration after 20 days would be 74,420 cells/mL, which is below the critical threshold for cell numbers. However, this strategy relies upon frequent rain events to further dilute the lake populations.

A trial was conducted in the summer of 2011/12 to determine how effective a flow release management strategy is at controlling cyanobacteria in the Torrens Lake to below the threshold necessary to avoid lake closure. It was noted that even below this concentration the cyanobacteria can accumulate at the surface and form unsightly surface scums. Because there is uncertainty of how well the inflows will mix with the lake water and dilute the population it will be necessary to monitor the inflows and their impact upon lake hydrodynamics and cyanobacterial abundance. The criteria for the monitoring is to confidently know that the flow dilution releases are stopping algal blooms and poor water quality episodes.

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. The NHMRC recreational guideline for cyanobacteria is a biovolume equivalent of 10 mm^3/L (biovolume = cell/mL multiplied by volume of cell). 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 based on toxin and have new targets for primary and secondary contact

Table 1 Cyanobacteria cell concentrations that reach the recreational guideline for cyanobacteria in the Torrens Lake derived from the NHMRC biovolume guideline of 10 mm^3/L.

Cyanobacteria	Cell count (cells/mL)	Biovolume equivalent (mm^3/L)
Anabaena circinalis	40,000	10
Microcystis aeruginosa	115,000	10.005
Microcystis flos-aquae	455,000	10.01
Planktothrix mougeotti	156,500	10.016

The scientific basis underlying this report is documented in the 2011/12 Amenity flow trial report (Brookes et al., 2012). This report is more operational detailing the practicalities, benefits and challenges of the trial.

2. Methods

Site description and sampling sites

The main site of interest was the Torrens Lake, which spans the reach of river from Hackney Rd to the City Weir. The Lake forms the northern boundary of the city of Adelaide and has high recreation and cultural significance for the city. The sampling sites used in this monitoring program (Figure 1) were the same 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.

Site No	Site ID	Type	Description
n/a	W5040022	Water quality	Downstream of Torrens Lake Weir
n/a	W5040036	Flow	Pumping station diversion to Bolivar sewer
1	W5040037	Water quality	Torrens River @ Torrens Lake Weir
2	W5040038	Water quality	Torrens River @ Morphett St Bridge
3	W5040039	Water quality	Torrens River adjacent Festival Theatre
4	W5040040	Water quality	Torrens River @ King William Rd Bridge
5	W5040041	Water quality	Torrens River @ University Footbridge
6	W5040042	Water quality	Torrens River @ Frome Rd Bridge
7	W5040043	Water quality	Torrens River @ Hackney Rd Bridge

Figure 1 Location of monitoring sites 1-7 on the Torrens Lake, Adelaide.

Hydrodynamics

The premise of controlled upstream water releases to control cyanobacteria in the Torrens Lake is that there is sufficient dilution and loss of cells downstream to overcome growth and biomass expansion in the lake. Two thermistor chains (RBR TR-1050 thermistors) were installed in the lake with an additional thermistor installed in the river upstream of the lake. Unfortunately all thermistors were lost and no data was available. The meteorological station and thermistor chain owned and operated by the Adelaide City Council was also not operational during the study period and data was unavailable.

Phytoplankton and nutrients

Phytoplankton was sampled twice a week at sites 1-7 (Table 2). Sampling was undertaken with a 2m hose pipe integrating over the water column. Cell counts were performed by the Australian Water Quality Centre, a NATA accredited laboratory.

Samples for nutrient analysis were collected weekly at sites 1, 2, 4, and 6 and were stored on ice prior to analysis for Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), Filterable Reactive Phosphorus (FRP), Ammonium (NH4) and oxidised nitrogen (nitrate and nitrite, NO3 and NO2, collectively termed NOx). All chemical analysis was undertaken by the Australian Water Quality Centre.

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

Site #	Site Description	Temperature	Cell counts	Nutrients
1	Torrens Lake Weir		Twice Weekly	Weekly
2	Morphett Street Bridge	Thermistor chain	Twice Weekly	
3	Elder Park	Thermistor chain	Twice Weekly	
4	King William Rd Bridge		Twice Weekly	
5	University Footbridge		Twice Weekly	
6	Frome Rd Bridge	Thermistor chain	Twice Weekly	
7	Hackney Rd Bridge		Twice Weekly	

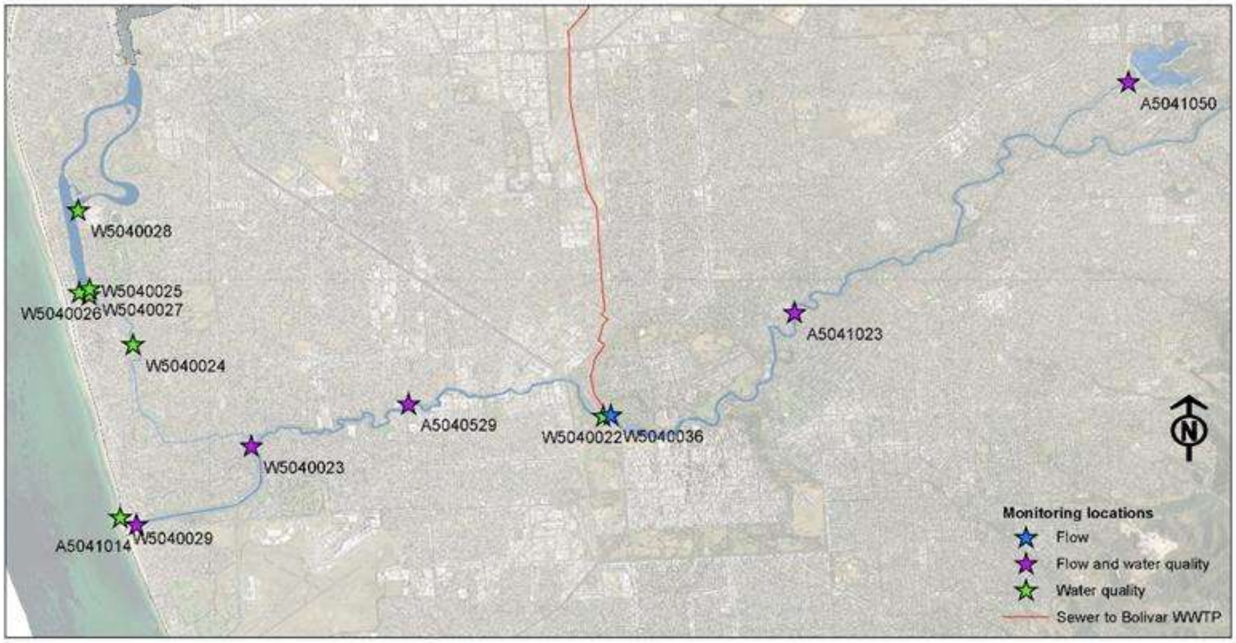
Rapid detection of cyanobacteria

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 Hope Valley Reservoir. 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 Western end of the Torrens Lake. The sensor recorded phycocyanin fluorescence every 10 minutes. It is reported here as cells/mL based on factory calibration.

Upstream and Downstream water quality considerations

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 what nutrients were coming from upstream, what cyanobacteria may have been exiting the lakes and whether dinoflagellates were responding to water and nutrients diverted into West Lakes. Sites of monitoring are shown in Figure 3. The faecal indicators, Enterococci were also measured to determine if there was any health risk associated with water being transferred from Hope Valley reservoir to lake and further downstream.



Site ID	Type	Description
A5040529	Flow and water quality	Torrens River @ Holbrooks Road
A5041014	Flow and water quality	Torrens River Outlet @ Seaview Road
A5041023	Flow and water quality	Torrens River downstream Second Creek
A5041050	Flow and water quality	Hope Valley scour d/s Hope Valley Reservoir
W5040022	Water quality	Downstream of Torrens Lake Weir
W5040023	Flow and water quality	Torrens River @ Riverway Fulham
W5040024	Water quality	Grange Lakes @ Captain Sturt's cottage
W5040025	Water quality	Trimmer Parade discharge into West Lakes
W5040026	Water quality	West Lakes near Lake inlet (DPT1 Site1)
W5040027	Water quality	West Lakes 100 metres north of discharge point
W5040028	Water quality	West Lakes @ Lakes Resort (DPT1 Site2)
W5040029	Water quality	Torrens River Outlet on the beach

Figure 2 Sampling sites upstream and downstream of the Torrens Lake

Reporting and communication

Cyanobacterial cell counts were reported within two days of sampling. The results were collated along with river flow data and packaged into a report titled the River Torrens Water Quality Improvement Trial Weekly update (see Appendix A for an example). The data was also used to inform decisions on the appropriate flow to be released from Hope Valley reservoir.

Flow and Pumping logistics

The engineering and logistics of this project formed a critical part of the trial. Flow was released from Hope Valley Reservoir in response to detection of cyanobacteria above 1000 cells/mL at several sites in the lake. When cyanobacterial count results were received the project team, Alan Ockenden (AMLRNRM Board), Kym Bowden (SA Water) and Justin Brookes (Adelaide University) conferred and decided on an appropriate flow rate. The maximum permissible flow was 40 ML/day. When cell counts exceeded the recreational guideline forcing lake closure the controlled amenity flow was terminated to conserve water. It was deemed that at these high cell concentrations a continued flow through the lake, achieving a 10% dilution, would have minimal impact daily and would not prevent continued lake closure.

The downstream capture of lake water that spilled because of the controlled flow release was achieved with a pump immediately adjacent to the railway bridge west of the city weir. Water pumped from this reach was either pumped to Bolivar for reuse or delivered via a series of culverts and drains to the Barker Inlet wetlands to the north of Adelaide (see Appendix C). This water was used to maintain wetlands that normally rely upon storm water which is low during summer. The total diesel consumption of the pump was 19,232L over the entire trial period.

Over the course of the trial the volume of water released from Hope Valley Reservoir was 1499.8 ML. This water was either pumped to Bolivar, pumped to West Lakes via the Riverway pump station, used to supplement flows to Barker Inlet wetlands or ‘lost’ by either transmission losses and filling of pools along the river reach from Hope Valley Reservoir to sea, discharged to sea or lost via evaporation (

Table 3). Natural catchment flow in response to rain events was not scored in this assessment and when sufficiently large would have discharged to sea.

Table 3 Volumes of water released from Hope Valley Reservoir and the fate of that water

Inputs	Hope Valley Reservoir flow releases	1499.8 ML
Outputs	Bolivar	562 ML
	West Lakes	257 ML
	Barker Inlet	82.5 ML
	Losses over the entire system	597.9 ML

3. Results

Flow and Hydrodynamics

Flow in the River Torrens was recorded at two sites, upstream and downstream of the Torrens Weir (Figure 3). The upstream site was situated immediately downstream of the confluence of Second Creek and the Torrens River. The site downstream of the Torrens Lake was at Holbrooks Rd. Only three flow events exceeded 60 ML/day at Holbrooks Rd (Figure 3). The highest recorded daily flow was 147 ML, in response to an 8.2mm rainfall event. The lake volume is 400 ML which implies that the maximum lake daily dilution was approximately 37%. On only six occasions did dilution exceed 10% per day.

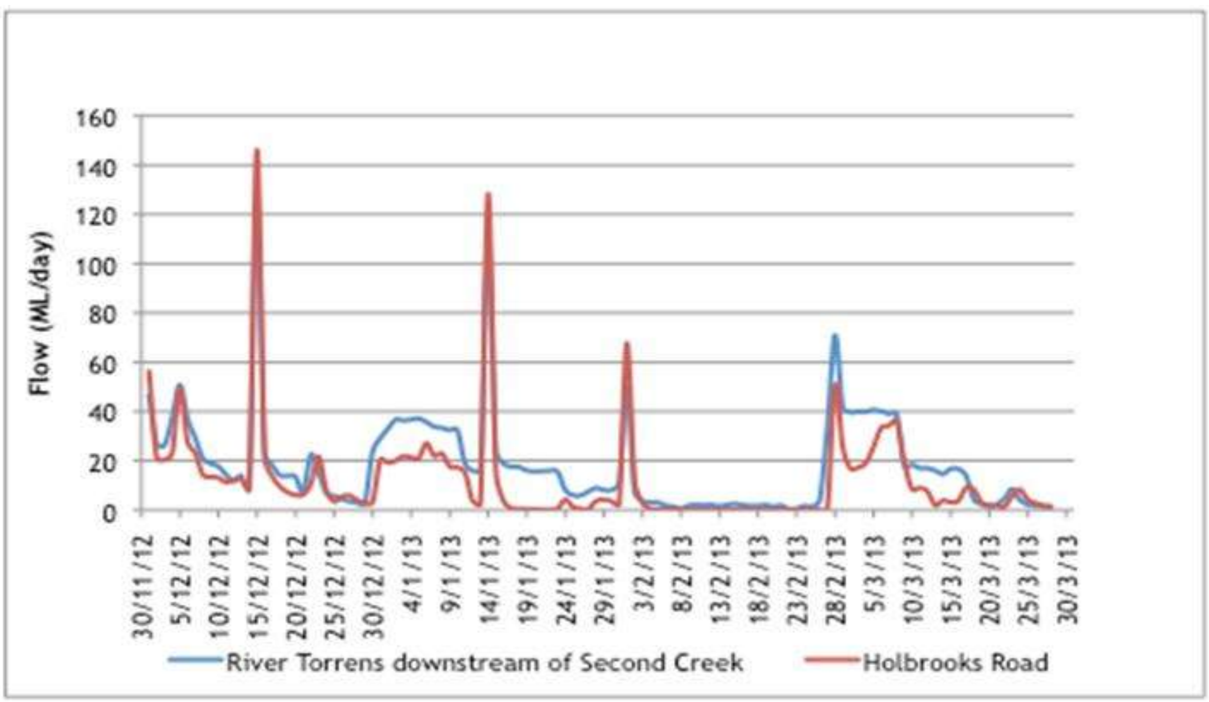


Figure 3 River Torrens Flow measured upstream of the Torrens Lake (D/S Second Creek) and downstream of the Lake (Holbrooks Rd).

Phytoplankton

Phytoplankton cell counts were determined twice weekly with a particular focus on the cyanobacteria. Cyanobacteria were summed into a total cyanobacteria count and reported as total cyanobacteria. The period of highest cyanobacterial abundance was between late December and early March (Figure 4). There was considerable heterogeneity in cyanobacterial cell numbers between sites and peak abundance generally occurred upstream of Morphett Street Bridge (Figure 4;

Table 4). There are three particularly interesting features of the cyanobacterial dynamics; where they originate, the fast rate at which the bloom develops and the succession between *Microcystis aeruginosa* and *Anabaena circinalis*.

The first detections of cyanobacteria were *Anabaena circinalis* on 13 Dec 2012 (

Table 4; Table 7). Cell numbers remained low but dominance switched to *Microcystis flos-aquae* and then *Microcystis aeruginosa* on 31 Dec 2102 (Table 6 ;

Table 5). *Microcystis aeruginosa* remained dominant through the main body of the lake (sites 1-6) until late January when *Anabaena circinalis* again grew to dominance (Table 7).

Microcystis aeruginosa was the most problematic species over the 2012/13 summer. Only 20 cells/mL were detected on 24 Dec 2012 but by the next sampling the populations had increased to a maximum of 124,000 cells/mL at site 4 (

Table 5). Based on the average cell counts across the entire lake the population had a growth rate over this period of 1.33 doublings per day. This logarithmic rate of growth is extremely high and the population increase is probably not just due to growth of the pelagic vegetative cells present on 24 Dec but probably also includes recruitment of dormant cells from the sediment which also grew. However, this meant that within 10 days of detection the population was at a concentration approaching the threshold that triggers lake close (115,000 cells/mL;

Table 4). After the initial very high growth rate the population continued to grow at a rate between 0.1 and 0.39 per day. By January 7 *Microcystis aeruginosa* was well established throughout the entire lake. A rainfall event on 14 January pushed most upstream populations downstream effectively flushing sites 5 and 6 and diluting the lake average cell concentration (

Table 5). From 29 Jan the population began to collapse in the main body of the lake but concentrations remained extremely high at site 7 until the end of February.

The collapse of *Microcystis aeruginosa* population in February in the main body of the lake (sites 1-6) coincided with an increase in *Anabaena circinalis* (Table 7). On only one occasion (7 February) did the average concentration exceed the recreational guideline concentration (40,000 cells/mL; Table 1), and most of this biomass was at site 7, the most upstream site. Microcystis flos-aquae also increased during February, occasionally reaching high concentrations, although on average the concentrations remained below the recreational guideline for this species (Table 6). *Planktothrix* were only detected at one location on one day and presented no risk.

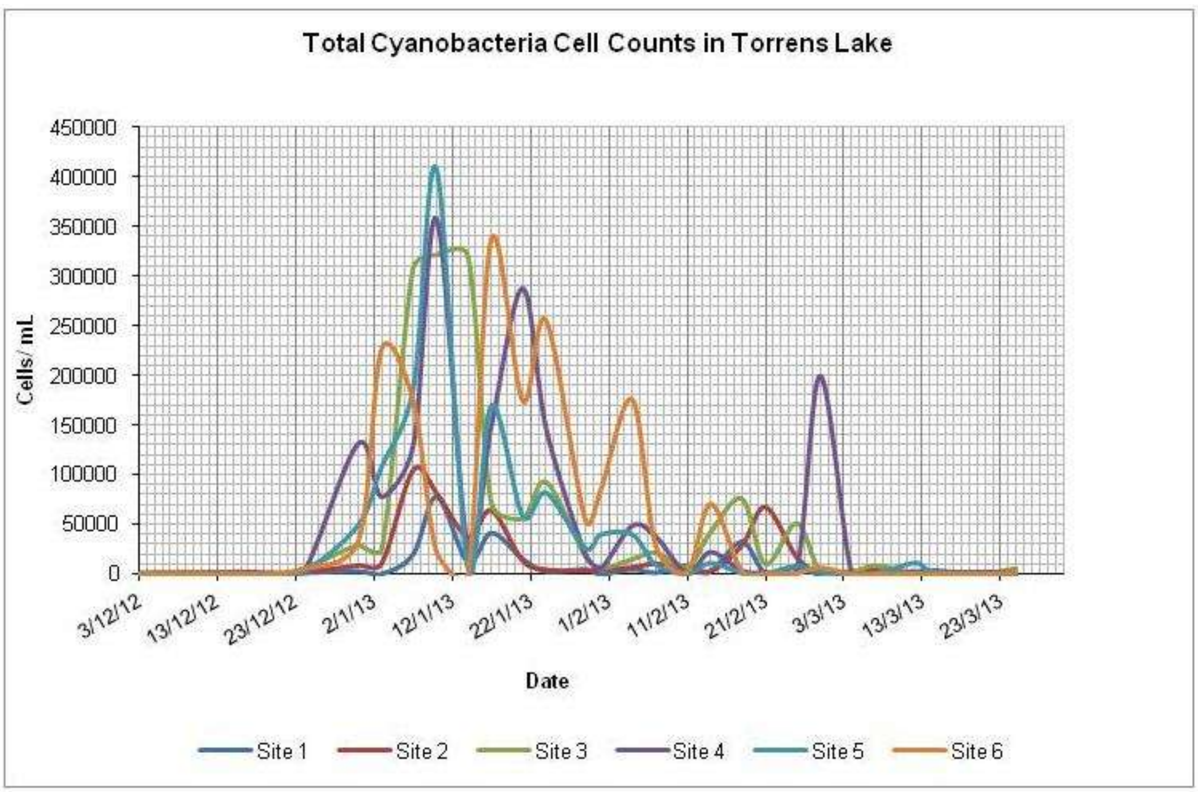


Figure 4 Total cyanobacteria at seven sites in the Torrens Lake, expressed as cells/mL.

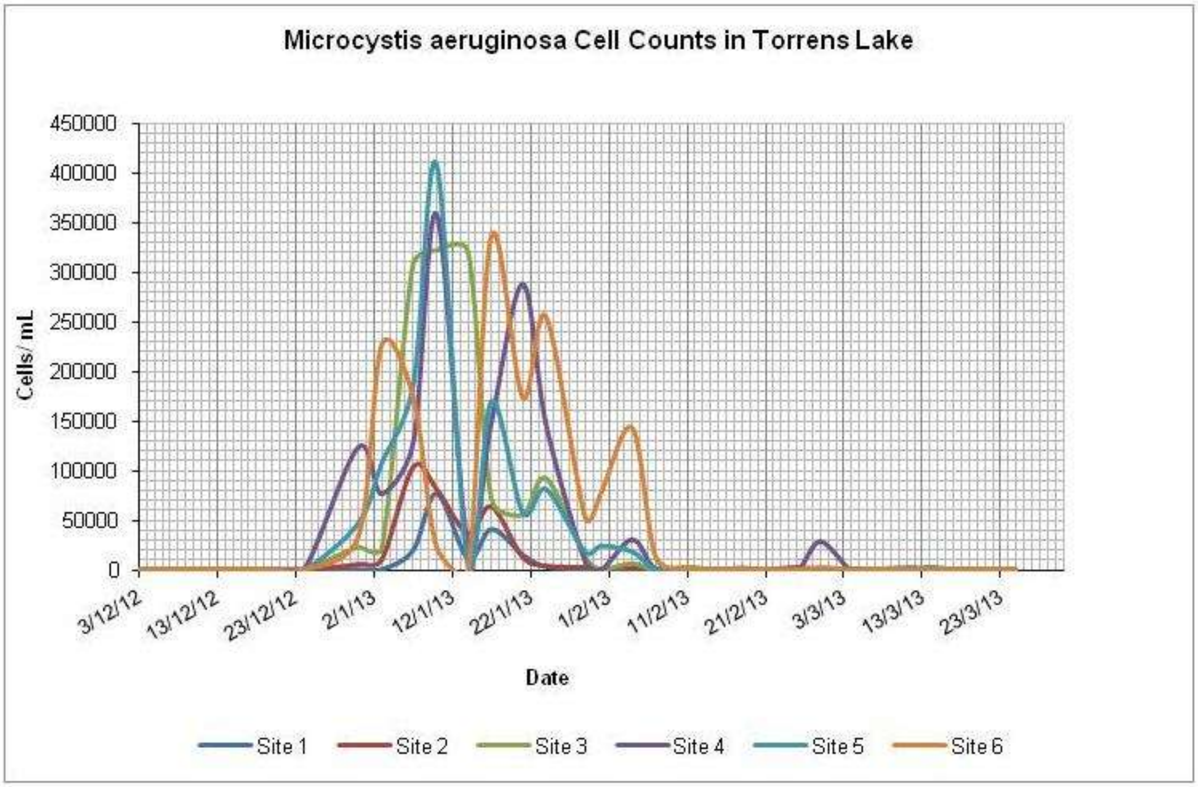


Figure 5 ***Microcystis aeruginosa*** **Cell Counts in the Torrens Lake.**

Table 4 Total Cyanobacteria cell counts (cells/mL).

Sample Date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Average
3/12/2012	ND	ND	ND	ND	ND	ND	ND	ND
6/12/2012	ND	660	800	ND	ND	ND	ND	209
10/12/2012	ND	930	590	ND	ND	ND	NS	253
13/12/2012	180	1420	1210	490	ND	ND	NS	550
17/12/2012	341	1539	12	ND	ND	ND	ND	270
20/12/2012	252	220	280	390	ND	248	NS	232
24/12/2012	1510	1438	5130	1070	1742	5640	NS	2755
31/12/2012	2985	8180	28790	131105	49232	33625	ND	36274
3/01/2013	450	10500	25010	77075	108415	227000	NS	74742
7/01/2013	19900	104805	308510	128470	186000	174500	NS	153698
10/01/2013	77300	81700	322000	358000	408000	22300	NS	211550
14/01/2013	12450	37190	321000	26400	5600	ND	ND	57520
17/01/2013	41200	64000	71200	149000	170000	337000	NS	138733
21/01/2013	15300	12800	55500	288000	58300	174000	NS	100650
24/01/2013	2900	4050	92300	146000	81700	255000	ND	83136
29/01/2013	5115	2590	17090	19215	25810	54600	1470000	20737
31/01/2013	120	4152	5742	5325	39660	85900	76	20139
4/02/2013	4987	6260	14430	47840	39700	175800	5570000	48170
7/02/2013	1578	9980	21076	37020	8890	27920	136284000	17744
11/02/2013	9160	5340	6583	364	16	1776	4050600	3873
14/02/2013	3426	1794	41920	21368	10900	70600	162220	25001
18/02/2013	32320	28440	75500	2480	750	3036	606704	23754
21/02/2013	1480	67390	9665	880	230	882	1696690	13421
25/02/2013	6980	16740	50900	4210	8000	690	2200190	14587
28/02/2013	ND	1000	3050	199200	2100	6720	46300	35345
4/03/2013	3160	1310	1260	590	0	0	630	1053
7/03/2013	1075	3075	8315	0	30	0	0	1785
12/03/2013	2930	0	0	1130	10935	560	0	2222
14/03/2013	16	0	55	2935	3500	0	0	929
18/03/2013	2335	350	1595	730	0	0	250	835
21/03/2013	1030	1420	190	980	0	0	0	517
25/03/2013	235	255	5268	1010	890	1680	0	1334

Table 5 *Microcystis aeruginosa* cell counts (cells/mL).

Sample Date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Average
3/12/2012	ND	ND	ND	ND	ND	ND	ND	ND
6/12/2012	ND	ND	ND	ND	ND	ND	ND	ND
10/12/2012	ND	ND	430	ND	ND	ND	NS	72
13/12/2012	ND	ND	ND	ND	ND	ND	NS	ND
17/12/2012	ND	ND	ND	ND	ND	ND	ND	ND
20/12/2012	ND	220	280	390	ND	ND	NS	148
24/12/2012	20	ND	ND	ND	ND	ND	NS	3
31/12/2012	360	5600	23200	124000	47600	33400	ND	33451
3/01/2013	450	10500	22,200	77000	108,000	227000	NS	108550
7/01/2013	19,900	104000	308,000	128000	186,000	174500	NS	153400
10/01/2013	77300	81700	322000	358000	408000	22300	NS	211550
14/01/2013	11800	37000	321000	26400	5600	ND	ND	57400
17/01/2013	41200	64000	71200	149000	170000	337000	NS	138733
21/01/2013	15300	12800	55500	288000	58300	174000	NS	100650
24/01/2013	2900	4050	92300	146000	81700	255000	ND	83136
29/01/2013	875	2350	12600	8600	18200	52000	1470000	15771
31/01/2013	ND	460	792	540	24800	77200	76	14838
4/02/2013	356	1780	6680	31300	18800	143000	5570000	33653
7/02/2013	40	1400	116	920	780	12300	136000000	2593
11/02/2013	290	ND	3150	ND	ND	960	4000000	733
14/02/2013	ND	ND	720	288	ND	ND	84600	168
18/02/2013	1620	1240	250	ND	110	146	560000	561
21/02/2013	ND	ND	ND	ND	ND	ND	1680000	ND
25/02/2013	ND	2540	ND	ND	ND	ND	808000	423
28/02/2013	ND	150	ND	29200	140	1880	32000	5228
4/03/2013	1050	670	170	0	0	0	630	315
7/03/2013	770	275	1240	0	0	0	0	326
12/03/2013	2180	0	0	100	935	0	0	459
14/03/2013	0	0	55	0	3500	0	0	508
18/03/2013	410	350	0	230	0	0	0	141
21/03/2013	0	0	70	0	0	0	0	10
25/03/2013	0	75	0	0	750	0	0	118

Table 6 *Microcystis flos-aquae* cell counts (cells/mL).

Sample Date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Average
3/12/2012	ND	ND	ND	ND	ND	ND	ND	ND
6/12/2012	ND	660	700	ND	ND	ND	ND	194
10/12/2012	ND	930	160	ND	ND	ND	NS	182
13/12/2012	180	740	1210	380	ND	ND	NS	418
17/12/2012	ND	279	ND	ND	ND	ND	ND	40
20/12/2012	72	ND	ND	ND	ND	248	NS	53
24/12/2012	340	804	3520	280	212	2420	NS	1263
31/12/2012	2610	790	2880	6250	965	ND	ND	2699
3/01/2013	ND	ND	1,550	ND	325	ND	NS	469
7/01/2013	ND	ND	510	ND	ND	ND	NS	85
10/01/2013	ND	ND	ND	ND	ND	ND	NS	ND
14/01/2013	650	ND	ND	ND	ND	ND	ND	93
17/01/2013	ND	ND	ND	ND	ND	ND	NS	ND
21/01/2013	ND	ND	ND	ND	ND	ND	NS	ND
24/01/2013	ND	ND	ND	ND	ND	ND	ND	ND
29/01/2013	1000	ND	ND	115	680	ND	ND	256
31/01/2013	30	3600	3020	985	2860	2160	ND	1808
4/02/2013	91	500	1110	3140	2000	17000	ND	3406
7/02/2013	560	1300	1060	1300	120	9600	ND	1991
11/02/2013	4700	1420	815	54	ND	266	48500	1209
14/02/2013	3230	774	17300	5780	3020	32500	74200	10434
18/02/2013	15400	9000	1250	470	305	1320	45000	4624
21/02/2013	400	64500	8770	576	230	318	16000	12466
25/02/2013	6980	3500	22500	4210	8000	ND	1390000	7532
28/02/2013	ND	850	2340	142000	690	1520	14300	24567
4/03/2013	240	250	1000	590	0	0	0	297
7/03/2013	305	2800	7000	0	30	0	0	1448
12/03/2013	750	0	0	1030	10000	560	0	1763
14/03/2013	0	0	0	2000	0	0	0	286
18/03/2013	1600	0	700	500	0	0	250	467
21/03/2013	0	0	0	0	0	0	0	0
25/03/2013	0	0	4500	0	0	0	0	643

Table 7 *Anabaena circinalis* cell counts (cells/mL).

Sample Date	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Average
3/12/2012	ND	ND	ND	ND	ND	ND	ND	ND
6/12/2012	ND	ND	100	ND	ND	ND	ND	14
10/12/2012	ND	ND	ND	ND	ND	ND	NS	ND
13/12/2012	ND	680	ND	110	ND	ND	NS	132
17/12/2012	341	1260	12	ND	ND	ND	ND	230
20/12/2012	180	ND	ND	ND	ND	ND	NS	30
24/12/2012	1150	634	1610	790	1530	3220	NS	1489
31/12/2012	15	1790	2710	855	667	225	ND	895
3/01/2013	ND	ND	1260	75	90	ND	NS	238
7/01/2013	ND	805	ND	470	ND	ND	NS	213
10/01/2013	ND	ND	ND	ND	ND	ND	NS	ND
14/01/2013	ND	190	ND	ND	ND	ND	ND	27
17/01/2013	ND	ND	ND	ND	ND	ND	NS	ND
21/01/2013	ND	ND	ND	ND	ND	ND	NS	ND
24/01/2013	ND	ND	ND	ND	ND	ND	ND	ND
29/01/2013	3240	240	4490	10500	6930	2600	ND	4000
31/01/2013	90	92	1930	3800	12000	6540	ND	3493
4/02/2013	4540	3980	6640	13400	18900	15800	ND	9037
7/02/2013	978	7280	19900	34800	7990	6020	284000	51567
11/02/2013	4170	3920	2618	310	16	550	2100	1931
14/02/2013	196	1020	23900	15300	7880	38100	3420	14399
18/02/2013	15300	18200	74000	2010	335	1570	102	18569
21/02/2013	1080	2890	895	304	ND	564	690	956
25/02/2013	ND	10700	28400	ND	ND	690	2190	6632
28/02/2013	ND	ND	710	28000	1270	3320	ND	4757
4/03/2013	1870	390	90	0	0	0	0	336
7/03/2013	0	0	75	0	0	0	0	11
12/03/2013	0	0	0	0	0	0	0	0
14/03/2013	16	0	0	935	0	0	0	136
18/03/2013	325	0	895	0	0	0	0	174
21/03/2013	1030	1420	120	980	0	0	0	507
25/03/2013	235	180	768	1010	140	1680	0	573

Rapid detection of cyanobacteria

Early detection of cyanobacteria is key to the 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. For example explosive cyanobacterial growth between Christmas and new Year went undetected. To try and overcome this problem a probe was trialled which offered the possibility of rapid online detection. The Phycocyanin of 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.

The phycocyanin probe was deployed near the weir and captured the upward trend of the cyanobacterial community in early January and the second prolonged biomass period in February (Figure 6). To tease apart whether there was consistent daily variation in the probe signal the cyanobacterial concentration (determined with the BGA probe) at 6am, 12pm and 6pm was plotted and compared over the course of 4.5 months (Figure 7). There was a consistent pattern in the phycocyanin signal with fluorescence increasing over the course of the day. There are two possible explanations for this 1) the cyanobacteria are vertically migrating and increasing concentration at the depth of the probe or 2) the phycocyanin fluorescence is light sensitive. The consistency of the variation suggests that the later is probably true. The inverse response would be expected if buoyancy regulation and vertical migration were responsible for the trend. Typically cyanobacteria cells are most buoyant in the morning as their carbohydrate stores are low following a night of respiration. As cells/colonies are exposed to light they accumulate carbohydrate, which has a density of 1600 kgm^{-3} and so can overcome the buoyancy provided by the gas vesicles and cells tend to sink lower in the water column. Consequently when buoyancy regulation not mixing is the dominate process determining the vertical position in the water column cells accumulate near the surface in the morning and move deeper in the water column during the day to return to the surface again at night.

Although there was daily variation in the phycocyanin reading (BGA probe) there were correlations with cyanobacterial abundance determined by manual cell counts. Pairwise Pearson's correlations between BGA probe counts at 6 am and 2pm and the manual cell counts showed significant relationships between the two techniques (6am $r = 0.50$, $p = 0.013$; 2pm $r = 0.66$, $p < 0.001$; Figure 8). However, because of the apparent light sensitivity of the phycocyanin fluorescence we cannot be confident in the ability of the BGA probe to accurately predict cyanobacterial abundance. The real value of the probe would be early detection and identifying cyanobacterial presence at very low cell concentrations. More laboratory trials would be required to determine the sensitivity of the probe particularly at low cyanobacterial concentrations.

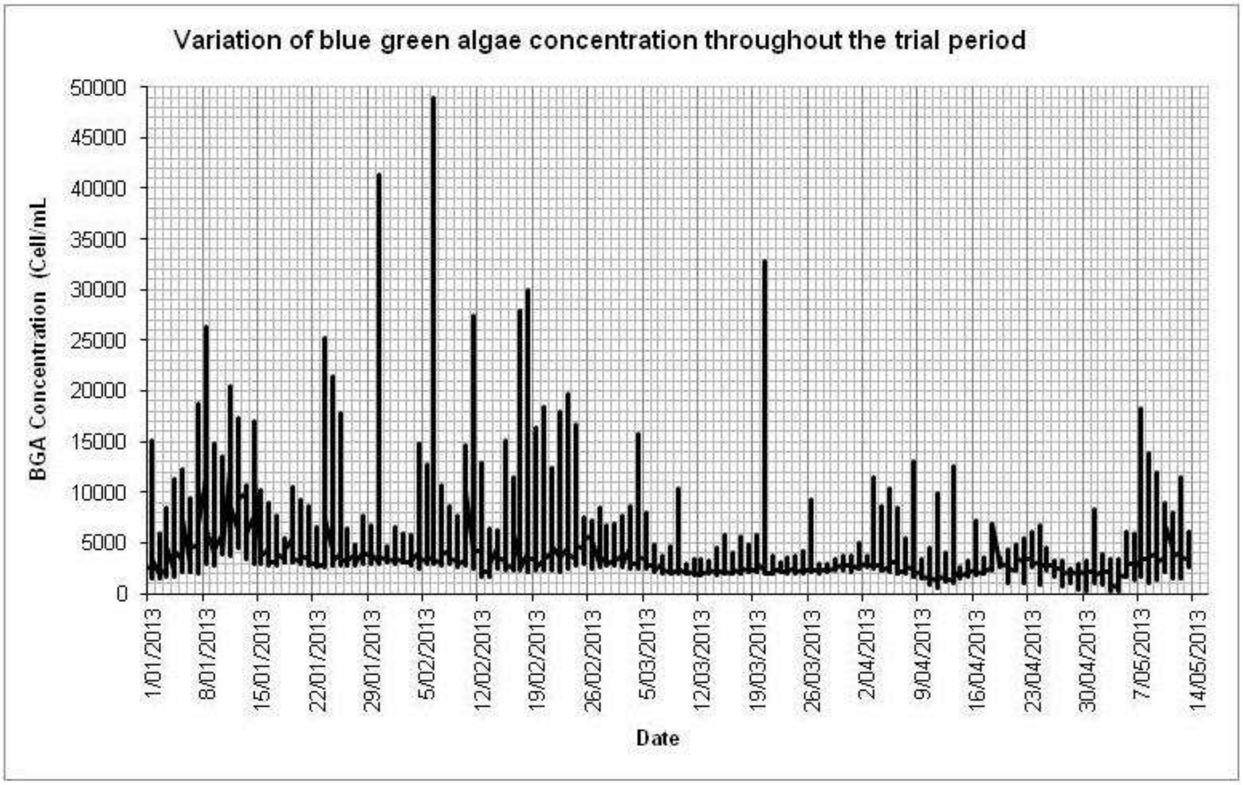


Figure 6 Mean daily cyanobacterial biomass measured with the 'Blue-green-algae" phycocyanin probe.

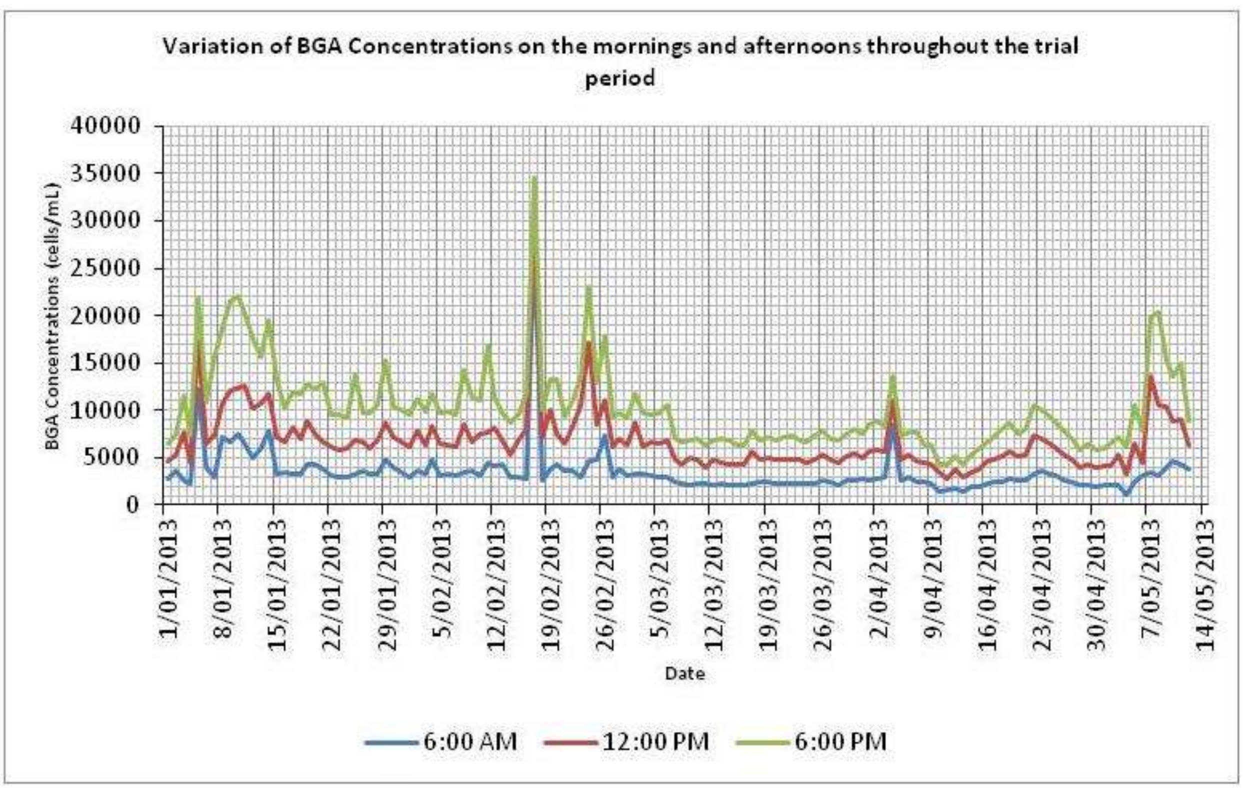


Figure 7 Phycocyanin measured with the "Blue-Green-algae" probe measured at 6am, midday or 6pm.

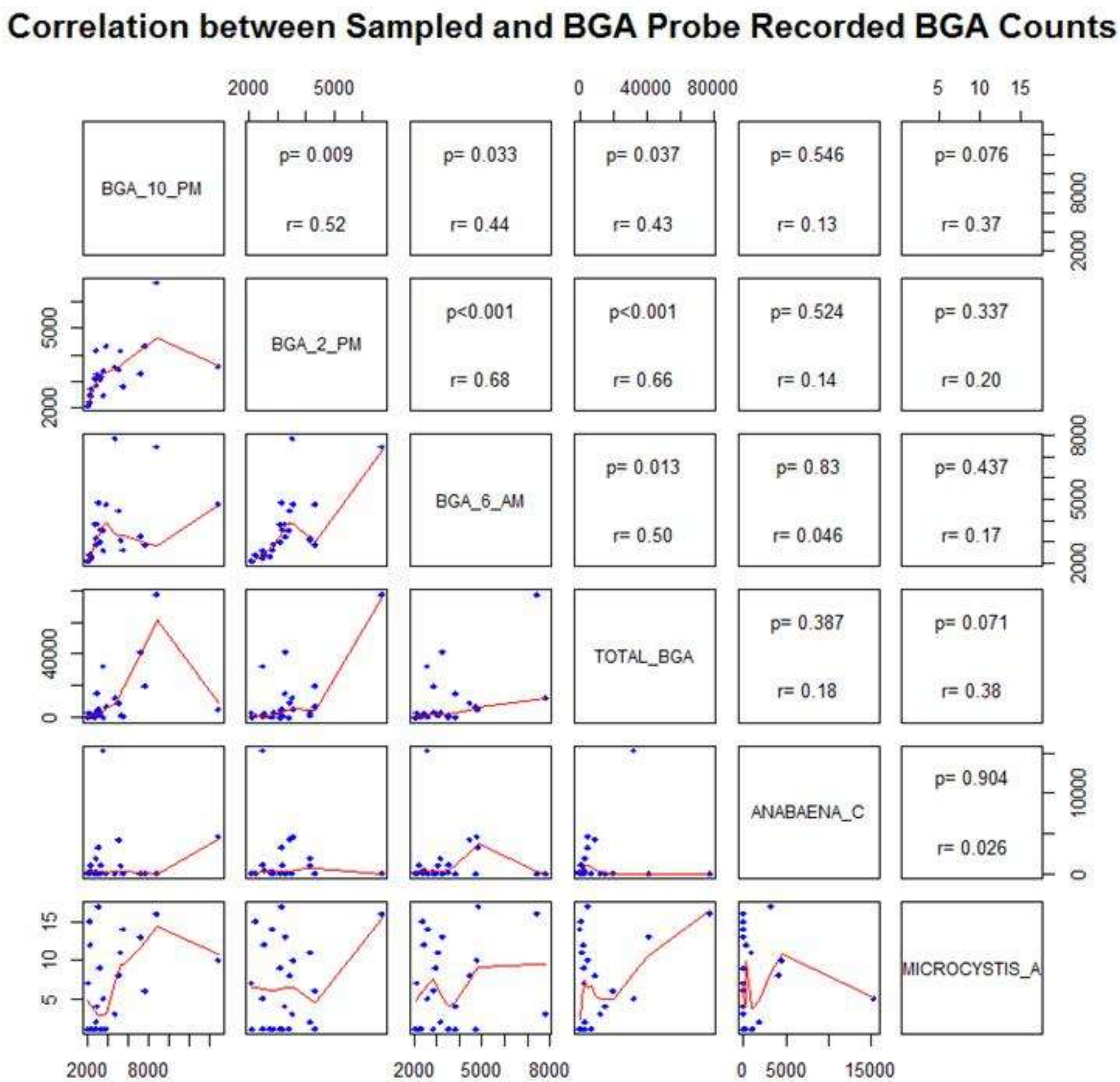


Figure 8 Matrix plot showing pairwise Pearson's correlation between sampled blue-green algae counts and timed BGA-probe recordings in River Torrens during the summer of 2013. The lower panel shows the scatterplots between the diagonally listed variable pairs while the upper panel shows the correlation coefficients (and p-values) between the corresponding variable pairs.

Downstream Water Quality

When attempting to minimise the cyanobacterial problem within the lake it is necessary that additional problems are not caused downstream. Water sent to Bolivar is not problematic but water that travels further downstream and is discharged to West Lakes or the sea needs to be of suitable water quality.

Enterococci are a useful indicator of faecal contamination as they tend to survive longer than *E.coli* and are shed from organisms at much lower concentrations than *E.coli*. There is no guideline for Enterococci in The Australian Drinking Water Guidelines (NHMRC, 2011) because any detection of Enterococci in treated drinking water is cause for alarm. In natural water we can draw inference from Enterococci counts to determine relative risk. Samples for Enterococci were taken at Riverway in Fulham and at West Lakes. Enterococci counts at Riverway ranged between 100 and 9,000 cells/100 mL, however, there was considerable attenuation of Enterococci as water travelled downstream considerably reducing the risk at West Lakes. A two log removal is observed as water travels from the River along the stormwater drain to West Lakes (Figure 9; Figure 11). Water Quality generally improved during transmission for water pumped from immediately below the weir and sent northwards to Barker Inlet (see Appendix C).

Cyanobacteria numbers are high immediately below the city weir but attenuated significantly as water travelled downstream, significantly reducing the risk to downstream recreational users (Figure 10).

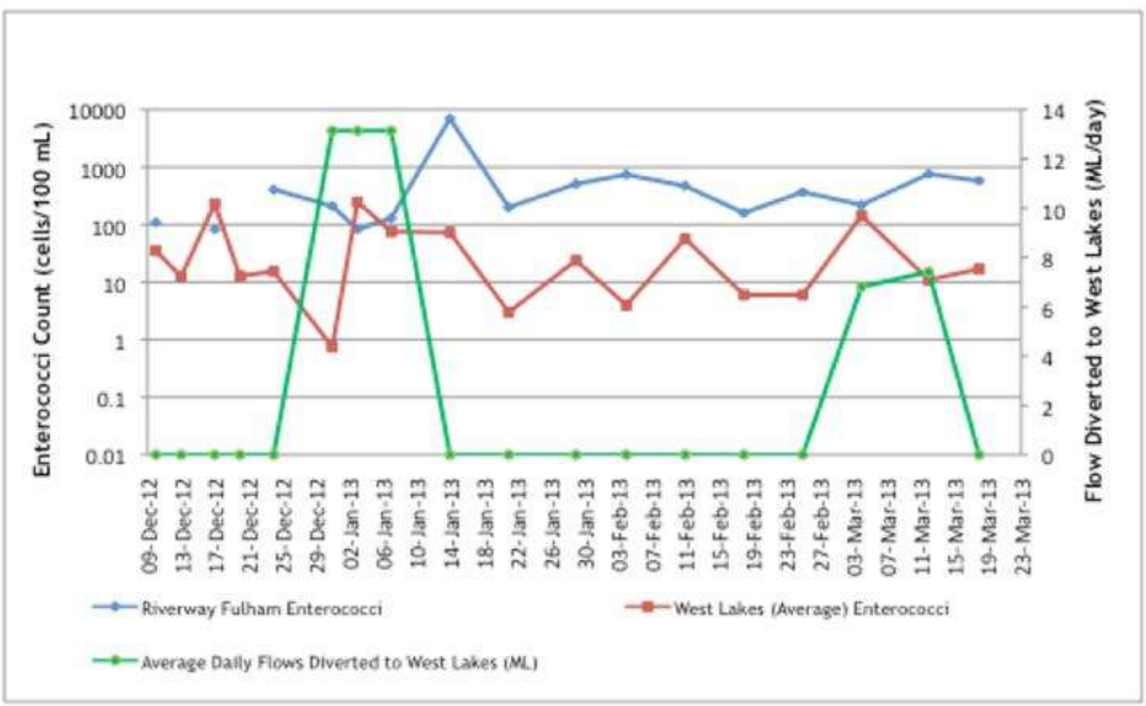


Figure 9 Enterococci counts at Riverway, Fulham and West Lakes

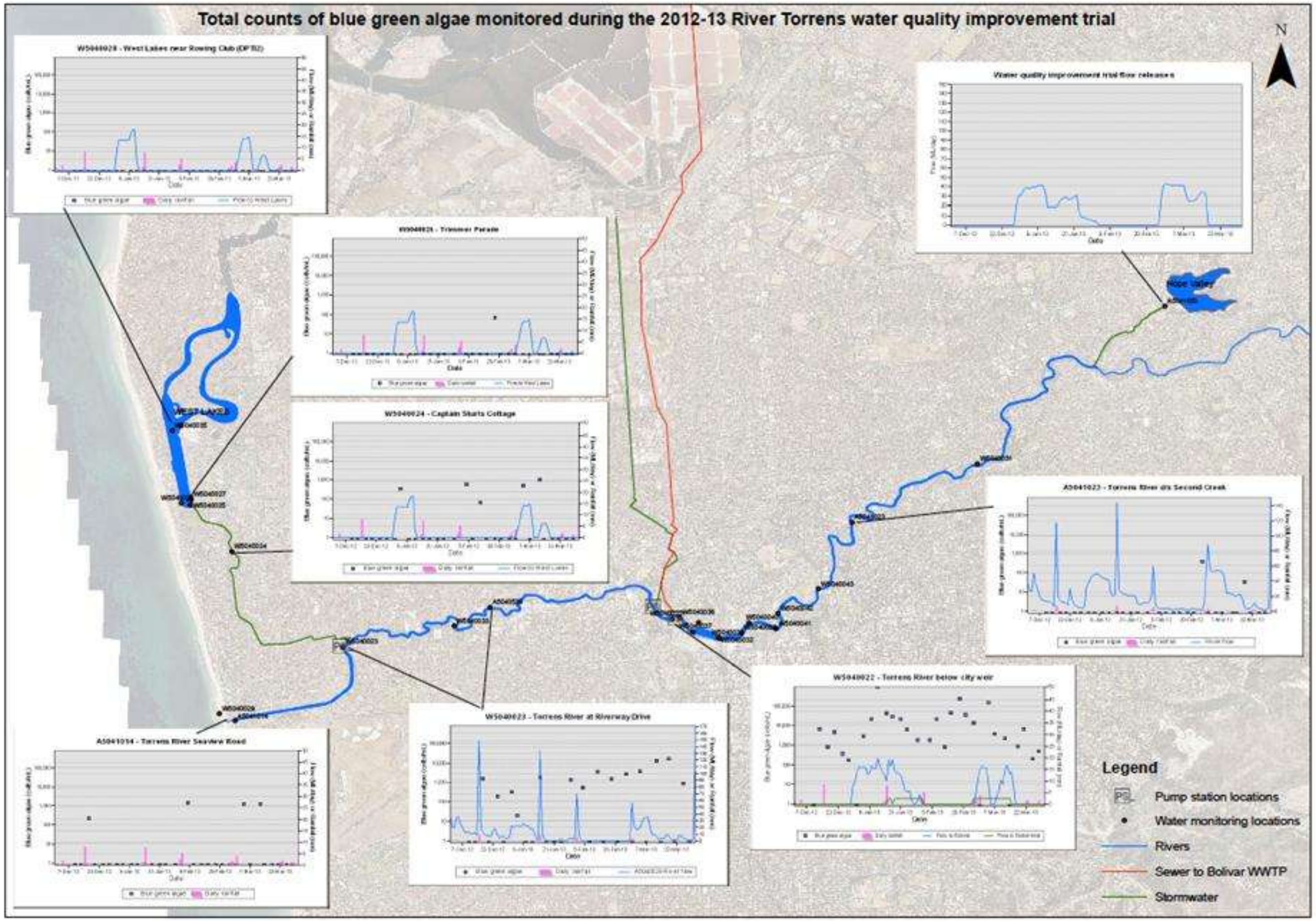


Figure 10 Cyanobacterial concentrations and flow record upstream and downstream of the Torrens Lake

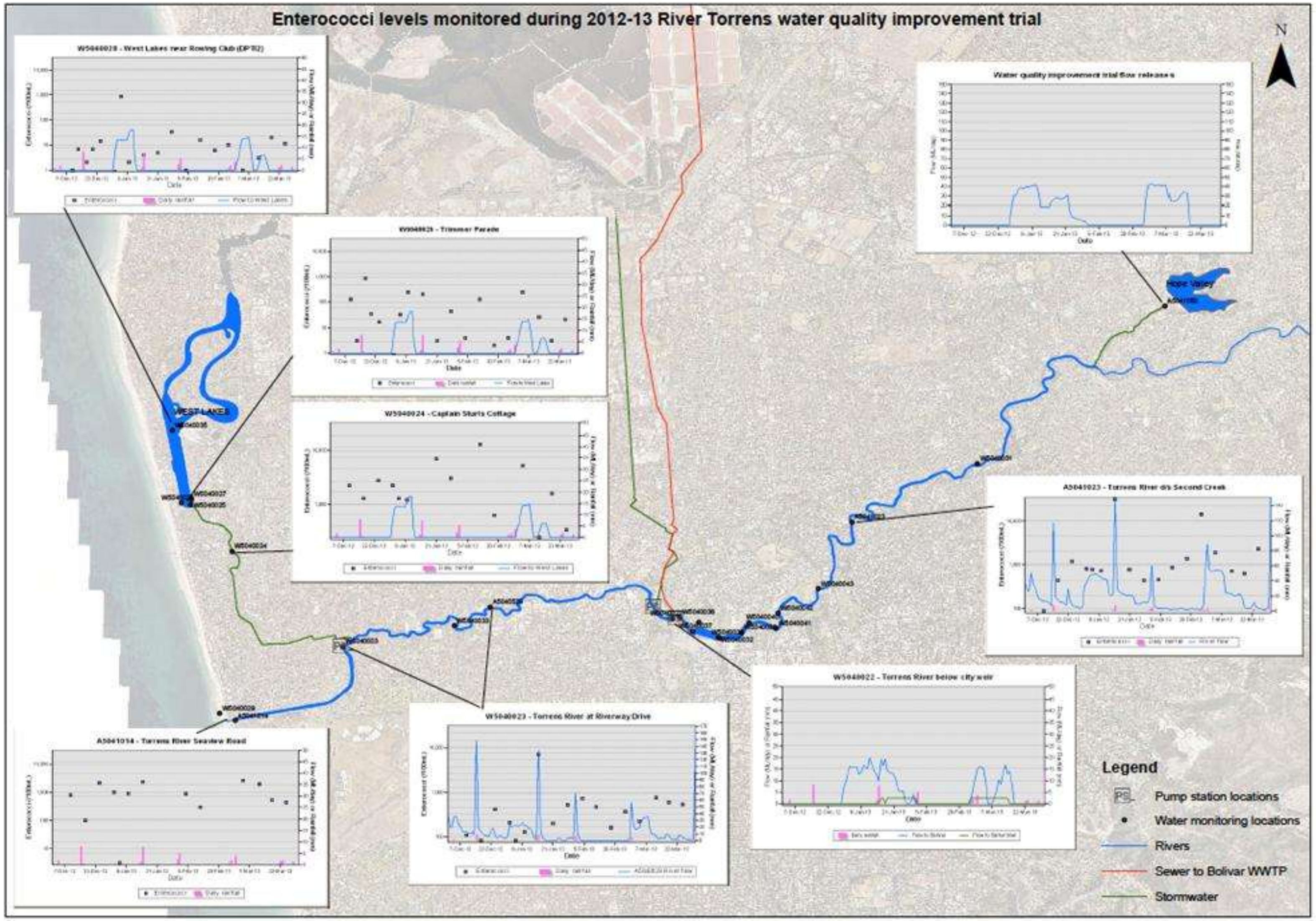


Figure 11 Enterococci concentrations and flow record upstream and downstream of the Torrens Lake

4. Discussion

Critical evaluation of the trial

There are a number of criteria by which this trial can be evaluated; maximum cyanobacterial abundance in the lake, coordination of management of flow releases, and water quality upstream and downstream.

The flow releases were unsuccessful at maintaining lake biomass below the recreational thresholds and so it can be concluded that dilution of the in-lake population with controlled flow at 40ML/day is insufficient to control populations below the threshold level of 10 mm^3/L (Table 1). In discussions with David Cunliffe (SA Dept of Health) it was considered feasible to increase the recreational threshold for the lake to 20 mm^3/L, twice the previous threshold (

Table 8). The justification for this increase was that:

1. The tolerable threshold was low given the relative risk
2. The chance of ingestion was extremely low given the activities on the lake are predominantly paddle-boating and rowing
3. The major route of exposure is via skin contact and epidemiological studies have shown no clear link between cyanobacterial concentration and symptoms. It is apparent that some individuals are simply more sensitive to exposure.

Microcytsis aeruginosa concentrations at numerous sites exceeded the revised concentration (

Table 5), however, the mean cell concentration was always lower than the concentration permissible under the revised guideline: 230,000 cells/mL. Depending upon the criteria for lake closure (i.e. two sites with cell concentrations greater than the trigger threshold or mean cell concentration below the trigger value), the lake could remain open even with high biomass at some sites. This may occur even without amenity flow. Regardless of the recreational guideline, cell concentration this high would form dense surface blooms, would be unsightly and may have odours associated with them.

Table 8 Historical and revised cyanobacterial threshold triggering Torrens Lake closure.

Cyanobacteria	Cell count (cells/mL)	Revised cell count corresponding to a biomass of 20 mm^3/L
Anabaena circinalis	40,000	80,000
Microcystis aeruginosa	115,000	230,000
Microcystis flos-aquae	455,000	910,000
Planktothrix mougeotti	156,500	313,000

Could we have controlled cyanobacterial growth if flow commenced earlier

A challenge that has been encountered in the Torrens Lake amenity trial is detecting cells early enough and releasing flow in response to cell counts exceeding 1000 cells/mL. There is a need to balance the cost of water with the ability to adequately dilute the cyanobacterial population. The strategy for control by dilution relies upon dilution starting early before cyanobacterial populations get too large. Cyanobacterial growth is logarithmic and so diluting flows have a relatively bigger impact at low cell concentrations than at higher concentrations.

Cyanobacteria tend to display extremely rapid growth and so populations can expand from barely detectable concentrations to bloom proportions within weeks. There was some concern that flow releases in the 2012/13 amenity flow trial commenced late and so were unable to adequately control cyanobacteria. Unfortunately the rapid development occurred over the Christmas-New Year period when sampling was reduced because of public holidays. *Microcystis aeruginosa* populations increased from non-detectable concentrations at six of seven sampling sites to a maximum of 124,000 cells/mL at site 4 over a seven day period from 24 December to 31 December 2012 (

Table 5). Flow was released from Hope Valley on 28 December 2012 (Table 9) in response to high temperatures and visual evidence of cyanobacteria. This water took two days to reach the lake, pass through and be detected at Holbrooks Rd gauging station.

Table 9 Initial flow release from Hope Valley Reservoir in response to visual evidence of cyanobacteria

Date	Flow released from Hope Valley (ML)
28/12/12	20.14
29/12/12	30.42
30/12/12	30.47
31/12/12	36.54
1/01/13	38.85
2/01/13	38.29
3/01/13	38.50
4/01/13	39.33
5/01/13	39.58
6/01/13	40.96
7/01/13	41.67
8/01/13	41.77

To determine whether releasing water from Hope Valley earlier would have had an impact on the cyanobacterial population the simple model detailed in Brookes et al., (2012) was used to model cyanobacterial growth in response to flow and dilution. Two growth rates were modelled, the 0.3 /day which is the historical average growth rate of cyanobacteria observed in summer (Brookes et al., 2012) and 0.9/day which represents the extremely high growth rate of *Microcystis aeruginosa* observed between 24-31 Dec 2012. The starting population size was set at 20 cells/mL which was the maximum observed cell concentration on 24 December, 2012 (

Table 5).

The prediction of the *Microcystis* population size with a growth rate of 0.3 /day did not accurately predict average population size over the period from 24 Dec – 7 Jan (Figure 12) although it captures reasonably well the growth rate at site 1 only. The simulation of cyanobacterial population increase with a growth rate of 0.9/day achieves a much better representation of the actual cyanobacterial abundance over this time period (Figure 12). To test whether increasing amenity flows earlier would have staved off the cyanobacterial bloom three model runs were undertaken; no dilution, 10% dilution (40ML/day) and the actual flows (Table 9). The rate of population increase is so rapid that regardless of dilution flows the population would have exceeded 100,000 cells/mL by 3 January (Figure 12). It can be concluded that the permissible maximum amenity flow of 40 ML/day is insufficient to control the cyanobacterial abundance when population growth are as high as observed during the period 24-31 December 2012.

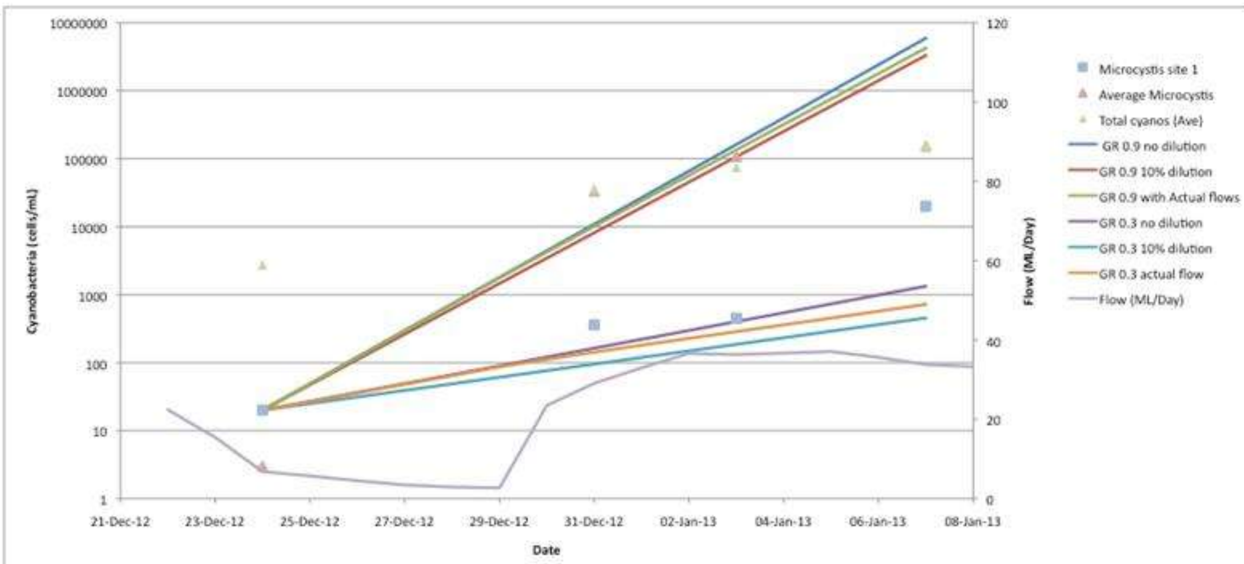


Figure 12 Modelled cyanobacterial population size with two different growth rates (0.3 or 0.9 /day) and either no dilution flows, 10% dilution flows or the actual measured flows.

Is early detection possible with a phycocyanin probe?

The phycocyanin probe showed considerable promise at measuring cyanobacterial pigments which correlated with cell numbers in some cases (2pm phycocyanin measurement and manual cell counts). However the fact that early morning measurement made with the probe did not correlate with manual cell counts raises some concerns about its broad applicability as a indicator of algal biomass. The apparent light sensitivity of the phycocyanin fluorescence needs further investigation before we can be confident in the ability of the BGA probe to accurately predict cyanobacterial abundance. The real value of the probe would be early detection and identifying cyanobacterial presence at very low cell concentrations. More laboratory trials would be required to determine the sensitivity of the probe particularly at low cyanobacterial concentrations. However, the modelling studies in Figure 12 suggest that a very rapid online method for detection would not be of additional advantage when growth rates are extremely rapid as flow is unable to control abundance at these growth rates.

A combination of the online BGA/phycocyanin probe and visual inspection of the lake might suffice for early detection and triggering of amenity flow release during periods when manual sampling and microscopic cell counts are impractical.

Are there additional benefits or challenges from controlled flow releases?

There are two primary concerns with the amenity flow trial; are we transporting nutrients into the lake and are we transporting cyanobacteria or pathogenic organisms downstream which may threaten recreational users at West Lakes or Henley Beach. Nutrient concentrations in Hope Valley tend to be low. This is because water has a long residence time in the River Murray before it is pumped to Kangaroo Creek Dam before another transmission to Hope Valley Reservoir. During this time there is considerable uptake of nitrogen and phosphorus reducing the ambient dissolved concentrations in the water. This varies seasonally but relative to nutrient concentrations typically found in the Torrens Lake and in the stormwater inflows to the lake the concentrations in Hope Valley Reservoir during summer are low.

The transport of cyanobacteria or pathogenic organisms downstream is a concern. High concentrations of cyanobacteria were present immediately below the city weir but cells are disrupted during river passage and decrease to well below the recreational guideline concentrations downstream of Port Rd (Figure 10). Similarly Enterococci are attenuated with downstream passage and the concentrations entering West Lakes are two orders of magnitude lower than those exiting the Torrens Lake.

There are several additional benefits from the amenity flow release beyond in-lake improvements. Continual flow in the reaches from just upstream of Paradise O-bahn interchange to Hackney Rd and from Port Rd to Henley Beach improved the general amenity of the river. Furthermore there were benefits of to native fish which are detailed in chapter 3.

Conclusions and Recommendations

- The amenity flow released from Hope valley was ineffective at reducing the cyanobacterial abundance during the highest growth period.
- 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
- Cyanobacteria and Enterococci were transported downstream from the lake as a result of the amenity flow releases, however, the abundance decreased significantly during river passage resulting in a two log removal.
- The amenity flow alone was insufficient to prevent lake closure
- The increase in the recreational guideline to 20 mm^3/L increases the length of time the lake can remain open. Depending on the criteria used to determine the whole lake concentration, the lake could remain open even with a dense bloom. For example if the mean cell concentration over the sites 1-6 is used then a mean concentration of 230,000 cells/mL of *Microcystis aeruginosa* would be permissible and the lake would have remained open all summer. A cautionary note is that at these concentrations dense surface blooms would be present which would be unsightly and may be odorous.
- It is recommended that the site 7 concentrations be excluded from whole lake determination of mean cell concentration. Cells often accumulate at the upstream site but persist there until they are washed downstream during storm events. The persistent upstream biomass presents a very low risk to lake users and so may unnecessarily bias the value used to determine lake closure.
- The amenity flows achieve environmental benefits other than dilution. They serve to maintain water in a river that would have had base flow during summer which has been largely lost by river regulation and catchment development; they provide habitat for native fish, the water is used to provide water to the barker inlet wetlands during long dry summer and there is freshening of water in the entire reach from Hope Valley reservoir to the coast.
- On balance, without summer rainfall to reset the lake population the amenity flows are insufficient on their own to provide relief against high cyanobacterial growth. However, if coupled with and algicidal technology such as hydrogen peroxide and/or additional volumes of flow to reset the lake, they may attain the upstream and downstream benefits and cyanobacterial control in-lake.

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

NHMRC (2011) Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy. National Health and Medical Research Council, National Resource Management Ministerial Council, Commonwealth of Australia, Canberra

Chapter 2 Hydrodynamic modelling

1. Introduction

Many questions were raised during the Torrens amenity trial that can't be answered from the monitoring data alone. To address some of these questions a coupled hydrodynamic-biogeochemical model was developed that simulates flow, stratification and cyanobacterial growth. A range of different scenarios were developed that represent decreasing the lake volume, variations to flow volume, algal growth, stratification and the impact on the rate of dilution.

The model was improved over the model used in the 2011/12 report. This included a more accurate bathymetry and increased vertical resolution to better account for stratification in a shallow waterbody.

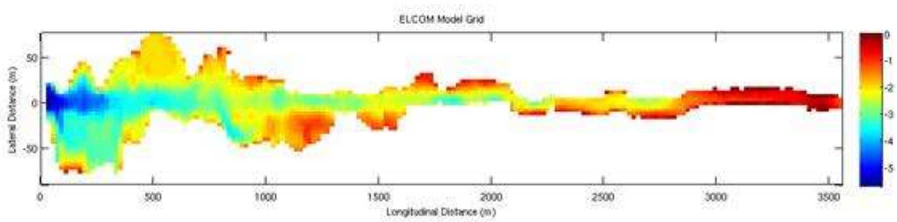
2. Modelling Input Data

- Due to the unavailability 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 to 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 downscaling was done on the data to apply it to 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.

3. Modification to the previous ELCOM model

A new model grid was created to improve the performance of the model (see Figure 13). Lake elevation data was sourced from the Adelaide city council and used to create a new bathymetry map. Compared to the previous model, the vertical resolution was increased to 0.25m (from 0.5m) to better model stratification in shallower parts of the river. The model grid was "straightened" to allow a rectangular grid to be created that improved the lateral resolution (4m) while decreasing the longitudinal resolution (20m) so that runtimes could be shortened. In a straightened grid the x coordinate represents the distance from the weir along the path of the river (thalweg). The y coordinate represents the lateral distance across the river from the deepest section.

An additional section of the lake from Frome Rd to Hackney Rd was added. No survey data was available so the edges were traced from aerial imagery and maximum depth estimated based on experience gained while collecting samples. The bottom profile was based on the shape downstream from Frome Rd. Three sections representing left/right bends and a straight reaches were selected and then scaled to fit the width, depth and curvature of the new section of lake.



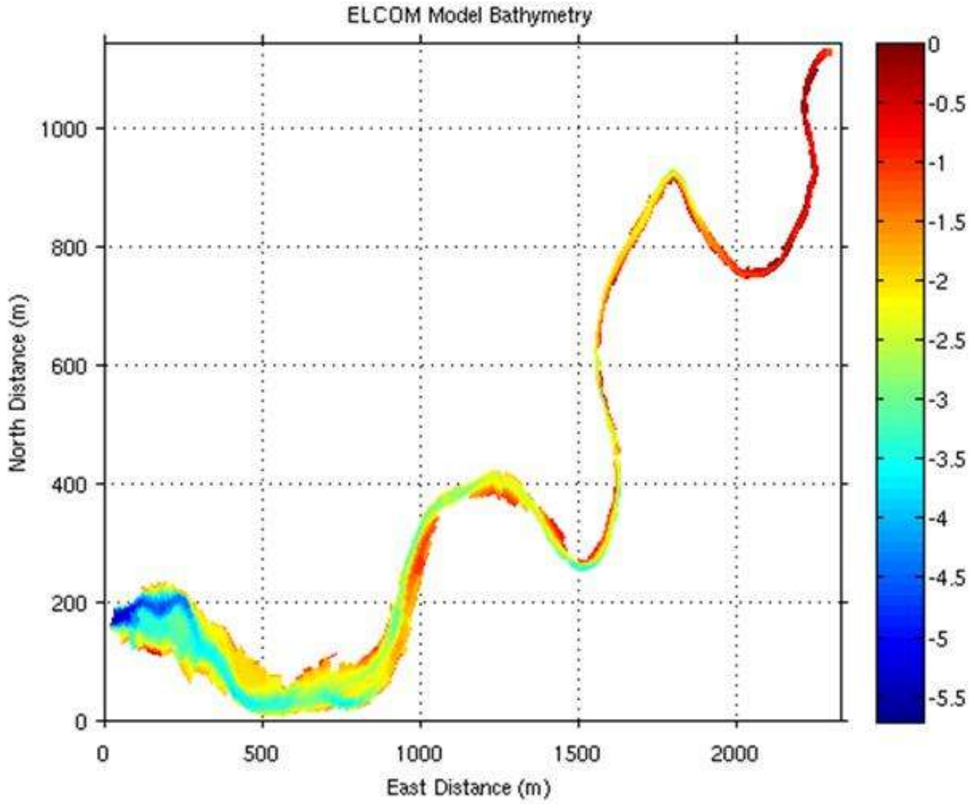


Figure 13 ELCOM Model grid: Straightened grid (top), corresponding geographic grid (bottom)

4. Validation of Torrens Lake model output during trial period

Modelled temperature was compared against measured temperature data for the time period 31 Dec. 2012 to 13 May 2013. The model results follow the weather/seasonal trends in temperature well (Figure 14). On average the model results compare favourably with the observed data (Figure 15) typically being within 0.5ºC of the observed value. The recorded data was measured near the surface of the lake, the diurnal fluctuations are more pronounced compared to the model because diurnal stratification can create thin surface layers of warm water. The model is restricted by the vertical resolution to be an average of the top 0.25m.

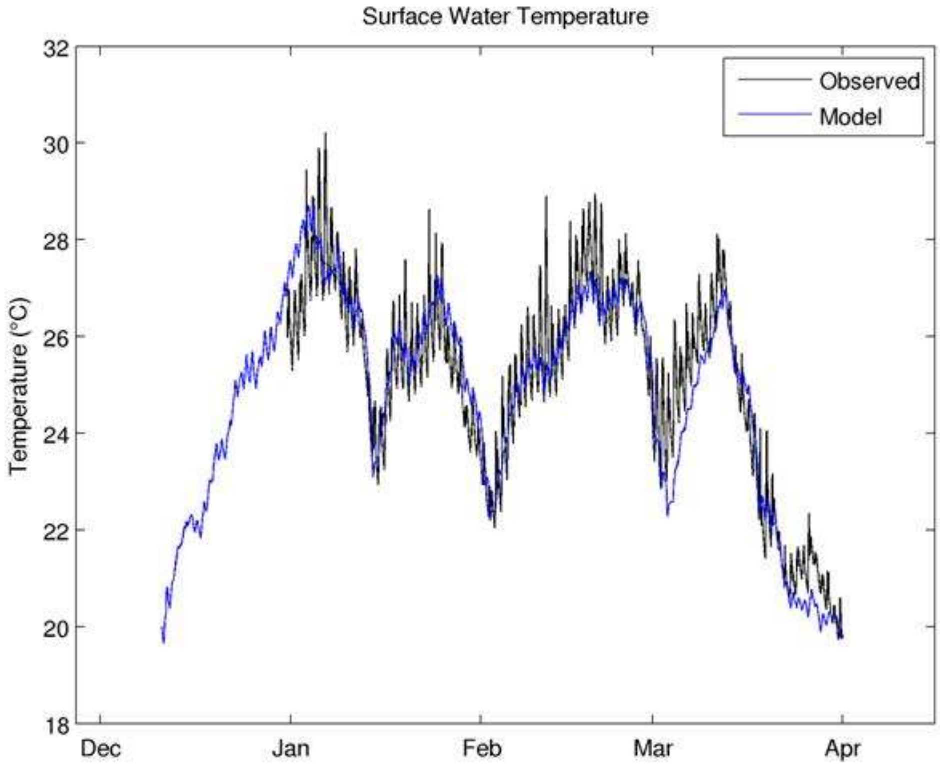


Figure 14 Comparison of modelled and observed surface water temperature near the Torrens Weir.

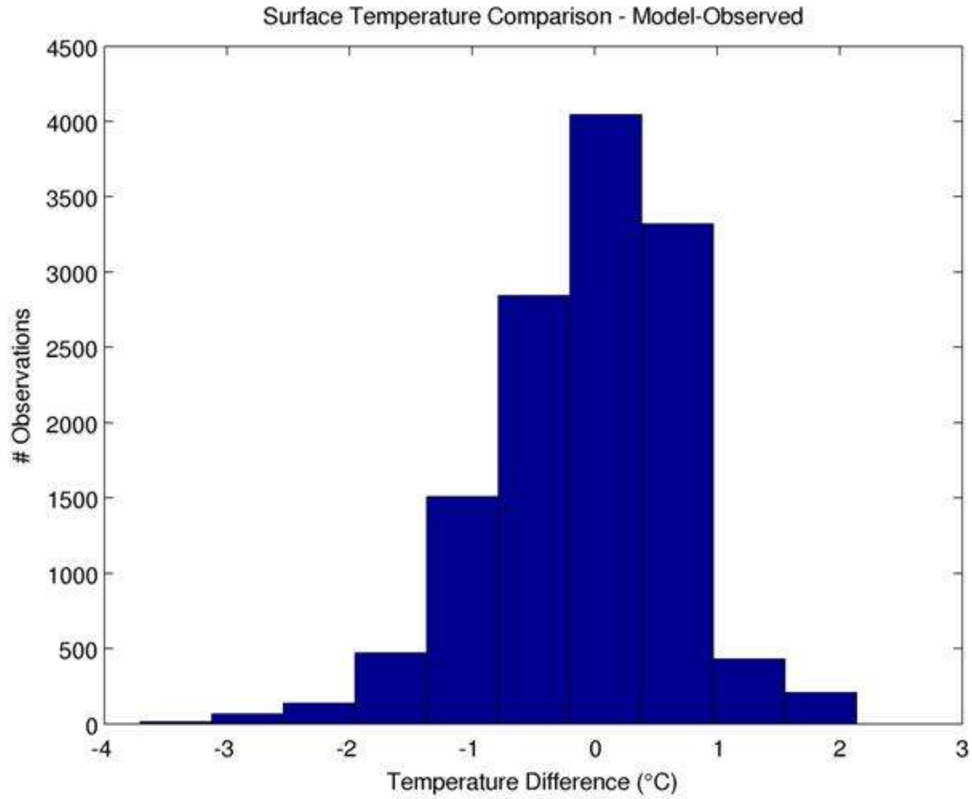


Figure 15 Histogram of temperature difference between modelled and observed surface water temperature near the Torrens Weir.

5. Tracer study of inflow events

To examine the dilution effects of water flowing into the Torrens Lake the addition of conservative tracers during inflow events was simulated during the period of the trial (Figure 16). The release duration for each tracer was two days.

1. Rain Event
2. 40 ML/day start event
3. 40 ML/day mid event
4. 20 ML/day + Rain
5. Rain Event
6. 40 ML/day
7. 20 ML/day

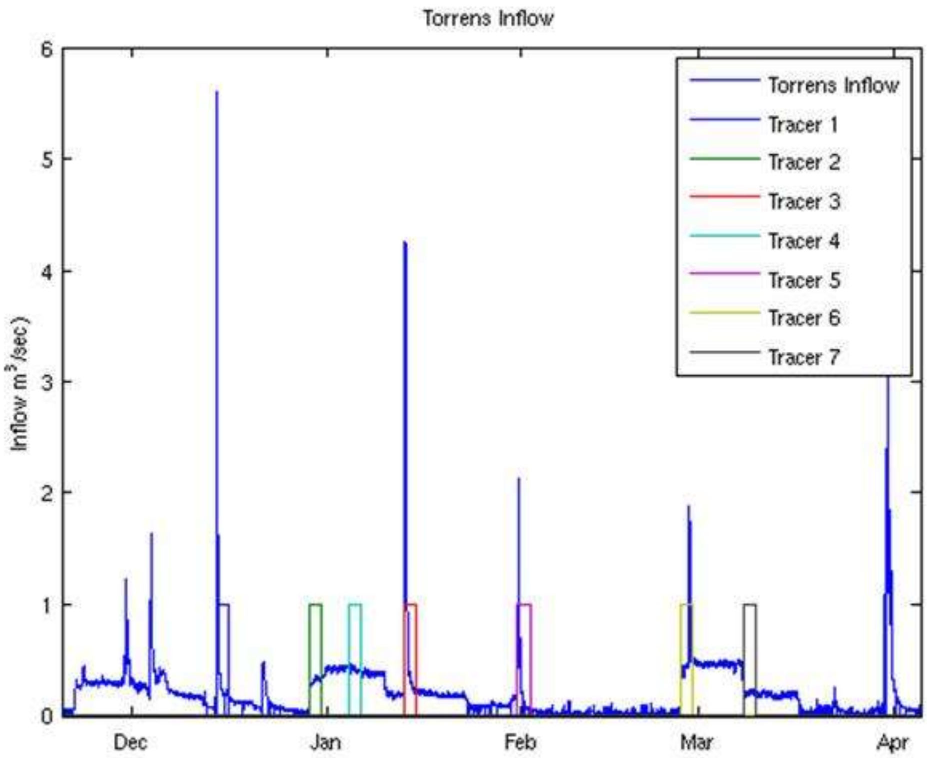


Figure 16 River Torrens hydrograph overlayed with simulated tracer releases

The results of the model output for Elder Park, Morphett St and the Torrens Weir are shown in Figure 17, Figure 18, Figure 19; each plot represents the average concentration in a transect across the river. In all cases the water with tracer added behaved as a "plug flow" in the shallow upstream areas of the lake with no significant intrusions or high density under flows occurring. Modelled temperature shows some diurnal stratification occurs due to solar heating, this is consistent with observed data from the 2011-12 trial. This stratification does not persist overnight so algae should (theoretically) be entrained in the amenity flow and diluted/flushed downstream.

In deeper/wider sections of the lake i.e. d/s Morphett St Bridge the amenity flow water has a tendency to sink below the surface and form a layer on the bottom. The layer progressively moves up the water column as more water is added. As it approaches the surface it becomes mixed with surface water by the action of wind. Strong wind events are capable of fully mixing the bottom layer.

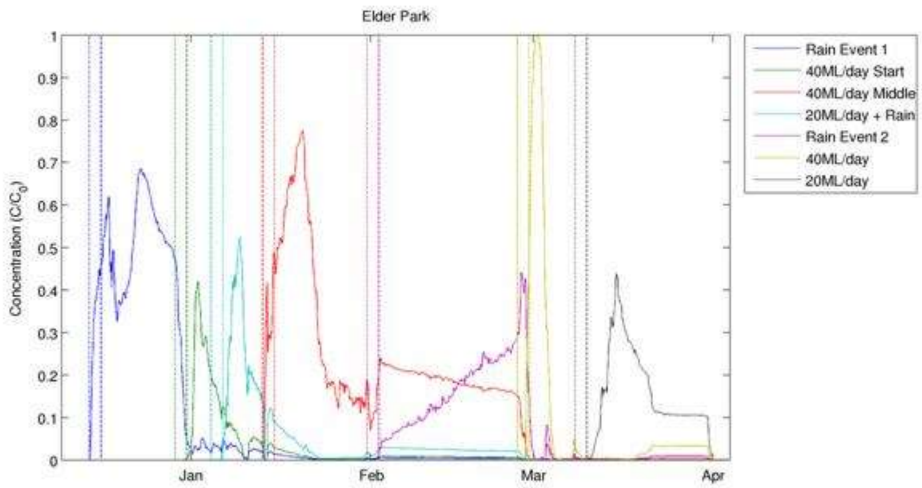


Figure 17 Simulated concentration of tracers at Elder Park relative to the initial concentration

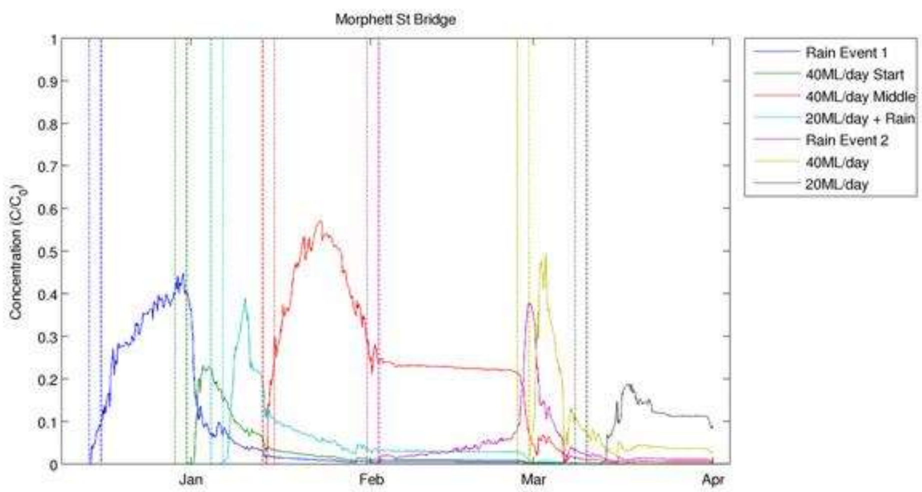


Figure 18 Simulated concentration of tracers at Morphett St Bridge relative to the initial concentration

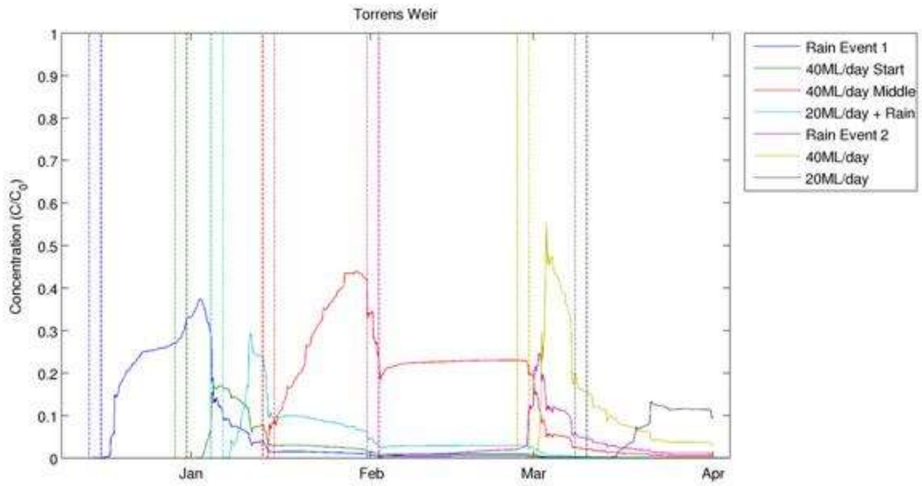


Figure 19 Simulated concentration of tracers at the Torrens Weir relative to the initial concentration

Table 10 The results of the tracer releases are summarised as travel times in the table below.

	Time to first appearance (days)	Time to Increase to 10% C_{max} (days)	Time to Maximum Concentration (C_{max})	Decrease to 10% C_{max} (days)
Elder Park				
Rain Event 1	0.1	0.3	8.8	16.6
40 ML/day Start	1.3	2.9	4	11.1
40 ML/day Middle	0.2	0.4	6.9	18.5
20 ML/day + Rain	1	2.3	5	9.1
Rain Event 2	0.7	2.5	26.5	28.3
40 ML/day	0.7	1.5	3.6	5.7
20 ML/day	1.5	3.5	7.2	23.1
Morphett St Bridge				
Rain Event 1	0.2	0.8	16.2	25.8
40 ML/day Start	1.5	3.4	4.9	21.8
40 ML/day Middle	0.4	0.9	10	46.2
20 ML/day + Rain	1.2	3	5.9	22.6
Rain Event 2	0.8	15.5	27.9	33.8
40 ML/day	0.9	2.4	4.9	8
20 ML/day	1.9	5.4	9.3	-
Torrens Weir				
Rain Event 1	0.3	3.7	19.1	27.8
40 ML/day Start	2.5	5.1	8.1	33.1
40 ML/day Middle	0.5	1.1	16	53.1
20 ML/day + Rain	1.6	3.4	6.8	28.9
Rain Event 2	1	26.7	29.6	43.3
40 ML/day	1.4	3.8	5	22.9
20 ML/day	2.7	7.4	13.1	-

6. Scenario 1 – 0.3m lower lake level

In an alternative scenario the lake level was set and held 0.3m below the normal surface level. This lowering decreases the volume of the lake and therefore increases the influence of the amenity flow on the lake. The modelling results are shown in figures Figure 20 - Figure 22. In terms of dilution the lower lake level increases the flushing effect of the amenity flow. At Elder Park and Morphett St there is ~10% increase in the concentration of "fresh" water compared the same scenario with normal lake level. This increased dilution would reduce the growth rate of algae remaining in the water. At the weir this dilution effect is reduced so that there is only a ~5% increase in the concentration of new water. Lowering the lake level also decreases the travel time of the amenity flow through the lake (see Table 11. In terms of controlling algae the fact that dilution occurs sooner would result in lower algal numbers since it would disrupt the exponential growth at an earlier stage while the cell densities are lower.

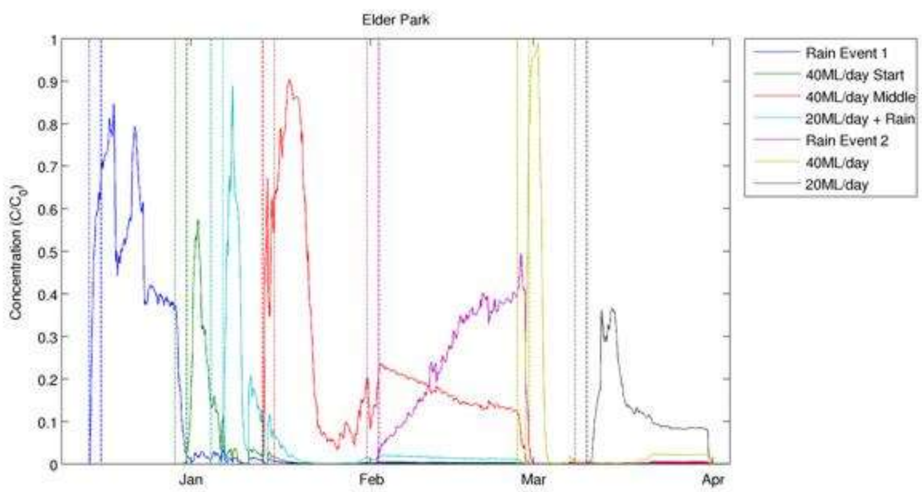


Figure 20 Simulated concentration of tracers at Elder Park relative to the initial concentration

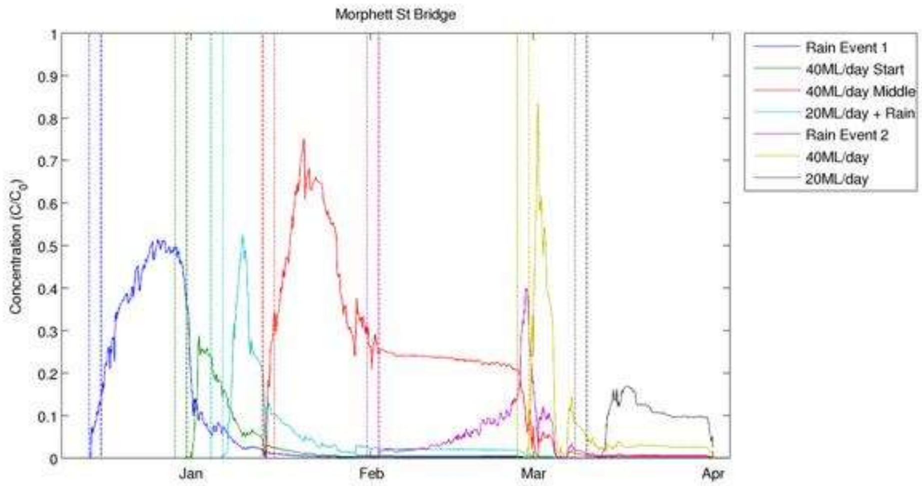


Figure 21 Simulated concentration of tracers at Morphett St Bridge relative to the initial concentration

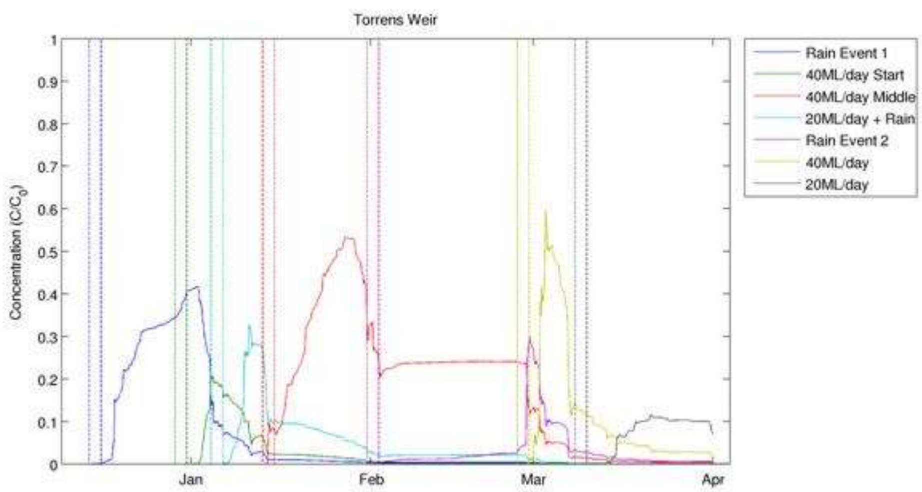


Figure 22 Simulated concentration of tracers at the Torrens Weir relative to the initial concentration

Table 11 The results of the tracer releases are summarised as travel times in the table below.

	Time to first appearance (days)	Time to Increase to 10% C_{max} (days)	Time to Maximum Concentration (C_{max})	Decrease to 10% C_{max} (days)
Elder Park				
Rain Event 1	0.1	0.2	4.2	16.1
40ML/day Start	1.1	2.4	4	7.8
40ML/day Middle	0.2	0.3	4.6	9.5
20ML/day + Rain	1.1	2.2	3.7	5.6
Rain Event 2	0.5	2.9	26.5	27.8
40ML/day	0.7	1.4	3.6	4.7
20ML/day	1.5	3	6.3	23
Morphett St Bridge				
Rain Event 1	0.1	0.4	11.8	23.8
40ML/day Start	1.5	3.2	4.2	15.4
40ML/day Middle	0.3	0.8	7.1	45.5
20ML/day + Rain	1.2	2.9	5.5	9.3
Rain Event 2	0.7	14	27.5	29.4
40ML/day	0.9	2.3	3.6	6.5
20ML/day	1.8	5	8.8	-
Torrens Weir				
Rain Event 1	0.3	4.1	18.6	27.4
40ML/day Start	2.4	4.6	6.4	22.5
40ML/day Middle	0.4	1	14.2	48.8
20ML/day + Rain	1.9	3.8	6.6	26.8
Rain Event 2	0.9	26.1	28	35
40ML/day	1.4	2.9	4.9	15.4
20ML/day	2.7	6.4	13.1	-

7. Scenario 2 – 0.5m lower lake level

Similar to the previous scenario, lowering the lake level by 0.5m further decreased the travel time of amenity flows and increased the dilution of the lake water (Figure 23- Figure 25;

Table 12).

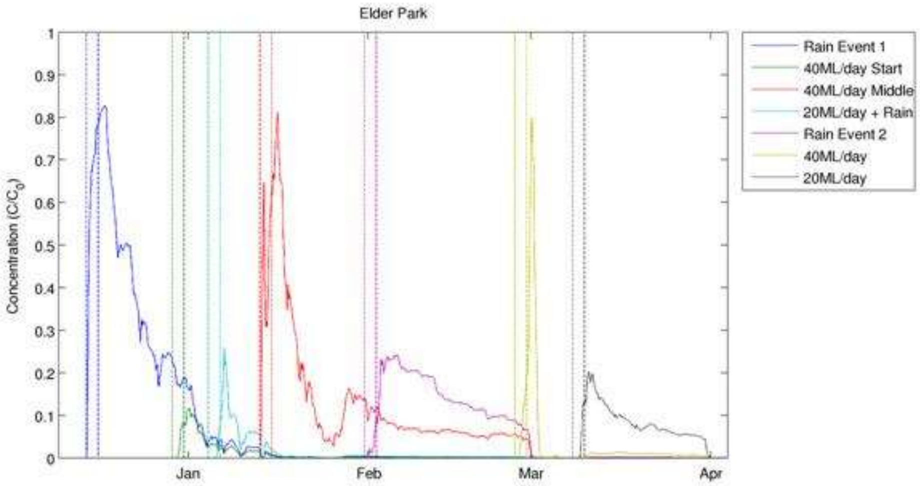


Figure 23 Simulated concentration of tracers at Elder Park relative to the initial concentration

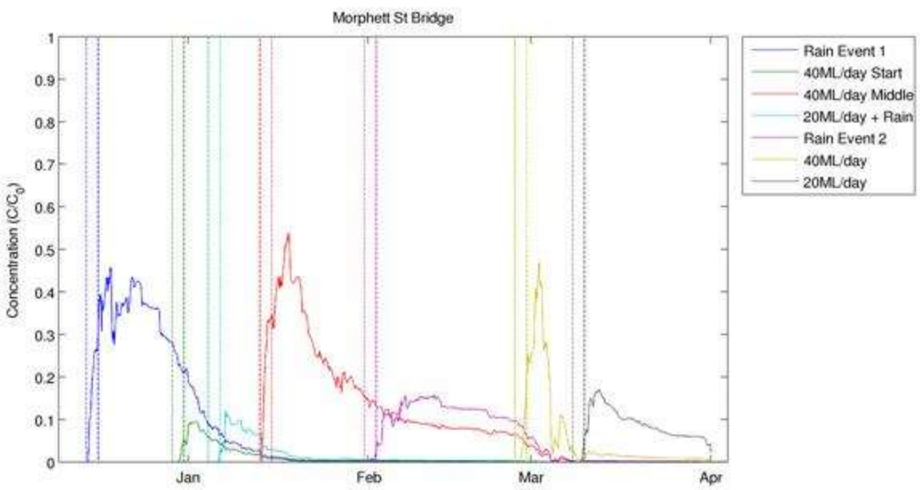


Figure 24 Simulated concentration of tracers at Morphett St Bridge relative to the initial concentration

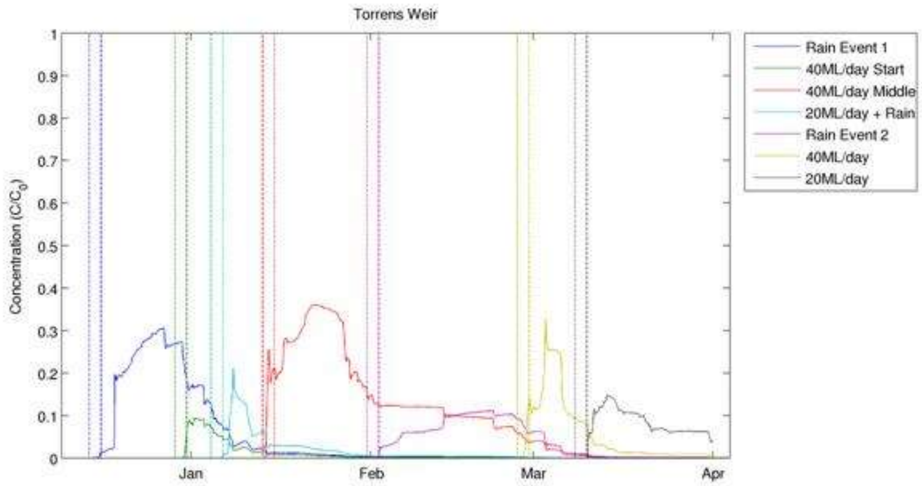


Figure 25 Simulated concentration of tracers at the Torrens Weir relative to the initial concentration

Table 12 The results of the tracer releases are summarised as travel times in the table below.

	Time to first appearance (days)	Time to Increase to 10% C_{max} (days)	Time to Maximum Concentration (C_{max})	Decrease to 10% C_{max} (days)
Elder Park				
Rain Event 1	0.1	0.2	3.1	19.1
40ML/day Start	0.5	1.2	3	8.9
40ML/day Middle	0.2	0.3	3.1	9.7
20ML/day + Rain	0.9	1.7	2.7	5.5
Rain Event 2	0.3	1.5	5.6	28.6
40ML/day	0.4	1.3	2.9	4
20ML/day	0.8	1.4	2.7	23
Morphett St Bridge				
Rain Event 1	0.2	0.5	4.2	23.9
40ML/day Start	0.8	1.4	4	15.5
40ML/day Middle	0.3	0.5	4.9	45.2
20ML/day + Rain	1	1.9	3	15.1
Rain Event 2	0.6	1.9	12	32
40ML/day	0.5	1.5	4.2	6.3
20ML/day	1.3	1.8	4.6	-
Torrens Weir				
Rain Event 1	0.6	4.3	12.9	24.8
40ML/day Start	1.2	1.8	3.3	15.8
40ML/day Middle	0.4	0.6	9.3	46
20ML/day + Rain	1.2	3	3.9	18
Rain Event 2	0.9	2.1	21.6	34.6
40ML/day	0.7	1.4	4.9	13.1
20ML/day	2	2.2	5.5	NaN

8. Scenario 3 – Higher Flow 100 ML/day

An alternative management strategy for applying Amenity flows was simulated using the model. In this scenario the amenity flow is supplied at a much faster flow rate (100 ML/day) over a shorter period (3 days). Increased water velocities would reduce travel times as well as increase mixing in the lake. The increased amenity flow in this scenario was timed similar to the first 40 ML/day flow applied near the end of December.

The plots showing the results of the simulation (Figure 26 - Figure 28) show that the concentration of the new water is increased compared to the 40 ML/day scenario during the same period. At Elder Park the amenity flow completely displaced the water that was there before the flow began. Similarly at sites downstream, the fraction of amenity flow water was significantly higher than the 40 ML/day scenario with peaks >75% amenity flow water. Compared to the 40 ML/day scenario the increased flow proportionately decreased the travel time for the flow to reach all sites (see Table 13).

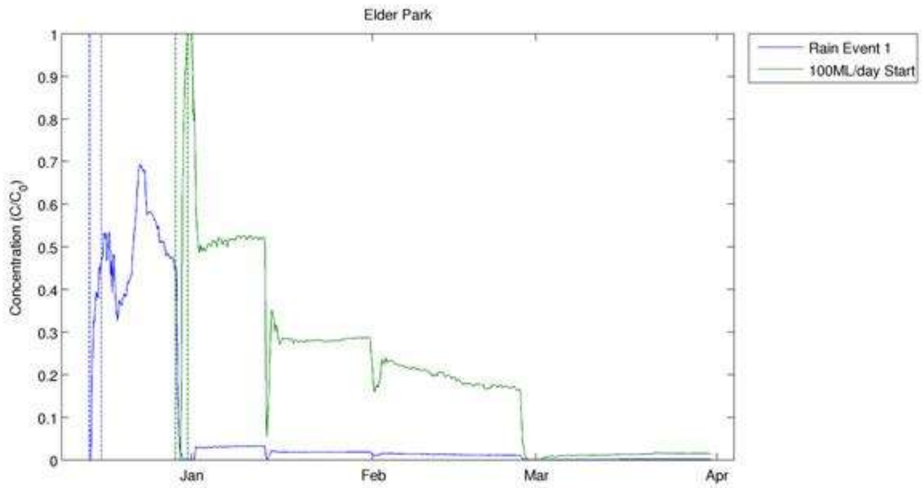


Figure 26 Simulated concentration of tracers at Elder Park relative to the initial concentration

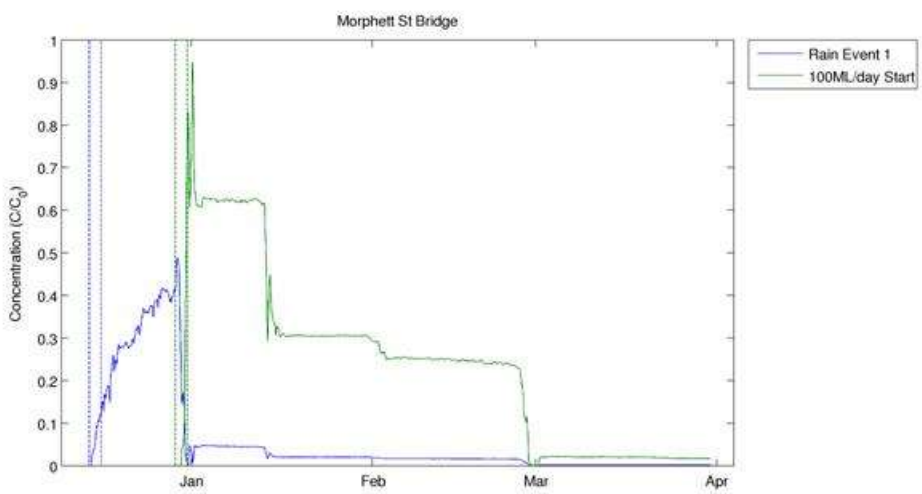


Figure 27 Simulated concentration of tracers at Morphett St Bridge relative to the initial concentration

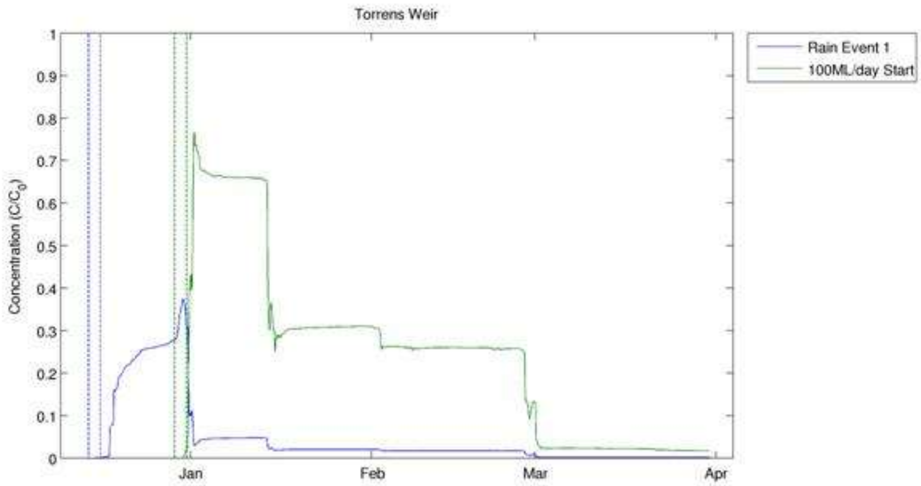


Figure 28 Simulated concentration of tracers at Torrens Weir relative to the initial concentration

Table 13 Travel times of tracer releases input upstream of the Torrens Lake with a flow of 100 ML/day

	Time to first appearance (days)	Time to Increase to 10% C_{max} (days)	Time to Maximum Concentration (C_{max})	Decrease to 10% C_{max} (days)
Location				
Elder Park	0.5	0.9	2.6	15.5
Morphett St Bridge	0.7	1.5	2.9	60.3
Torrens Weir	1.2	2.3	3.3	61.8

9. Algal Growth Modelling

To assist in the comparison of the different scenarios described above a simple constant growth model of algae was applied to the Torrens Lake. In all cases the simulation started on 24 Dec and the lake was initialised with a uniform starting concentration of algae (average of observed 2755 cells/mL). The algal growth rate was set at 0.3/day which is consistent with the growth rate observed during the first 40 ML/day amenity flow. Only one event was modelled and the release was initiated on 29 Dec similar to what occurred during the trial.

In all cases the amenity flow limits the growth of algae compared to the continued exponential growth assumed in the model (see Figure 29). The effectiveness of the flow increases with lower lake levels by decreasing the arrival time of the flushing water as well as increased dilution of the algal population. At a 0.3 /day growth rate, the normal lake level scenario did not maintain the algal population at the level present when the amenity flow began i.e. a gradual increase. The lower lake level scenarios performed much better in this regard with populations remaining relatively stable while the 40 ML/day flow lasted. In these three scenarios, when the flow was decreased to 20 ML/day the algal population began to increase rapidly again.

The short duration 100 ML/day flow scenario produced a rapid reduction in the algal population however once the flow stopped algal population soon recovered and in the absence of continuing amenity flows returned to an exponential growth pattern. After one week the algae population had increased to a level higher than the other scenarios with continuing flow.

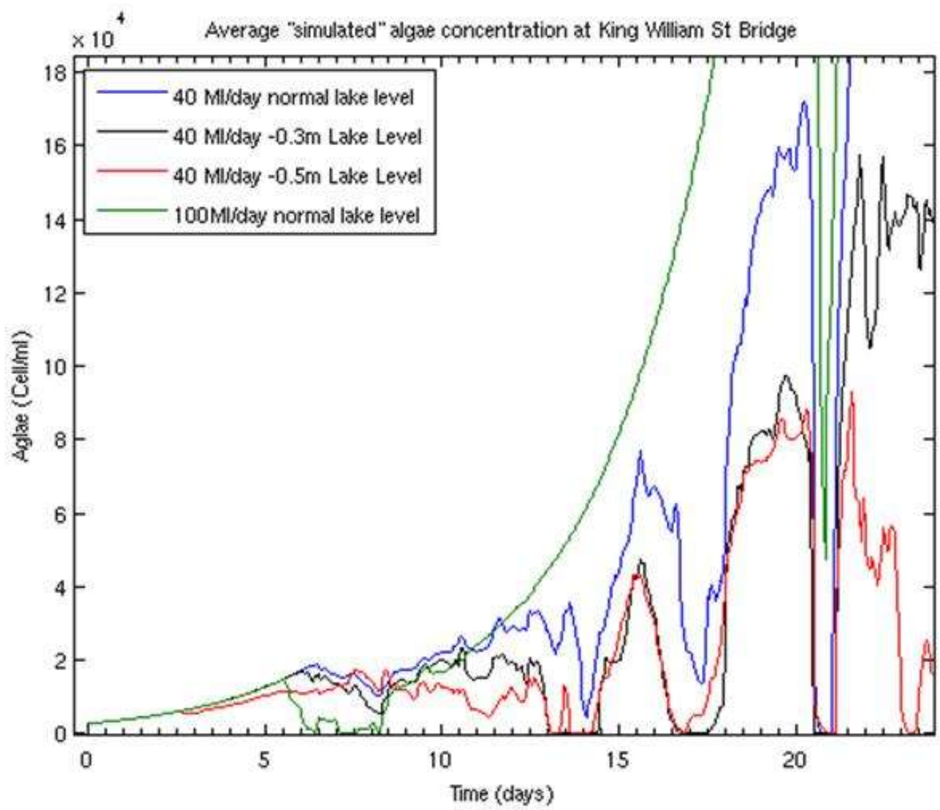


Figure 29 Average simulated algal concentration at the King William St Bridge during several amenity flow management scenarios.

Surface stratification may play a role in preventing the algal cells in upstream reaches getting flushed downstream. An additional scenario was simulated to investigate the effect of increased stratification during the amenity flow. To create a more stratified situation the temperature of the inflow was reduced by 2ºC. The colder inflow began to form an underflow sooner (further upstream) than the normal inflow (see Figure 30). Compared to the “normal” simulation the stratified scenario resulted in the algal population extending over a much bigger stretch of the lake. At the King William St Bridge the cell concentration was considerably higher because of less dilution of the surface layer which results in a much faster algal growth rate (seeFigure 29). There was a marginally lower algal population at the weir because of increased dilution from the subsurface layer mixing to the top of the water column.

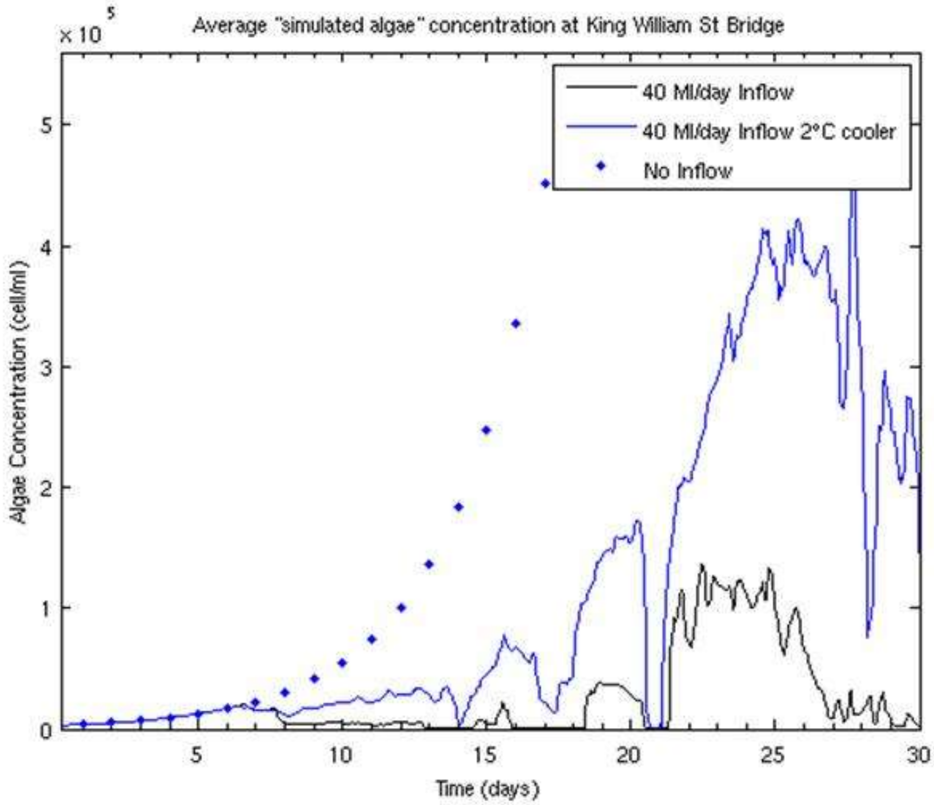


Figure 30 Comparison of amenity flows with different degrees of stratification

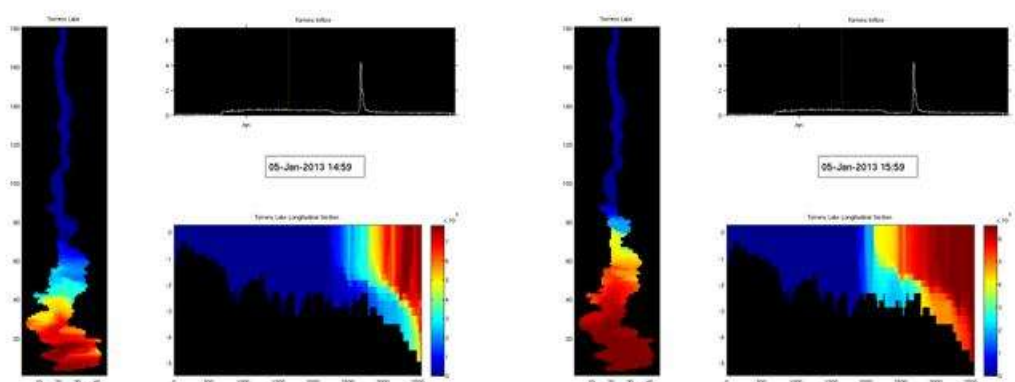


Figure 31 Spatial comparison of amenity flows with different degrees of stratification. Left: normal, Right: increased stratification.

10. Wind and Algae Dispersion

During the flow trial algae persisted in the upper reaches of the Torrens Lake. This is in contrast to the modelling presented here that suggests that the amenity flow should be effective at flushing the algae downstream. One possible explanation could be that surface scums of algae get blown back up stream by the wind.

An examination of summer wind data from Adelaide over several years (2007-2013, Figure 32) reveals a very strong tendency for an "afternoon sea breeze" to develop around mid-day and continue until early evening. The direction of the wind is from the south west (225º) which corresponds with the general alignment of the upper reaches of the Torrens Lake (i.e. King William St to Hackney Rd). During this time of day the lake would have a warm surface layer resulting from solar heating. Cyanobacteria have the ability to float and will remain in this layer or on the surface as a scum. A strongly stratified (thin) layer on the lake is effectively shielded from the effects of the amenity flow. The wind may act to blow the algae in the surface layer back up stream.

There is not a similar tendency for wind to blow from the opposite direction (NE) at any other time of the day. So wind that would help push algae out of the upper reaches of the Torrens is not a feature of Adelaide's climate during summer.

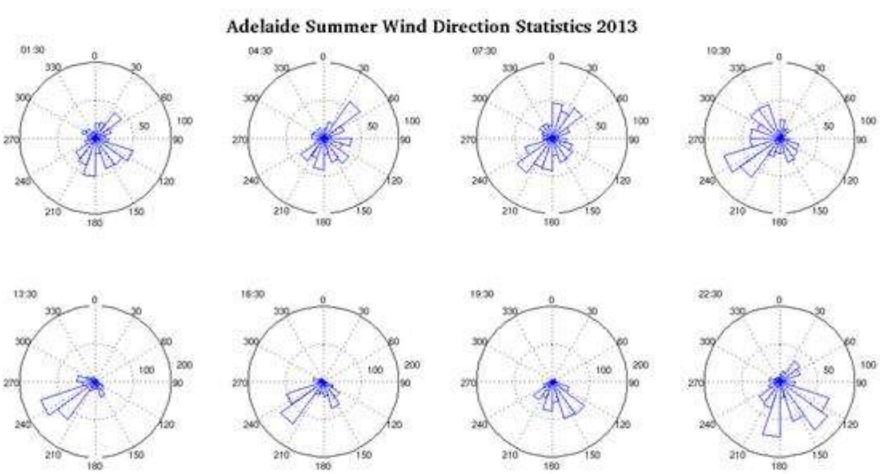


Figure 32 Wind statistics for different times of day during Adelaide summer. Bars represent the number of observations recorded for a given wind direction between 2007-2013. The wind direction is where the wind is coming from i.e. which way a weather vane will point.

A model simulation was set up to track particles that remain on the surface of the lake under the influence of wind and an amenity flow. This feature of the model turned out to be not well suited to the situation of a narrow “river” (more designed to be used in wide round lakes). The particles would rapidly disperse by the wind but would become trapped in the corners of the model grid at the edges of the lake. The simulation indicated that it in the short term it was possible to blow surface particles upstream but can offer no insight into whether the pattern of wind over a number of days is sufficient to maintain the algae in the upper reaches of the Torrens.

Chapter 3 Fish Monitoring

1. Introduction

The fish monitoring component of the Torrens Water Quality Improvement Trial aims to examine the responses of the lower Torrens fish community to the release of Environmental Water Provisions (EWP's) optimized to control cyanobacteria in the Torrens Lake. If amenity flows are seen as a long-term solution to management of cyanobacteria in the lower lkes then it is necessary to ensure there are no adverse impacts on native fish populations and no additional benefits to non-native species.

The initial baseline assessment of the freshwater fish assemblage in the River Torrens (downstream of the Torrens Lake) was completed during December 2011, prior to the commencement of flow provision (McNeil *et al*, 2012). This baseline fish assemblage was dominated by alien species and translocated native species endemic to the Murray-Darling Basin, with extremely low numbers of endemic fishes observed. Subsequent surveys were undertaken in December 2012 and July 2013 to provide post-flow communities assemblage against which flow response could be gauged. It was hypothesised that:

1. During dilution flows of the Torrens Lake, the presence of cyanobacteria and associated toxins in effluent water will not negatively impact on downstream fish communities.
2. Upstream movement of Diadromous fish would be facilitated by the Breakout Creek fish ladder towards the city weir because of increased flow through the fish ladder and lower reaches of the river;
3. In-channel barriers between Breakout Creek and the city weir will prevent upstream fish movements resulting in aggregations below barriers.
4. Changes in water quality resulting from the dilution flows will impact negatively on fish populations where tolerance thresholds are breached.
5. Flows will induce spawning and/or recruitment responses measurable in fish populations.
6. Freshwater inflows into the relatively poorer water quality environment of the Torrens Lake will result in aggregations of spawning carp and lead to increases in carp abundance, biomass and distribution.

2. Methods

Surveys were conducted between the 17th and 19th of December 2012 and between the 15th and 17th of July 2013. Sampling was conducted above and below seven anthropogenic in-stream structures located between the city weir and Breakout Creek (Figure 33). These were selected as the seven structures most likely to impede the movement of fish along the lower Torrens (Schmarr *et al*, 2011).

Ecologists used a combination of small fyke nets (3 m wing, 4 mm mesh, 3 m funnel, 0.6 m high) and double-winged fyke nets (2 x 5m wing, 4 mm mesh, 3m funnels, 0.6m high). Three small fykes and one double-winged fyke were deployed above and below each of the seven structures. The larger double-winged fykes (2 x 10 m wing, 12 mm mesh, 5 m funnels, 1.2 m high) used in the baseline survey were excluded from response sampling because their contribution to relative abundance, species richness, species type or size of the fish captured were deemed insignificance to the baseline survey.

Fyke nets were deployed to target the widest variety of in-stream microhabitats, within a 50 metre reach upstream and downstream of each of the seven structures. Nets were collected after approximately 17 hours to harness both dusk and dawn feeding periods. At each barrier the first 100 fish of each species were measured (total length), with subsequent fish counted prior to release. Records were kept of the presence of spawning and diseased individuals.

Figure 33 Map of lower Torrens sampling locations. (Google Earth, Image © 2013 DigitalGlobe)

3. Results

Flow Context

Flows recorded within the lower Torrens reach over summer 2011-12 were higher than historic average. In summer 2011-12 there were four flushes over 200 megalitres per day observed at Holbrooks Weir and base flow was also elevated above the historic average during this period (Figure 34). Flows recorded in 2012-13 were lower than those of the previous year with all flushes during this period less than 60 megalitres per day. Baseflows during this period were lower than historic averages.

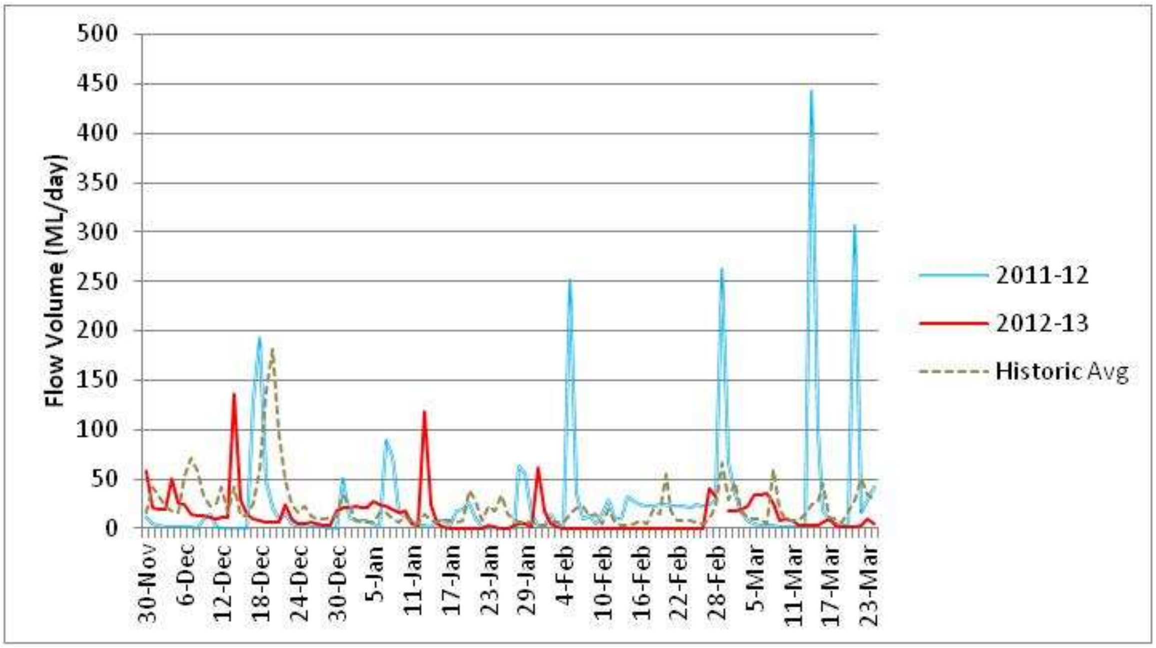


Figure 34 Comparison of flows at the Holbrooks Rd gauging station from December through March.

The baseline population assessment during summer 2011 identified ten species from 22,654 fish (four local, three translocated and three alien). During summer 2012 the fish population was 17,576 from 11 species (five local, three translocated and three alien). During winter 2013 fish abundance was reduced, finding 761 fish from eight species (three local, three translocated and two alien). Multiple size classes were observed in most species on most occasions (Table 14). Disease prevalence was consistent between sampling events. All species detected had been previously recorded within the reach (McNeil *et al*, 2011a).

Local native Species

Five species recorded during the study are considered local natives in the Torrens catchment; short-finned eel *Anguilla australis,* common galaxias *Galaxias maculatus,* flathead gudgeon *Philypnodon grandiceps*, congolli *Pseudaphritis urvillii*, and western blue-spot goby *Pseudogobius olorum*. The most abundant and ubiquitous fish during each survey round was *P. grandiceps*. Both summer surveys recorded a similar number of endemic species overall, with 7,746 individuals caught in 2011 and 9,926 individuals caught in 2012. Abundances of *P. urvillii* and *P. olorum* increased slightly during 2012 relative to the initial survey. Winter 2013 sampling saw a significant reduction in the abundance of most fish species, with the exception of *P. urvillii* which remained stable.

Notable observations include an increase in *G. maculatus*' range and abundance during the 2012 survey. This species was found above both barriers in Bonython Park, the furthest upstream observations during this study. Juvenile *P. urvillii* were recorded below the Holbrooks Rd weir in 2013, where previously only a few individual adults (greater than 200 mm) had been recorded above Breakout Creek. A notable catch was a single *A. australis*, captured at the base of the city weir in 2012.

Translocated Species

Three translocated Murray-Darling fish species (McNeil and Hammer, 2007), *Hypseleotris spp.*, *Melanotaenia fluviatilis* and *Tandanus tandanus*, were observed on each sampling occasion. The abundance of *M. fluviatilis* remained steady between summer 2011/12 and 2012/13 sampling. The *Hypseleotris spp.* numbers were lower by 50% and there was and a marginal increase in the number of *T. tandanus* observed. During winter 2013 there was a decrease in the number of translocated fish observed.

Exotic Species

Three exotic species were recorded throughout the study; *Carassius auratus*, *Cyprinus carpio* and *Gambusia holbrooki*. During baseline sampling in summer 2011 the majority of exotic fish were juvenile *C. auratus* (*n* = 5,344) recorded below Henley Beach Rd. During summer 2012 sampling *C. auratus* numbers had declined being replaced by a large juvenile cohort of *C. carpio* again confined to the reach below Henley Beach Rd. Several large, dead *C. carpio* and one *T. tandanus* were observed immediately below Tapleys Hill Rd at this time. Over the three sampling rounds *G. holbrooki* numbers steadily decreased. Winter sampling saw a decrease in fish numbers of all three exotic species, with no *C. carpio* observed.

Table 14 Summary data for local native (green), translocated native (blue) and alien (red) species within the River Torrens, from December 2011 (baseline survey) through to July 2013.

Common Name	Scientific Name	Dec-11	Dec-12	July-13	Size Classes	Spawning	Disease	Notes
Short-finned Eel	*Anguilla australis*	0	1	0		No	No	Diadromous, rare taxa
Common galaxias	*Galaxias maculatus*	32	756	1	Multiple	No	No	Diadromous
Flathead Gudgeon	*Philypnodon grandiceps*	7,712	9,157	370	Multiple	Yes	Yes	High parasite prevalence in winter, low rates of spawning in summer
Western Blue-spot Goby	*Pseudogobius olorum*	1	3	0		Yes	No	Amphidromous, one gravid female recorded
Congolli	*Pseudaphritis urvillii*	1	9	8	Multiple	No	No	Diadromous
Carp Gudgeon	*Hypseleotris spp.*	5,360	2,357	336		No	Yes	Low rates of disease in winter
Murray Rainbowfish	*Melanotaenia fluviatilis*	2,931	2,410	11		Yes	No	Low rates of spawning in summer
Freshwater Catfish	*Tandanus tandanus*	64	193	32	Multiple	No	No	"Protected' in SA and thriving in the Torrens
Goldfish	*Carassius auratus*	5,344	278	1	Multiple	No	No	Decreased abundance observed in 2012 coincided with a greater spatial distribution
European Carp	*Cyprinus carpio*	4	1,710	0	Multiple	No	Yes	Large Increase in numbers recorded in 2012
Eastern Gambusia	*Gambusia holbrooki*	1,205	702	2		Yes	No	High rates of spawning in summer
Total Catch		22,654	17,576	761				

4. Discussion

General Discussion

Comparable fish abundances between summer 2011 and summer 2012 suggests that environmental flow releases containing high levels of cyanobacteria and cyanotoxins did not have significant observable negative impacts upon lower Torrens fish communities. Although a 22% decrease in overall abundance was observed in 2012, the specific changes in fish community structure, including a reduction in the proportion of exotic fish and a increase in the number and range of diadromous fish, indicates that any influence of flow was predominantly positive, favouring native and disadvantaging exotic fish species. The substantial reduction of fish caught during winter 2013 is consistent with seasonal variation in fish abundance (McNeil and Hammer, 2007;McNeil *et al*, 2011a;McNeil *et al*, 2011b) and may relate to limited fish activity, due to lowered metabolic rates and reduced migration and spawning behaviour (McNeil and Hammer, 2007). Without data from consecutive years, robust consideration of winter 2013 sampling is not possible.

Although *P. grandiceps* is endemic to the lower Torrens, increases in abundance of this species should not necessarily be viewed as an indication of improved ecosystem health. This species is an ecological generalist both resistant and resilient and is able to thrive in highly degraded habitats with significant water abstraction and poor water quality (McNeil and Hammer, 2007). High abundance of this species may instead reflect the poor ecological health of lower Torrens fish communities. The proportional reduction of *P. grandiceps* from 99.6% of the total endemic fish catch during summer 2011 to 92.3% during summer 2012 may be a possible indication of improved fish community health, which is supported by the increase in *P. grandiceps* abundance (from 7,712 to 9,157) during the same period.

The three translocated species displayed variable responses to the trial. The small bodied, translocated *Hypseleotris* spp. displayed a 56.1% decrease in abundance between summer 2011 and summer 2012. It favours still water (McNeil *et al*, 2011a) and the more dynamic flow and variable water quality appears to have disadvantaged this species. Alternatively this species may have been unable to keep station under increased water velocities and was flushed downstream. Numbers of *M. fluviatilis* remained stable through the trail. A positive response was observed in *T. tandanus* with a threefold increase in abundance between summer 2011 and summer 2012, suggesting that amenity flows may have provided some benefit to this species, such as habitat improvement or food availability. This is notable as despite its translocated status in the Torrens, this species is protected in South Australia under the Fisheries Management Act 2007.

Diadromous Species

Four of the five endemic fish species detected (*A. australis, G. maculatus, P. olorum* and *P. urvillii*) share a necessity of oceanic life stages (diadromy). The diadromous species require a timely river-ocean connection to complete their life cycles, which requires timing of river flows to match natural seasonal migrations between freshwater and the ocean (Poff and Allan, 1995). Juvenile *G. maculatus* and *P. urvillii* have been recorded successfully ascending the fish ladder at Breakout Creek during late spring flows (McNeil *et al*, 2010). Between summer 2011 and summer 2012 *G. maculatus* increased in both abundance (from 32 to 756) and range. As immigration events into the system occur during spring flow events the summer flows provided during an amenity flow for cyanobacterial control are unlikely to be the driver of population variations. The increase in *G. maculatus* in the Torrens may not specifically be linked to diadromy, as this species displays partial migration, where only a proportion of the population undertakes migration (Mathwin, 2010) and is also known to persist in land-locked populations (Hammer, 2002; Wedderburn and Hammer, 2003). Without microchemical analysis of otoliths we are unable determine the proportion of the summer 2012 *G. maculatus* population that has immigrated from the ocean (during spring) and the proportion that were recruited within the Torrens. Regardless of the natal origin of this population they thrived between 2011 and 2013 and so it appears that the amenity flows may have played a role in this, possibly through freshening of summer water quality or through providing improved passage between habitats.

The moderate increase in *P. urvillii* abundance from one in summer 2011 to nine in summer 2012 is unlikely to be directly related to summer flow releases. Unlike *G. maculatus* this species is an obligate migrant and all individuals observed must have immigrated from the ocean during late spring flows, however flow delivered during the trail may have contributed to their continued survival in the reach through improved water quality and possibly summer connectance between refugia.

Both *A. australis* and *P. olorum* are distributed unpredictably within this reach. Their suitability as indicators of diadromous fish community health or as indicators of the effects of summer flows is limited. Regardless the presence of the regionally rare *A. australis* at the base of the city weir is encouraging.

Exotic Species

The exotic *G. holbrooki* is widely distributed throughout the WMLR (McNeil and Hammer, 2007; McNeil *et al*, 2011b). It thrives where flows are low or absent and water quality is poor (Pyke 2008). Low flow conditions, particularly over summer, assist in the proliferation and persistence of this species, so it is recommended that these conditions be avoided (McNeil *et al*, 2011a). Decreases in *G. holbrooki* abundance between summer 2011 (n = 1,205) and summer 2012 (n = 702) suggest that amenity flows disadvantaged this species.

Cyprinid (*C. auratus* and *C. carpio*) abundance varied dramatically following the flow improvement trial, falling from 5,348 in summer 2011 to 1,988 in summer 2012. On both occasions populations were dominated by a single large cohort, restricted below two anthropogenic barriers located between Tapleys

Hill Rd and Henley Beach Rd, however there was a notable shift from a community dominated by *C. auratus* in 2011 to a community dominated by *C. carpio* in 2012. As initially hypothesized (McNeil *et al*, 2012), it appears that flow into the Torrens lake during summer provided a stimulus for *C. carpio* summer spawning *in situ*. New recruits were subsequently transported downstream and restricted to the lowest Torrens reach between Henley Beach Rd and the ocean (below the two impassable barriers at this site). This cohort appears to have perished by winter 2012, because no *C. carpio* were detected at this site. This pattern of downstream flushing of cyprinids and mortality *in situ* during late summer suggests that these barriers are not only blocking the inland migration of diadromous fish during spring but also providing an unexpected service in the control of cyprinids in this system. The recent installation of fish ladders at these sites, although positive for diadromous fish, may aid juvenile cyprinids to escape summer mortality events, but this proposition requires testing. This effect is likely to be promoted by the provision of unchecked amenity flows which may cause these fish ladders to become passable. The proportion of flow through the fish ladders and behavioural response of juvenile *C. carpio* and *C. auratus* to these warm summer flows will determine the extent to which these species are able to escape mortality and repopulate the river.

Hypothesis Testing

Hypothesis 1 - During dilution of the Torrens Lake, the presence of cyanobacteria and associated toxins in effluent water will not negatively impact on downstream fish communities.

A biotic transect survey carried out during summer in 2011 found that flows produced no notable impact on the aquatic fauna below the Torrens Lake (McNeil *et al*, 2012). This is further supported by the observed changes to the fish community between summer 2011 and summer 2012 which saw an increase in local native fish abundance and diversity, and a decrease in alien fish abundance.

Hypothesis 2 – Diadromous fishes would be facilitated in moving upstream of the Breakout Creek fish ladder towards the city weir.

Since 2011 *G. maculatus* have increased in abundance and their range has expanded upstream, towards the city weir. There has also been an increase in *P. urvilli* distribution to the Holbrooks Rd weir. The presence of two anthropogenic barriers (beneath Tapleys Hill Rd and between Tapleys Hill Rd and Henley Beach Rd) suggest that this effect was produced during high flow periods where these barriers were submerged. This hypothesis appears true although the role of dilutions flows is unclear.

Hypothesis 3 – In-channel barriers between Breakout Creek and the city weir will prevent upstream fish movements resulting in aggregations below barriers.

Endemic juvenile *P. urvillii* were recorded below the Holbrooks Rd weir, but no further upstream, indicating that this species has extended its range upstream but that barriers to fish movement still exist within the river. Large aggregations of exotic *C. carpio* and *C. auratus* aggregations below barriers at Breakout Creek in 2012 also support this hypothesis.

Hypothesis 4 – Changes in Water Quality resulting from the flows will impact negatively on fish populations where tolerance thresholds are breached.

The increases in endemic diversity and diadromous survivorship over summer suggest that no tolerance thresholds have been breached and that summer flow delivery has provided a protective effect for water quality in pools.

Hypothesis 5 - Flows will induce spawning and/or recruitment responses measurable in fish population structure.

Recruitment responses were observed in *G. maculatus*, *T. tandanus*, and *C. carpio*, thereby supporting the hypothesis.

Hypothesis 6 - Freshwater inflows into the relatively poorer water quality environment of the Torrens Lake will result in aggregations of spawning carp and lead to increases in carp abundance, biomass and distribution.

A large recent *C. carpio* spawning event was apparent during summer 2012 sampling. Compared to the four individuals caught during summer 2011, this species had increased in abundance, biomass and distribution, which supports the hypothesis.

5. Conclusion

Amenity flow releases within the lower Torrens appear to have had a positive effect on local native fish communities. This translated to increased local native fish abundance and diversity and a decrease in alien and translocated fish abundances. No immediate negative effects resulting from changes in water quality due to summer flow releases were apparent and, although *C. carpio* spawning was stimulated, idiosyncrasies in the Torrens morphology meant that these events were of little consequence to fish diversity downstream of the Torrens weir.

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Appendix A – Front page of the weekly Torrens report

Natural Resources
Adelaide & Mt Lofty Ranges

Government of South Australia

CURRENT STATUS

FLOWS

Releases from Hope Valley reservoir:
0 ML/day

Diverted to sewer:
0 ML/day

Diverted to stormwater (and West Lakes):
0 ML/day

WATER QUALITY

Last sampled in Torrens Lake on:
28 March 2013

Current results for samples taken on:
25 March 2013

Average total algal count in Torrens Lake:
1,334 cells/mL

Last sampled in the River on:
25 March 2013

Last sampled in West Lakes on:
25 March 2013

Water quality alerts:
Nil

River Torrens water quality improvement trial - 2012-13

PROGRESS REPORT 28 MARCH 2013

Cyanobacteria levels have remained low since the end of February. And, with the start of cooler and wetter autumn weather it is expected that counts will continue to stay low.

Today marks the official end of the trial for 2012-13. This year's trial has been successful in helping gather data and test dilution as a method of controlling algal growth in the river.

The next step is for the Goyder Institute for Water Research to undertake a detailed analysis of the data collected and prepare an independent assessment of the trial. This report is expected to be available by mid 2013.

SUMMARY OF DILUTION FLOWS

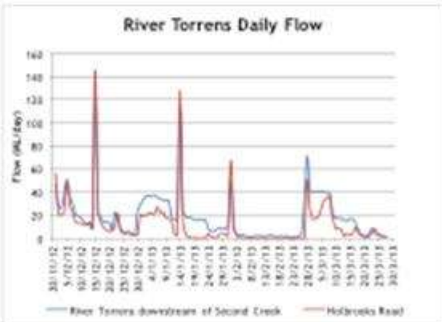
During the 2012-13 trial just under 1.5 GL of water was released from Hope Valley reservoir. Of this approximately 560 ML was diverted to Bolivar wastewater treatment plant for reuse, 260 ML was diverted to West Lakes and 85 ML was diverted to Barker Inlet Wetland.

WHAT'S NEXT

The signs in place along the river which are promoting the trial will be removed in the coming week.

Similarly, the two temporary pump stations, at North Adelaide and Fulham Gardens, will be removed.

Our website will continue to be updated with information about the trial and once completed the full report by the Goyder Institute for Water Research will be available on this site.



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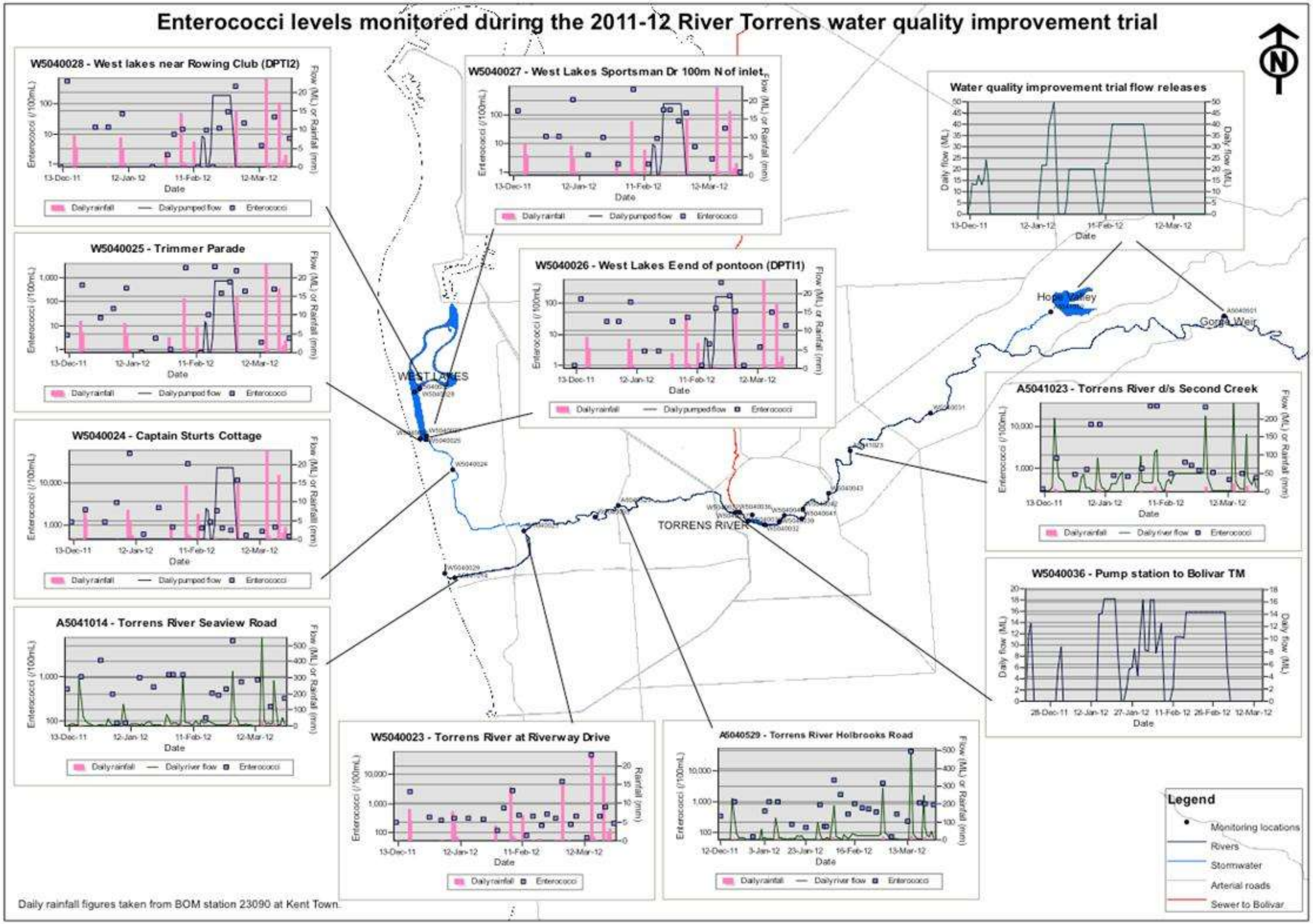
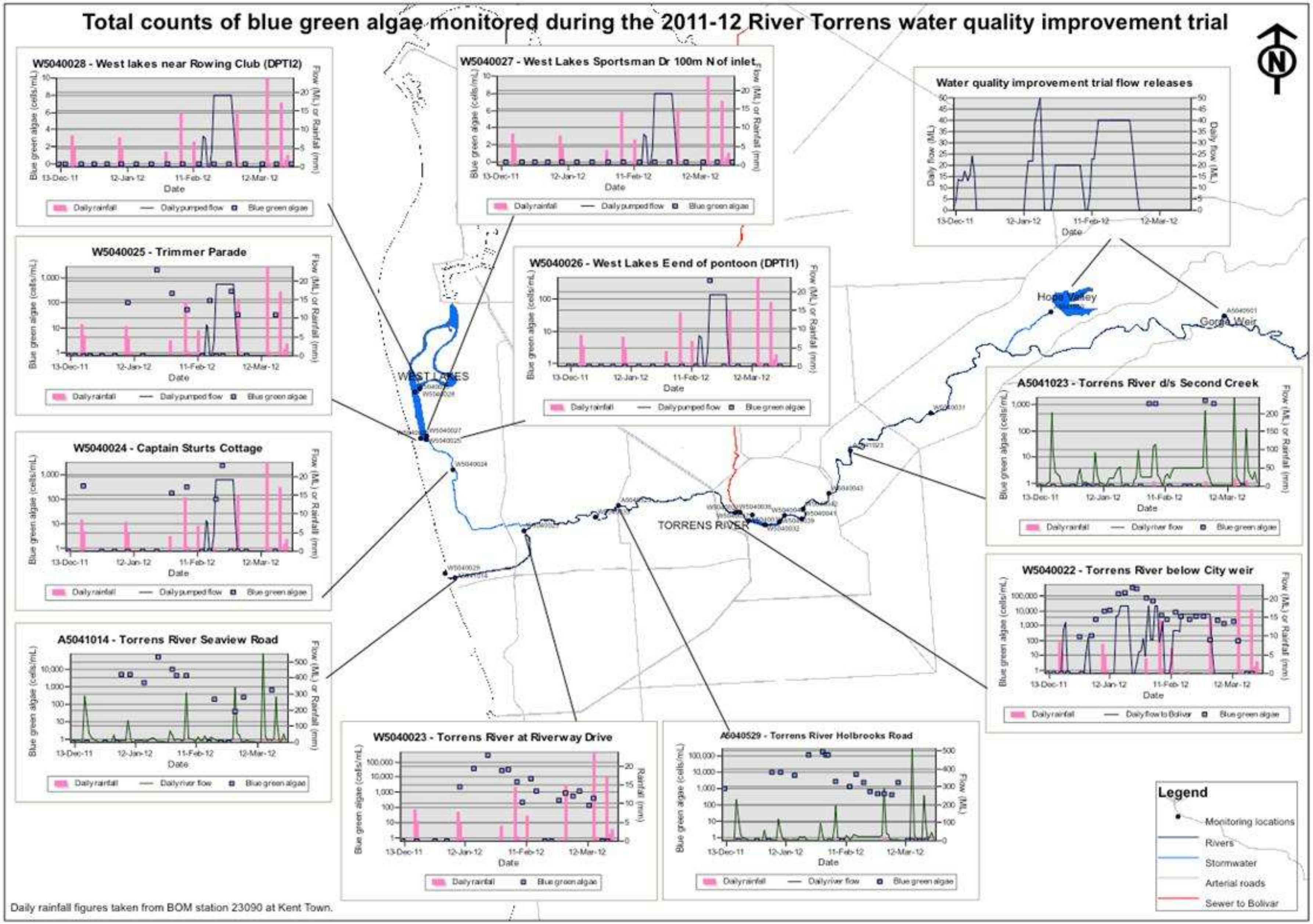


Enterococci levels monitored during the 2011-12 River Torrens water quality improvement trial
W5040028 - West lakes near Rowing Club (DPTI2)
W5040027 - West Lakes Sportsman Dr 100m N of inlet
Water quality improvement trial flow releases
W5040025 - Trimmer Parade
W5040026 - West Lakes E end of pontoon (DPTI1)
W5040024 - Captain Sturts Cottage
A5041023 - Torrens River d/s Second Creek
W5040036 - Pump station to Bolivar TM
A5041014 - Torrens River Seaview Road
W5040023 - Torrens River at Riverway Drive
A5040529 - Torrens River Holbrooks Road
Enterococci (/100mL)
Flow (ML) or Rainfall (mm)
Rainfall (mm)
Daily flow (ML)
Date
Daily rainfall
Daily pumped flow
Daily river flow
Enterococci
WEST LAKES
TORRENS RIVER
Hope Valley
Gorge Weir
Legend
Monitoring locations
Rivers
Stormwater
Arterial roads
Sewer to Bolivar
Daily rainfall figures taken from BOM station 23090 at Kent Town.



Total counts of blue green algae monitored during the 2011-12 River Torrens water quality improvement trial
W5040028 - West lakes near Rowing Club (DPTI2)
W5040027 - West Lakes Sportsman Dr 100m N of inlet
Water quality improvement trial flow releases
W5040025 - Trimmer Parade
W5040026 - West Lakes E end of pontoon (DPTI1)
W5040024 - Captain Sturts Cottage
A5041023 - Torrens River d/s Second Creek
W5040022 - Torrens River below City weir
A5041014 - Torrens River Seaview Road
W5040023 - Torrens River at Riverway Drive
A5040529 - Torrens River Holbrooks Road
WEST LAKES
TORRENS RIVER
Hope Valley
Gorge Weir
Daily rainfall
Daily pumped flow
Daily river flow
Daily flow to Bolivar
Blue green algae
Blue green algae (cells/mL)
Flow (ML) or Rainfall (mm)
Daily flow (ML)
Date
13-Dec-11
12-Jan-12
11-Feb-12
12-Mar-12
Legend
Monitoring locations
Rivers
Stormwater
Arterial roads
Sewer to Bolivar
Daily rainfall figures taken from BOM station 23090 at Kent Town.

The Goyder Institute for Water Research is a partnership between the South Australian Government through the Department of Environment, Water and Natural Resources, CSIRO, Flinders University, the University of Adelaide and the University of South Australia.