LAKE WYANGAN AND CATCHMENT MANAGEMENT STRATEGY – TECHNICAL REPORT

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PROJECT DETAILS

PROJECT NAME	Lake Wyangan and Catchment Management Strategy
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GLOSSARY

Algal biovolume	Algal biovolume is commonly calculated to assess the relative abundance (as biomass or carbon) of co-occurring algae varying in shape and/or size
Apatitie	A widely occurring pale green to purple mineral, consisting of calcium phosphate with some fluorine, chlorine, and other elements. It is used in the manufacture of fertilizers
Bioretention	Bioretention is the process in which contaminants and sedimentation are removed from stormwater runoff. Stormwater is collected into the treatment area which consists of a grass buffer strip, sand bed, ponding area, organic layer or mulch layer, planting soil, and plants.
Blue-green algae	A widely distributed grouping of cyanobacteria occurring singly or in colonies in diverse habitats. Some species can fix nitrogen.
BMAA	The toxin ss-N-methylamino-L-alanine (BMAA)
Chlorophyll a	A green pigment, present in all green plants and in cyanobacteria, which is responsible for the absorption of light to provide energy for photosynthesis.
Coagulant	A substance that causes a fluid to form into a thickened mass.
Cyanobacteria	Any of various photosynthetic bacteria of the phylum Cyanobacteria that are generally blue-green in colour.
Desiccation	Desiccation is the state of extreme dryness, or the process of extreme drying.
Diurnally	Occurring in a 24 hour period
Eutrophication	Excessive abundance of nutrients in a lake or other body of water, which causes a dense growth of plant life
Evapotranspiration	The process by which water is transferred from the land to the atmosphere by evaporation from the soil and other surfaces and by transpiration from plants.
Flocculant	A substance which promotes the clumping of particles, especially one used in treating waste water.
FRP – Free Reactive Phosphorus	A form of phosphorus generally considered to be chemically indicative of orthophosphate
Gross pollutants	Gross Pollutants are anything larger than sediment.
HAB	Harmful Algal Bloom
Heterocyst	A differentiated cyanobacteria cell that carries out nitrogen fixation.
Hydrochory	The dispersal of seeds or spores by water
Hypolimnion/Hypolimnetic	The hypolimnion or under lake is the dense, bottom layer of water in a thermally-stratified lake. It is the layer that lies

	below the thermocline. Typically, the hypolimnion is the coldest layer of a lake in summer, and the warmest layer during winter. Hypolimnetic aeration is aeration of these bottom layers.
Infiltration	Infiltration is the process by which water on the ground surface enters the soil.
Lyse	To break down. Lysis refers to the breaking down of the membrane of a cell, often by viral, enzymic, or osmotic mechanisms that compromise its integrity. A fluid containing the contents of lysed cells is called a lysate.
Macrophyte	A macrophyte is an aquatic plant that grows in or near water and is either emergent (above surface), submergent (below surface), or floating. In lakes and rivers macrophytes provide cover for fish and substrate for aquatic invertebrates, produce oxygen, and act as food for some fish and wildlife.
NTU	Nephelometric Turbidity Units (NTU) is a unit of measurement for turbidity
Oxic	A process or environment where oxygen is involved or present
Pathogens	A bacterium, virus, or other microorganism that can cause disease.
Residence time	The average length of time during which a substance, a portion of material, or an object is in a given location or condition, such as adsorption or suspension.
Lake Stratification	Lake stratification is the separation of lakes into three layers: Epilimnion - top of the lake. Metalimnion (or thermocline) - middle layer that may change depth throughout the day. Hypolimnion - the bottom layer.
Thermocline	An abrupt temperature gradient in a body of water such as a lake, marked by a layer above and below which the water is at different temperatures.
Turbidity	Turbidity is a measure of the degree to which the water loses its transparency due to the presence of suspended particulates. The more total suspended solids in the water, the murkier it seems and the higher the turbidity.
Vivianite	A mineral consisting of a phosphate of iron which occurs as a secondary mineral in ore deposits. It is colourless when fresh but becomes blue or green with oxidization.

1. INTRODUCTION

Griffith City Council (GCC) in partnership with Murrumbidgee Irrigation (MI) commissioned Water Technology and Professors Perran Cook and John Beardall of Monash University to undertake the Lake Wyangan and Catchment Management Strategy project.

Lake Wyangan is situated 6 km's northwest of the Griffith CBD and is the epi-centre for a diverse range of land uses and recreational uses. The immediate area surrounding Lake Wyangan comprises the villages of Lake Wyangan and Nericon, several Rural Residential developments, intensive horticultural farms, grazing land and recreational areas. The North Lake is a very popular recreational facility with several clubs using the area for boating, water-skiing, sailing, rowing, fishing, picnicking, barbequing, and wildlife observation. Rural Residential developments are becoming increasingly popular due to their proximity to these facilities and the aesthetics of lakes.

This diverse land use mix now presents significant water management challenges, particularly as community expectations regarding both water quantity and quality have risen significantly. Of particular concern is the reoccurring incidence of Blue-Green Algae (B-GA) in the lakes. Lake Wyangan regularly attains the NHMRC 2008 Recreational Guideline 'Red Alert' status with biovolume readings ≥10mm^3/L subsequently restricting all access to the lake.

To develop a long-term management strategy, it is therefore necessary to understand the drivers of water quality and ecological condition in Lake Wyangan and how land use in the catchment impacts upon this. This information then informs the development of specific management directions and actions to address water quality concerns.

1.1 Purpose of this Investigation

The project comprised two components; a technical evaluation, and the development of the management strategy. This report details the technical evaluation, which had the following objectives:

- Using available information describe the North and South Lake Wyangan receiving water bodies,
- Define the management objectives of the North and South Lake Wyangan,
- Identify the major potential threat to North and South Lake Wyangan environmental and use value,
- Assess 'in-lake' and 'catchment' water quality and ecological condition and determine what are the 'in-lake' physical, chemical and biological processes, stressors/drivers and modifiers enhancing B-GA dominance in both lakes.
- Determine what are the 'in-lake' and 'catchment' management intervention options available to restore North and South Lake Wyangan 'environmental' and 'use' values, and
- Determine an ongoing program of water quality monitoring for the North and South Lakes to support the understanding of the lake and catchment system and impacts on water quality as well as underpin any modelling and assessment of management interventions.

The outcomes of the technical evaluation then fed into and guided the development of the accompanying Lake Wyangan and Catchment Management Strategy document.

1.2 Methodology Overview

The technical evaluation detailed in this report involved improving understanding of the physical condition of North and South Lake Wyangan, particularly with respect to algal bloom dynamics, nutrient inputs and potential management options. This information directly informs management actions in relation to both the lake and the catchment. The assessment of proposed management actions then involved further technical analysis, resulting in considerable interaction between the technical and strategy components of the project. The overall study process is summarised in Figure 1-1.

Figure 1-1 Overview of the Study Methodology

1.3 Project Team

This project was undertaken as a partnership between Water Technology (Lead Consultant and project manager) and several independent technical experts who provided specialist input to aspects of the assessment.

The team members are summarised as follows:

- Dr Christine Lauchlan Arrowsmith (Water Technology) – project management, hydrodynamics, physical processes
- Yafei Zhu and Dr Cintia Dotto (Water Technology) – water quality modelling specialists
- Jamie Kaye (Water Technology) – ecologist
- Associate Professor Perran Cook (Monash University) - biogeochemist
- Professor John Beardall (Monash University)- biologist

1.4 Reporting

This document presents the outcomes of technical evaluation. This includes details of the water quality and algal monitoring programs, in-lake and catchment processes, as well as the assessment of potential management options.

- Section 2 provides background information on the Lake Wyangan catchment,
- Section 3 details existing water quality data for the lake and presents the results of the recent monitoring program,
- Section 4 describes the ecosystem processes involved in algal bloom development and water quality conditions in the lake and catchment,
- Section 5 presents a detailed overview of both in-lake and catchment management options available for managing algal blooms within Lake Wyangan and water quality in the lake in general, and
- Section 6 summarises the outcomes of the technical investigation including recommendations for future monitoring programs.

Accompanying the main body of the report are also a series of appendices which provide additional information collected for the project.

Outputs from this technical evaluation have been used in the development of the accompanying management strategy for North and South Lake Wyangan and its catchment.

1.5 Public Exhibition and Feedback

Public exhibition of the Lake Wyangan and Catchment Management Strategy occurred in December 2016 and feedback was received via several written submissions. These submissions were reviewed by Council and the final Strategy Report along with the accompanying Technical Report (this document) incorporate the relevant feedback.

2. PHYSICAL SETTING

2.1 Land Use

Situated 6 km north of Griffith, the Lake Wyangan catchment lies within the Murrumbidgee Irrigation Area (MIA) and is bordered on three sides by the McPherson Range, forming a basin which drains towards the lake. Although within the MIA, the topography, vegetation types and soil characteristics are quite different.

Most of this catchment is productive farming land, including intensive horticulture, vegetable growing as well as broad acre agriculture. Much of this agriculture is irrigated through an extensive network of supply and drainage channels. The dominate land uses are horticulture farms growing vineyards, citrus and pasture (McCaffery, 2003). The catchment also includes uncultivated land, land used for commercial uses, remnant vegetation, residential areas, a golf course and oval, the Griffith Airport, irrigation supply and drainage channels, wetland areas, lakes and reserves (McCaffery, 2003).

Close to the lake there are pockets of peri-urban development including the villages of Lake Wyangan and Nericon.

2.2 Geology & Soils

The geology of the Lake Wyangan catchment is much older than the adjacent Riverine Plain which covers much of the MIA. The McPherson Range was formed in the late Devonian Age (approximately 400 million years ago) from the Cocopara Group and comprises sandstones, siltstones, pebbly conglomerate and quartzite sandstone (Pels, 1960).

Most of the surface material within the catchment is weathered deposits with a substantial addition of aeolian clays. The erosion and eluviation of these materials have produced a range of soils and recent geological formations such as lunettes, gypsum deposits and heavy clay soils (Umwelt, 2004).

The revised CSIRO soil survey for the area (Bulletin No. 289, 1979) indicated the soils generally consist of a mantle of loams and sub-plastic clays, with a small and variable component of colluvial and windblown materials (Umwelt, 2004).

2.3 Climate

The Lake Wyangan Catchment is characterised as a Mediterranean type climate with hot summers and cold to mild winters. The average maximum temperature in summer is around 32^{o} C usually with extended periods of temperatures reaching 35^{o} C or more. The average maximum winter temperature is 16^{o} C, with the average minimum only 4^{o} C.

Griffith has an average annual rainfall of around 400 mm, with fairly constant rainfall year-round. Monthly averages range from 28 mm in April to 41 mm in October. Temperatures are highest in January (average maximum 32 degrees) and lowest in July (14 degrees). The mean annual pan evaporation rate is around 1780 mm and follows a clear seasonal trend, with high evaporation rates over summer trending to much lower rates over winter. A summary of average monthly rainfall and evaporation is shown in Figure 2-1, for the Griffith CSIRO weather station 75028, covering the period 1914 to 1989 (rainfall) and 1962-1989 (evapotranspiration).

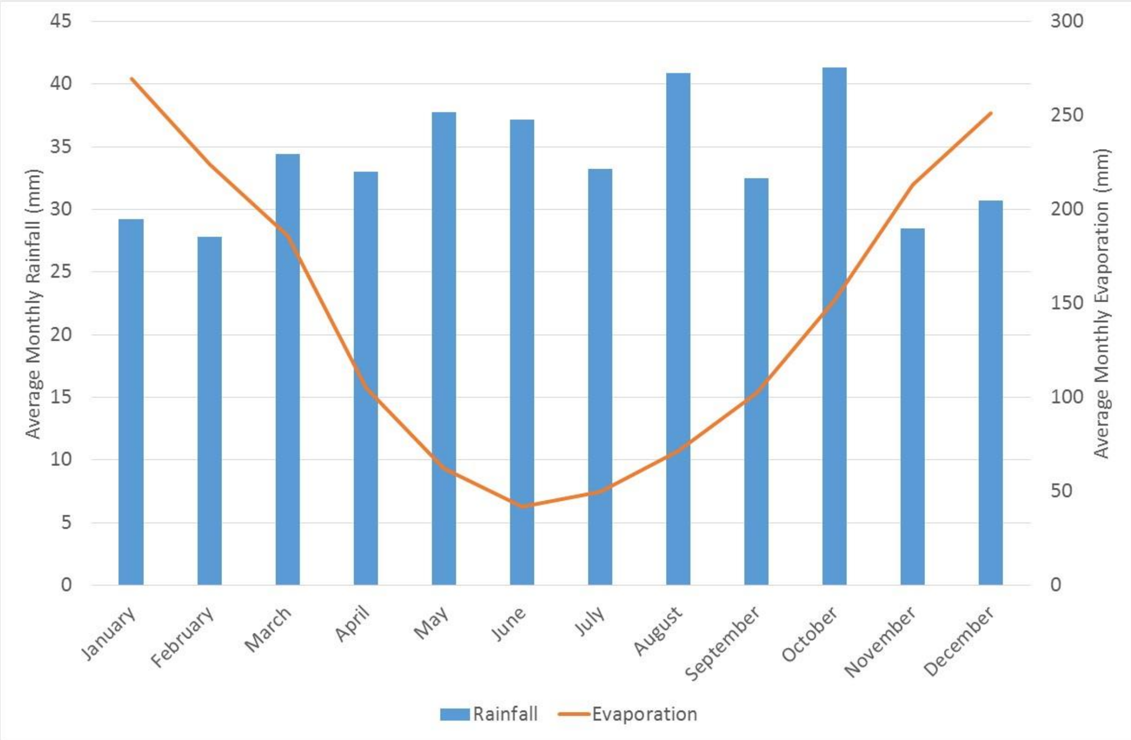


Figure 2-1 Average Monthly Rainfall and Evaporation (Griffith CSIRO)

As can be seen from the data presented in Figure 2-1 the average monthly evaporation exceeds the monthly average rainfall over much of the year. There is therefore a net deficit in rainfall across the catchment.

2.4 Surface Water Catchment

2.4.1 Catchment Area

The Lake Wyangan catchment is a closed system as there is no natural outlet. All runoff and irrigation overflows drain to low points in the catchment including Nericon Swamp, Campbell Swamp, and Lake Wyangan (north and south). Lake Wyangan itself was formed in the 1950's out of a former gypsum mine at the northern end and a low-lying swamp area to the south. North and South Lake Wyangan are separated by an earth embankment along which runs Jones Road. Although currently permanent water bodies, both North and South Lake Wyangan would previously have been considered ephemeral wetlands.

The natural surface water catchment of Lake Wyangan is approximately 75 km^2 (termed "flood catchment") and it lies adjacent to the much larger Tharbogang Swamp catchment (750 km^2) as shown in Figure 2-2. The lake flood catchment extent was confirmed by the flood study investigation for Lake Wyangan (BMT WBM, 2012).

Under low flow conditions and during the irrigation season, the presence of the Murrumbidgee Irrigation (MI) drainage network extends the Lake Wyangan catchment further to the north, encompassing an additional 46 km^2 and therefore totalling around 121 km^2 (12,100 ha). The drainage system collects runoff from the irrigation areas served by the Lakeview Branch Canal system, and collects runoff from the villages of Lake Wyangan and Nericon and any rural sub-division lands. Prior to the Lake Wyangan modernisation project undertaken by MI and completed in 2015, the drainage network also conveyed irrigation escape flows from the Lakeview Branch Canal system to the lake.

This is also shown in Figure 2-3 (termed “drainage catchment”). The flood and drainage catchment areas shown in the figure are less than those attributed to Lake Wyangan in previous studies (e.g. Umwelt, 2004; Port, 2006). Prior to the flood study investigation, it was thought that much of the larger Tharbogang Swamp catchment drained to the lake.

2.4.2 Lake System

The combined water surface area of North and South Lake Wyangan is approximately 300 hectares (Umwelt 2004). A preliminary bathymetric survey of North Lake, undertaken for this project (Appendix A) indicates the bed of North Lake is around 102.5 m AHD. Assuming a maximum operating level of around 106.3 m AHD (the approximate level of Jones Road) this gives a maximum depth of 3.8 m and an approximate storage volume of 6,000 ML.

The lowest bed elevation of South Lake measured during the survey was around 103.7 m AHD, with much of the lake bed at 104 m AHD. This agrees with previous studies which give the mean water depth of South Lake Wyangan at around 2.1 metres (Hoys and Stephens, 1979). The storage capacity of South Lake assuming a top water surface elevation of 106.3 m AHD is therefore around 2,000 ML.

2.4.3 Groundwater Contribution

Problems with high groundwater levels affecting horticultural farm production has been a problem in the catchment in the past and tile drainage systems have been implemented on several farms surrounding the lake. The volumes and quality of tile drainage effluent has not been systematically monitored at Lake Wyangan although intermittent monitoring has been conducted by MI (McCaffery, 2003). The groundwater contribution to the surface water drainage network is therefore uncertain.

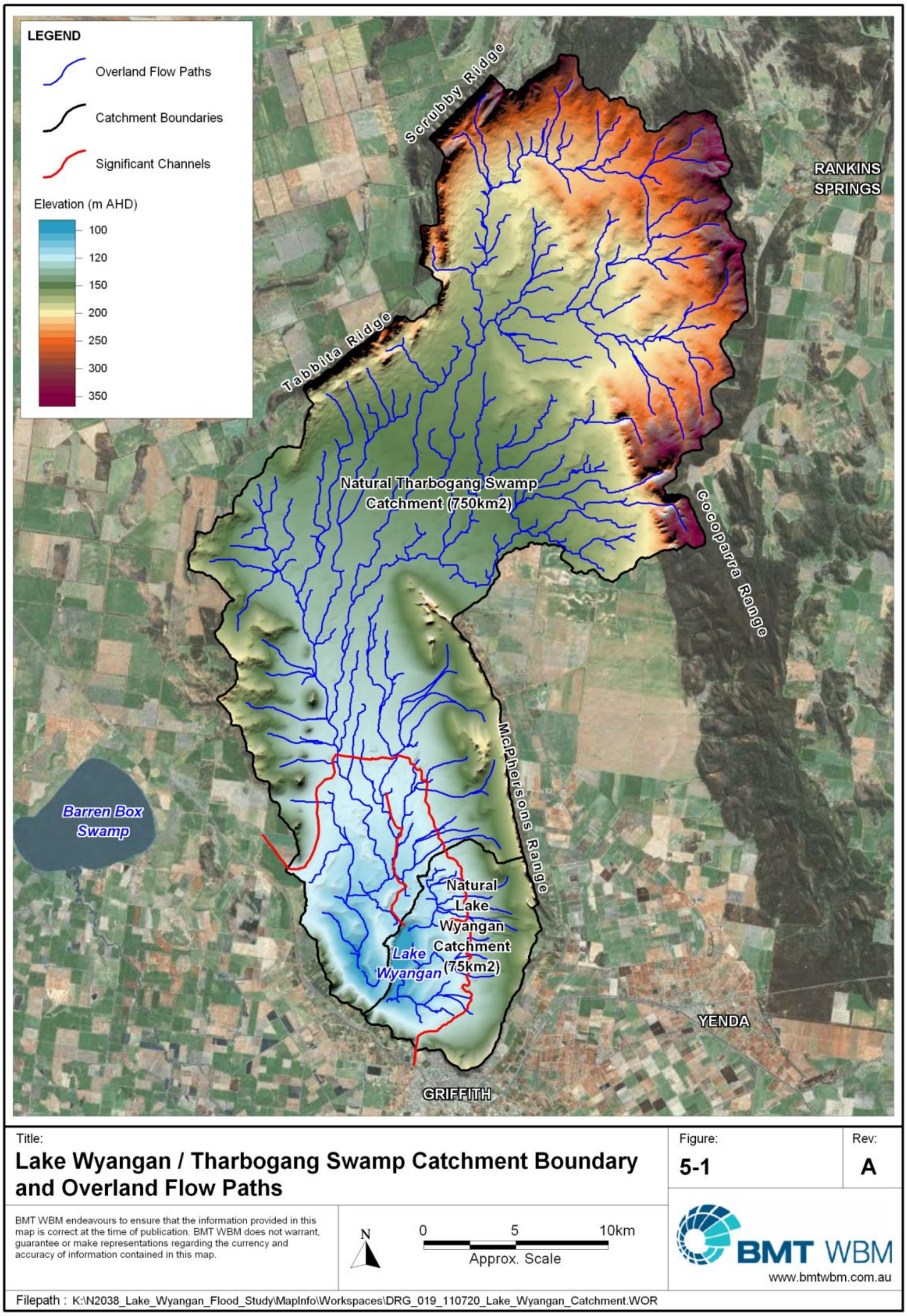


Figure 2-2 Overview of Lake Wyangan and Tharbogang Swamp Natural catchments

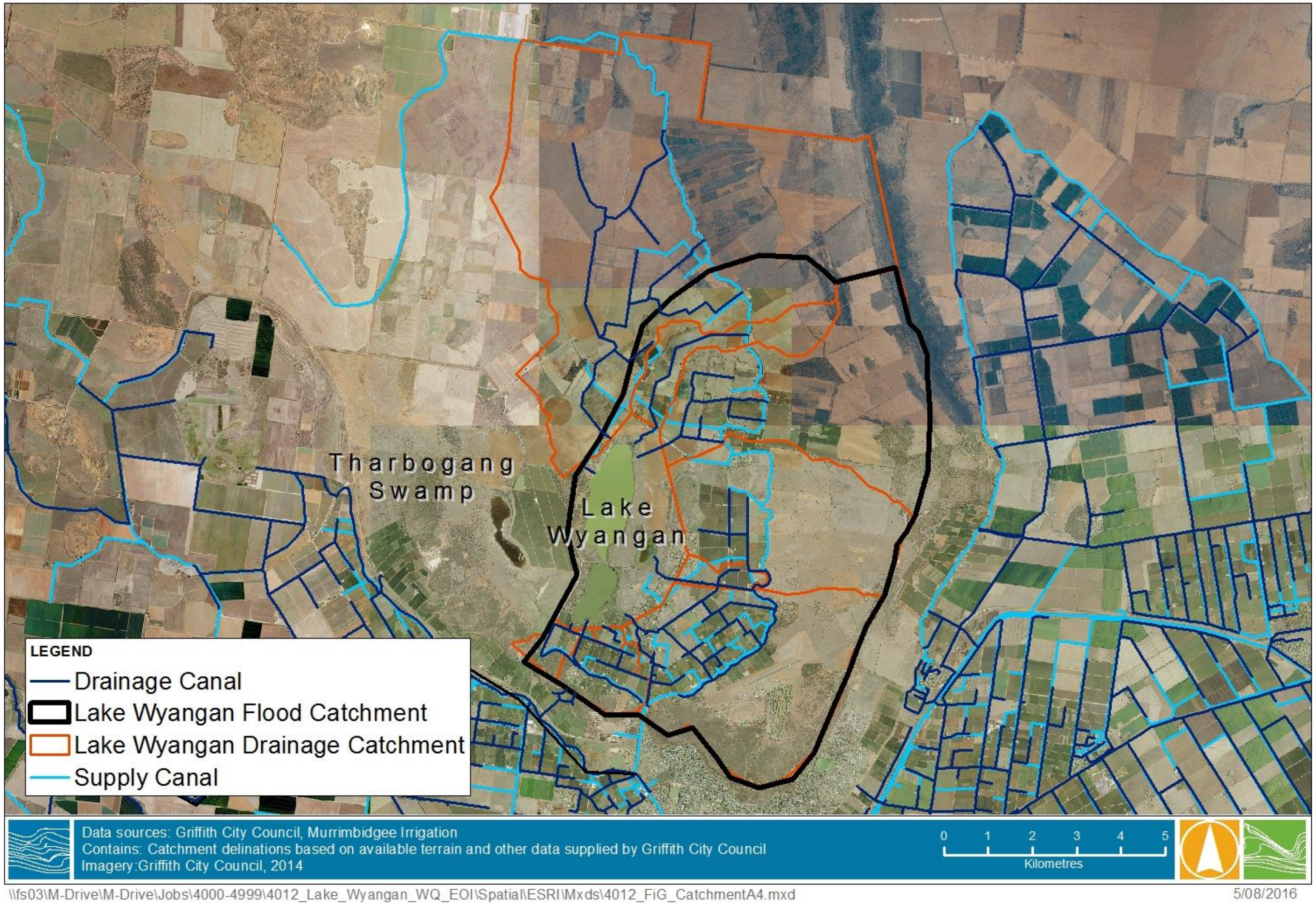


Figure 2-3 Outline of Lake Wyangan Flood and Drainage Catchment

3. MONITORING DATA REVIEW AND ANALYSIS

3.1 Overview

Operationally, North Lake is managed by Griffith City Council (GCC) while South Lake Wyangan is managed by Murrumbidgee Irrigation (MI), forming part of the Lake Wyangan Hydrozone, situated within the Mirrool Irrigation Area of the MIA. Both GCC and MI have water quality monitoring programs in Lake Wyangan, and there have been several previous studies to assess the water quality conditions in the lake.

Water quality monitoring in recent times has focussed on detection of B-GA however a detailed summary of previous bloom occurrence and duration, bloom severity, or species composition is not available. An internal analysis by Council in 2006 found that the previous MIA and Districts Community and Water Management Plan (1998) identified the Lake Wyangan water quality as a concern due to the nutrient levels being above the threshold levels for algal blooms. In 2001 there was a blue green algal bloom on Lake Wyangan owing to high levels of nitrogen and phosphorus, adequate light, low turbidity, limited turbulence and warm water temperatures.

For this technical assessment, previous data and reports were reviewed and used to assess data gaps in relation to the water quality processes of Lake Wyangan. An enhanced monitoring program was then developed and implemented for the lake and catchment to address these data gaps. In addition, a pilot project was undertaken to assess the possible use of satellite imagery analysis to enhance or expand more traditional field monitoring approaches. The section is structured as follows:

- Overview of existing water quality monitoring data for Lake Wyangan,
- The results and analysis of additional sediment and water quality sampling undertaken for this project,
- The results from a revised sampling project undertaken by Griffith City Council and Murrumbidgee Irrigation over the course of this project (September 2015 to June 2016),
- Further analysis of algal data collected over the course of the project and comparison to previous data,
- The results of the pilot application of satellite imagery for detecting B-GA within the lake,
- An overview of the existing vegetation communities around the lake and drains, and
- Recommendations for future monitoring to support the Lake Wyangan and Catchment Management Strategy.

The results of the monitoring program and data collection described in this section have been used to inform the analysis of potential management options for the lake which are detailed in Section 5.

3.2 Existing Water Quality Monitoring

3.2.1 Griffith City Council Sampling

Pre 2008

A previous summary of the water quality results found that over the period 2001-2006:

- The total coliforms range from a minimum of 10 org/100ml to a maximum 44,000 org/100ml and faecal coliforms averaged 347 orgs/100ml,

- pH range between 6.9 – 9.5 but averaged at 8.5,
- Nitrogen levels at Lake Wyangan North and South sample locations ranged between 5.5 mg/L and 0.5 mg/L.

A summary of the nitrogen concentration data for the monitoring site in North Lake at the South Lake inlet is provided in Figure 3-1. No details of any algal sampling data for this period and no flow information is available for any of the incoming drains.

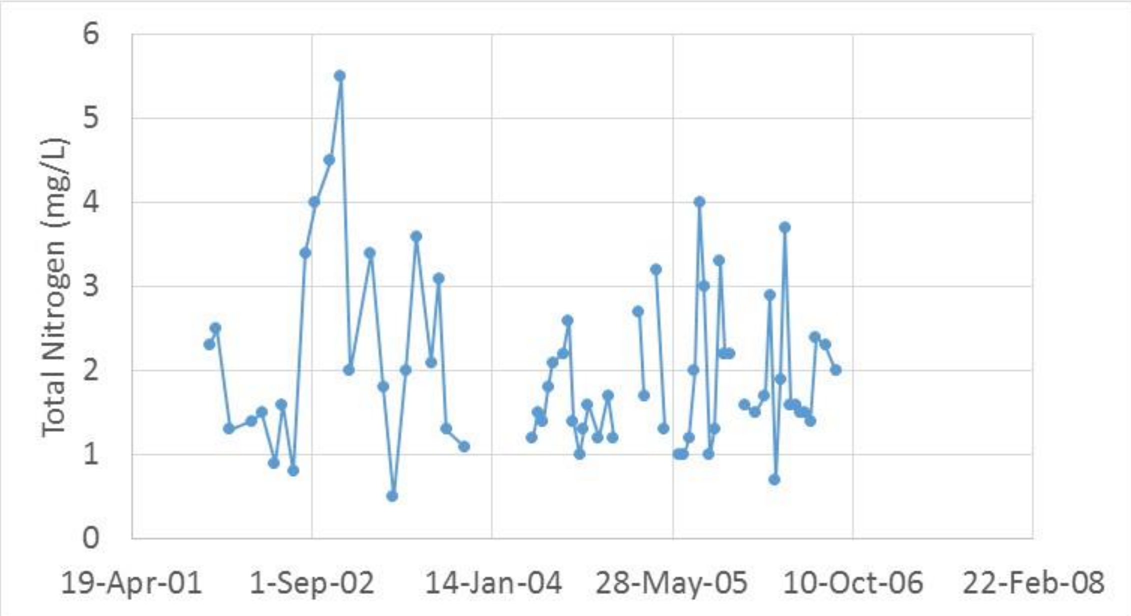


Figure 3-1 Nitrogen Concentrations in North Lake near Jones Road Causeway

Post 2008

Griffith City Council has undertaken water quality monitoring of Lake Wyangan since 2008 on a monthly or fortnightly basis. There are six existing sampling sites, five in North Lake Wyangan (North, Recreation Area, Camping Area, Boat Club, and East), and one in South Lake Wyangan (the red dot locations as shown in Figure 3-2). The sampling program has predominantly focussed on the presence of animal or human pathogens (total and faecal coliforms as indicators), algae (types and biovolumes), pH, turbidity and nitrogen. Again, no inflow information has been captured for any of the inflowing drains.

- **Existing GCC Lake Sampling, red dot sites:** LW-N = North, LW-S = South, LW-RA = Recreation Area, LW-CA = Camping Area, LW-BC = Boat Club, LW-E = East.

The green dot sites shown in the figure are additional sites included as part of an expanded monitoring program for this study. These sites are discussed further in Section 3.4

- **Additional GCC sampling sites, green dot sites:** NLW-1 and NLW-2 = north lake drains, NLW-3 = recreation area, SLW-1, SLW-2 and SLW-3 = south lake drains, LW6 = south lake

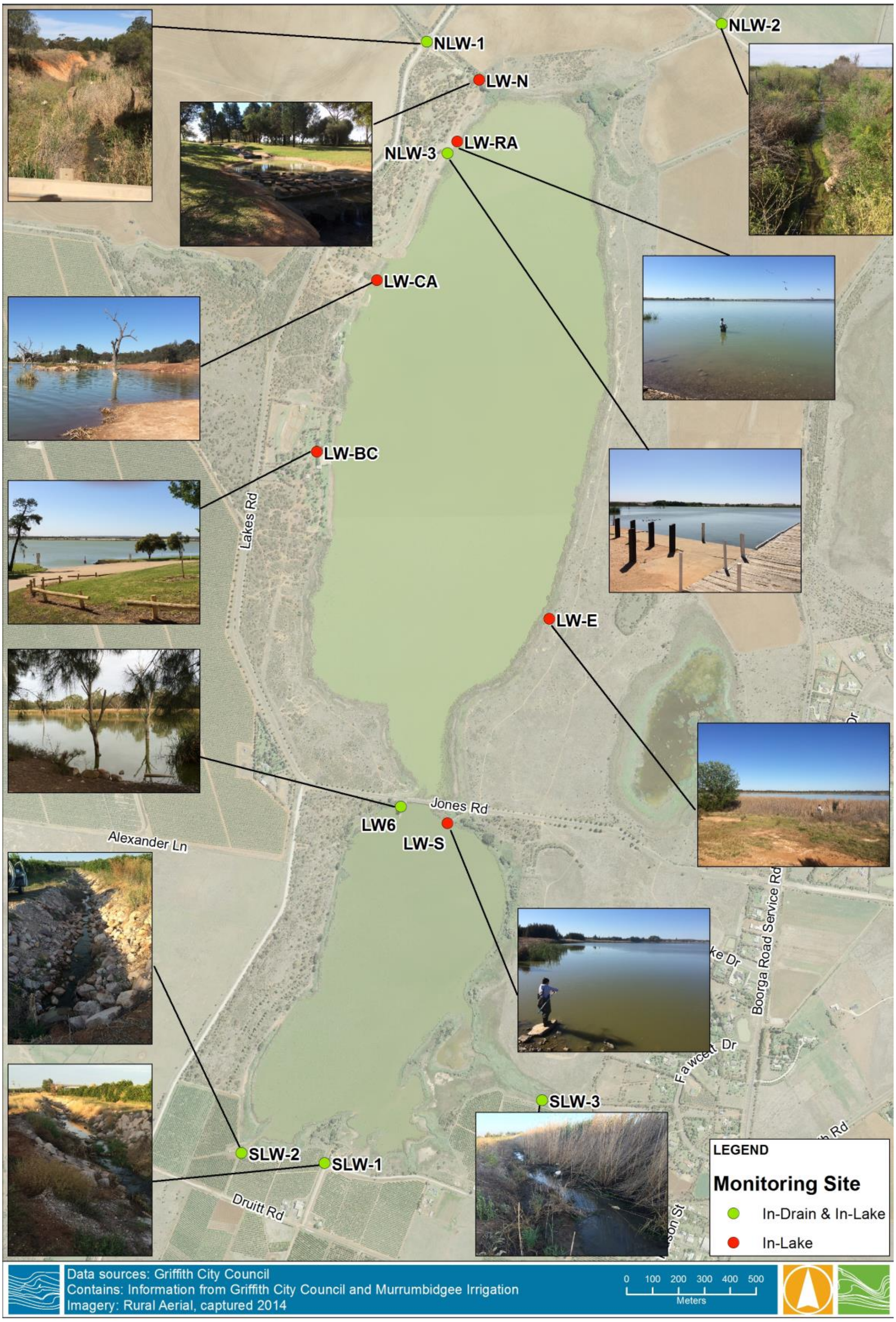


Figure 3-2 *GCC Lake Wyangan Monitoring Locations*

The monitoring data for B-GA since 2008 is shown Figure 3-3. This clearly shows a consistent increase in B-GA volumes in North Lake since 2013. Interestingly, this follows a significant rainfall event in March 2012 during which the Lake Wyangan catchment experienced widespread flooding. As detailed in BMT WBM (2013), the 2012 event resulted in widespread overland flows from the north of the catchment flowing south towards Lake Wyangan and Tharbogang Swamp. This area to the north of the lake is used for dryland farming, spray or drip irrigation (ERIC, 1999) and it is likely that the overland and drainage flows from this event which entered the lake would have contained high levels of nutrients. Other significant rainfall events occurred in 1985 and 1989, however no monitoring information is available for the lake after these events.

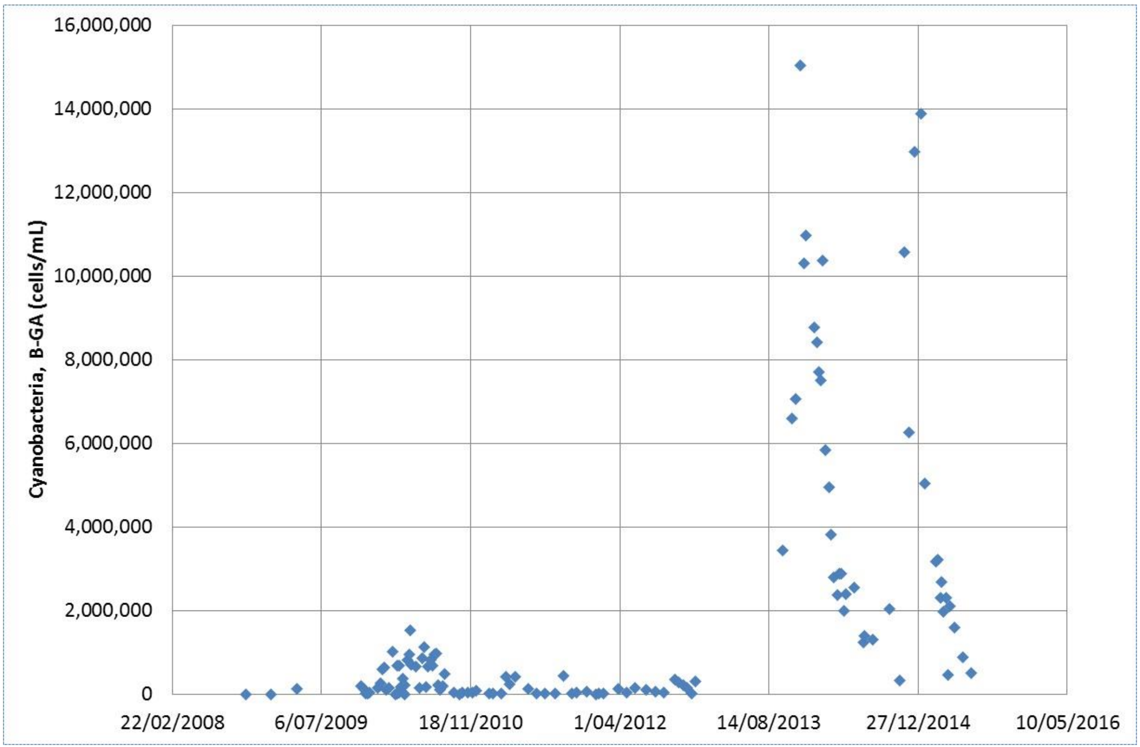


Figure 3-3 B-GA Volumes (2008-2015)

To investigate the link between the algal biomass and nutrient levels the total biomass volumes in North Lake Wyangan along with Total Nitrogen measured at the Boat Club is shown in Figure 3-4 for the period August 2014 to May 2015. Total Nitrogen concentrations are similar to the earlier monitoring data.

The following nitrogen fixing cyanobacteria were identified in Lake Wyangan from the previous monitoring:

Aphanizomenon gracile, Cylindrospermospsis racibororskii, Gleocapsa (now called *Gloeothece*; can fix N_2 in darkness), *Pseudanabaena, Planktolyngbya minor, Planktolyngbya microspira, Anabaena bergii, Anabaena, Aphanothece spp*. (some strains fix N_2), *Pseudanabaena Limnectica, Anabaena aphanizomenioides, Anabaenopsis elekinii, Aphanizomenon ovalisporum, Phormidium* (some species might be N_2 fixers), *Anabaena torulosa, Oscilliatoria, Aphizomenon issatchenkoi, Cylindrospermopsis,* Nostocaceae, *Anabaenopsis*

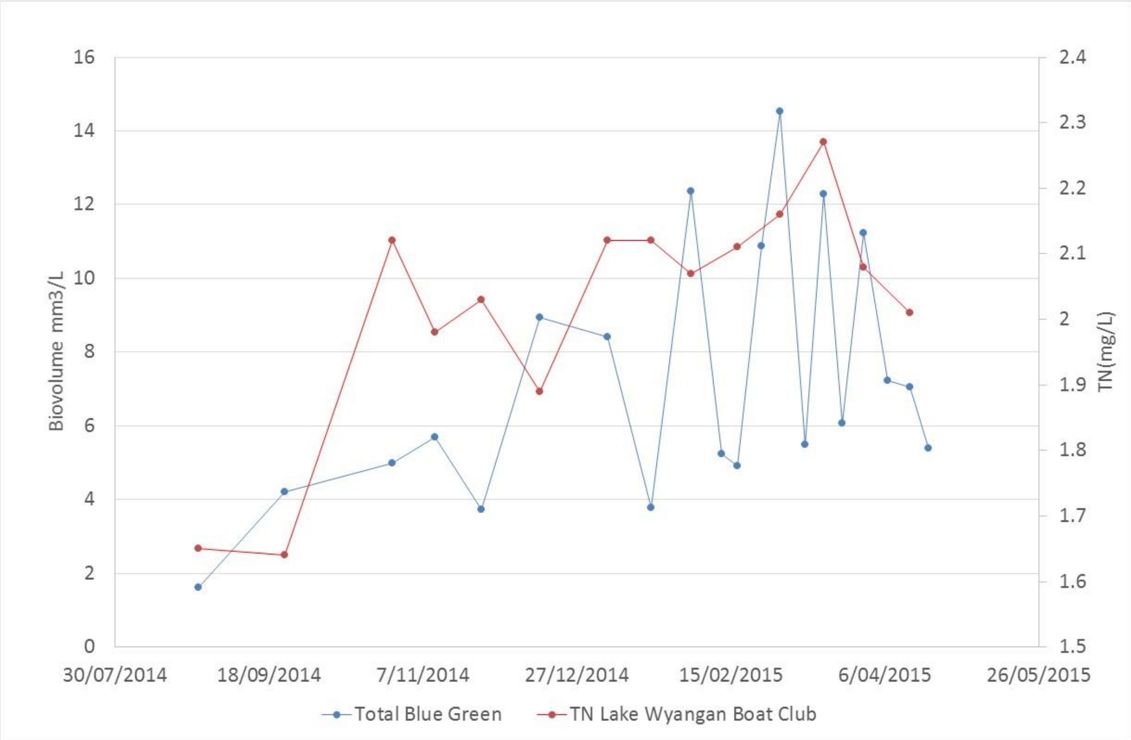


Figure 3-4 ***Total Blue Green Algae Biomass Volumes and Total Nitrogen in North Lake (July 2014 to May 2015)***

3.2.2 Murrumbidgee Irrigation Sampling

MI have collected Lake Wyangan water quality data as early as 1957 and sampling is on-going at the Lake Wyangan pump site located in the northern extent of South Lake Wyangan in from sampling site LW6 and adjacent to Jones Road. The water quality sampling has focussed on water temperature, pH, turbidity and pesticides.

A 2006 analysis found South Lake Wyangan water quality parameter data collected has been inconsistent over the years, with no single set of parameters collected continuously. In general, water temperature ranging from 0°C to 29.5°C, and lake turbidity tended to be around 114 NTU.

3.3 Sediment and Water Quality Sampling

To manage and potentially improve the water quality within Lake Wyangan it is necessary to identify the relative importance of nitrogen and phosphorus in driving current blooms and the relative importance of catchment and internal sources of nutrients (derived from the sediment). This study collected six (6) cores from the North and South Lakes on the 11 August 2015 and analysed them for different forms of nitrogen and phosphorus. In addition, water quality samples were also taken from the Lake itself and three (3) inflowing drains to complement the sampling programs currently being undertaken by GCC and MI. Refer to Appendix A for the full report.

3.3.1 Approach

Sediments within the lakes can provide a potential source of nutrients which can drive the generation of algal blooms. In the sediment, phosphate is usually bound to iron coatings on the surface of mineral particles and is not available to the biota. However, in the absence of oxygen, bacteria can dissolve the iron coating, which releases the phosphate back into the water column. Thermal stratification facilitates this process by establishing oxygen-free conditions on the sediment surface.

To assess the potential for lake sediment as a source of nutrients six intact sediment cores were collected from a boat in North and South Lake Wyangan as shown in Figure 3-5. Cores were aerated and stored at in-situ temperature (~48 hrs) before being sectioned in the lab. Sediment sections were subsampled for centrifugation to collect porewater and sequential extraction for phosphorus (Ruttenberg, 1992). Water samples were also collected within the lake at the same sites as cores as well as 3 inlet drains (north drain ND, and 2 south drains SD1 and SD2) for later analysis of total nitrogen (TN), total phosphorus (TP) as well as samples for ammonium, phosphorus and nitrate (filtered through a 0.2 mm filter).

Nutrient samples were analysed at the Monash University Water Studies Centre using standard methods in a NATA accredited laboratory. Solid samples for stable isotopes were analysed on Hydra 20–22 isotope ratio mass-spectrometer and coupled ANCA-GSL2 elemental analyser (Sercon Ltd., UK). Samples of dissolved nitrate were analysed for $\delta^{15}N$ using the method of (McIlvin and Altabet 2005). Isotope values are reported in the δ notation relative to ambient air with precision = 0.1%.

Figure 3-5 **Sampling locations for sediment cores and water quality within North and South Lake Wyangan (blue markers) as well as three return drains sampled (red markers)**

3.3.2 Results and Discussion

Temperature and Dissolved Oxygen

The physicochemical data shows that the North Lake Wyangan was slightly temperature stratified and that this caused dissolved oxygen concentrations to drop to <80% saturation at depths >1 m (Figure 3-6). The South Lake Wyangan was slightly stratified, although this was not reflected in the dissolved oxygen profiles, which showed super saturation at all depths. The lowest data point shown in the plots is within 0.5 m of the bottom. As only a single series of measurements was taken for this study it is not known if the stratification observed persists or whether it breaks down or changes at night or when there is increased turbulence as a result of wave action or other factors. Further measurements are required to investigate stratification effects further.

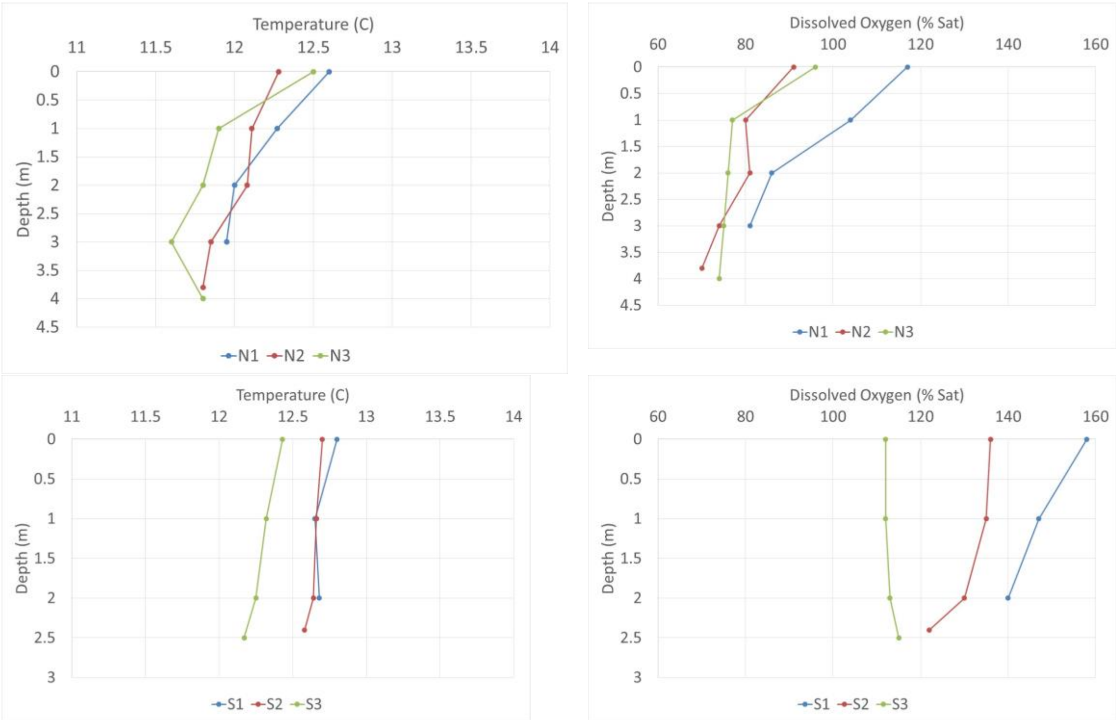


Figure 3-6 Temperature and Dissolved Oxygen Profiles at the North Lake (top) and South Lake (bottom), 11 August 2015

Water Column Nutrient Concentration

Concentrations of all forms of nutrients are detailed in Table 3-1 and were consistent within the North and South Lakes, with average concentrations of 0.38 and 4.1 mg/L for TP and TN respectively in the South Lake and 0.04 and 1.8 mg/L in the North Lake for TP and TN respectively. Key findings were:

- Concentrations of total nutrients were much higher than ammonium, nitrate+nitrite and filterable reactive phosphorus (FRP) suggesting nutrients are bound up in biomass which is consistent with the very high chlorophyll-a concentrations. The TN to TP ratios averaged 24 and 94 in the South and North Lakes respectively. This is well above the Redfield ratio of 16, suggesting that the phytoplankton are phosphorus limited (Guildford and Hecky, 2000).
- Phosphorus concentrations within the drains were very low, consistent with the high water clarity observed.
- Nitrogen was dominated by nitrite+nitrate, which is to be expected from water draining agricultural sources, although the concentrations were not considered high for this land use.
- Chlorophyll concentrations were highest in the South Lake, falling in the range 85-100 μg/L and 5-8 μg/L for the North Lake. For reference > 20 μg/L is regarded as hypereutrophic and 6-20 μg/L is regarded as eutrophic (Hakanson et al. 2007). The $\delta^{15}N$ values fell in the range 1.9-2.8 ‰ for the North Lake and 3.6-4.2‰ in the South Lake. Isotopic analysis of the nitrate entering from the drains showed the values were much

higher – with $\delta^{15}N$ values in the range of 6.9 – 14.8 ‰. The lower isotope values of algae in the lake than the source nitrogen entering from the catchment are consistent with algae deriving most their nitrogen requirements from N2 fixation (Woodland et al. 2013) as well as the large number of cyanobacteria species capable of nitrogen fixation within the lake (refer to Appendix report for species list).

Table 3-1 **Concentrations of total phosphorus (TP), total nitrogen (TN), ammonium (NH_4^+), filterable reactive phosphorus (FRP) and nitrate + nitrite (NOx)**

Site	TP	TN	NH_4^+	FRP	NOx	Chlorophyll *a*	Turbidity NTU	$\delta^{15}N$ ‰	TN:TP (molar)
S1	0.37	4.2	0.002	0.003	0.003	110	172	4.2	25
S2	0.37	4.0	0.001	0.003	0.002	79	155	3.8	24
S3	0.39	4.0	0.002	0.003	0.002	83	156	3.6	23
N1	0.05	1.9	0.10	0.003	0.041	5.3	18	2.8	84
N2	0.04	1.8	0.11	0.003	0.042	8.9	16	2.2	100
N3	0.04	1.8	0.11	0.003	0.043	8	17	1.9	100
SD1	0.06	2.3	0.029	0.013	1.8	-	-	11.5	85
SD2	0.06	5.6	0.006	0.008	3.2	-	-	14.8	207
ND1	0.04	1.5	0.011	0.002	0.87	-	-	6.9	83

Note: All concentrations are given in mg/L (as N or P) except chlorophyll a, which is given in $\mu g/L$ and $\delta^{15}N$ in ‰. The $\delta^{15}N$ values in the lakes are given for suspended particulate material and the values in the drains are given for NO_3^-.

Sediment Nutrient Profiles

Nutrients, particularly phosphorus, can be bound within the sediment. A typical sediment nutrient depth profile of the different phosphorus fractions extracted from the sediment is shown in Figure 3-7. Easily exchangeable (free) phosphorus comprised a negligible fraction of total phosphorus. Iron bound phosphorus (Asc P) typically comprised the largest fraction of P extracted, with the highest concentrations occurring at the sediment surface. During water column anoxia, this phase of phosphorus is most easily released from the sediments (Scicluna et al. In press). HCl P is likely to represent a variety of phases including various forms of apatite and vivianite as well as P sorbed onto clay surfaces. This form of P is typically increased with depth and is relatively stable within the sediment. Organic P (org P) is most likely associated with phytoplankton and plant detritus. This fraction of P typically decreased with depth in the sediment. This fraction of P is only likely to be available over month-year timescales.

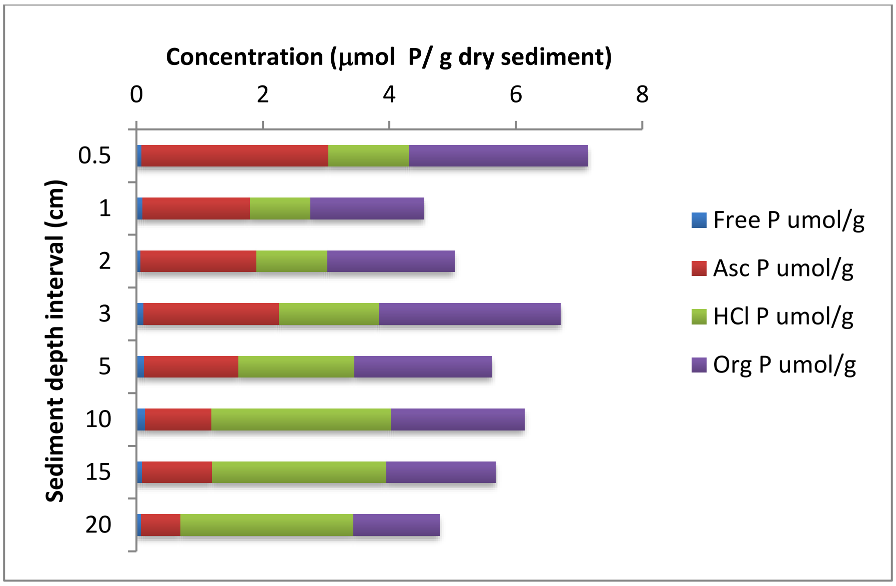


Figure 3-7 Different fractions of P for N1

Within the context of water quality, the iron bound phosphorus is of greatest relevance because it can be rapidly released during stratification, and the profiles of this fraction are shown at all sites (Figure 3-8). All profiles showed a characteristic peak at the surface reflecting the highest concentration of available iron oxides in this region of the sediment. Consistent with the water quality data, sediment phosphorus concentrations were highest at South Lake Wyangan. Below 15 cm, concentrations decreased to ~2 µmol P/g dry sediment in South Lake Wyangan and 1 µmol P/g dry sediment in North Lake Wyangan.

Assuming that concentrations of iron bound P above these background concentrations can be released during anoxia, then this conservatively equates to a releasable concentration of 1.7 and 1.07 µmol P/g dry sediment in the South and North Lakes respectively. Scaling this to the porosity (0.84), density (2.65) and volume per square meter (0.2 m^3) over the area of the North (2.1 km^2) and South Lakes (0.9 km^2) gives a total mass of 3.9 and 5.5 tonnes of P in the South and North Lakes respectively. This compares to a standing mass of 0.76 and 0.48 tonnes of P in the water column of the South and North Lakes respectively.

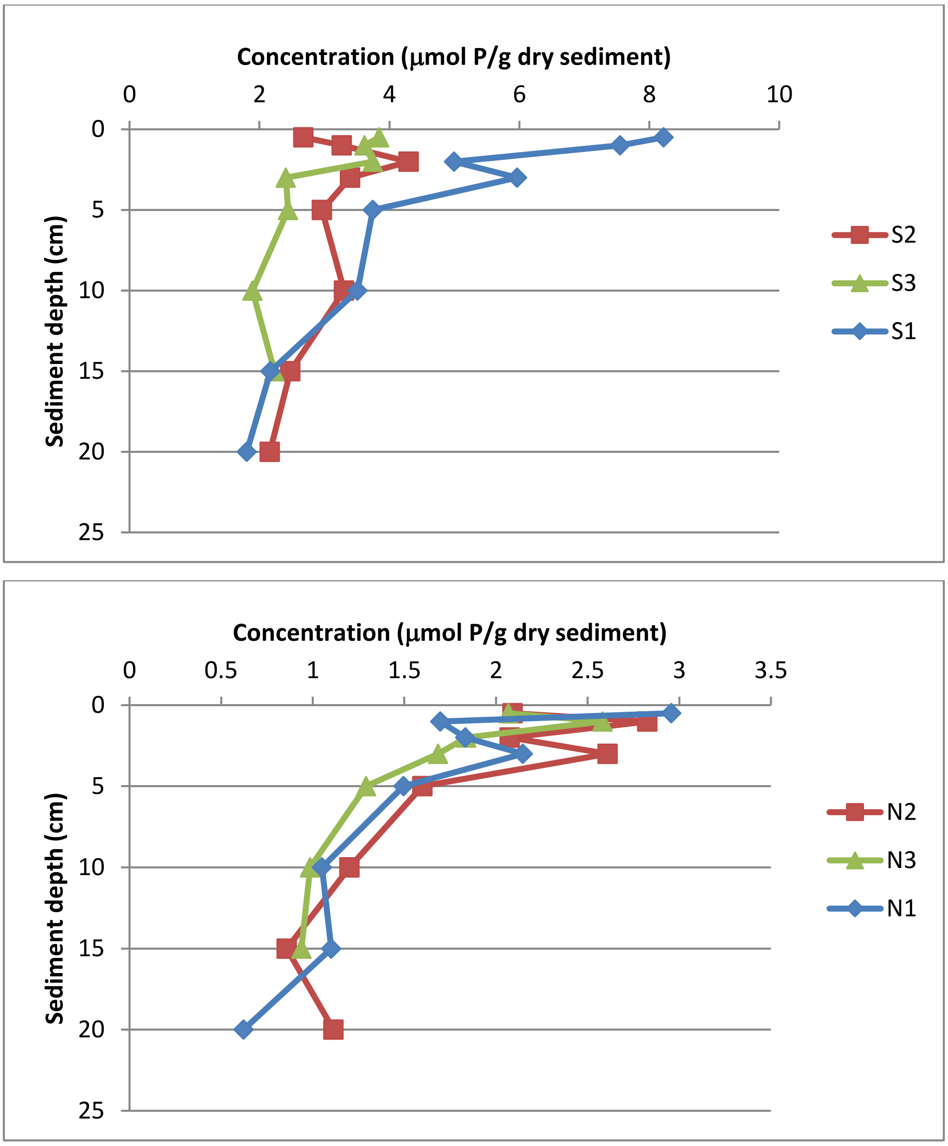


Figure 3-8 *Profiles of iron bound (ascorbate extractable) phosphorus in Lake Wyangan South (top) and North (bottom).*

3.4 Updated Monitoring Program Results

3.4.1 Overview of Sampling

Based on a review of the existing monitoring data, a site visit, and discussions at the first expert panel meeting the following knowledge gaps were identified in relation to the water quality processes in North and South Lake Wyangan:

- The inflow rates and water quality in the drainage channels flowing into the North and South Lake is unknown.
- Phosphorus concentrations in the lakes are unknown.
- The existing sampling programs provides only limited spatial coverage.

To address these knowledge gaps and aid the development of the catchment and lake management strategy an updated collaborative water quality monitoring program was developed between Griffith City Council and Murrumbidgee Irrigation. The key components of the program are described in Figure 3-9 and Figure 3-10. This program commenced in September 2015 and continued through to end of June 2016. The final sampling schedule for the project is provided in Appendix B. Unfortunately, inflow rates in the drains could not be included in the monitoring program for this project but have been identified as a critical requirement for future monitoring.

1. In-Drain & In-Lake Sampling - GCC #	Site	Location	Criteria	Parameters Analysed (where possible)
Weekly	NLW-1	In-Drain	Sampling to occur during/after significant (>15mm) rainfall when possible	Total Suspended Solids, Total Nitrogen, Total Phosphorus, Ammonia, Phosphate, Nitrate + Nitrite as N, EC (salinity), Temperature, Dissolved Oxygen
Refer Figure 3-10 for Site Locations (green dots)	NLW-2	In-Drain		
	NLW-3	In-Lake		
	LW6	In-Lake		
	SLW-1	In-Drain		
	SLW-2	In-Drain		
	SLW-3	In-Drain		

2. In-Lake Sampling - GCC ●	Site	Location	Criteria	Parameters Analysed
Continuing	LW-N	In-Lake	Samples to be taken In-Lake at existing GCC sites & frequency	Blue-Green Algae cell counts and biovolumes, Faecal Coliforms, Heterotrophic Count, Total Coliforms, Total Nitrogen, Total Phosphorus
NB. Using current GCC Site Naming	LW-RA	In-Lake		
Refer Figure 3-10 for Site Locations (red dots)	LW-CA	In-Lake		
	LW-BC	In-Lake		
	LW-E	In-Lake		
	LW-S	In-Lake		

3. In-Lake Sampling (Boat) - MI ✖	Site	Location	Criteria	Parameters Analysed
Monthly	NLW-4	In-Lake	Samples to be taken by boat	Total Suspended Solids, Total Nitrogen, Total Phosphorus, Ammonia, Phosphate, Nitrate + Nitrite as N, Phytoplankton Cell Counts/Biovolumes
Refer Figure 3-10 for Site Locations (blue dots)	SLW-4	In-Lake		

Figure 3-9 Outline of Updated Water Quality Monitoring Program

The weekly in-drain and in-lake sampling (Item #1) was programmed to be undertaken weekly, with the samples to be taken during or immediately after significant rainfall (>15mm) when possible.

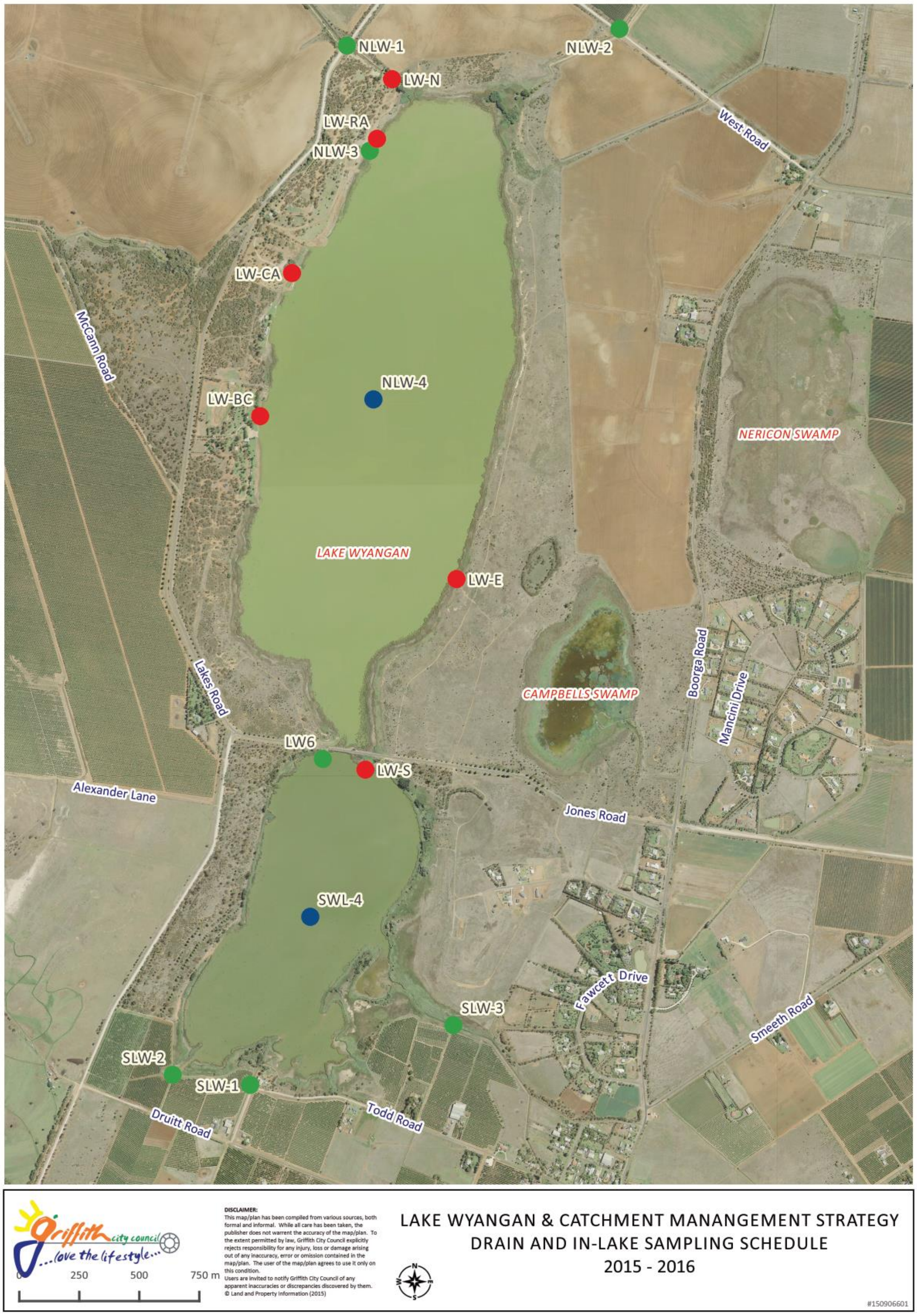


Figure 3-10 Overview of Sampling Sites

In-Drain & In-Lake GCC Sampling, green dot sites: NLW-1 and NLW-2 = North Lake drains, NLW-3 = recreation area, SLW-1, SLW-2 and SLW-3 = South Lake drains, LW6 = South Lake

Existing GCC In-Lake Sampling, red dot sites: LW-N = North, LW-S = South, LW-RA = Recreation Area, LW-CA = Camping Area, LW-BC = Boat Club, LW-E = East

MI In-Lake Sampling (boat), blue dot sites: NLW-4 = North Lake central, SLW-4 = South Lake central

The drains entering North Lake Wyangan capture runoff from a range of land uses. Crop types upstream of NLW-1 and NLW-2 include viticulture, citrus, almonds, melons, winter cropping and livestock grazing. An area on the northeast of North Lake has been identified for future peri-urban development.

South Lake Wyangan drains SLW-1 and SLW-2 drain areas of horticultural crop, predominantly citrus and viticulture. Drain SLW-3 drains areas of horticultural crops as well as urban/peri-urban areas around Lake Wyangan village.

3.4.2 Nutrient Results

The following section summarises the results of the nutrient and algae monitoring program. No flow measurement information was collected during the study.

GCC In-Drain and In-Lake Sampling (Green Dots)

The results for TN and TP for samples taken in the drains (NLW-1, NLW-2, SLW-1, SLW-2 and SLW-3), one site in North Lake (NLW-3), and one site in South Lake Wyangan (LW-6) are shown in Figure 3-11 and Figure 3-12 for the period September 2015 to end of March 2016. Additional sampling was conducted in June 2016 and shows similar trends.

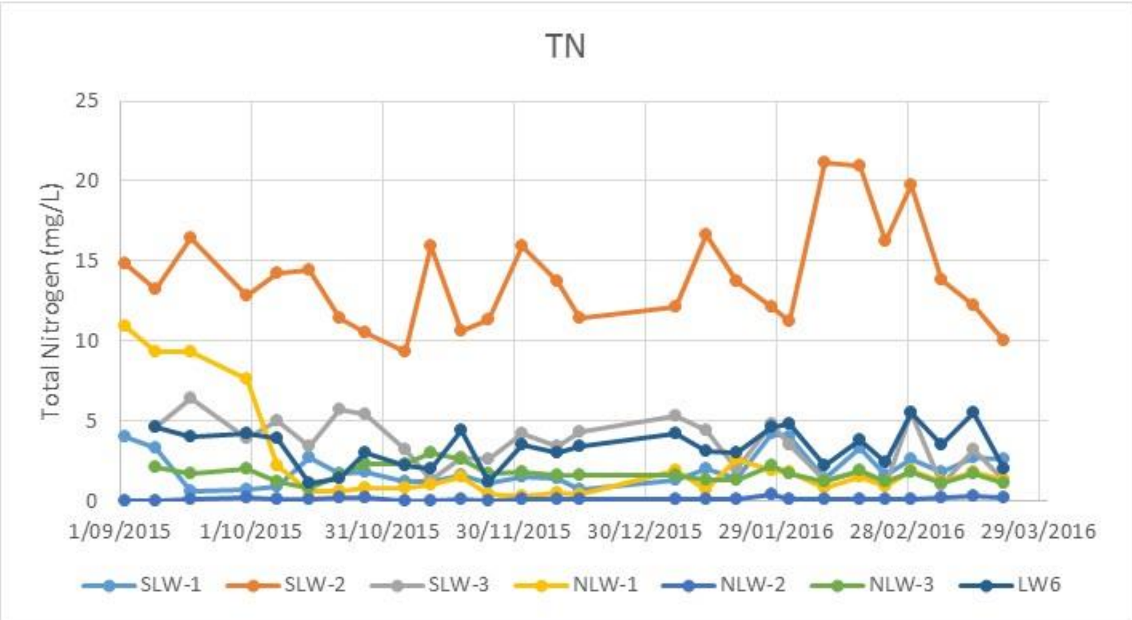


Figure 3-11 Total Nitrogen Concentration – Green Dot Sampling

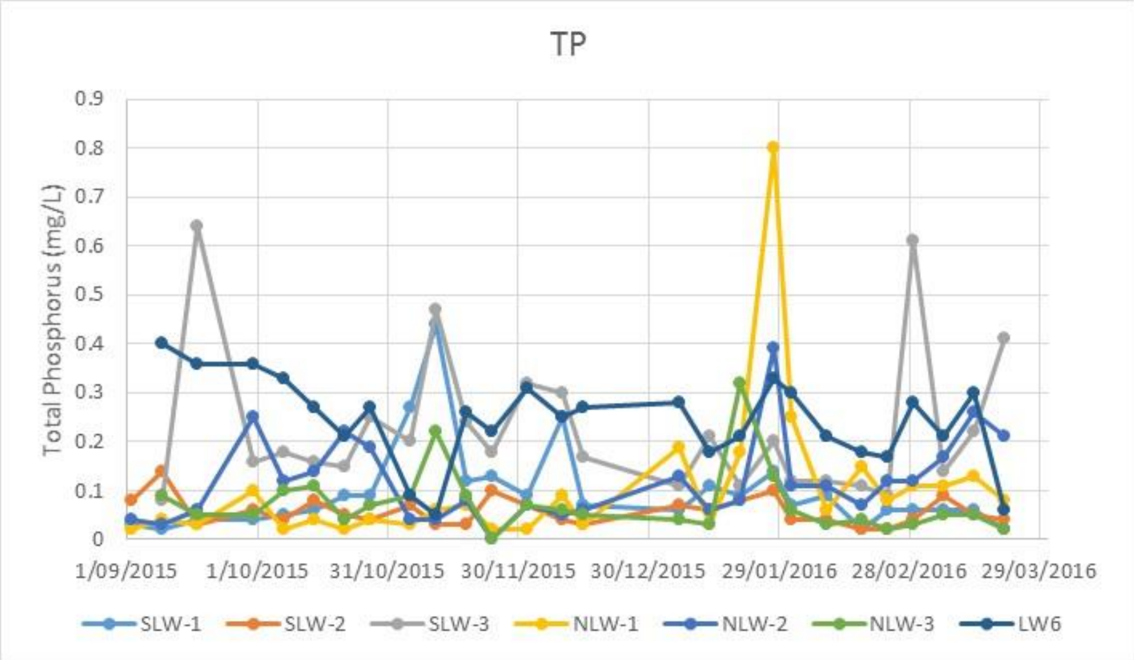


Figure 3-12 *Total Phosphorus Concentration – Green Dot Sampling*

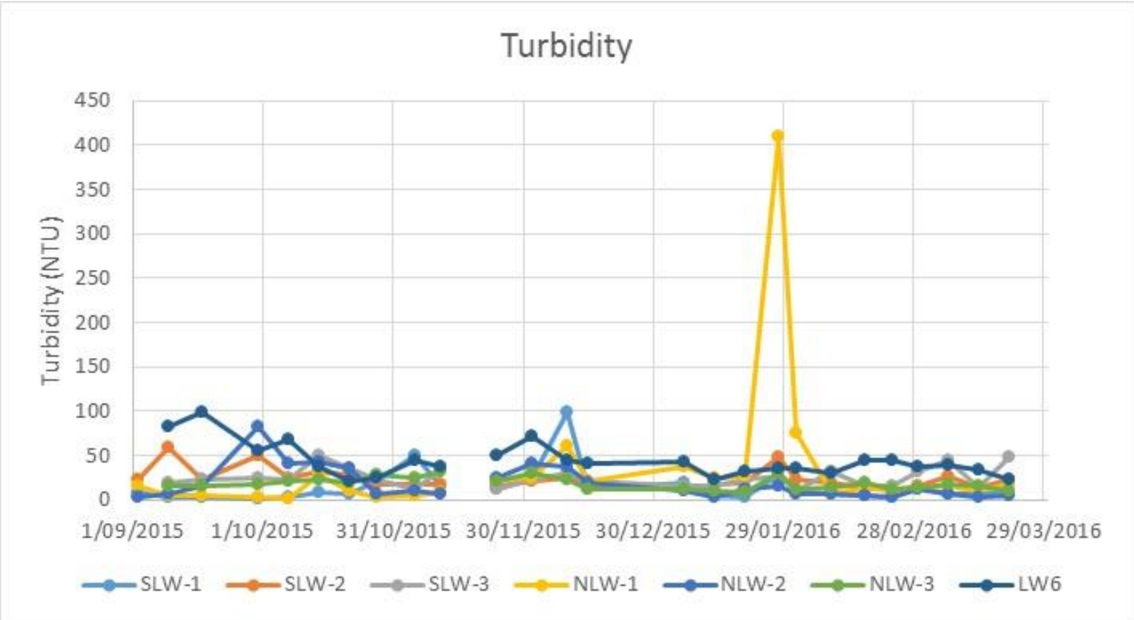


Figure 3-13 *Turbidity Concentration - Green Dot Sampling*

For comparison, the measured nutrient levels for the lake and the drains can be compared to the range of nutrient and chlorophyll-a concentrations, within which a shallow lake system is likely to have manageable algal growth. The closer to the lower end of the range, the less the likelihood of having regular algal blooms, and the closer to the higher end is more likely (Melbourne Water, 2005).

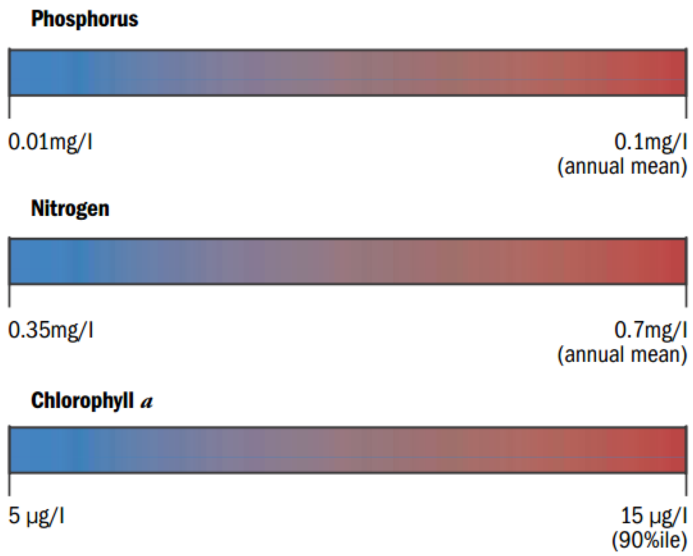


Figure 3-14 Acceptable range of Phosphorus, Nitrogen and Chlorophyll-a concentrations for a "manageable" lake (Melbourne Water, 2005)

Appendix B contains a paper on additional sampling that was undertaken by GCC following rainfall events in January and June 2016. It was observed that the flow in NLW-1 following these events had a distinct ochre orange brown colour and resulted in a "plume" across the northern section of North Lake. These types of inflows are likely to have contained high levels of phosphorus absorbed to the sediment.

Existing GCC Sampling Sites (Red Dots)

Overall, results across the 6 red dot monitoring sites showed a range of TN values from 0.41 to 9.6 mg/L, with an average of 2.2 mg/L (Figure 3-15); TP values ranged from 0.015 to 0.14 mg/L with an average of 0.08 mg/L. TN to TP ratios ranged from 10 to 630, with an average of 46.

Sites in North Lake at the Boat Club (LW-BC), Camping Area (LW-CA), Recreation Area (LW_RA), and on the East side of the lake (LW-E) show consistent results across each of the site, except for a spike in both Nitrogen and Phosphorus for the East (LW-E) site in mid-April 2016. This sampling was taken following rainfall events and the site itself is adjacent to Campbell's Swamp. Concentrations are typically higher during the start of the irrigations season from September to December then decline across January to April.

The South (LW-S) site is the only site on South Lake and clearly shows elevated levels of both nitrogen and phosphorus across the monitoring period. Nitrogen levels show an increasing trend. Which is different to North Lake, with levels approximately 3 times the concentration at the North Lake sites. Phosphorus concentrations are consistently greater than 6 times the concentration at the North Lake site.

The North (LW-N) site is located in the drain which flows through the recreation area. This site showed very high nitrogen concentrations at the start of the monitoring which decreased rapidly. Sampling was not possible at this time in some periods due to lack of flow.

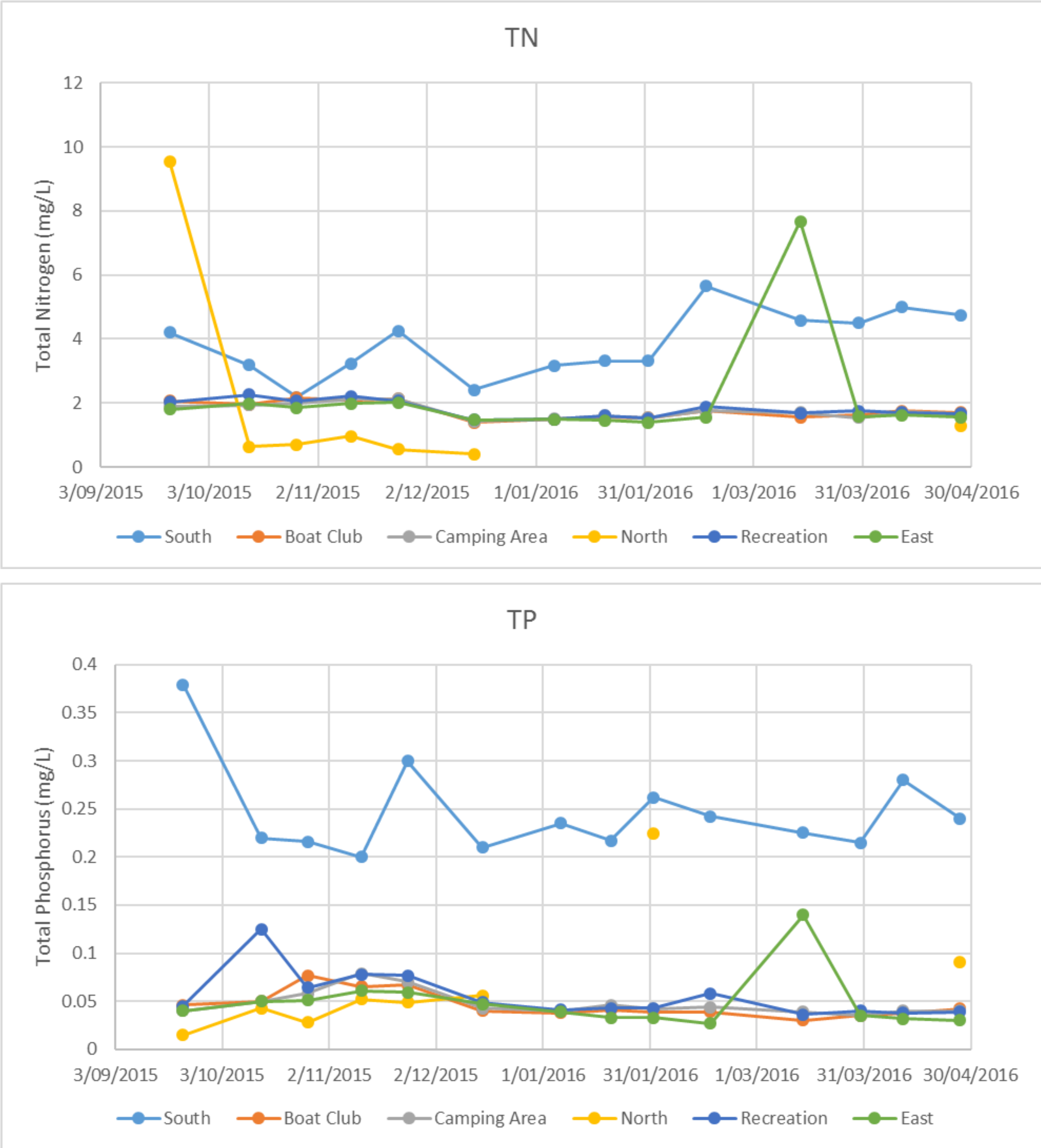


Figure 3-15 Sampling Results for Existing GCC Sampling Locations (Red Dots)

MI In-Lake Sampling (Blue Dots)

MI conducted in-lake sampling at sites SLW-4 and NLW-4. The results showed Nitrogen concentrations in South Lake were approximately twice the level in North Lake and Phosphorus concentrations were up to 4 times higher in South Lake than North Lake. This is consistent with the GCC sampling data.

3.4.3 Algal Sampling & Analysis

Algal sampling was also undertaken both in-lake and in-drain from September 2015 to March 2016.

GCC In-Drain and In-Lake Sampling (Green Dots)

Figure 3-16 shows the results of the sampling. B-GA biovolume was typically less than 0.01 mm^3/L except for NLW-3 which ranged from 0.07 mm^3/L to 0.65 mm^3/L and LW6 which ranged from 0.002 mm^3/L to 0.178 mm^3/L. NLW3 is located off the jetty at the Recreational Area

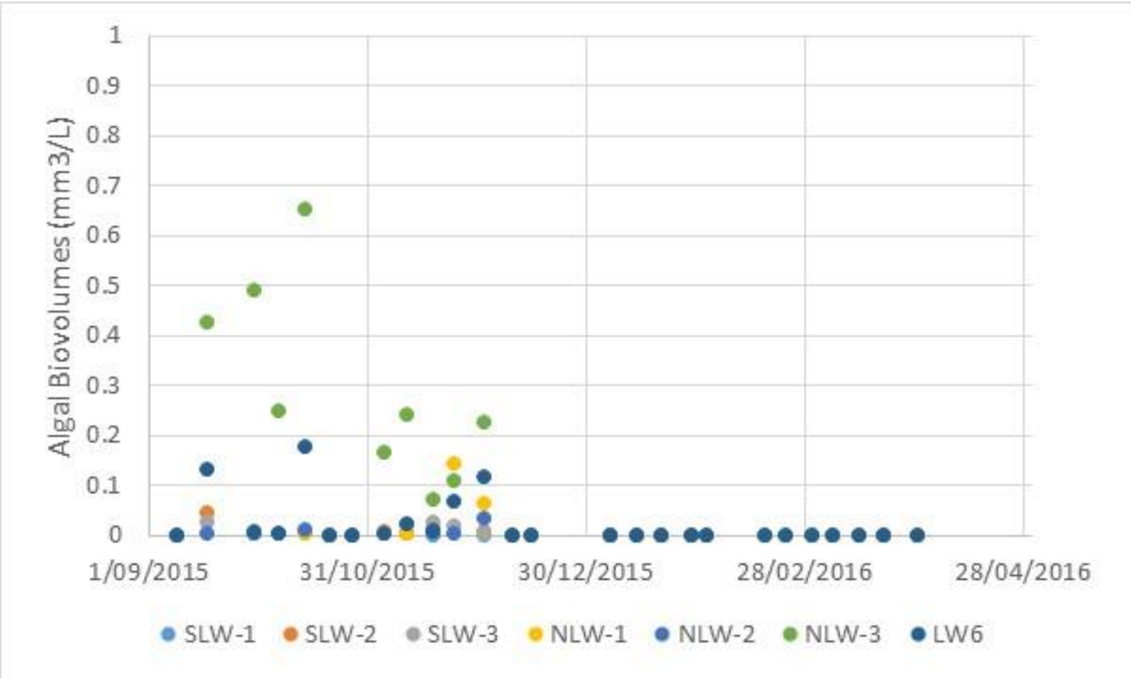


Figure 3-16 B-GA Algal Biovolumes (Green Dots)

Existing GCC Sampling Sites (Red Dots)

Algal sampling conducted by GCC at the existing sampling sites (Red Dots) is analysed as a composite sample. The laboratory analysis determines the total B-GA biovolume and also estimates the potentially toxic B-GA biovolume within the other sample. The results of the sampling over the project are shown in Figure 3-17.

Only 3 or 4 commonly occurring B-GA bloom forming taxa are potential toxin producers in Australia (*Microsystis* spp., *Dolichospermum circinale*, *Cylindrospermopsis racaborskii*, *Nodularia spumigena*), with around another 8 to 10 much less commonly occurring taxa also considered having the potential to produce toxins. Even within the species that are considered potentially toxic, some genetic strains are capable of producing toxins, while other strains within the same species lack the genes for the biosynthesis of these toxins, and are therefore non-toxic.

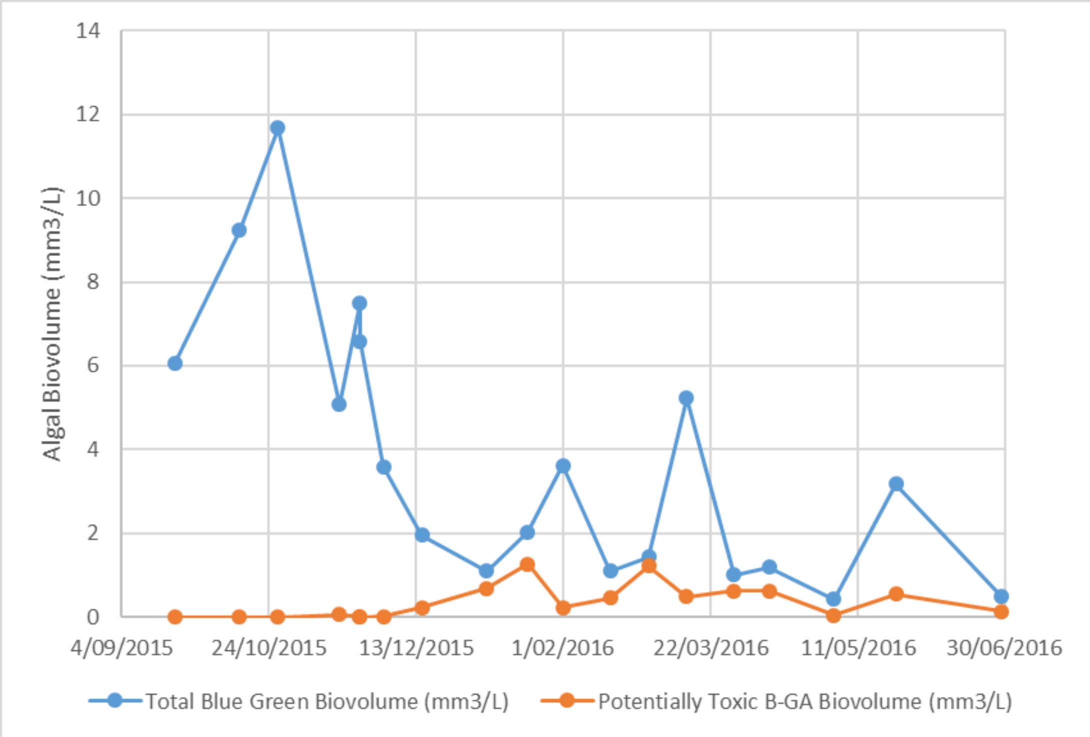


Figure 3-17 B-GA Algal Biovolumes (Red Dots)

To investigate this further, Dr Lee Bowling, a Principal Limnologist from the NSW Department of Primary Industries undertook an analysis of the available algal monitoring data supplied by GCC covering the period March 2007 to June 2016 to understand the potential toxicity associated with the various B-GA taxa present in the lake. Dr Bowling was on the steering committee for this project.

The analysis, as shown in Figure 3-18, indicates B-GA blooms have occurred in the lake in 2008 and then from 2013 onwards, with B-GA algal biovolumes at or above the level of 10 mm^3/L which would trigger the Red alert criteria for recreational water use. He observed that most of the blooms were dominated by taxa not known to produce toxins in Australia, with potentially toxic taxa usually comprising less than 40% of the total biovolume. Different potentially toxic taxa tended to contribute to the blooms in different years.

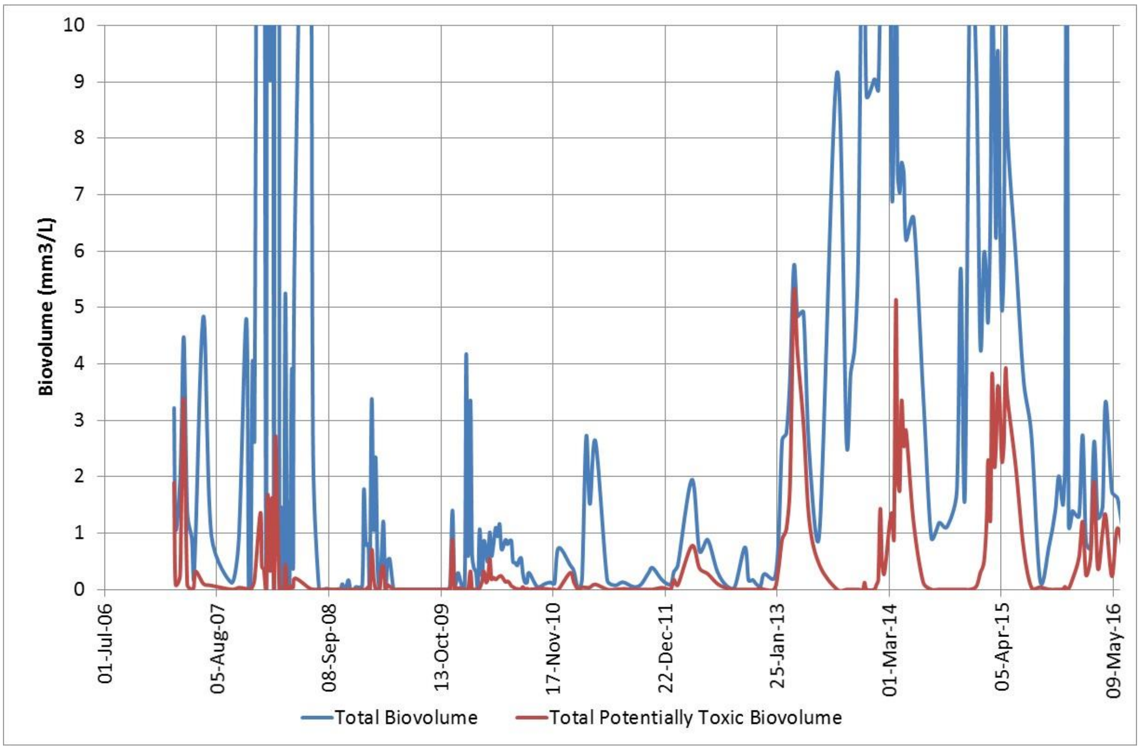


Figure 3-18 Comparison of total B-GA Biovolume and potentially toxic B-GA biovolume in Lake Wyangan

For the analysis the following assumptions were made:

- "Anabaena" and "Anabaena (coiled)" have been combined. Without any further information, as to what taxa either of these groups may be, it is assumed that they are both Anabaena circinalis (now Dolichospermum circinale), as this species is potentially toxic and therefore the worst-case scenario.
- "Microcystis" and Microcystis aeruginosa" have been combined and assumed that they are all M. aeruginosa, as this species is potentially toxic and therefore the worst-case scenario. Other morphotypes of Microcystis, such as M. flos-aquae, (and which may also be potentially toxic) are just as likely to be present and may be part of the "Microcystis" count, but this is an unknown. M. flos-aquae has much smaller cells than M. aeruginosa, so if it was part of the count the Microcystis biovolumes that has been calculated based on M. aeruginosa may be overestimates.
- All Pseudanabaena taxa are considered as P. galeata.
- The data included 8 different groups for Planktolyngbya, some identified to species, others not (some just as "large filaments", "small filaments" - whether this meant filament length or width is unclear, or whether these are counts of actual filaments only or counts of the cells within the filaments). The different nomenclature also varied at different times during the sampling period.
- The laboratory changed on 27th May 2014 - before this date a range of small Chroococcales were reported separately, after this date none were reported, but a new group "Coccoid Blue-Green Picoplankton" has been reported. Therefore, the analysis has totalled up the pre 27th may 2014 cell counts for Aphanocapsa, Aphanothece, Chroococcales, Cyanonephron, Cyanocataena, Cyanodictyon, Cyanogranis, Gleothece, Gleocapsa and Synechococcus and called this total "Coccoid Blue-green Picoplankton" to allow comparison between the pre 27 May 2014 counts with the post 27 May 2014 counts.

The potential toxicity of B-GA species in Lake Wyangan was discussed in detail by the project steering committee and the following points noted:

- Within a single potentially toxic species, it is not possible to determine whether a bloom is composed of a potential toxin producing strain, or a non-toxic strain, simply by looking at them under a light microscope. A bloom is likely to be composed of a range of different genetic strains of the same species, some potential toxin producing, others not.
- In the past, for management purposes and because testing for toxin presence in the water by chemical means was very expensive, if a potentially toxic species was present it was considered a risk as a toxin producer, whether it was producing toxins or not.
- Modern advances in molecular technology now enable the actual genes responsible for toxin biosynthesis to be targeted in laboratory analyses, reasonable cheaply. This now gives the opportunity to determine whether a bloom can produce toxins or otherwise, and even the proportion of the bloom that may be able to produce toxins and the proportion of the bloom that is genetically incapable of producing toxins.
- The steering committee strongly support a suggestion that this form of analysis be incorporated into routine monitoring of cyanobacterial blooms in waters used as source waters for potable supply, for stock watering, and for recreation.

The current NHMRC (2008) recreational guidelines differentiate between toxic blooms and non-toxic blooms:

- When there are blooms of known potentially toxic taxa present (in future with genetic testing this can be changed to known toxic genotypes present) this is 4 cubic mm per litre of biovolume.
- Where the predominant taxa are not considered to be toxin producers, the guideline is 10 cubic mm per litre.
- This second guideline is set to cover the secondary potential health impacts of cyanobacterial presence, due mainly to the presence of contact irritants (not toxins).
- These secondary potential health impacts are generally minor, and not life threatening - skin rashes, eye irritations, gastric upsets, etc., but can include asthma.
- The other problem with contact irritants is that prospective cohort studies and skin patch studies have shown that only about 15% of the population react to them - the bulk of people appear to be immune to the contact irritants.

As noted by the steering committee, this creates a management problem - how do you protect the minority from the possible harmful effects of cyanobacteria to those people, but without impacting on the water usage of the majority who may not be affected by the cyanobacteria. Council, as water manager, has a duty of care responsibility to all water users.

As noted in the community consultation, for Lake Wyangan, there is the added question of whether BMAA produced by B-GA is a potential risk factor in neurodegenerative illnesses (specifically motor neurone disease) as has been hypothesised in the literature. Therefore, a Precautionary Principal approach is recommended that considers all B-GA as a potential risk until cause and effect in relation to this issue is proved or disproved.

3.5 Satellite-Based Water Quality Monitoring

3.5.1 Overview

To complement and augment the water quality monitoring program the ability of satellite-based mapping to detect and monitoring B-GA blooms was investigated. EOMAP was commissioned to undertake an analysis of a sequence of 10 satellite images captured over the September 2015 to April 2016 monitoring period.

Three water quality parameters (turbidity, chlorophyll a, and the presence of blue-green algae) were derived from satellite sensor image data and the results were compared to the field monitoring data collected over the same period, as detailed in the preceding section. EOMAP uses a Harmful Algae Bloom Indicator (HAB) classification to indicate the presence of cyanobacteria (Appendix C). It is not a quantitative measure but uses spectral analysis to infer the intensity of the algal bloom signal. Turbidity and chlorophyll a are quantitative measures.

A general summary of the results and discussion of their implications for Lake Wyangan are provided in following section. Further details of the methods, data, quality control, and processing along with the results are presented in Appendix C.

3.5.2 Results and Discussion

Turbidity

Observations have indicated that high sediment loads enter the lakes following rainfall events through inflows from the drains. This has been observed for the North Lake at the inflow through the Recreation Area. Dates for analysis of the satellite imagery were selected where possible to coincide with rainfall periods, although this it was not always possible. The rainfall record along with the imagery dates are shown in Figure 3-19. The turbidity data as produced by the satellite analysis is presented in Figure 3-20.

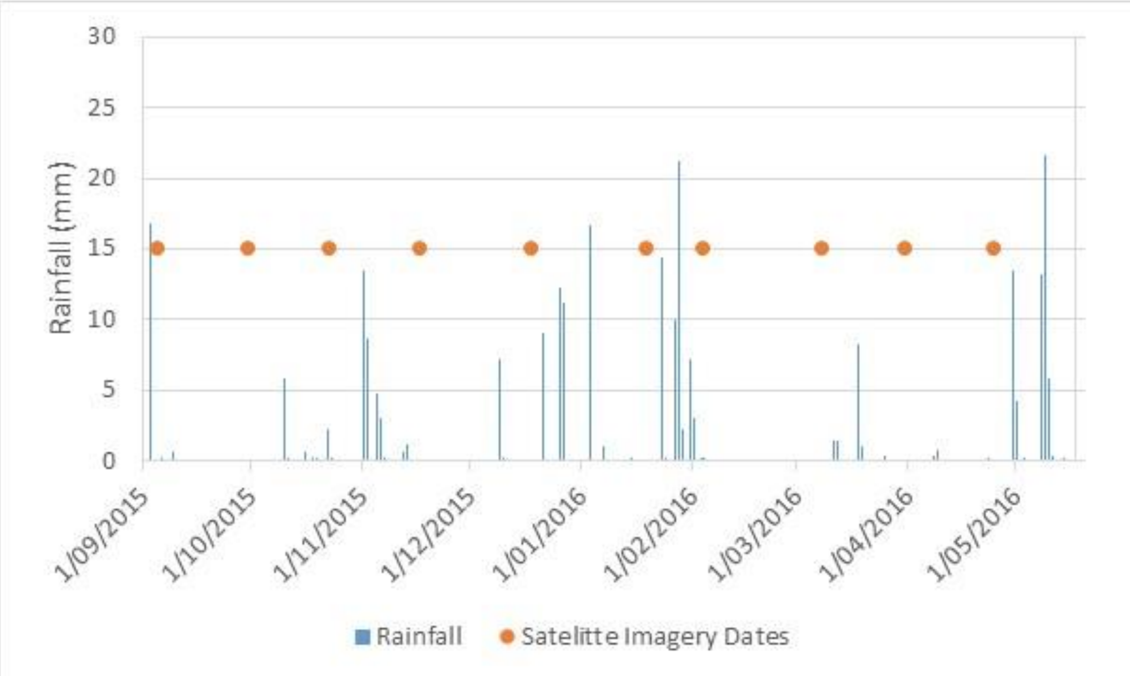


Figure 3-19 Dates of Satellite Imagery and Rainfall

The first image, from the 05/09/2015 was taken two days after 16.8mm of rain occurred in the catchment. It shows high levels of turbidity across all South Lake, with values typically above 75 NTU. Turbidity levels in North Lake typically ranged from 25 -35 NTU with higher values in the north near the drain entry locations and at the south adjacent to the roadway.

From the 09/09/2015 to the next image on the 30/09/2015 there was no rainfall and the turbidity levels drop across both lakes. There is an area of elevated turbidity in North Lake (around 40-45 NTU) around the drain at the recreation reserve while the rest of the lake is typically around 25 NTU. South Lake level have dropped but are still elevated, particularly where the drains enter at the south end of the lake.

The next image is for the 23/10/2015, which was preceded by 2 weeks of intermittent rainfall. Turbidity levels across both lakes are above 40 NTU, with higher levels in South Lake. Further rainfall occurs over the 4-week period to the next image (17/11/2015) and turbidity levels remain above 40 NTU in North Lake, and higher (> 50NTU) across South Lake.

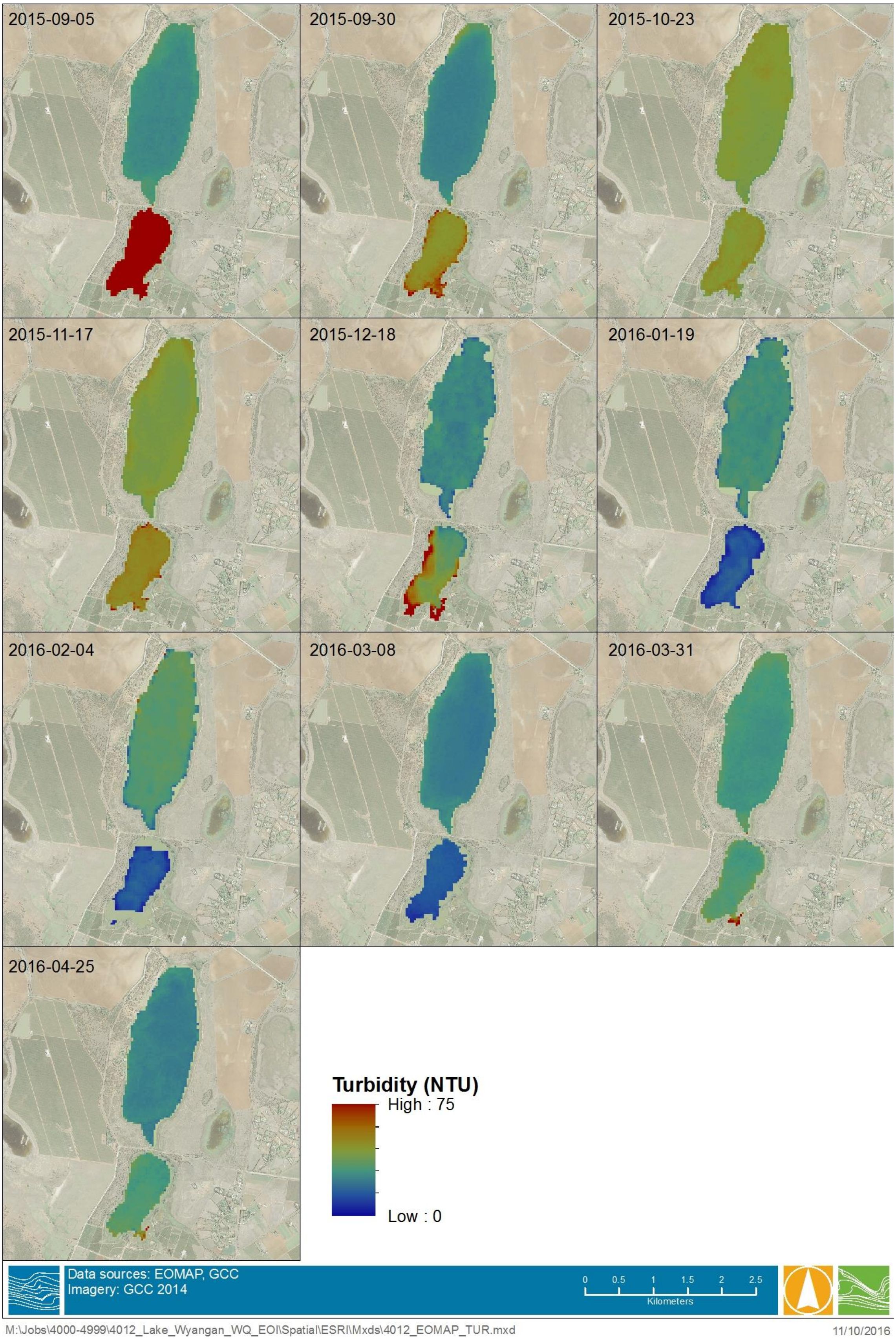


Figure 3-20 Satellite Analysis of Turbidity in Lake Wyangan

The next image on the 18/12/2015 follows the significant fill event in North Lake (shown in Figure 4-2) and turbidity levels have clearly reduced across the lake. South Lake shows a mixed profile. There appears to be a reduction in turbidity at the north end of the lake, perhaps indicting some exchange of water with North Lake. Turbidity levels along the south and western edges of the lake have increased to over 100 NTU. The southern areas coincide with the drain inflows. There was 1 rainfall event over this period.

The turbidity conditions have changed significantly by the 19/01/2016, with turbidity in South Lake reduced to less than 20 NTU, while for the North Lake it varies between 25-35 NTU. There was no rain for the 10 days prior to the image. Into February (04/02/2016) the pattern remains the same, although turbidity levels are increasing in North Lake, particularly in the northern section. There was rainfall between the 23/01/2016 and the image date which was observed to result in a sediment plume in North Lake (refer Appendix B). Although no clear plume is present in the imagery data the increase in turbidity correlates well with the observations.

The next image is in March (08/03/2016). There was no rainfall between this and the previous image and the turbidity levels have dropped in North Lake. There appears to have been a drop in water level in South Lake as the water surface extent has reduced.

By the end of March turbidity levels are increasing again in both lakes. The northern section of North Lake shows elevated levels while there is a clear plume of turbid water in the southeast section of South Lake. The turbidity levels reduce in April, corresponding to a period of little rainfall.

Overall these results confirm that there is significant input of sediment into both North and South Lake via the drainage network following rainfall event. Although only observed at the recreation reserve in North Lake the imagery analysis shows the results are similar for the other inflow locations.

Chlorophyll-A

The time series results for Chlorophyll-A are shown in Figure 3-21. The levels are fairly consistent across North Lake over the period, while there is more variability in South Lake over the monitoring period. For instance, there are elevated levels in late December which have decreased by late January, continuing to decrease until late April where the levels pick up again.

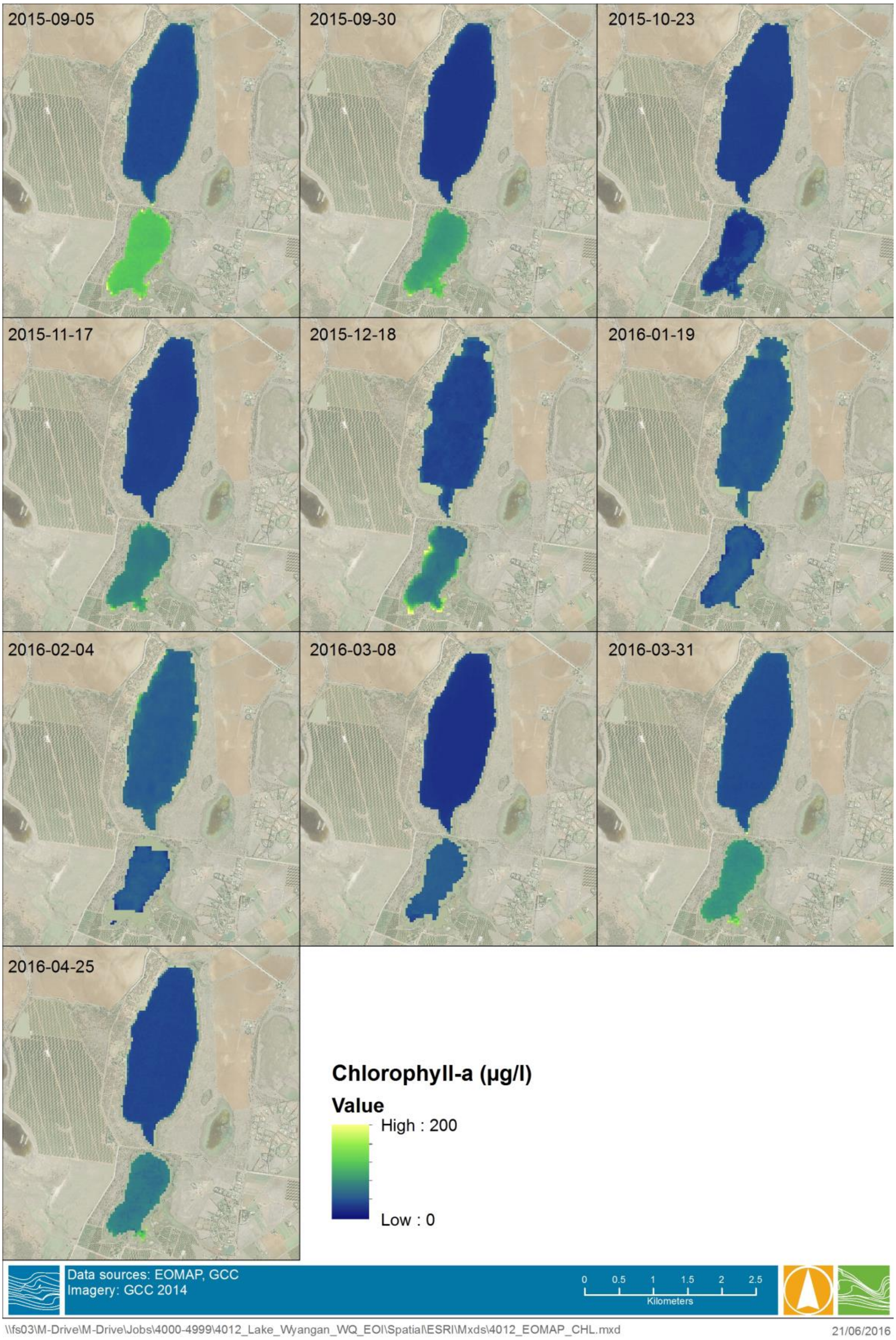


Figure 3-21 Satellite Analysis of Chlorophyll-A in Lake Wyangan

B-GA

The time series of the results of HAB are shown in Figure 3-22. There is clearly B-GA present in both North and South Lake in September 2015, with levels increasing in North Lake over this period. Interestingly the analysis indicates levels are elevated along the western side of the lake where the recreational facilities are located.

By the 23/10/2015 the HAB indicator is showing the presence of B-GA in North Lake as being unlikely and not at all in South Lake. There was a small fill event into the North Lake in October. The results for the next two images in November and December are similar and there was a large fill event that occurred in late November/early December (described in Figure 4-2). By January the presence of B-GA is detected in a small section of South Lake, but unlikely over most of North Lake.

A significant change occurs in the March image (08/03/2016) with much of South Lake showing the likely presence of B-GA along with some areas along the western shore of North Lake. By the end of March B-GA is dominant across South Lake but only detected along the western margin of North Lake. The most dramatic change is in the late April image (25/04/2016) where there is B-GA across most of both North and South Lake.

The measured in-lake algal biomass data are presented in Figure 3-23, and show similar trends to the HAB indicator analysis.

Overall, the HAB indicator data provides an improved spatial understanding of the potential presence of B-GA across both lakes and this sort of information could be used to direct management actions, such as in-lake mixers (as described in Section 5.2.2).

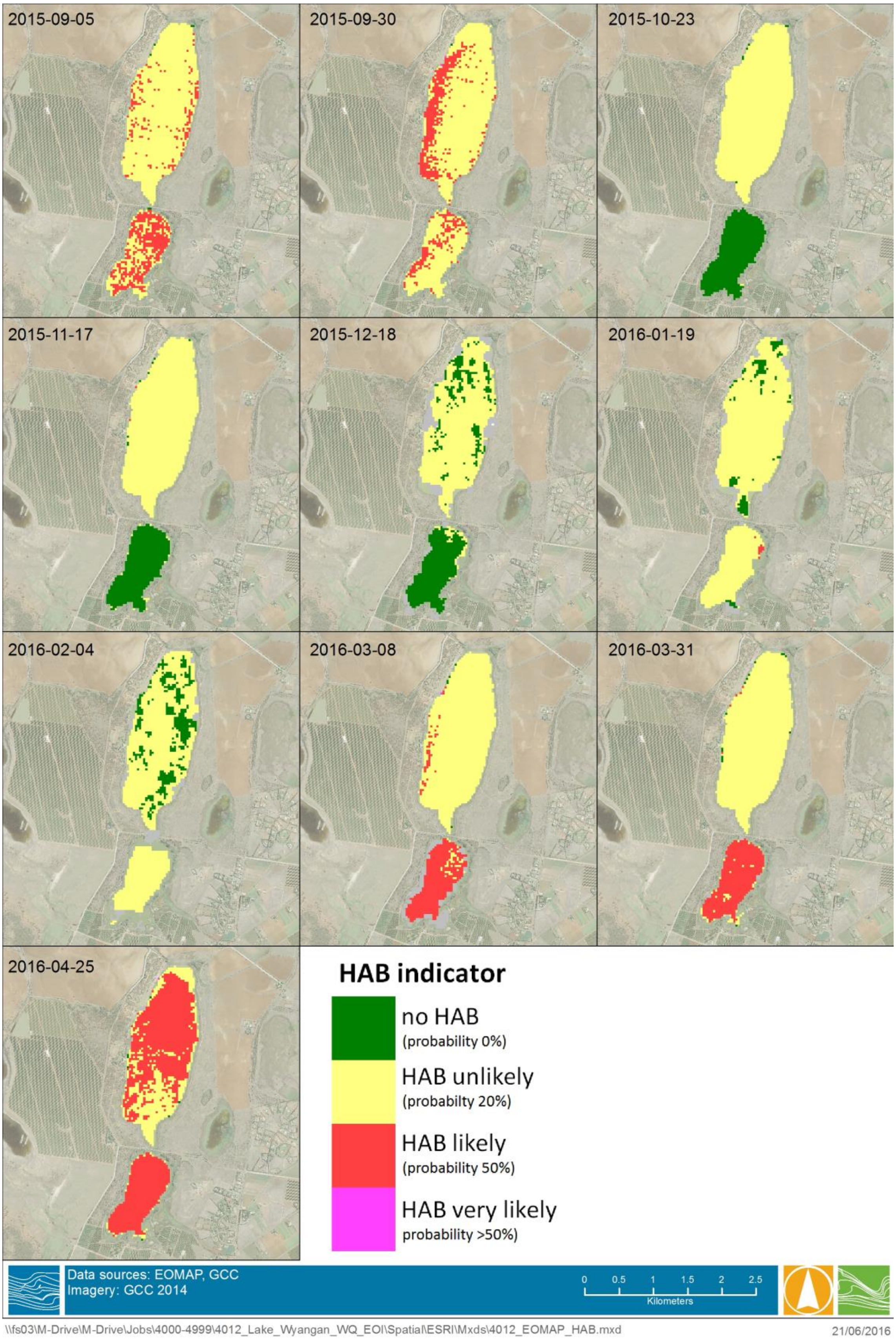


Figure 3-22 Time Series of HAB Indicator in Lake Wyangan

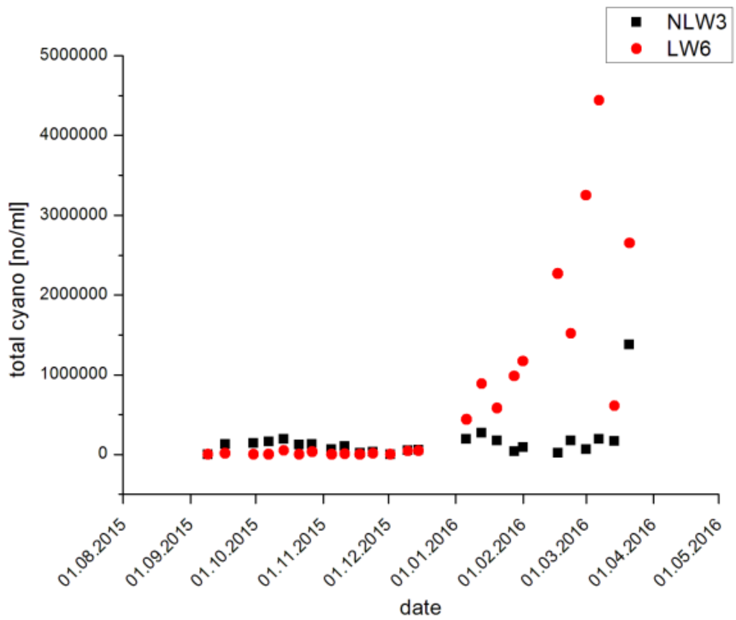


Figure 3-23 In-situ measured total algal biomass for in-lake stations NLW-3 (North Lake) and LW6 (South Lake)

3.5.3 Implications for Monitoring Program

The satellite-based water quality monitoring has significant potential to enhance the overall water quality management of Lake Wyangan. The spatial resolution of the data across both North and South Lake has shown clearly that conditions are variable and that shore based monitoring may not always provide a representative assessment of conditions in the two lakes.

The turbidity and HAB analysis have shown good potential to direct management actions and supplement the existing field monitoring program. The results could also be used to clearly communicate the lake conditions to other stakeholders.

The providers of the imagery analysis, EOMAP, also note that there will soon be access to additional higher resolution satellite imagery (Sentinel 2a – a new satellite from the European Space Agency) which could further enhance the outcomes from this type of analysis.

They make the following recommendations:

- Schedule further in-situ sampling on the days of a relevant satellite overpass. Overpass days and exact times are known in advance, and if the day is cloud free, the sampling would yield very useful coincident information. This will provide data for further calibration of the HAB (and turbidity) algorithms, as well as for validating the results to a higher degree of confidence, gradually fine tuning the system to be more sensitive to local variations in these particular lakes. For an example of how to determine overpass times and dates see https://publiclab.org/notes/nedhorning/08-02-2013/determining-landsat-8-overpass-times
- Conduct the in-situ sampling at a minimum the equivalent of 2-3 satellite image pixels (30-90m depending on the satellite) from the lake shore, in order to avoid having to offset the corresponding satellite-measurement location.

- Once the HAB algorithms have been fine-tuned it is likely the frequency of in-situ sampling can be reduced, and/or better targeted in terms of timing and locations.

The satellite imagery analysis could be used as a decision-making tool in the future. Examples of how this approach has been applied are provided at the following links. Note that the 'free' HAB monitoring eoApp for the Great Lakes is using free 500m pixel resolution data, which is easy to do inexpensively, but this resolution is not applicable to Lake Wyangan. However, the eoApp as a delivery platform (for 30m data) could be applied for on-going monitoring at the lake.

http://www.eomap.com/featured-image-blooming-baltic-sea/

http://www.eomap.com/daily-satellite-tracking-of-harmful-algae-blooms-for-the-great-lakes-now-online/

3.6 Vegetation

Vegetation provides an important role in the management of water quality within Lake Wyangan. Vegetation can provide natural, low cost and ongoing services to water quality. This can be achieved by vegetation through the direct uptake of nutrients in water before or after entering the lake. Vegetation can also filter or prevent sediment from entering the lakes. Therefore, it is important to identify and consider the opportunities vegetation provides within and outside the lake system.

A field inspection of the fringing vegetation around both North and South Lake Wyangan was undertaken on the 15^{th} July 2015. Information collected during this survey is summarised in the following section.

3.6.1 Fringing Vegetation

Both North and South Lake Wyangan are typically fringed by Cumbungi (*Typha orientalis*) within the permanent water. As the water shallows towards the lakes edge, the Cumbungi transitions to Common Reed (*Phragmites australis*) that then extends up behind the lakes shoreline to the surrounding lunettes and terrestrial areas where soils are moist at depth. Cumbungi prefers stable water levels rather than fluctuating water levels and is typically found where water is permanent or where seasonally or periodically dry. Common Reed however prefers fluctuating water levels rather than permanently wet conditions. Although much of the lake's margins transition from Cumbungi to Common Reed (see Figure 3-24 and Figure 3-25), occasionally there will be bare bed or open water between the two where it might occasionally be too dry for Cumbungi yet too wet for Common Reed.

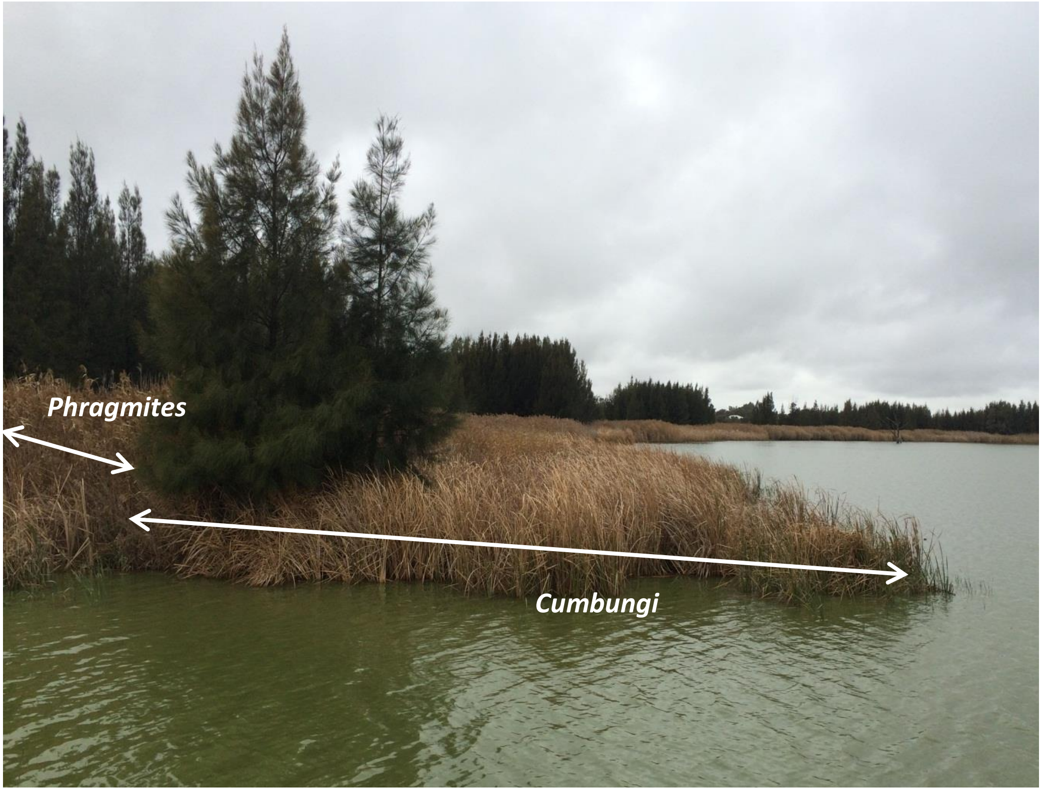


Figure 3-24 *Looking south along eastern edge of south Lake Wyangan, Cumbungi in the water transitioning to Phragmites on the bank*

Figure 3-25 *South Lake Wyangan looking north in north-east corner*

The Cumbungi and Common Reed appear brown and dry in Figure 3-24 and Figure 3-25, however this is the normal appearance for mid-winter (photos were taken in mid-July) when both plants species have dormant shoot systems.

The key characteristics of the two dominant fringing species are as follows (summarised from Rogers and Ralph 2011):

Cumbungi (*Typha orientalis*)

- Large stands of Cumbungi are located in the Murray-Darling Basin within terminal wetlands.
- Rapid above-ground growth typically occurs in spring and early summer, while below-ground growth increases after mid-summer. New shoots emerge in autumn and winter.
- Cumbungi may form distinct communities in locations with relatively stable water levels. Cumbungi has a high water requirement and may survive in water depths up to approximately 2 m.
- Cumbungi is suited to stable water rather than fluctuating water levels. It prefers water regimes from permanently wet to periodically dry and may survive dry conditions for three to four months.
- Extended dry conditions increase the exposure of cumbungi to the desiccating effects of salinity. Cumbungi is considered moderately salt-tolerant. Growth is reportedly reduced at sodium chloride concentrations of 50 mM, while individuals become severely damaged at 100 mM concentrations.
- Cumbungi is able to reproduce by vegetative expansion and by seed. Vegetative expansion is slow while seed reproduction is rapid and can occur some distance from the parent plant due to the seed being light and dispersed on the wind.
- Flowering occurs during the warmer summer months from November to march, with seed production generally occurring during late summer from January to April.

Common Reed (*Phragmites australis*)

- Common Reed is a clonal perennial grass growing to 4 m tall under ideal conditions.
- Common Reed is largely limited to temperate regions of Australia within creeks, streams, channels and drains, swamps and areas that are seasonally inundated, or areas where rainfall runoff can accumulate.
- Common Reed is a well-adapted plant with considerable tolerance to flooding and exposure. Due to its ability to tolerate extensive drought periods, Common Reed may occur in wetlands with highly fluctuating hydroperiods.
- Under static water conditions, Common Reed stands generally occur at shallow water depths, ranging from an average 45 ± 20 cm, or within the range of 50cm above to 20cm below the water level.
- Common Reed has been reported at sites where the groundwater is at a depth of 4 m, and rhizomes may grow to considerable depths when the watertable is below surface.
- Budding and germination of young shoots appears dormant throughout the late winter months, but rapid growth occurs by early October. Growth continues throughout summer with a peak by late summer or early autumn. Dry matter then accumulates until mid-winter and coincides with peak below-ground biomass.
- Flowering commences in late summer during the peak growing season and flowers grow quickly, reaching maturity by March.
- To adapt to drier conditions, Common Reed may reduce leaf area and biomass, and increase the proportion of water-absorbing root biomass.

- Common Reed can regenerate from seed and vegetatively. It is more effective when expanding vegetatively, particularly in deeper water. Vegetative expansion is so effective that stands of common reed may be one entire clone.
- Flowering generally occurs rapidly during summer with full height attained in early spring. Seed is generally available for germination in spring, or it may enter the seed bank if conditions are not suitable. Stored seeds remain viable for three to four years. Seeds rely on hydrochory for establishment.
- Common Reed exhibits a degree of salt tolerance and can establish in brackish conditions. It can survive in water with up to 10ppt total dissolved salt.

3.6.2 Waterway Vegetation

The North and South Lake receive water from many sources. The North Lake receives water from several open drains, a single canal and a natural waterway via Campbells Swamp. The South Lake receives its water via a series of open drains and has the capability to receive water via pipe infrastructure directly from supply canals.

Drains

The drains entering the two lakes carry excess irrigation water, surface water runoff or pumped ground water from tile drainage systems. Most of these drains are vegetated with a variety of species both native and exotic. Since these drains carry water throughout much of the year, even if only small volumes, the inverts and banks tend to support emergent rushes and reeds as is found fringing the two lakes.

The drains are typically more open away from the lake and contain a variety of herb and grass species that are both native and exotic. These drains tend to become ill-defined as they approach the lakes and enter the reed swamps surrounding both water bodies. Figure 3-26 (North Lake) and Figure 3-27 (South Lake) show relatively incised channels within farmland that transition into ill-defined channel swamps as they approach the lakes.

Figure 3-26 North Lake Wyangan drain

Figure 3-27 *South Lake Wyangan drain*

Drain at Recreation Area

The drain through the recreation area enters the North Lake in the north-west corner. This is a large channel that has been cut into the hillslope to the north-west of the lake to deliver water directly to the lake. The drain is relatively large and not concrete lined. The drain usually contains permanent pools, even if not flowing. It does therefore support aquatic vegetation such as Cumbungi in the bed of the canal with terrestrial vegetation colonising the upper banks.

Figure 3-28 *Drain Canal showing terrestrial vegetation on the upper bank and aquatic vegetation in the bed*

The outfall to the drain is a series of concrete pools that then spill into an earthen section of channel with some bed control rock structures. The channel at this point (Figure 3-29) is clear of vegetation other than a stand of She-oaks on the left bank. The channel then passes into the fringing reeds before entering North Lake Wyangan.

Figure 3-29 Downstream end of outfall

3.6.3 Existing Vegetation Management

North and South Lake Wyangan

The vegetation within both lakes does not appear to undergo high levels of active management. The Cumbungi and Phragmites are self-sustaining so long as the water levels within the lakes is not dramatically changed for long durations. The fringing reeds provide important habitats and shore protection from human physical activity and boat wash. The reeds in themselves discourage access by foot or boat and their density and habitat preferences allow them to outcompete other species. The zone at the back of the reeds where they transition to a terrestrial environment is where most of the weed invasion occurs and where most vegetation management will take place.

Drains

Murrumbidgee Irrigation have indicated that vegetation management within drains is to ensure flow is not impeded. There is no active management of drain vegetation outside of this requirement. Vegetation is controlled by spraying with an approved herbicide or excavated from the bed.

Drains are periodically cleaned out principally due to sedimentation. It has been indicted by MI that when this occurs, the bed is excavated however the banks are usually retained where possible. This practice means that bed vegetation is occasionally excavated from the drain although this is only undertaken as required. There is no programmed maintenance of drain cleaning or spraying.

The photographs in Figure 3-30 indicate that drain cleaning has cleared vegetation from the bed and the bank from which the excavator was operating.

Figure 3-30 Recent (left) and old (right) drain cleaning evident with Cumbungi and Common Reed retained on one bank

Vegetation Values and Threats

There are several values and threats to vegetation within the lakes and the receiving waterways. A few values and threats are listed below:

Vegetation values include:

- Take-up of nutrients from drainage network and fringes of lakes
- The controlling of sediment input to the lakes
- Bank protection from boatwash and wind generated wave action
- Restriction of access to much of the lakes margins, reducing recreational pressure including physical impacts (e.g. erosion)
- Important fauna habitat, particularly for JAMBA & CAMBA birds
- Aesthetics

Vegetation threats include:

- Urban encroachment – This perhaps poses the greatest threat to vegetation in and around Lake Wyangan. Clearing of vegetation may be undertaken or requested for:
    - urban lot/housing development,
    - associated recreational infrastructure (paths, boardwalks, piers, marinas)
    - views
    - safety concerns (e.g. snakes)
- Large fluctuations in water levels, particularly periods of low levels affecting (desiccating) Cumbungi
- Water quality –
    - high nutrient levels from urban development (e.g. septic systems or fertilisers)
    - salinity from tile drains and farming practices (e.g. pesticides and fertilisers)
- Drain management – Drain vegetation may be sprayed with herbicide or excavated to improve flow conveyance or purely for aesthetics (cleaning out the drain)
- Recreational pressures including physical disturbance from people, vehicles and boats

3.7 Recommendations

Based on the analysis of all previous and current monitoring data the following recommendations are made for the future monitoring at Lake Wyangan:

In-Lake Sampling

- The existing GCC monitoring sites (Red Dots) should be maintained. Existing frequency of sampling to be maintained.
- Existing analysis parameters should continue to be analysed.
- Genetic analysis of the B-GA samples should be incorporated into the sampling to further understand the potential toxicity of the taxa present in Lake Wyangan.
- Installation of a fixed temperature/dissolved oxygen logger in both North and South Lake Wyangan recording temperature and DO concentrations at the surface and in the bottom waters at 15 minute intervals (or less). Ideally this would be telemetered. This could be used as a reference site for the satellite imagery analysis calibration.

In-Drain Sampling

- Continued sampling at the in-drain sampling sites (Green Dot sites NLW-1, NLW-2, NLW-3, SLW-1, SLW-2, SLW-3).
- Weekly sampling frequency of TSS, N, P, EC and Temperature sampling at these site (to occur during/after significant rainfall >15mm when possible)
- Inclusion of (preferably) telemetered continuous flow measurement of all inflowing drains (NLW-1, NLW-2, NLW-3, SLW-1, SLW-2, SLW-3)

To supplement, and possibly reduce the extent of the field monitoring program in the future, it is recommended that the use of satellite imagery analysis continued to be explored. Further calibration of the analysis with field measurements would allow for further calibration and validation of the results. To do this, the following recommendations are made:

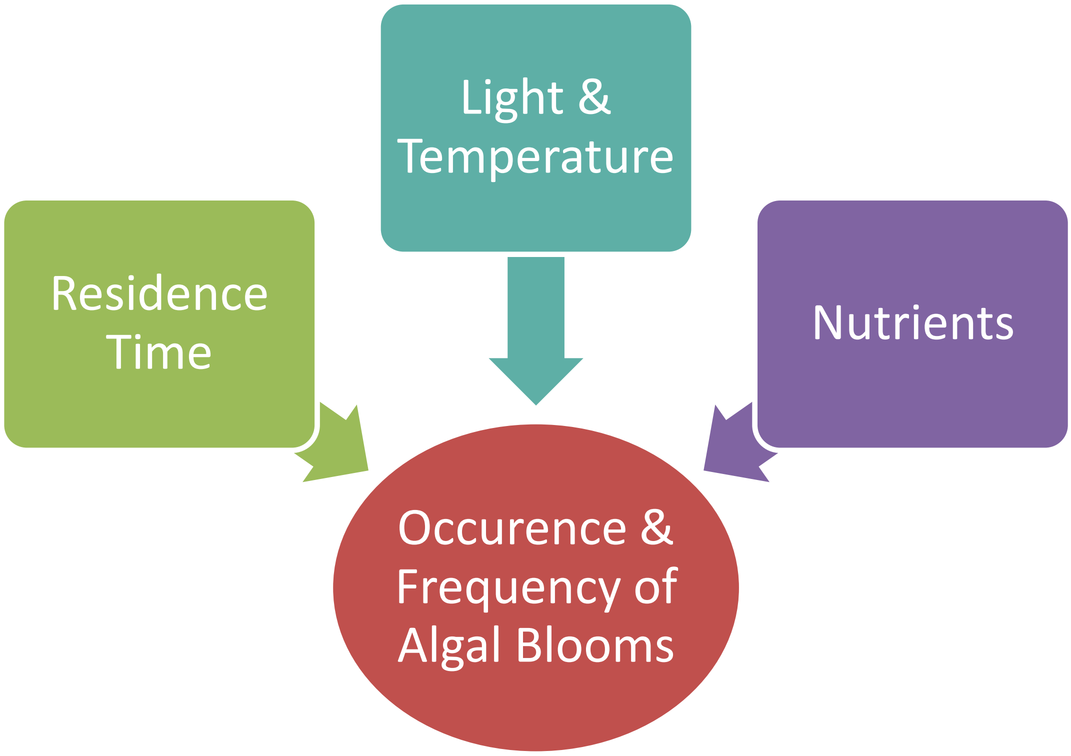
- Schedule further in-situ sampling on the days of a relevant satellite overpass. Overpass days and exact times are known in advance, and if the day is cloud free, the sampling would yield very useful coincident information. This will provide data for further calibration of the HAB (and turbidity) algorithms, as well as for validating the results to a higher degree of confidence, gradually fine tuning the system to be more sensitive to local variations in these particular lakes. For an example of how to determine overpass times and dates see https://publiclab.org/notes/nedhorning/08-02-2013/determining-landsat-8-overpass-times . EOMAP could provide guidance on suitable dates.
- Conduct the in-situ sampling at a minimum the equivalent of 2-3 satellite image pixels (30-90m depending on the satellite) from the lake shore, in order to avoid having to offset the corresponding satellite-measurement location. This would be possible using the proposed fixed in-lake sampling sites or by moving the existing GCC Red Dot sampling away from the shoreline.
- Once the HAB algorithms have been fine-tuned it is likely the frequency of in-situ sampling can be reduced, and/or better targeted in terms of timing and locations.

4. LAKE ECOSYSTEM DESCRIPTION

Shallow lakes are dynamic systems which change over time in response to internal and external inputs and processes. Eutrophication in these systems occurs when there is an excess of inorganic nutrients which often leads to excessive growth of algae, termed an algal bloom. Algal blooms in lake systems like Lake Wyangan can have a significant impact on the local communities who use the lake as well the environmental values of the lake itself.

4.1 Factors Controlling Algal Blooms

The three main factors controlling an algal bloom are the residence time of the water, the availability of light in the water column and the temperature of the water, and nutrients.



- **Residence time** - water quality problems can arise when there are insufficient water inflows to circulate and/or displace water stored in the lake. The longer the residence time the greater the chance of an algal bloom occurring. Reducing the residence time means the algal biomass becomes regulated by the rate it is removed from the lake by flushing.
- **Nutrients** – algal blooms are driven by the availability of sources of nitrogen and phosphorus. Nutrients can enter from catchment sources via drains and waterways and the lake sediments themselves can also be a source.
- **Light & Temperature** – the turbidity and mixing conditions in a lake will determine the light and temperature environment. The depth of light penetration can be reduced by turbidity and therefore limit algal biomass. However, the depth of light penetration can also be a limiting factor for submerged aquatic plants. Temperature variations with

depth can also drive mixing conditions and can be important for nutrient release from sediments.

To understand how each of these factors is contributing to the on-going occurrence of algal blooms in Lake Wyangan the study assessed the inputs and processes occurring both within the North and South Lakes and also the broader Lake Wyanagan flood and drainage catchments. The results are described in the following sections.

4.2 Previous Studies

Previous studies such as Umwelt (2004) attempted to develop a preliminary water balance model for the North and South Lakes.

Umwelt (2004) investigated the contributions of rainfall, evaporation, pumping, catchment runoff and irrigation return flows on lake volume. The study showed that "a water balance consisting of rainfall, evaporation, pumping (from South Lake), and catchment runoff provided the best fit to the available level of information for the lake. However, calculated lake volumes provided a poor estimate of measured lake volumes between December 1998 and August 2002. Further investigation of the relative contributions of evaporation and catchment runoff to the water balance have shown that the interaction of these parameters alone are unable to explain the differences in the calculated water balance between December 1998 to August 2002. This suggested that other external variables, such as private pumping and municipal pumping for drinking water, may be important in the water balance. The coarse temporal resolution of data used in the water balance model (such as the monthly pumping data, and weekly lake level data) may provide additional sources of error."

The report suggested that attempt should be made to quantify water usage from the following:

- Private pumping and municipal pumping.
- Possible irrigation return flows should also be examined to determine the magnitude, timing and frequency of such flows.
- Escape laterals in the irrigation area should also be monitored to allow further investigation of return flows to Lake Wyangan.
- Information regarding groundwater inflow and/or seepage may also allow further quantification of the relationships between components of the Lake Wyangan water balance.

Since the Umwelt study Murrumbidgee Irrigation has undertaken the Lake Wyangan modernisation project. The work involved refurbishing and upgrading of aging irrigation infrastructure in the Lake Wyangan area. Works included rebuilding almost 16 km of irrigation channel, and the replacement of 13.7 km of open channels with gravity pipelines. All regulators along the Lake View Branch Canal were placed into automatic Channel Control mode. This work has 6000 ML's of efficiency savings achieved through replacement of failing original concrete lined delivery canals and channels and piping of open channels (reducing accessions and evaporation losses). Additional water savings have been achieved through increased adoption of water efficiency technologies, drip and sub-surface drip irrigation. Both activities have resulted in reduced drainage back into Lake Wyangan, particularly into Lake Wyangan South. (Vittucci, Pers. Com.).

4.3 In-Lake Processes

In shallow lakes receiving high levels of nutrients eutrophication can occur. In systems such as Lake Wyangan, which have a long residence time, algal blooms can be persistent and can be difficult to manage. It is therefore important to understand what the key physical, chemical and biological processes involved, and how these processes interact. Figure 4-1 illustrates the key processes relate to the water quality in the lakes and these will be described in detail in the following sections.

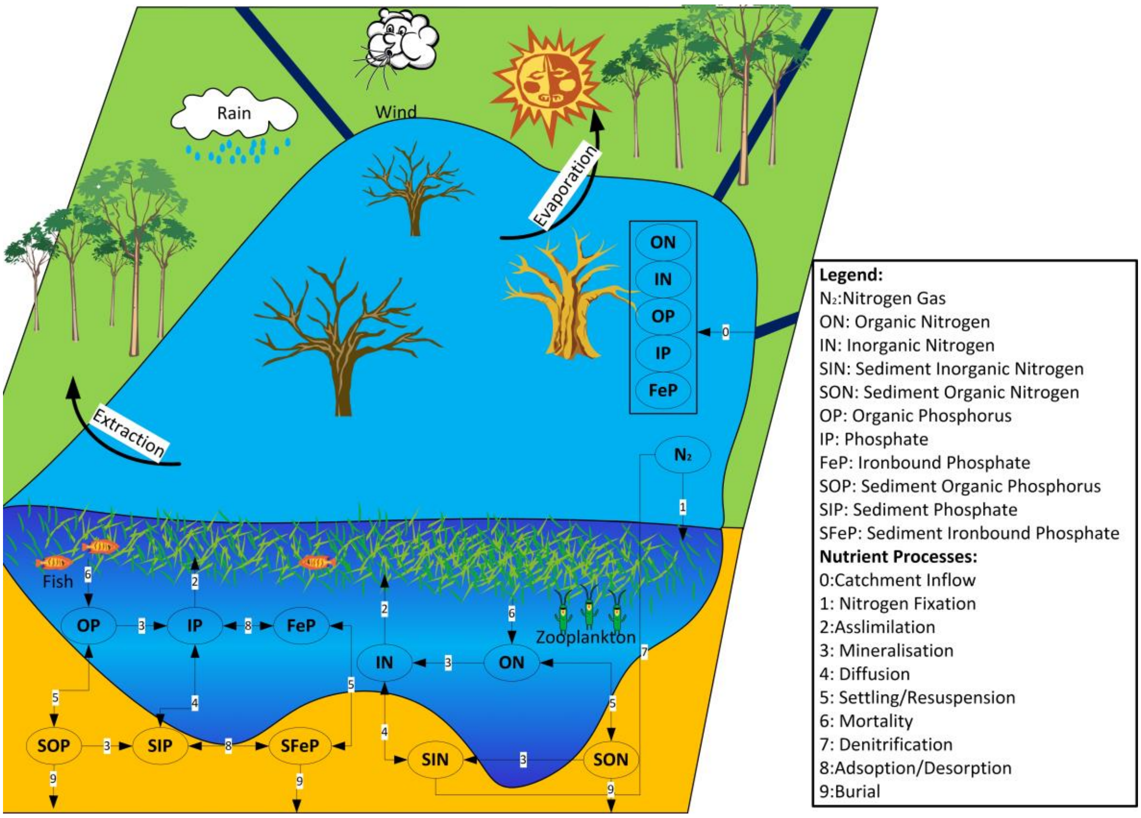


Figure 4-1 ***In-Lake Processes Related to Water Quality in Lake Wyangan***

4.3.1 Physical Characteristics

The important physical characteristics of the Lake Wyangan system are:

- Catchment setting
- Inflows and extraction
- Rainfall and evaporation
- Wind and mixing

Catchment Setting

As described in Section 2.4, the catchment within which Lake Wyangan is located covers an area of approximately 121 km^2 which is made up of a natural 'flood" catchment of around 75km^2 and an additional "drainage" catchment of 44km^2 which provides water to the lake via the MI drainage network. There is no natural outlet from the catchment, with all runoff and irrigation overflows draining to Nericon Swamp, Campbell Swamp, and Lake Wyangan (north and south). Lake Wyangan itself was formed in the 1950's out of a former gypsum mine at the northern end and a low lying swamp area to the south. Although currently permanent water bodies, they previously would have been considered ephemeral wetlands.

Inflows and Extractions

Natural inflows to the lakes are limited, with the majority of inflows occurring as a result of surplus irrigation water and irrigation escape flows (prior to the recent upgrade by Murrumbidgee Irrigation of the Lake Wyangan irrigation supply system). The supply and drainage network is shown in Figure 4-3. Unfortunately, there is no gauging information available on any of the drains flowing into the lake and therefore the contribution of rainfall and irrigation water to the lake system cannot be quantified. There is also additional input of water to the drainage network through tile drainage, although again it is not possible to quantify this contribution based on the limited data available.

The previous Lake Wyangan flood study (BMT WBM, 2012) found that significant rainfall events have only limited impact on the lake levels. This was thought to be because:

- It has a relatively small catchment area of around 121 km^2, including diverted catchment runoff through the drain network (Lake Wyangan's natural catchment is around 75 km^2. For comparisons, the natural catchment of the adjacent Tharbogang Swamp is 750 km^2.
- Significant rainfall (> 60mm) is required before runoff is generated and a response in the lake can be observed.
- A proportion of the catchment runoff volume is retained in temporary storages in the catchment (i.e. Nericon Swamp and Campbells Swamp), rather than flowing directly into the lake.

Lake Fill Events

In addition to the rainfall and drainage inflows to Lake Wyangan, North Lake also receives inflows, termed "fill events". Griffith City Council, as a Water Holder with a Water Access License, is able to order nominated volumetric inflows to use as "fill events" into North lake delivered by Murrumbidgee Irrigation. The aim of these fill events is to provide additional volume to the North Lake to raise the water level for recreational and environmental purposes. It was previously thought that the volume of North Lake was around 2500 ML at a target level of around 1.04 m (gauge level), however the revised storage volume estimate is closer to 6000 ML at this level. The water is supplied to the lake via the MI drainage network.

Data is available for four fill events; November 2014 and February, October and November 2015. The inflow volumes are shown in Figure 4-2.

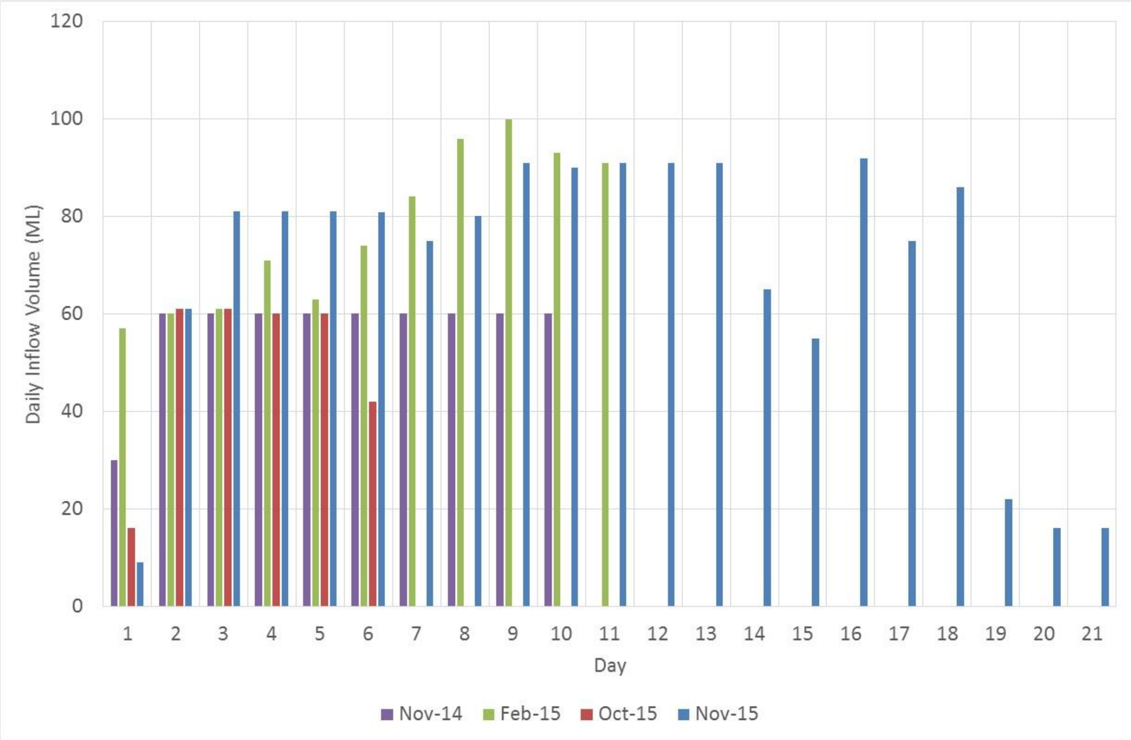


Figure 4-2 Daily Inflow Volumes to Lake Wyangan for Fill Events in 2014 and 2015

The total volumes of water added to North Lake varied for the different fill events, from 570ML in November 2014, 850 ML in February 2015, 300 ML in October 2015, and 1430 ML in November 2015. The November fill event provided a substantially larger volume of 1430 ML to the lake compared to the previous fills, raising the lake level approximately 0.5m, to a gauge level of 1.35m. The previous events targeted a lower level of 1.04m on the gauge.

For the purposes of dilution of the lake waters the greater the inflow volume the greater the dilution that can be achieved. The small October 2015 fill event volume was only 5% of the total lake volume while the November 2015 event was closer to 25%.

To assess the dilution and mixing conditions in the lake associated with these inflows a 2D hydrodynamic model was created of the North Lake using the industry standard modelling package MIKE21 by DHI (https://www.dhigroup.com/). The bathymetric survey data captured for this project was used to create the model, as shown in Figure 4-4. The November 2014 and the November 2015 fill volumes was then applied to the model and the movement of the inflow watering within the lake simulated. Mixing was assessed by assuming the lake has an arbitrary initial condition of 100% and the inflow 0%.

Figure 4-5 shows the change in conditions across the lake over the 4 days for the 2014 fill event. The wind conditions over this period as measured at the Griffith Airport weather station were applied to the model to ensure any wind mixing processes were also captured. The model results indicate that the effect of the inflow on mixing conditions in the lake is limited predominantly to the northern areas. The volume added to the lake was insufficient to significantly mix the lake waters.

Results for the larger November 2015 fill are shown in Figure 4-6. In this scenario, a more significant amount of mixing was possible over the 20-day event. There is an obvious dilution of up to 25% in North Lake which matches the inflow volume. Wind conditions were found to be important for enhancing the mixing processes.

Until recently South Lake has been operated as an irrigation supply storage by Murrumbidgee irrigation, however since 2012 this has occurred infrequently due to water quality issues in the lake. No specific inflow events have been undertaken over the last two years for South Lake.

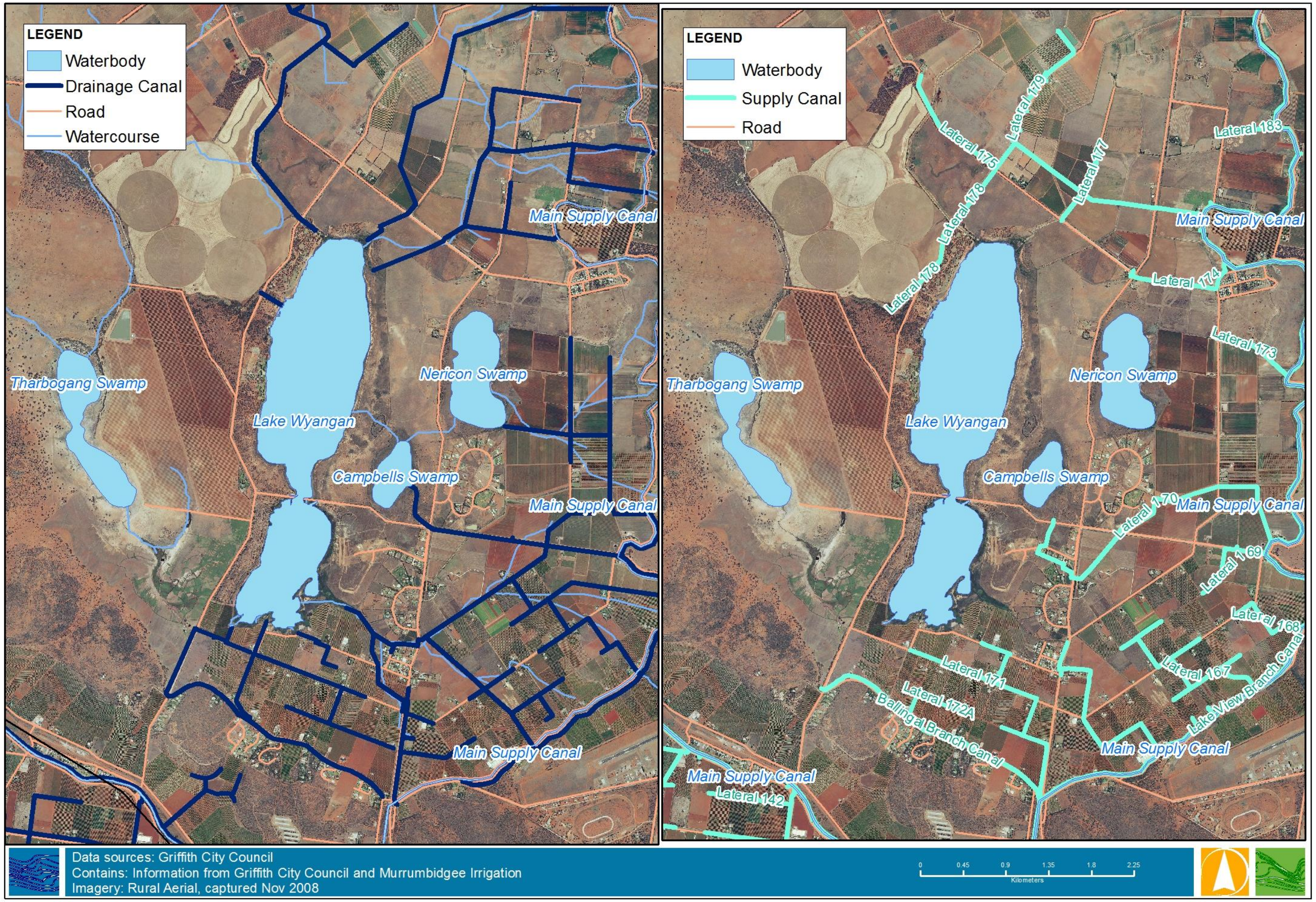


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Figure 4-3 ***Murrumbidgee Irrigation Supply and Drainage Channels, Lake Wyangan***

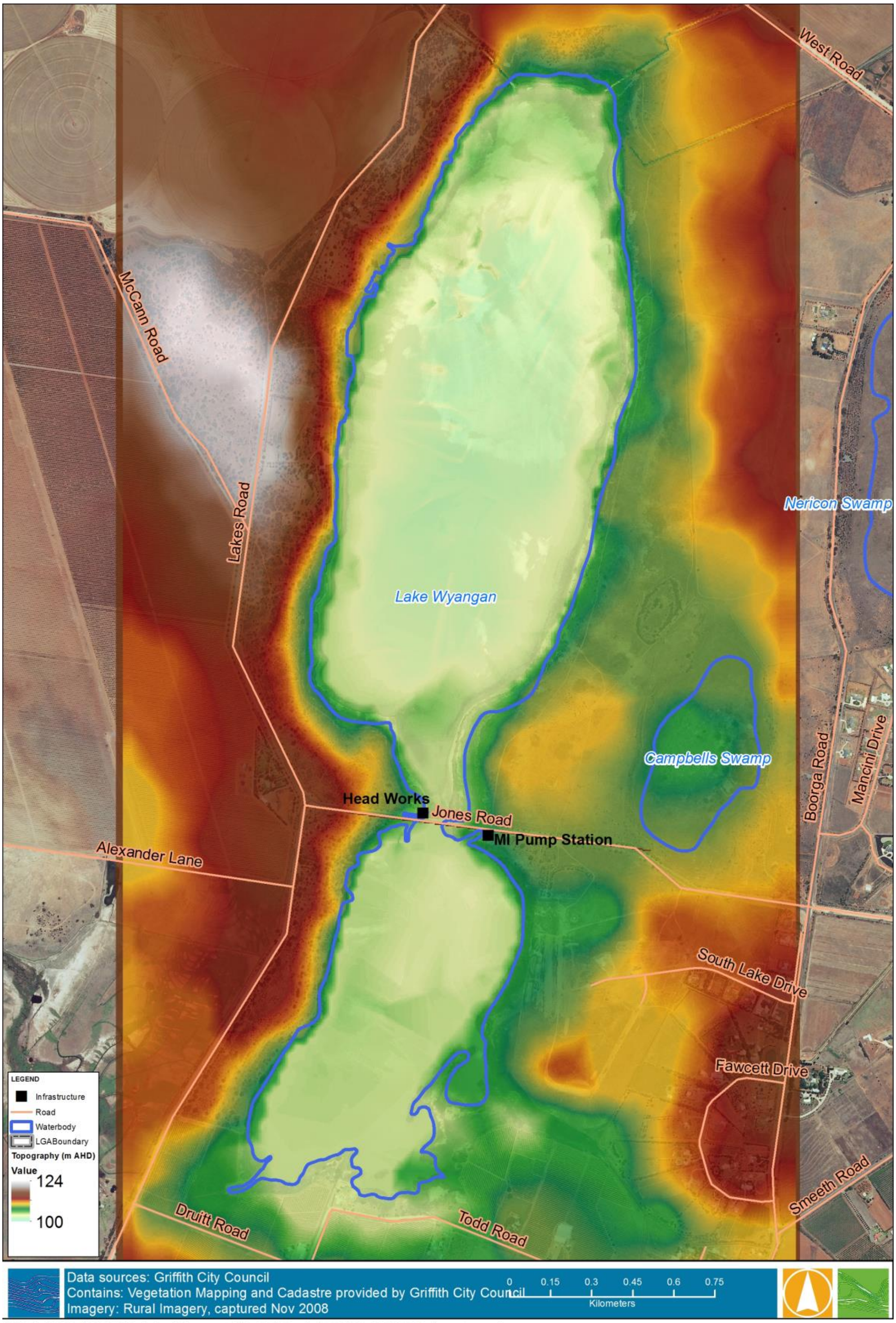

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Figure 4-4 Bathymetry of Lake Wyangan

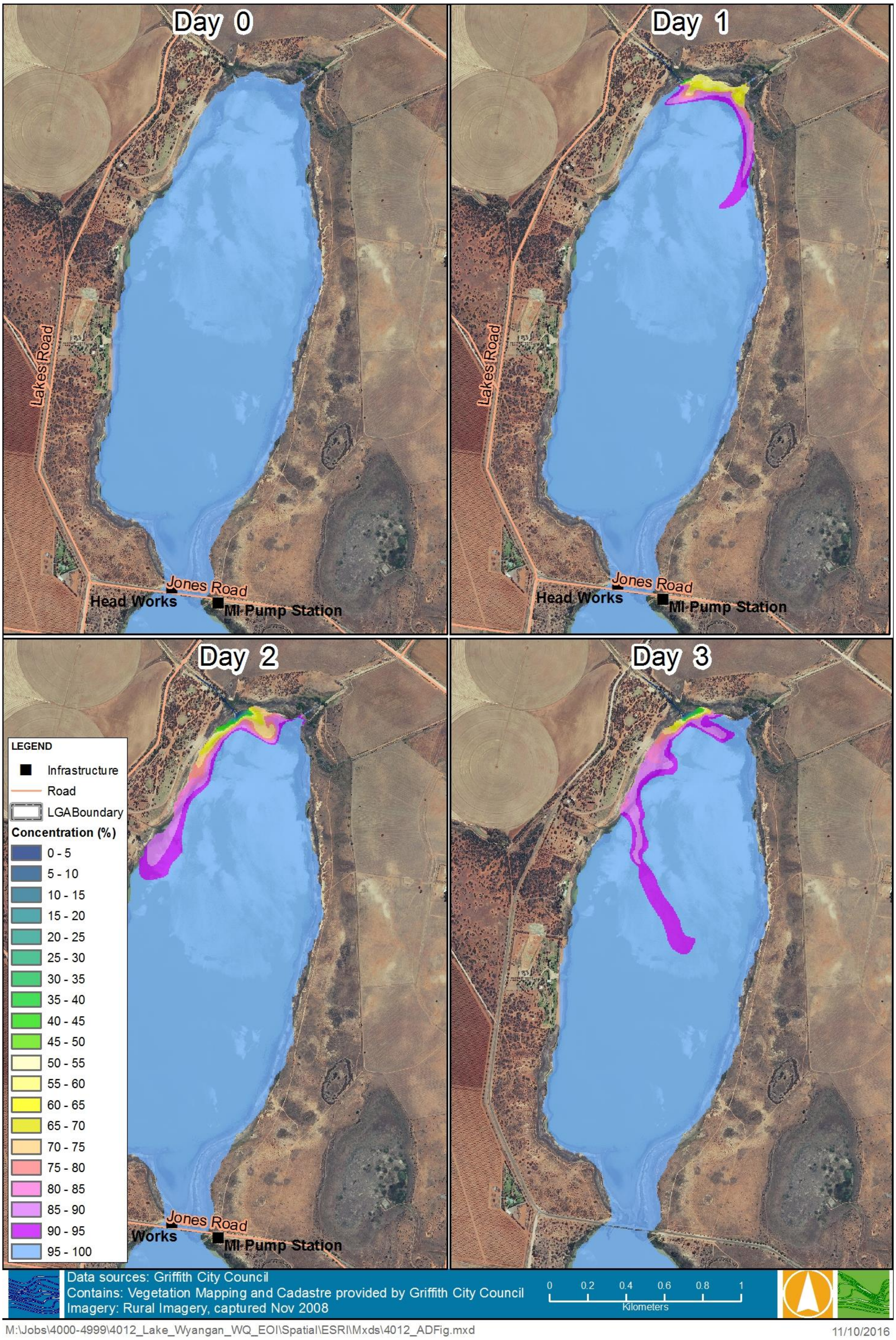

Figure 4-5 Mixing Processes as a Result of Inflows (November 2014 fill event)

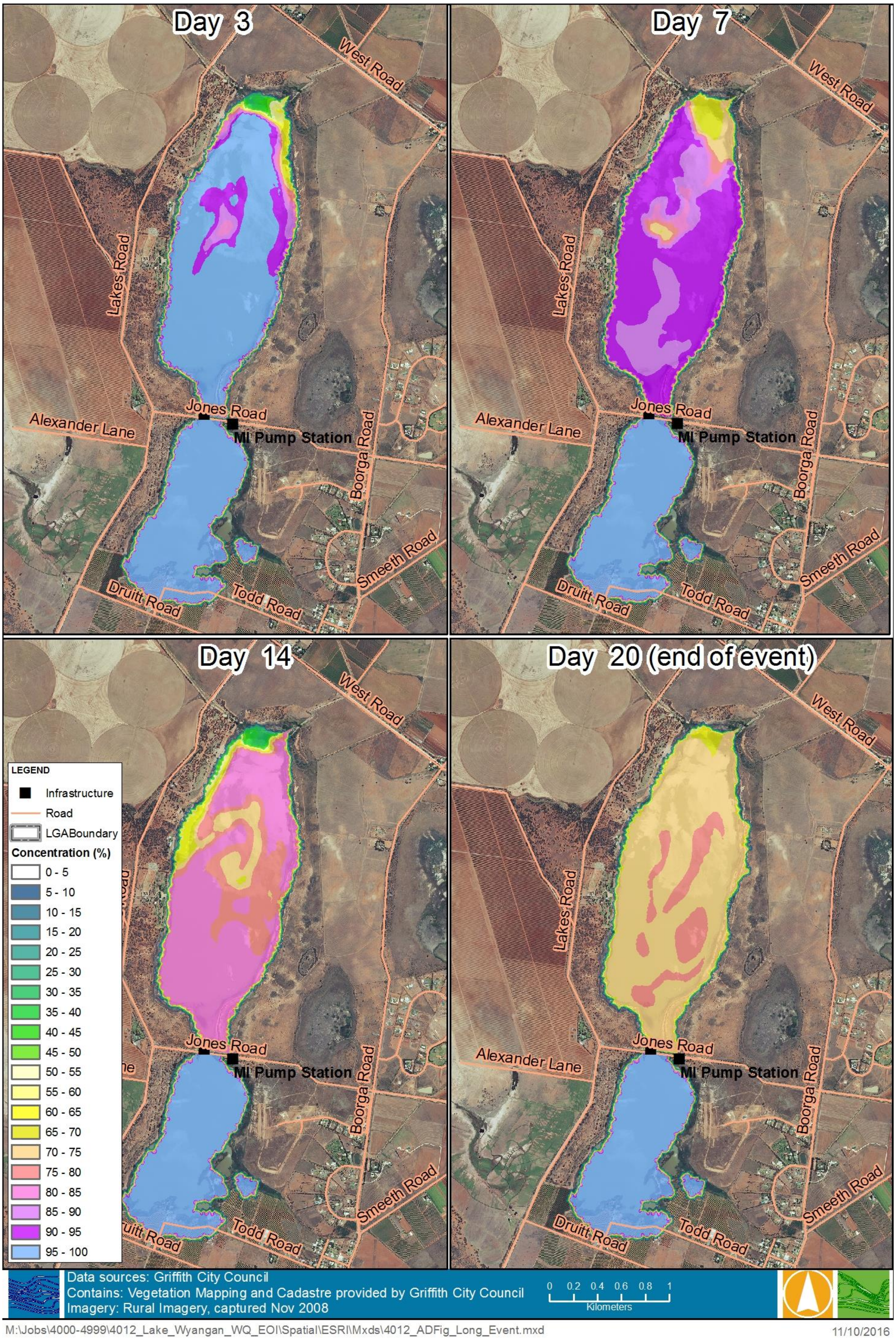

Figure 4-6 Mixing Processes for a Large Inflows (November 2015 fill event)

Rainfall and Evaporation

As detailed in Section 2, Griffith has an average annual rainfall of around 400 mm, with fairly constant rainfall year-round. Monthly averages range from 28 mm in April to 41 mm in October. Temperatures are highest in January (average maximum 32 degrees) and lowest in July (14 degrees). Mean annual pan evaporation is around 1780 mm and follows a clear seasonal trend, with high evaporation rates over summer trending to much lower rates over winter.

The average monthly evaporation exceeds the monthly average rainfall over the majority of the year. There is therefore a net deficit in rainfall across the catchment and without additional inflows to match or exceed the rate of evaporation, the water levels in the lakes would be expected to decrease.

GCC has initiated "fill events" into North Lake Wyangan to improve the water quality, allay community concerns regarding B-GA and improve access to North Lake Wyangan for recreational activities by increasing the overall volume of water within the lake.

Wind Mixing

Without inflows and outflows to generate currents within the lakes, circulation of the water is driven predominantly by wind. Wind measurements from the nearby Griffith Airport indicate that the average wind speed is only 1.9 m/s. From this the corresponding surface wind-driven drift current speed can be estimated to be 3.5% of the wind speed, giving a current speed of only 0.057 m/s in the surface water. This indicates the wind mixing of even the surface waters is likely to be low.

In summer, as the lake waters heat up the lakes could potentially become stratified. This means a thermal barrier (a thermocline) could form and it can prevent the mixing of the surface and bottom water. Wind provides the primary energy to mix the water column and the amount of energy required to break the thermocline is related to the temperature difference between the surface and bottom water. The greater the difference, the stronger the wind energy required to enable mixing to occur.

Research undertaken by the Cooperative Research Centre for Freshwater Ecology on Canberra pollution control ponds (Lawrence et al 1998), indicated that low wind strength over summer periods resulted in "diurnal stratification" in shallow (<3 m depth) waters over summer, with the potential for enhanced release of nutrients from the sediments. The same conditions would apply to Lake Wyangan.

To assess mixing and stratification in the lakes during this project a limited number of spot measurements for dissolved oxygen (DO) have been collected in North and South Lake. Only the recent (December 2015) measurement in South Lake has shown significant difference between the top and bottom water of the lakes which would indicate stratification. Based on a review of the monitoring to date it is suggested that a dissolved oxygen logger be deployed in the lakes to continuously monitoring DO levels and the potential for stratification or wind mixing.

4.3.2 Nitrogen cycle

Nitrogen is an essential nutrient for all plant and animal growth. Nitrogen exists in two main forms in the water column, namely, organic N and inorganic N. The nitrogen cycle in a shallow lake system is summarised in Figure 4-7.

The organic nitrogen is contained in organic matter. Mineralisation of organic nitrogen releases ammonia (NH_4^+). When the water is well oxygenated, ammonia is converted to NOx (Nitrate and Nitrite) by nitrifying bacteria. Dissolved inorganic nitrogen (NOx + $NH4^+$) is assimilated by phytoplankton and they convert inorganic nitrogen to organic nitrogen through photosynthesis.

Organic nitrogen can settle down into the sediment from the water column and it can also be resuspended into the water from the sediment. Some portion of the organic nitrogen deposited in the sediment becomes permanently immobilised over time. Mineralisation and nitrification also occur in the sediment.

Inorganic nitrogen can be exchanged at the sediment-water interface through diffusion. Nitrate is denitrified in the anoxic sediment zones, releasing nitrogen gas (N2). Some cyanobacteria is able to fix nitrogen gas with heterocyst when inorganic nitrogen in the water column is depleted. Grazing in some systems may control algal blooms. However, it is possible that grazing pressure is low in Lake Wyangan and this is another reason for the high phytoplankton biomass. Unfortunately, there has been no field data about the grazing activities available for the lakes.

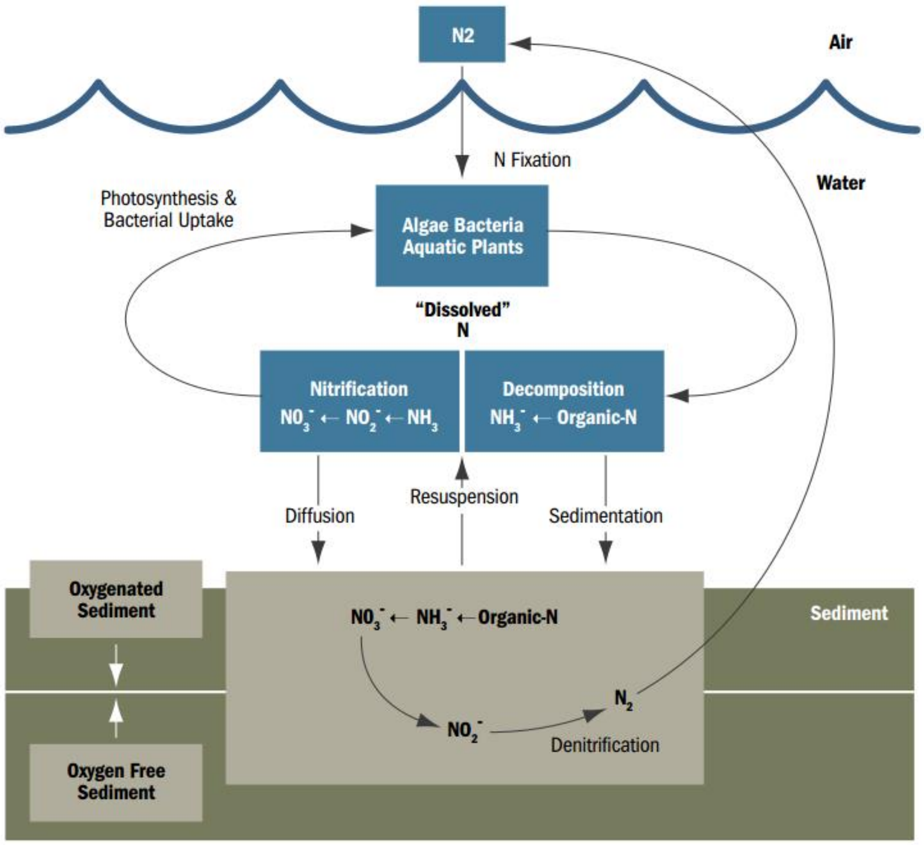

Figure 4-7 Nitrogen Cycle in a Lake System (Melbourne Water, 2005)

4.3.3 Phosphorus cycle

In freshwater lakes, phosphorus is typically the limiting nutrient, meaning that algae deplete all available phosphorus before depleting other nutrients. Therefore, phosphorus levels often regulate the abundance of algae.

Phosphorus can exist in the lakes mainly in three forms, organic phosphorus, phosphate (inorganic phosphorus), and ironbound phosphate. Apart from mineralisation, assimilation, diffusion, settling/resuspension and burial, phosphate can also be adsorbed on sediment particles (mainly iron (III) oxyhydroxides) and this can reduce the bioavailable phosphorous to phytoplankton. When oxygen is low, iron (III) is reduced to iron (II) and the absorbed phosphate is then released. The equilibrium of inorganic phosphorus is heavily affected by the adsorption and desorption processes. Furthermore, the pH in both lakes is generally high based on recent field observations. The adoption process is also highly pH dependent, and the adsorption capacity decreases if pH increases. Primary production can produce alkalinity and increase pH which can stimulate desorption of phosphate. Unlike nitrogen, phosphorus does not have any chemical or biological removal reaction; it undergoes repeated transformations and cycles within an aquatic system until it is removed from the system by burial or by outflows.

In situations where a large quantity of phosphorus is stored in the bottom sediment of a lake it will continue to build up in the lake over time. It has been found in other lake systems that phosphorus-rich sediment can prevent water quality improvement even if the external nutrient supply has been reduced.

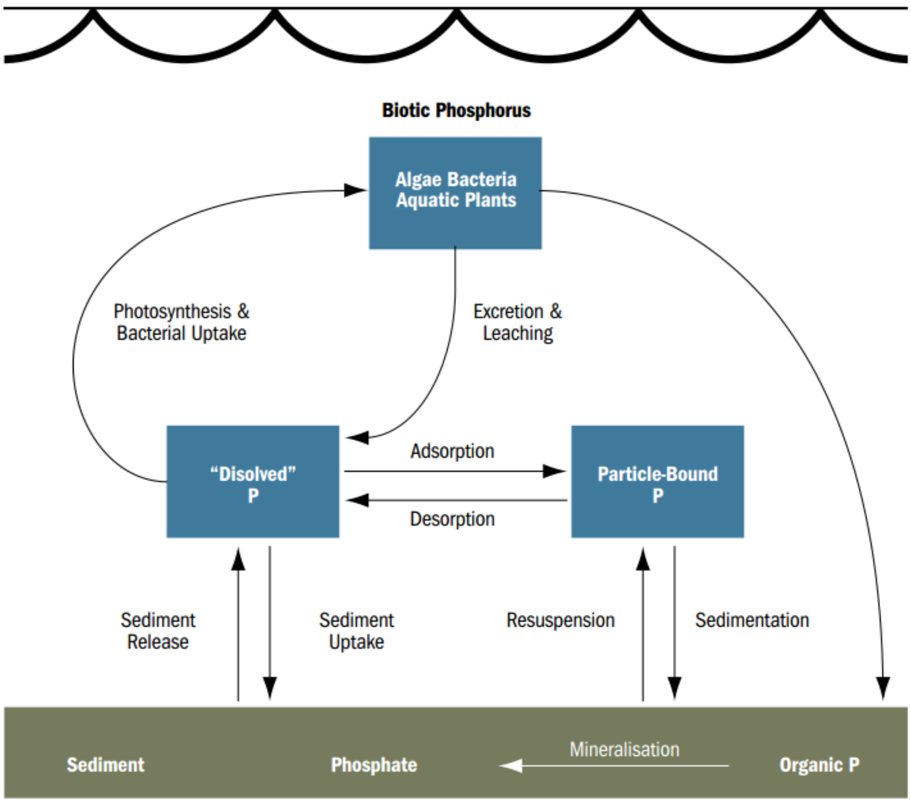

Figure 4-8 Phosphorus Cycle in a Lake System (Melbourne Water, 2005)

4.4 Catchment Processes

Catchment processes account for inflows of both flow and nutrients into the Lake Wyangan system. The volumes of flow, sediment and nutrients will depend on the hydrological regime as well as on the catchment land uses and physical characteristics such as the supply and drainage channel.

The eWater "Source Catchments" model has been used to develop a platform to simulate catchment processes including water flows, sediment and nutrient loads originated from the different land uses and arriving into the lakes. Figure 4-9 provides an example of the different catchment processes and components that can be incorporated into the Source model. Effectively this creates an updated water and nutrient balance model for the system.

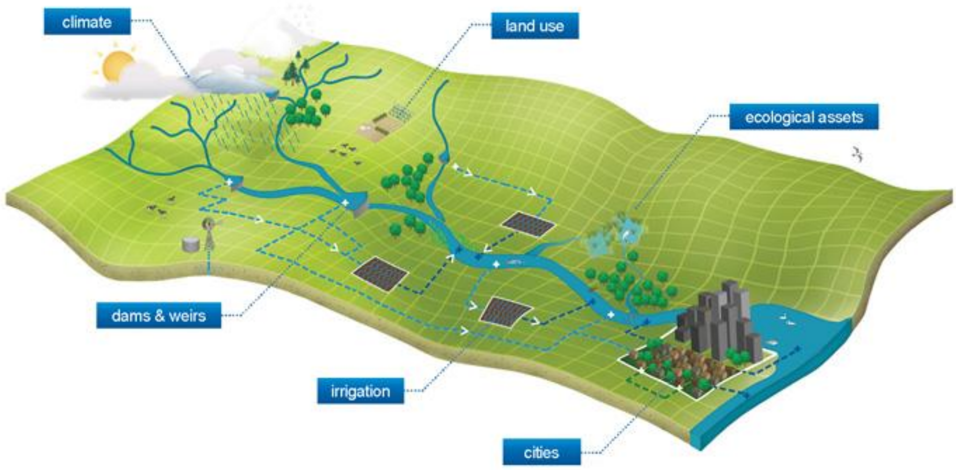

Figure 4-9 ***Schematic of the main catchment processes in Source model (eWater)***

4.4.1 The Source Catchment Modelling Tool

The Source modelling environment (developed by eWater) was chosen for this task because it provides a flexible modelling environment that can be tailored to the specific needs of individual investigations. Source can also be calibrated and modified as new data becomes available and can be regenerated to develop new scenarios so that the implications of changes in climate or land uses can then be investigated.

The accuracy of the modelled scenarios is constrained by the availability of long term water quantity and quality monitoring data, and also by the availability of spatial data showing the location and likely contaminants generated by land management activities.

A Source model is a simplification of the real world, and uses certain conventions to represent important characteristics of the system being simulated. Key features include:

- Catchments and sub-catchments - areas that generate runoff and constituent loads;
- Functional Units - areas within a sub-catchment that have similar behaviour in terms of runoff generation and/or nutrient generation. These could be, for example, areas with common land use;
- Nodes - points where flows and nutrients enter the river network, or where some process that is important for modelling, occurs (e.g. flow measurements at a stream gauge); and
- Links - used to join nodes and to store, route and process flow and constituents.

Source uses a node-link style modelling system for generating, transporting and transforming water and constituents within the major channels in a catchment (see Figure 4-10).

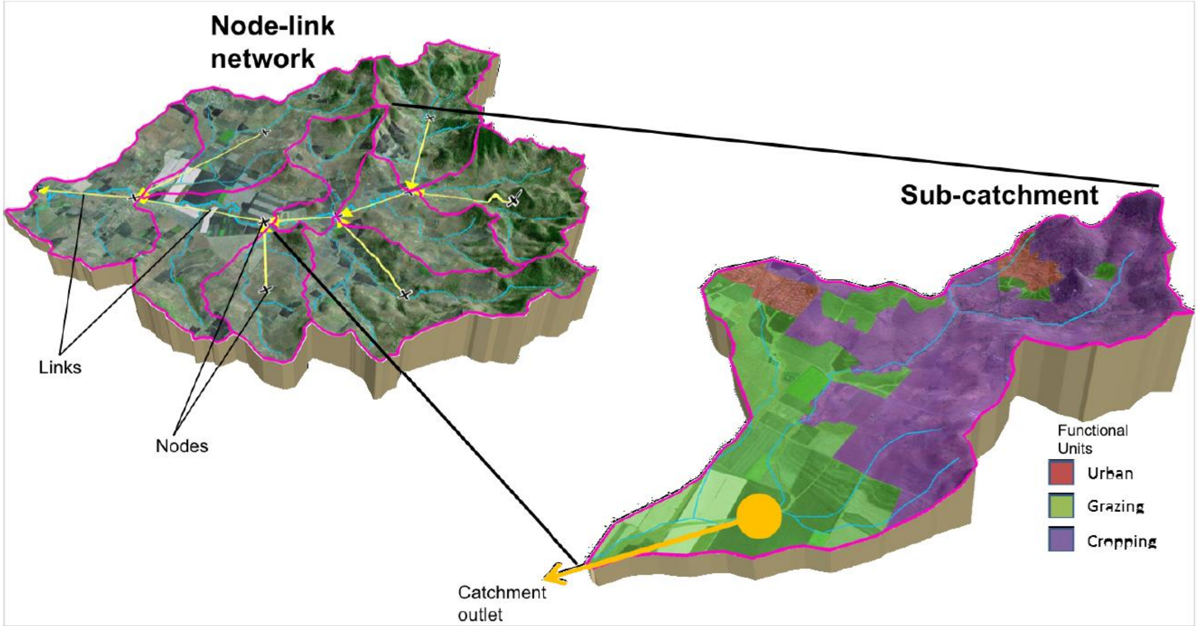

Figure 4-10 Node-Link Networks and Sub-catchments in a Source Model

The model consists of a number of component modules that determine factors such as:

- How rainfall is accumulated and apportioned to flow across different land uses within the catchment;
- How constituents (material transported in water, e.g. nutrients, sediments, pathogens, etc.) are handled;
- Handling of flow peaks (storm events) and base flows (dry weather flows).

The broad approach that will be used to model different surface water management scenarios involves alterations to settings within particular component models. For the Lake Wyangan Catchment Model the following component models will be used to develop scenarios:

- A Constituent Generation Model that deals with Event Mean Concentration (EMC) and Dry Weather Concentration (DWC).
- A Filter Model which reduces the amount of constituent that is generated in a Functional Unit (i.e. representing the treatment effect of a range of surface water treatment techniques).

Modelling of nutrients is most common, whilst modelling of pesticides and pathogens is more challenging due to inherent variability in their quantity, timing and area of application to the catchment and in their individual propensity to bind to sediment, break down, or in the case of pathogens, die off. For the Lake Wyangan catchment model, nutrients (TP and TN) and suspended solids were initially modelled. A range of other nutrients and pathogens can potentially be included in the future if needed and measured data becomes available data.

4.4.1 Model Setup

Based on the current available data, the model was setup to represent the current climate and land use conditions of the sub-catchments draining into Lake Wyangan (North and South). The next stage will consist of developing new scenarios so that the implications of changes in land uses and surface water management initiatives can be explored.

As noted previously, Umwelt (2004) undertook a preliminary water balance for the Lake Wyangan catchment and also noted that no data was available to quantify water sources (catchment runoff, irrigation return flows, and groundwater inflows) except for direct rainfall. At present there is no further information to quantify these variables and therefore **due of the lack of long term measured data (i.e. flows and pollutant concentration) for model calibration, this modelling exercise was performed to provide a more qualitative investigation of the catchment process than a quantitative one.**

As an outcome of this stage of the project, it has been identified that quantifying the inflow rates in the drainage channels is critical to understand the water and nutrient balance in the Lake Wyangan system. GCC and MI are currently assessing options for implementing flow monitoring in the drains.

This would involve installation of flow meters or flow measurement weirs on each of the inflowing drains, as close as possible to the lake outlets. Ideally the water level, flow rate and turbidity would be measured continuously at each site in order to characterised inputs to the system under both dry weather and wet weather conditions.

Additional data that would add development of the model include tile drainage pump rates from all farms discharging into the drainage network. This has been collected intermittently in the past but more regular data would enable these flows to be incorporated into the model.

If this data becomes available, the current model can be updated and improved calibrated achieved.

Input data preparation

The main input data required to setup a Source catchment model is related to the local (or regional) climate data, the catchment form, land use and points of interest to evaluate the results (e.g. discharge points):

- *Climate data.* Daily rainfall and evapotranspiration data from the Griffith Airport AWS (075041) site has been used. Continuous data was available from May 2010 to August 2015; the corresponding mean annual rainfall was 466 mm and mean annual evapotranspiration was 1446 mm. Figure 4-11 and Figure 4-12 show the monthly recorded climate data.

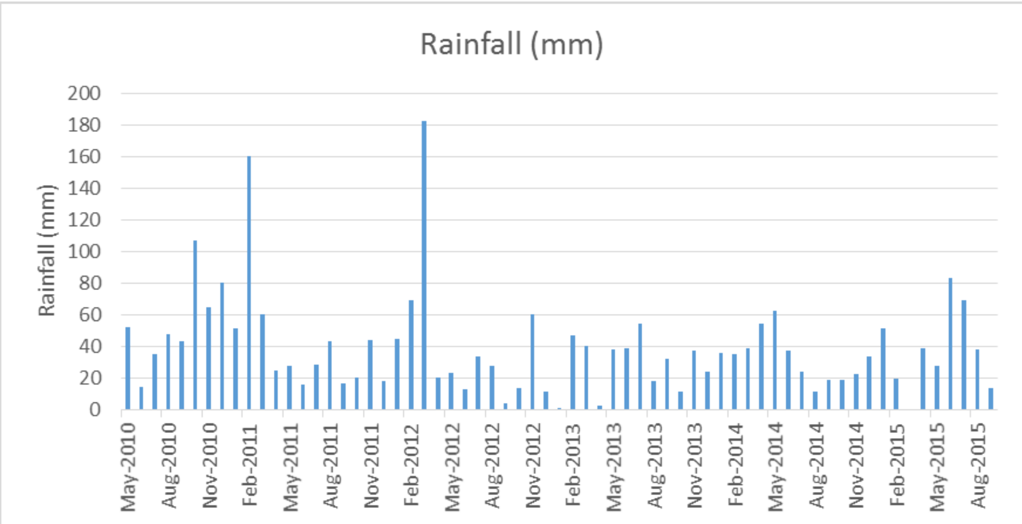

Figure 4-11 Griffith Airport AWS Monthly Rainfall Data

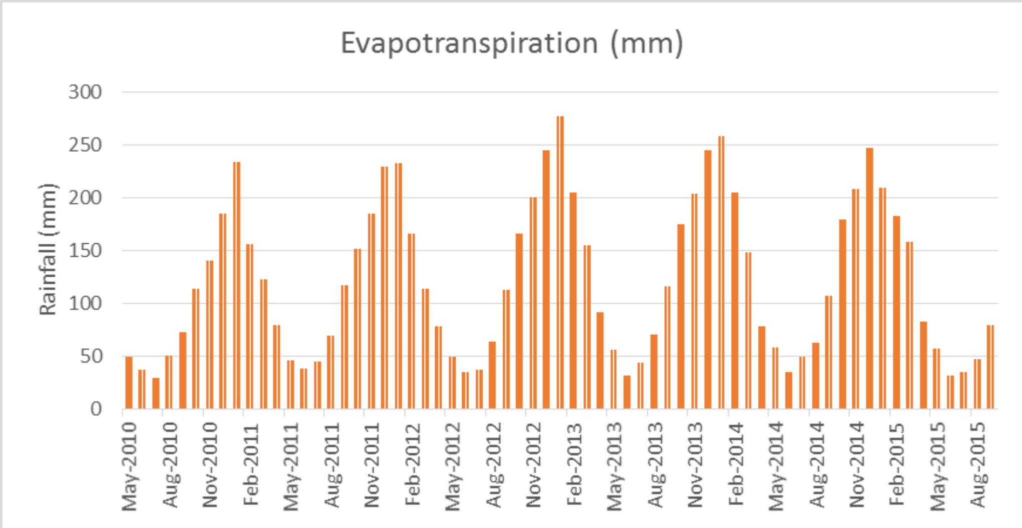

Figure 4-12 Griffith Airport AWS Monthly Evapotranspiration Data

- *Catchments and sub-catchments*. The sub-catchments were identified using the Geoscience Australia 1 second DEM and information provided by Griffith City Council and Murrumbidgee Irrigation. The North and South Lake catchments have been split into a series of sub-catchment based on the location of inflow points into each lake. Figure 4-13 presents the sub-catchment boundaries and outlets into Lake Wyangan. This includes all the drainage catchments to the lake as well as the flood catchment areas. The sub-catchment areas can be further refined as required.

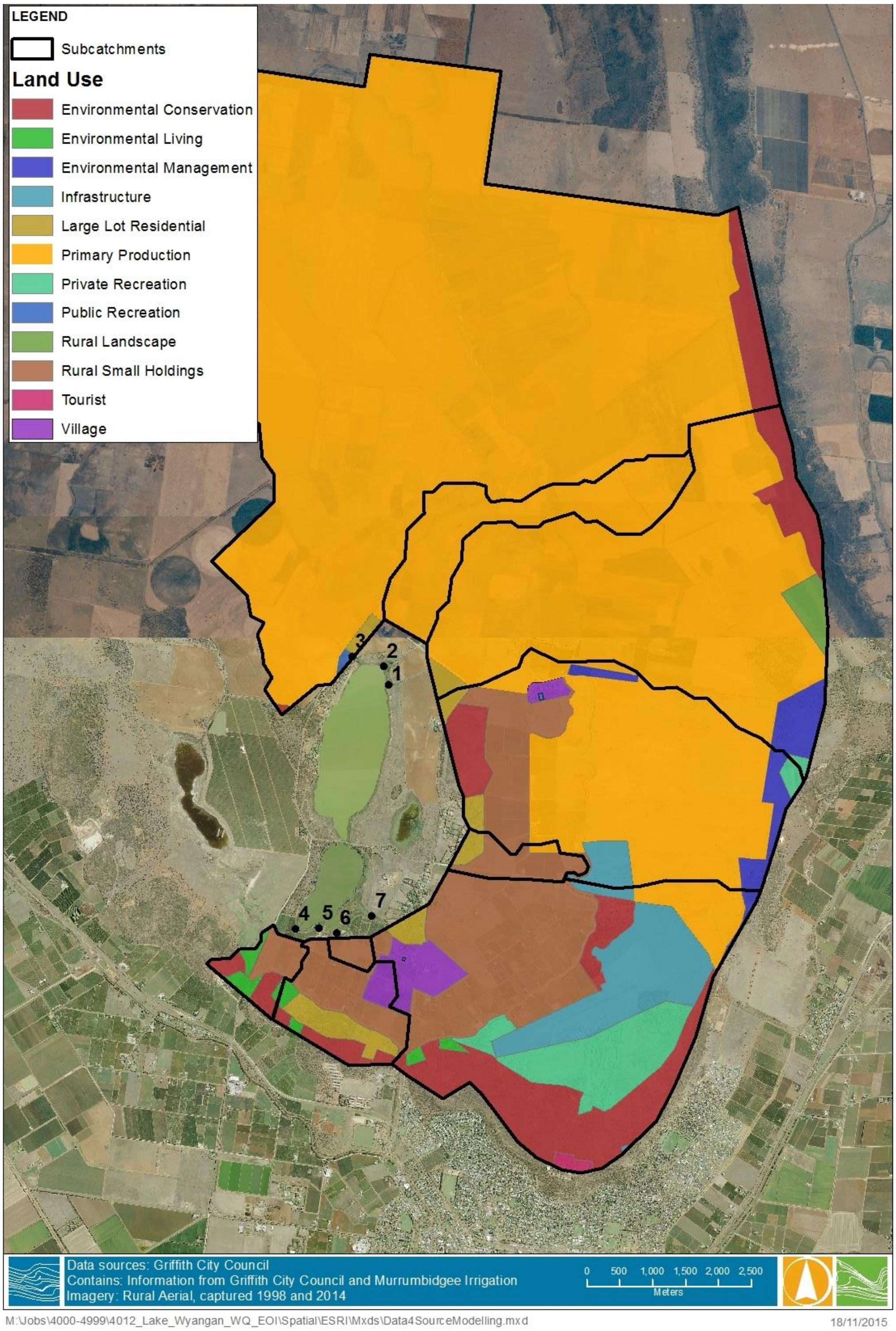

Figure 4-13 Sub-catchment boundaries and land use classification for Source modelling

- *Functional Units*. Functional units are parcels of land representing specific catchment characteristics (e.g. land use, catchment management behaviours, soil types, etc) from which the flows and pollutant loads are generated. The type of functional units have been based on the land use, defined by aerial imagery and data provided by Griffith City

Council and Murrumbidgee Irrigation. Figure 4-13 shows the functional units (here corresponding to the major land uses in the area) used for Source catchment modelling. Figure 4-14 shows relative area occupied by the different functional units. The items in the legend were listed in ascending order of the area they cover in the catchment. Thus "Primary production" is the dominant land use in the catchment.

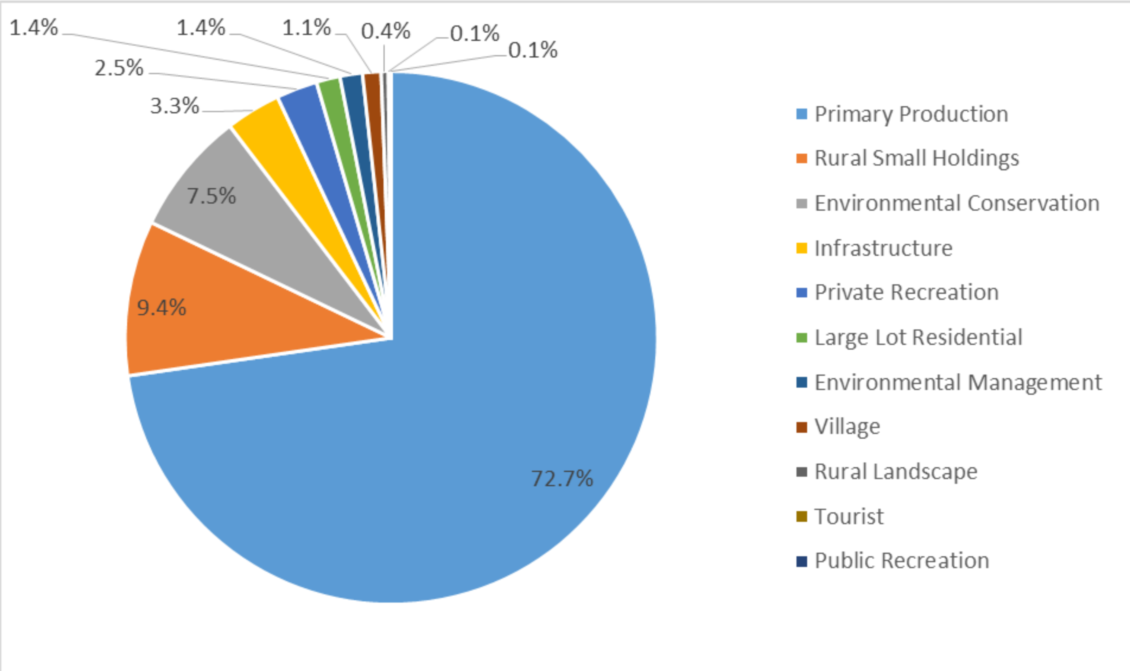

Figure 4-14 *Functional Units Used in the Source Modelling*

- *Nodes and links*. Source uses a node-link style modelling system for generating, transporting and transforming water and constituents within the major channels in a catchment.

Model setup

The model setup involves the following:

- *Rainfall-runoff model.* SIMHYD (developed by Chiew & McMahon, 1997) was developed for Australian conditions, and has been adopted for this study. SIMHYD is a daily conceptual rainfall-runoff model that estimates daily stream flow from daily rainfall and areal Potential Evapotranspiration (PET) data. The model contains 3 stores for interception loss, soil moisture and groundwater and has 7 parameters. In the absence of measured flow data to calibrate the model, the default values presented in Table 4-1 were adopted.

The pervious area fraction adopted for the different functional units are presented in Table 4-2.

Table 4-1 Default Values for the SIMHYD Model

Parameter Description	Units	Default
Baseflow Coefficient	None	0.3
Impervious Threshold	None	1
Infiltration Coefficient	day^{-1}	200
Infiltration Shape	None	3
Interflow Coefficient	day^{-1}	0.1
Rainfall Interception Store Capacity	mm	1.5
Recharge Coefficient	day^{-1}	0.2
Soil Moisture Store Capacity	mm	320

- Specification of the constituents and their modelling approach (i.e. pollutants) for modelling. Total suspended solids and nutrients (total nitrogen and total phosphorus) were modelled in this study. The model chosen to use for all constituents is a model that predicts with Event Mean Concentration (EMC) and Dry Weather Concentration (DWC). Source requires estimates of generation rates for each constituent in EMC and DWC and these were adopted from the literature.

Table 4-2 Pervious Area Fraction, EMC and DWC Values Adopted for the Existing Land Uses

Land use	Comments	Pervious Area Fraction	Suspended solids (mg/L)		TP (mg/L)		TN (mg/L)	
			EMC	DWC	EMC	DWC	EMC	DWC
Environmental Conservation	Forest; Swamp	0.9	79.43	7.94	0.08	0.03	0.84	0.72
Environmental Living	Rural	0.9	158.49	12.59	0.35	0.15	2.63	2.09
Environmental Management	Rural	0.9	158.49	12.59	0.35	0.15	2.63	2.09
Infrastructure	Future Cemetery; Airport; Landfill and Quarry	0.9	158.49	12.59	0.35	0.15	2.63	2.09
Large Lot Residential	Rural	0.8	89.13	14.13	0.22	0.06	2.00	0.89
Primary Production	Mostly horticulture	0.9	199.53	25.12	0.54	0.13	3.89	1.19
Private Recreation	Golf Course; Racing/walking track/park	0.25	0.75	12.59	0.35	0.15	2.63	2.09
Public Recreation	Park	1	158.49	12.59	0.35	0.15	2.63	2.09
Rural Landscape	Rural	0.9	79.43	7.94	0.08	0.03	0.84	0.72
Rural Small Holdings	Rural	0.75	89.13	14.13	0.22	0.06	2.00	0.89
Tourist		0.75	158.49	12.59	0.35	0.15	2.63	2.09
Village	Urban	0.55	158.49	12.59	0.35	0.15	2.63	2.09

The model has been used to simulate the period 2010 to 2015, applying the current land use types (based on information supplied by Griffith City Council and Murrumbidgee Irrigation). In future, the model can be used to test the impacts of land use changes, as well as land and water management practices within the catchment.

4.4.2 Flow, Nutrient, and Sediment Results

Figure 4-15 shows the percentage coverage of the different sub-catchments draining directly into Lake Wyangan. Sub-catchment 3 (SC3) is the largest draining to the North Lake and is predominantly used for horticulture. The same land use is predominant in the North Lake contributing sub-catchments. Differently, the sub-catchments draining to the South Lake have a mixture of land uses, including most of the residential parts of the area. Sub-catchment 7 (SC7) is the largest one draining to the South Lake and holds the local airport.

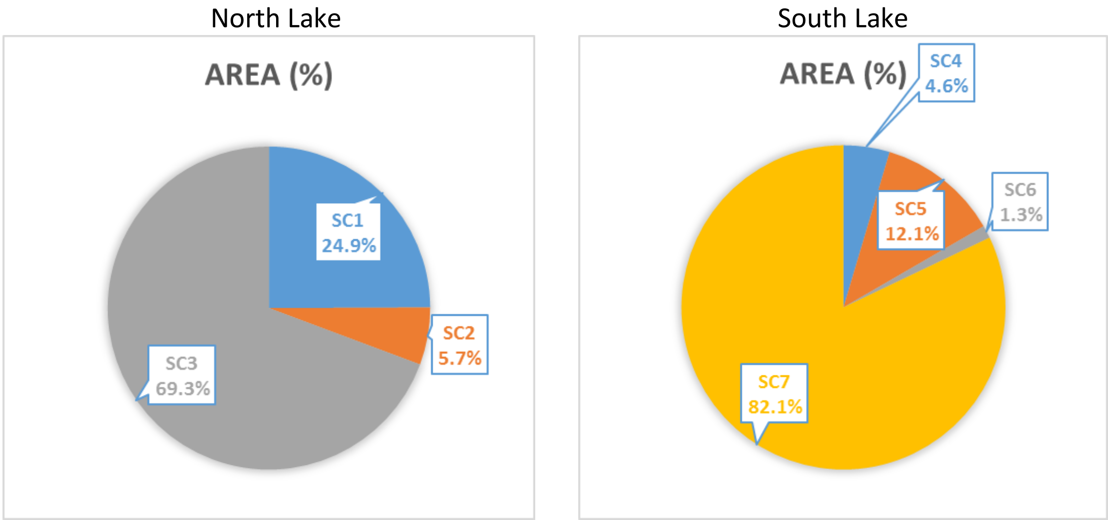

Figure 4-15 Coverage of the Sub-Catchment Areas

Figure 4-16 shows the percentage contribution per area to the total load of total dissolved solids (TSS), total nitrogen (TN) and total phosphorous (TP) entering each lake over the simulation period. The results presented are for current land use conditions.

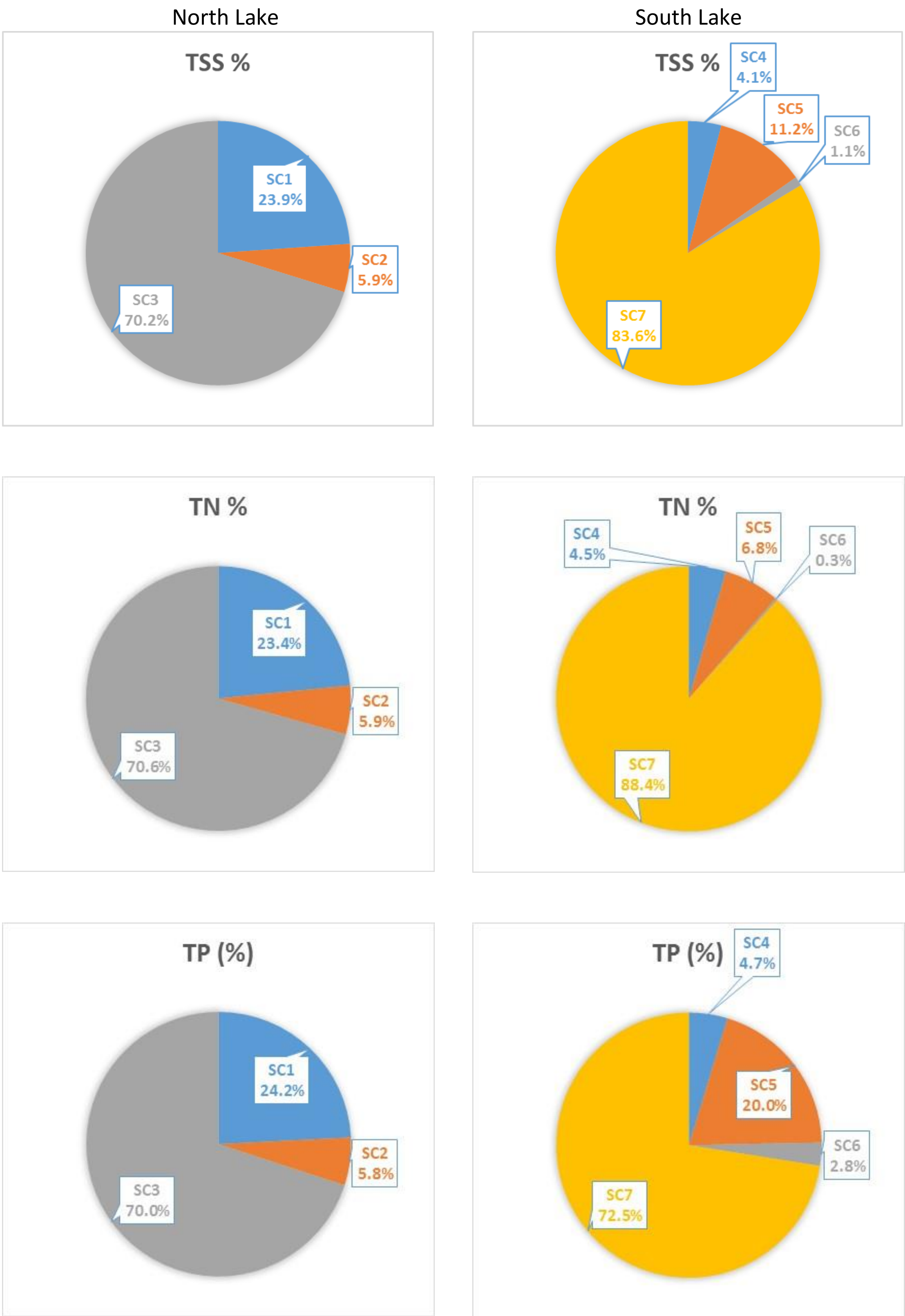

Figure 4-16 ***Percentage contribution per area to the total load of total dissolved solids (TSS), total nitrogen (TN) and total phosphorous (TP) entering each lake over the simulation period***

Due to the uniform land use in the sub-catchments contributing to the North Lake, the overall contribution of each catchment with each pollutant is also quite uniform. These figures are different in the South Lake contributing sub-catchments, where a mixture of land uses can be found.

In terms of nutrient concentration, the averaged modelled TN concentration was found to be larger in the runoff draining to the North Lake than the in the runoff draining to the South Lake. This is not in agreement with averaged measured values presented in Figure 3-11, which indicates the contribution of extra pollutant inputs into the South Lake. Most of the residential area is located within the sub-catchments draining into the South Lake and it is possible that the private septic tanks overflows are providing an additional source of pollutant input. Likewise, the North Lake catchment is predominantly used for a range of crops and the excess of irrigation water supply generated within these areas may dilute the pollutant concentration.

In terms of TP, higher averaged modelled concentration was in the runoff draining to the South Lake, which is again not in agreement with the mean of all measured data presented in Figure 3-12, but is in agreement with the average of the data presented in Sub-section 3.3.

The discrepancy between the preliminary modelled and measured nutrient concentrations derived from the catchment is a result of limitations in the available data underpinning the model. Analysis of the measured nutrient concentration with time (showed in Figure 4-17) shows that while some of the peaks in the pollutant concentration occurred after the rainfall events, a number of the peaks in nutrient concentration in the drains also occur during dry weather periods. Such results suggest that the rainfall-runoff process is not the only source of nutrients and that there are flows and nutrient inputs into the drains that are not currently accounted for in the model.   These are likely to be associated with irrigation escape flows and tile drainage. These results support the previous analysis by Umwelt (2004).

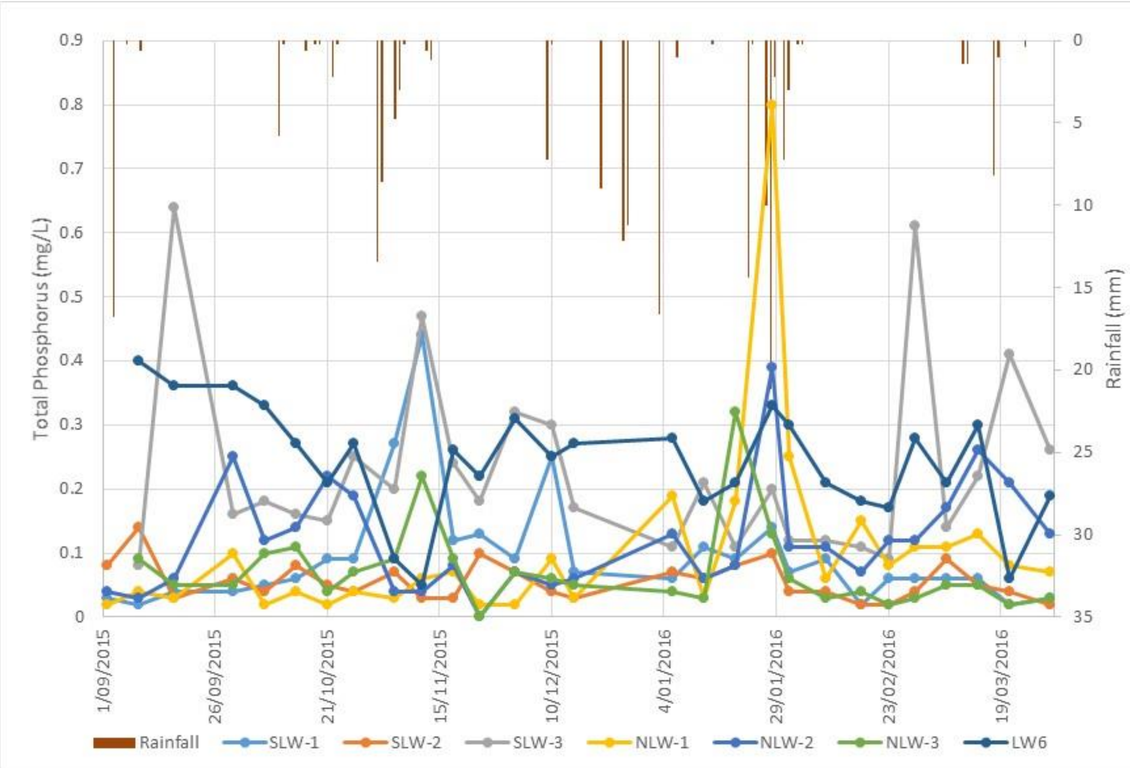

Figure 4-17 *Measured TP concentration at the catchment drains*

While the model is not yet able to accurately reproduce the monitoring results, it has been setup so that with additional data (drain flows etc) it can be refined and developed further.

4.4.3 Summary

The analysis of the pollutant concentration data suggested that the runoff originated from the rainfall-runoff process in the catchment is not the only source of inflows and nutrients and that additional flows and their associated nutrients (mainly TP) are discharged into the drains, likely from tile drainage and irrigation escape flows.

It is recommended that flow rates in the drains should be measured during dry and wet periods to better quantify the magnitude and temporal variation of the volumes discharged into the lake. Such a dataset can also be used for a preliminary model calibration, which will then provide a more realistic indication of the annual flow volumes and nutrient loads reaching the lake. Flowrates should ideally be measured on each drain as close to the lake outlet as possible. This may involve the installation of a flowmeter or flow measurement weir on each drain. Monitoring would ideally be continuous.

Interestingly, the results of this preliminary modelling are supported by the earlier water balance assessment by Umwelt (2004) which noted that catchment runoff (from tile drainage) along with direct pumping are important variables for understanding the water balance of the lake. It was suggested that possible irrigation return flows be examined to determine the magnitude, timing and frequency of such flows and that escape laterals should be monitored to allow further investigation of returns to Lake Wyangan.

Griffith City Council has noted that the eastern area around the lake (North and South) may be developed in the future for residential purposes. The change in the land use will impose considerable addition of impervious areas and therefore an increase of runoff flows and nutrients entering the lake. The impact of these changes can be investigated along with the potential water quality improvements achievable through catchment water quality management options (detailed in Section 5).

5. MANAGEMENT OPTIONS

5.1 Overview

Managing the frequency and duration of algal blooms within Lake Wyangan focuses on the three main contributing factors: residence time, light and nutrients.

- Residence time is amenable to management action and constitutes a tangible tool to assess the likelihood of potential algal problems within a lake.
- Nutrient inputs can be managed by installing pre-treatment measures upstream and by managing the high levels of nutrients currently present within the lake system.
- Light can be managed to a certain extent but some blue green algae are able to regulate their position in the water column and migrate vertically, increasing their exposure to optimum light intensities.

The preceding project stages including the existing conditions modelling were used to develop a selection of potential water quality management options for both North and South Lake Wyangan. The following criteria were used in the process of assessing the options:

- *Reduces residence time.* At present the lakes are a terminal system and evaporation is the only means of water loss. In this situation phosphorus and nitrogen will continue to build up in the lakes over time. Circulation of water through the lakes will reduce phosphorus and nitrogen concentrations in the lakes.
- *Improves mixing conditions in the lakes.* Thermal stratification in the lakes can enhance algal growth by enabling the release of phosphorus from the sediment. Increased mixing keeps the water column well oxygenated and reduces the likelihood of phosphorus release.
- *Reduces nutrient concentrations in or into the lakes in the short and/or long term.* There is currently excess Phosphorus and high levels of nitrogen in the lakes and inflowing drainage channels. Reducing the existing and future nutrient load in and into the lakes is important for management of algal blooms.
- *Cost and feasibility.* The potential cost and feasibility on a "whole of lake scale" are important considerations. For this reason, a preliminary review of these factors has been included as part of the assessment.

5.2 In-Lake Management Options

5.2.1 Review of Available Options

A comprehensive overview of potential in-lake management options for the management of algal blooms is provided in Table 5-1. Many of the options have been taken from http://www2.epa.gov/nutrient-policy-data/control-and-treatment which is based on the following sources:

- Hudnell, K. H., "A Systems Approach to Freshwater Management: Waterbody Treatments", U.S. EPA Webinar, May 14, 2014.
- International Guidance Manual for the Management of Toxic Cyanobacteria. Water Quality Research, Australia, Ed. G. Newcombe. 2009.

Additional options were identified during the second expert panel meeting and community meeting held in Griffith on the 25 November 2015.

Table 5-1 Review of In-lake Management Options for Algal Blooms

Waterbody Management Method	Description	Benefits/Effectiveness	Limitations	Advantages for Lake Wyangan	Constraints for Lake Wyangan
Physical Controls					
Aeration	Aerators operate by pumping air through a diffuser near the bottom of the waterbody, resulting in the formation of plumes that rise to the surface and create vertical circulation cells as they propagate outwards from the aerator. This mixing of the water column disrupts the behaviour of cyanobacteria to migrate vertically in addition to limiting the accessibility of nutrients.	Successfully implemented in small ponds and waterbodies. Proven effectiveness in several field studies. May also provide more favourable growth conditions for competing organisms.	Generally, more efficient in deeper water columns. Also highly dependent upon the degree of stratification and the air flow rate.	Increased mixing may be important for LW to reduce the risk of stratification and release of phosphorus. The iron to phosphorus ratio in the lake sediments is consistently > 10, and iron oxides are known to bind phosphorus down to a ratio of 6:1. The sediment therefore has very high capacity to bind iron if the water column remains oxic.	Lake Wyangan is typically a shallow water system with mixing regime not yet confirmed. If the lake is already mixed frequently naturally then further aeration and mixing may not be effective. Energy costs may be high for the number of units required across the North Lake in particular and will have ongoing operation and maintenance costs. Potential navigation hazard for lake users (boats etc.). Does not address current algal bloom issue but could be used to limit continued bloom development.
Hypolimnetic oxygenation	Techniques used to achieve hypolimnetic oxygenation include: airlift pumps, side stream oxygenation and direct oxygen injection. The primary goal of this method is to increase the oxygen concentration in the hypolimnion in	Maintains water column structure (thermocline, pycnocline, etc.).	Techniques are relatively expensive. Requires a significant understanding of system in order to	As above.	As above.

Waterbody Management Method	Description	Benefits/Effectiveness	Limitations	Advantages for Lake Wyangan	Constraints for Lake Wyangan
	order to prevent or reduce the release of nutrients from the sediment while maintaining water column stratification. This serves to limit upper level nutrient levels thereby inhibiting cyanobacterial growth.		determine effectiveness.		
Hydrologic manipulations (environmental flows, use of lake as irrigation storage, alternation of inflow/outflow system)	Low flow conditions in waterbodies can lead to stratification of the water column, which aids cyanobacterial growth. Particularly in regulated systems, the inflow/outflow of water in the system can be manipulated to disrupt stratification and control cyanobacterial growth. At present Lake Wyangan is a terminal system and evaporation is the only means of water loss. In this situation phosphorus will continue to build up in the lakes over time. Circulation of water through the lakes will reduce phosphorus concentrations in the lakes. Any plan to recycle water through the lakes would need to occur during periods of stratification to ensure that phosphorus released from the sediment was flushed out of the lakes.	Easy to implement in controlled systems (i.e., reservoirs, dams, treatment facilities).	Requires sufficient water volume and the ability to control flow. Often can be expensive. Unintended consequences for other aquatic organisms are likely.	An option to improve circulation in the lakes and flush the excess phosphorus from the system could involve provision of freshwater inflows to each lake and then pumping back out via the existing South Lake discharge. Can be combined with provision of water for recreational purposes. Small scale options for storing allocations in North Lake are also possible. Submersible pumps to gradually circulate the water are an option. Likely only needed at certain times of the year when stratification likely.	Concerns were raised during stakeholder discussion as to the feasibility of this option due to potential limitations associated with existing infrastructure and water supply constraints. Possible options were however identified for further investigation. Volumes required to provide sufficient mixing likely to be large in North Lake. Infrastructure and implementation costs need to be considered. South Lake already has existing infrastructure to implement but this will have cost implications.

Waterbody Management Method	Description	Benefits/Effectiveness	Limitations	Advantages for Lake Wyangan	Constraints for Lake Wyangan
					(Umwelt, 2004) did investigation some options for diverting flows from the MI system into Lake Wyangan.
Mechanical mixing (circulation)	Mechanical mixers are usually surface-mounted and pump water from the surface layer downwards or draw water up from the bottom to the surface layer. This mixing of the water column disrupts the behaviour of cyanobacteria to migrate vertically in addition to limiting the accessibility of nutrients.	Successfully implemented in 350+ waterbodies in the U.S. Also used in other countries.	Individual devices have limited range; areas further away may remain stratified and provide a suitable environment for growth.	Increased mixing is likely to be important for LW to reduce the risk of stratification and release of phosphorus. The iron to phosphorus ratio in the lake sediments is consistently > 10, and iron oxides are known to bind phosphorus down to a ratio of 6:1. The sediment therefore has very high capacity to bind iron if the water column remains oxic.	Lake Wyangan is typically a shallow water system but mixing regime not yet confirmed. If the lake is already mixed frequently naturally then further aeration and mixing may not be effective. Likely to be costly. May be difficult to implement effectively over the whole area of North Lake - particularly in areas with reeds or aquatic vegetation. Need to minimise inadvertently mixing surface sediments which contain the phosphorus. Does not address current algal bloom but will aid reduction in likelihood of future blooms.
Reservoir drawdown/desiccation	In reservoirs and other controlled waterbodies, can draw down the water level to the point where	Easy to implement in controlled systems (i.e.,	Can have a significant impact on other aquatic	Occurs naturally through evaporation.	Limited ability to undertaken this in a

Waterbody Management Method	Description	Benefits/Effectiveness	Limitations	Advantages for Lake Wyangan	Constraints for Lake Wyangan
	cyanobacteria accumulations are exposed above the waterline. Subsequent desiccation and/or scraping to remove the layer of cyanobacteria attached to sediment or rock is required, in addition to the reinjection of water into the system.	reservoirs, dams, treatment facilities).	organisms in the system. Often times is expensive and requires a significant input of resources.	Possible in South Lake but limited for North Lake due to current lake user requirements. Drying sediment can immobilise nutrients.	controlled manner in Lake Wyangan. Fish kills possible. Need to mechanically remove the algae. Cyanobacterial propagules may be resistance to desiccation and simply re-seed a new bloom once higher water levels return. Need to be careful not to stress/kill Cumbungi in the process (can survive dry conditions up to about 3 months). Potentially high costs associated with artificial refilling of the lakes. Natural refilling may not be feasible on timescales required. Will significantly disrupt recreational use of the lake.
Surface skimming	Cyanobacterial blooms often form surface scums, especially in the later stages of a bloom. Oil-spill skimmers have been used to remove cyanobacteria from these surface scums. Often times this technique is coupled with the	Useful method for blooms that are in later stages and have formed surface scums. Successful results seen in field studies in Australia.	This technique cannot be effectively employed until the later stages of a bloom, at which point many of the harmful aspects of a	Could be effective to address the current bloom but will not prevent future blooms occurring.	Short term solution only. May only remove surface scums and will not address cyanobacteria entrained within the water column. Labour intensive. Costly and Reactive - may need to do it multiple times

Waterbody Management Method	Description	Benefits/Effectiveness	Limitations	Advantages for Lake Wyangan	Constraints for Lake Wyangan
	implementation of some coagulant or flocculent.		bloom have materialized. Requires proper equipment prior to implementation.		each summer (or more frequently).
Sediment Removal (Dredging) of bottom sediments	Potential application for removal of surface sediment layers containing high levels of phosphorus.	Can be effective in small systems but disposal costs can be high. Any contaminants in the sediment may be dispersed during dredging.	High cost and slow. Temporary impacts on water quality. Disposal can be an issue. Minimising resuspension of bottom sediments required during dredging operations as disturbance of bottom sediments is likely to stimulate algal growth.	Long term removal of phosphorus in the lake sediment to limit future development of algal blooms.	Will have significant adverse short term impacts – high turbidity and potential for increased release of nutrients into the water column. Moderate cost but may be difficult to implement given the debris (trees etc.) on the bed of the lakes. Disposal costs for sediment need to be considered.
Ultrasound	An ultrasound device is used to control HABs by emitting ultrasonic waves of a particular frequency such that the cellular structure of cyanobacteria is destroyed by rupturing internal gas vesicles used for buoyancy control.	Successfully implemented in ponds and other small waterbodies. A single device can cover up to 8 acres. Non-chemical; inexpensive.	Also disrupts cellular functioning of green algae. Effectiveness is dependent upon waterbody geometry and cyanobacteria species. Further research of method is required.	Commercial systems available and marketing material provided indicates good effectiveness in lake environments. Costs per unit range from $3500 to $4500 plus installation, operation and maintenance costs.	Effectiveness not quantified in literature. Supplier has been asked to provide additional information. Only cells in range can be killed and can take 4-5 weeks of continuous application May be difficult to be effective in North Lake due

Waterbody Management Method	Description	Benefits/Effectiveness	Limitations	Advantages for Lake Wyangan	Constraints for Lake Wyangan
			As with algaecides, by breaking open and killing algal cells this method also runs the risk of releasing toxins into the water column.		to size of lake and fringing vegetation. Potential navigation hazard for lake users while in operation. Lawrence (2012) notes "while the research papers supporting the application of the devices conclude that the system does not harm insects, fish or humans, if applied widely across a lake, the devices would seriously impact on the plankton of the lake – the base of the food web for the lake." This also does not address the potential risks for release of toxins. Short term solution and algae may return rapidly. Further investigation of costs for large scale application is required. Will still require dead algae to be removed from the lake.

Waterbody Management Method	Description	Benefits/Effectiveness	Limitations	Advantages for Lake Wyangan	Constraints for Lake Wyangan
Chemical Controls					
Algaecides	Algaecides are chemical compounds applied to a waterbody to kill cyanobacteria. Several examples are: • Copper-based algaecides (copper sulphate, copper II alkanolamine, copper citrate, etc.) • Potassium permanganate • Chlorine • Lime	Wide range of compounds with a history of implementation. Relatively rapid and well-established method. Properties and effects of compounds are typically well-understood.	Risk of cell lysis and the release of toxins. Thus, is often used at the early stages of a bloom. Certain algaecides are also toxic to other organisms such as zooplankton, other invertebrates, and fish.	Short term removal of all algae from the lake system.	A license is required from the NSW EPA before application to lakes, and reservoirs. Licenses are difficult to obtain.
Barley straw	Barley straw bales are deployed around the perimeter of the waterbody. Barley straw, when exposed to sunlight and in the presence of oxygen, produces a chemical that inhibits algae growth. Field studies suggest significant algistatic effects. Several causes for the observed effects have been suggested; however, the exact mechanism of this process is not well understood.	Studies have shown that decomposed barley straw inhibits the growth of cyanobacteria Microcystis sp. Successfully implemented in many reservoirs and dams in the United Kingdom with positive results.	Does not kill existing algae, but inhibits the growth of new algae. May take anywhere from 2 to 8 weeks for the barley straw to begin producing active chemical. Potential to cause fish kills through the deoxygenation of the waterbody due to decay.	A limited number of papers in the literature indicate this is potentially effective. Could be part of in-drain filter system. Could do small trial of effectiveness - within a drain (so contained).	Does not typically kill algae already present but may inhibit growth of new algae. Unlikely to be useful on a large scale in the lakes themselves.

Waterbody Management Method	Description	Benefits/Effectiveness	Limitations	Advantages for Lake Wyangan	Constraints for Lake Wyangan
Plant harvesting	The shoot system can be harvested (i.e. cut above water level) in late spring - early summer to remove phosphorus from the system.	Literature contains conflicting recommendations from "Harvesting for nutrient removal is not practical and is not recommended" to "Harvesting macrophytes has the potential to enhance phosphorus removal in wetands". The middle ground suggests "the amount of phosphorus removed by harvesting is usually low".	Harvesting typically requires expensive mechanical equipment and is labour intensive. Bed rooted macrophytes are difficult to access/harvest.	The lakes are mostly fringed with Cumbungi and/or Common Reed. Could be more effective in the drains for managements. Potential pilot application for active management of lake vegetation.	Likely to be costly. Potential to exacerbate weed growth in areas where reeds are removed.
Coagulation	Coagulants are used to facilitate the sedimentation of cyanobacteria cells to the anoxic bottom layer of the water column. Unable to access light, oxygen, and other critical resources, the cells do not continue to multiply and eventually die.	Several studies have shown that cells can be coagulated without damage; however, further research is required. Successfully implemented in several treatment facilities.	Subject to depth limitations. Coagulated cells become stressed over time and lyse, releasing toxins to the waterbody.	Short term removal of algal cells from the surface waters.	Longer term implications are uncertain (e.g. How does is breakdown). Potential release of toxins into the water body presents a significant risk.

Waterbody Management Method	Description	Benefits/Effectiveness	Limitations	Advantages for Lake Wyangan	Constraints for Lake Wyangan
Flocculation	Flocculants are used to facilitate the sedimentation of nutrients to the anoxic bottom layer of the water column, thereby limiting nutrient levels in the waterbody and inhibiting cyanobacterial growth.	Successfully implemented in larger lakes and ponds (e.g., Florida DEP, Lake Hilaman). Flocculants which bind dissolved reactive phosphorus in the water column include products that may also act as active capping agents (see below, e.g. Alum and Phoslock).	Subject to depth limitations. Should be applied when nutrient or algal concentrations are high. If using Alum, consideration needs to be given to effect of algal blooms on the pH of the entire water column to ensure it is within limits for effective flocculation.	Example: when Phoslock is applied to a water body as a slurry, it moves down through the water column, up to 95% of the FRP is rapidly removed and adsorbed onto the surface, forming an insoluble complex within the clay structure. As the Phoslock settles on the sediment-water interface it forms a ~1 – 3 mm layer (depending on application rate). This layer of Phoslock is capable of adsorbing the FRP from the sediment layer on its available binding sites. Once the FRP is bound to Phoslock, it is no longer bioavailabile. Likely to have good short term effects.	Results in smothering of sediment (and associated flora and fauna) with algae and the flocculants/capping agent. Toxicity effects possible (see above). Based on the mass of bioavailable phosphorus calculated to be in the lake (around 10 tonnes) then 1000 tonnes of Phoslock would be needed. Phoslock cost is $3000/tonne. While application of flocculants such as Phoslock will improve short term water quality conditions in the lake it may require multiple applications and only applies to excess phosphorus. National Industrial Chemicals Notification and Assessment Scheme (NICNAS) report details issues associated with application of Phoslock.

Waterbody Management Method	Description	Benefits/Effectiveness	Limitations	Advantages for Lake Wyangan	Constraints for Lake Wyangan
Nutrient inactivation products	Nutrient inactivation products (known as sorption media) can be used to remove nutrients by surface bonding or incorporation into the media. May be applied to ponds or lakes as an active capping agent - designed to reduce nutrient release. Active capping agents such as aluminium sulphate, modified zeolite (e.g. Aual-P), calcite or clays such as bentonite (e.g. Phoslock) irreversibly bind dissolved inorganic phosphorus to prevent release under anoxic conditions.	Most effective in deep ponds or lakes that are anoxic (in the bottom waters) for part or all of the year.	In shallow systems that are affected by high rates of wind-driven resuspension, capping agents are likely to be quickly reworked into the bottom sediments and buried rendering the material largely ineffective. Toxicity of some products needs to be considered.	As above.	As above. Toxicity of some products needs to be considered. Adverse food web effects (e.g. reduction in grazers, fish kills) have been indicated in some Alum and Phoslock applications. Need to implement in conjunction with reduction in nutrient load from the catchment.
Substrate capping	Sediment lining relies on a passive capping agent such as sand, gravel or clay which buries organic matter and sediment and reduces the diffusion of nitrogen and phosphorus into the water column. Some methods of sediment lining (e.g. gravel) may also reduce resuspension of sediment and associated nutrients by replacing light organic material with mineral materials with higher bulk density.	Used in water treatment systems. Application and/or effectiveness on lake scale system not documented in the literature.	Uses sand, gravel or clay to create thick layer (>5cm) and so potentially large logistical and financial constraints in large systems. Not effective in systems that do not stratify. Shallow systems require coarser material to reduce	Potential application for Lake Wyangan but may be limited due to spatial scale of the lakes. This approach is used in water treatment systems. Could be used to target specific areas (if known). Further detailed sediment sampling would be required.	Requires further investigation of potential materials, costs and logistical for lake wide application.

Waterbody Management Method	Description	Benefits/Effectiveness	Limitations	Advantages for Lake Wyangan	Constraints for Lake Wyangan
			resuspension or burial.		
Biological Controls (Bio-manipulation)					
Floating artificial wetlands	Artificial wetlands are constructed using floating mats and placed in a waterbody. As the plants grow, they function as a sink for excess nutrients such as phosphorous and nitrogen. Periodic harvesting of mature plants is conducted to prevent the stored nutrients from re-entering the aquatic ecosystem, which helps to mitigate the risk of cyanobacterial blooms by keeping nutrient levels in balance.	Implemented in small waterbodies with limited success.	Often dependent upon the amount of input (i.e., the number of plants and mats). Also subject to depth limitations. Good info from manufacturers but limited academic information to support it.	Potential to reduce nutrient levels in the water column but further investigation is required to assess costs (implementation and maintenance) as well as overall effectiveness.	The size of the North Lake may limit application of extensive floating wetlands. Potential navigation issues for boating/recreational users of the lake. May be adversely effected by waves/boat wake. Does not address phosphorus stored in sediments.
Increasing grazing pressure	Various measures can be introduced to encourage the growth of zooplankton, benthic fauna, and other aquatic organisms that feed on cyanobacteria, thereby limiting the proliferation of cyanobacteria populations. Techniques include:	Biomanipulation has fewer direct detrimental effects on other aquatic organisms when compared to chemical and physical methods.	Unintended consequences may arise related to the deliberate modification of the biodiversity of the system. Requires constant monitoring. Increasing resource competition has only proven effective in shallow water bodies with	Silver Carp have been breed in NZ to control phytoplankton. They feed on suspended particles greater than 0.01 mm can consume a range of Phytoplankton as well as zooplankton and detritus. Will consume cyanobacteria including Anabaena and Microcystis.	Not a lot of evidence for long term suppression of algal blooms. Little information on use of Silver Carp in conditions other than tropical areas - no info on environmental risks available. Not considered an option when high certainty of outcome for cyanobacteria control is required.

Waterbody Management Method	Description	Benefits/Effectiveness	Limitations	Advantages for Lake Wyangan	Constraints for Lake Wyangan
			moderate nutrient levels		
	• The removal of fish that feed on zooplankton and other benthic fauna or the introduction of predators to these fish, and		Grazing of phytoplankton by zooplankton may be limited when (typically) inedible cyanobacteria are the dominant phytoplankton species.		Zooplankton grazing unlikely to be effective in deeper areas of the lakes.
	• The development of niches to encourage the growth of beneficial organisms.				Option does not address current algal bloom.
Macrophyte restoration	Enhancement of extent of emergent and submerged macrophytes across a lake system. Emergent and submerged macrophytes/wetlands at lake inlets and across shallow zones and embayment encourages sedimentation and reduces nutrient loads into the system. The introduction of other primary producers such as macrophytes can limit the available phosphorus and therefore limit cyanobacterial growth.	Macrophytes reduce wind driven resuspension of bottom sediments and may uptake nutrients otherwise used to fuel algal growth. Added benefit may be a reduction in turbidity levels.	Requires other control options (e.g. fish removal) in place to reduce algae, suspended sediment and nutrient concentrations.	Suitable for drains, at inlets to the lakes and around the lake margins (see catchment controls, Section 5.3).	Successful in shallow, sheltered water bodies so more suitable to South Lake. Does not address current algal bloom issue but should be part of longer term management.

Waterbody Management Method	Description	Benefits/Effectiveness	Limitations	Advantages for Lake Wyangan	Constraints for Lake Wyangan
Removal of carp	Pest fish species such as carp can significantly disturb sediments and uproot macrophytes when they feed which increases water column sediment and nutrient concentrations and enhances phytoplankton and reduces macrophyte biomass.	Reduces resuspension of sediment in shallow areas where the fish feed. Removal of carp provides improved conditions for native fish and aquatic plants.	Will not address currently algal bloom.	DPI undertake annual stocking of native fish into North Lake Wyangan including Golden Perch, Murray Cod, and Silver Perch for recreational fishing. Removal of carp would aid growth of native species. Could be part of the long term management of the lakes.	Will not address current algal blooms. Contribution of carp to disturbance of bottom sediment within the lakes is currently unknown.
Harvesting of Algae for biofuels	Manual harvesting techniques include raking and netting. Other methods involve microscreens, centrifugation, flocculation and froth floatation.	Algae can yield over 30 times more energy per unit area than other biofuel crops.	Harvesting is likely to be the limiting factor. Very labour intensive. Harvesting and drying of algae for biofuel currently consume large quantities of energy. Currently considered too expensive to be commercially viable.	As for surface skimming.	Difficulties to remove algae efficiently from the system. Further investigation of costs required. May have competing requirements - likely to want to promote algae growth rather than complete removal.

5.2.2 Short Term In-Lake Options

Based on the review of available in-lake management options, 8 short term options were identified and summarised in Table 5-2. Of these options, aeration/mixing and hydrologic manipulation have the potential to provide the best outcomes for the lake taking into account the effectiveness of the option in reducing or eliminating algal blooms and the likely costs involved. However, it is noted that none of the options reviewed provide complete short-term solutions to managing an algal bloom once it has developed.

Table 5-2 Short-Term Options Review

Option	Likely Effectiveness	Indicative Costs
Aeration	**Medium** – potential to limit or prevent stratification from occurring and therefore further release of phosphorus. Further investigation of the mixing regime in the lake is necessary in order to understand the potential effectiveness of aeration processes for managing algal blooms.	**Medium** – costs $50,000+ per unit (including capital, operation and maintenance over 10 years). Will require multiple units, however could be used to target specific locations.
Mechanical Mixing	**Medium** - potential to limit or prevent stratification from occurring and therefore further release of phosphorus. Further investigation of mixing regime required to confirm effectiveness.	**Medium** – costs $20,000 per unit with some on-going maintenance costs. Will require multiple units, however could be used to target specific locations.
Hydrologic Manipulation	**Low to High** – depends on volumes and ability to effectively mix across the systems.	**Medium –** use of environmental water (State or Commonwealth) or use of GCCs Water Access License to add water to the lake for community or environmental requirements. This is effectively the approach taken for lake fill events in 2014 and 2015. **High** – further investigation of potential options including infrastructure requirements and costs is required. This options covers a range of scales – from environmental flows to use of the lake as an irrigation storage.
Nutrient inactivation (i.e. Phoslock)	**High** – potential for removal of all bioavailable phosphorus but will require on-going application if nutrient inputs are not addressed.	**Medium to High** – cost ranges from $300,000 (treatment of P in the water column only) to $3,000,000 (full treatment of P in both the water column and within the

Option	Likely Effectiveness	Indicative Costs
		sediment). The majority of P is stored in the sediment and hence the higher treatment cost associated with treating all forms of P in the lake.
Surface Skimming	**Low to Medium**	**Low to Medium** – depending on scale and approach. Would require multiple undertakings and does not address the underlying issue.
Substrate capping	**Low to Medium**	**Medium**
Ultrasound	**Low to High** – depending on scale and duration of application. Would require on-going application.	**Low to Medium** – depending on scale and duration of application

Algaecides were not included, i.e. as a license from NSW EPA is required for their application.

For the indicative cost estimates Low = <$50,000, Medium = $50,000 to $500,000, High = > $500,000.

Aeration/Mixing Systems

The monitoring to date has indicated that the release of phosphorus stored in the sediment into the water column is likely an important factor in blue-green algae bloom generation. This happens when temperature stratification occurs. Although not confirmed by monitoring to date, this is thought likely to occur diurnally with conditions most conducive to stratification in late Spring through to late Summer. Further monitoring is recommended to confirm these conditions. The lack of mixing of the lake waters in turn exacerbates this process.

A wide range of mixing and aeration techniques have been developed both in Australia and internationally to ameliorate the impacts of stratification in lakes, including (Lawrence, 2012):

- Mixing and/or aeration of the bottom waters, significantly reducing the energy required to work against the temperature - density differential through the water column;
- Mixing of the surface water – to promote cycling and growth of the Green (Chlorophyta) group of algae in preference to the blue-green (cyanobacteria) algae.

The option of mixing/aeration within the bottom waters is an approach that significantly reduces the energy requirements compared to raising the heavier bottom water to the surface, but it does not incorporate the wind re-aeration of surface water contribution to the re-aeration of the bottom water. This approach **does not directly manage the summer surface water algal growth**. It will, however, reduce the risk of algal blooms following autumn mixing of the bottom and surface waters, and the amount of phosphorus available at the commencement of the next growing season (Lawrence, 2012).

Mixing within the surface water, is primarily focused on providing the turbulence necessary to cycle the Green algal cells through the light (euphotic) zone, promoting their growth in preference to blue-green algal growth. However, in shallow systems like Lake Wyangan this approach will also promote oxidation of sediments, reducing the release of sediment phosphorus in shallow waters. As with all "mixer" options, there are also risks with this arrangement – turning on a mixer post de-oxygenation of the sediments, may result in the mixing of bottom phosphorus throughout the surface waters, thereby enhancing algal growth (Lawrence, 2012).

Visser et al (2015) undertook a detailed review of artificial mixing for controlling cyanobacteria blooms. They found that "of the various effects that artificial mixing has on the environmental conditions in a lake, it is mainly the decreased stability of the water column, which causes the shift from cyanobacteria to green algae and diatoms." Important considerations for successful mixing included the depth of the lake (not too shallow), the coverage of the system, and the ability of the mixer to encourage good vertical mixing conditions. They conclude that it can be a good solution to prevent nuisance blooms of cyanobacteria but recommended that the main focus of lake restoration works be too reduce external nutrient input to the lake or reservoir.

Cost estimates for a solar powered mixing system were received from Aquago, who manufacturer a mixing system specifically setup to address issues of odour and algal blooms in lake system. Each unit can mix an area of 5000 m^2 so 100 units would be required to cover the entire Lake Wyangan system. The total cost for 100 units is $1,6000,00 ex GST. A more cost effective approach is to target specific locations around the lake which are "hot spots" for algal bloom generation. For instance, the satellite imagery analysis did identity that during some periods the B-GA bloom developed on the western side of the lake near the recreational facilities. Mixing devices could be used along this area to prevent of manage these conditions. The proposal from Aquago is provided in Appendix D.

Hydrologic Manipulation

As noted in Table 5-2, at present Lake Wyangan is a terminal system with limited inflows no outflows. Evaporation is the only significant means of water loss and mixing of water in the lake is limited to wind-driven processes. In this situation phosphorus will continue to build up in the lakes over time and there is no flushing of existing phosphorus released from the sediment. Circulation of water through the lakes would help to reduce phosphorus concentrations in the lakes. Any plan to recycle water through the lakes would need to occur during periods of stratification to ensure that phosphorus released from the sediment was flushed out of the lakes.

To date GCC has undertaken a number of fill events into North Lake to provide additional depth of water for recreational use and also potentially to reduce the potential for algal blooms to develop. As discussed in Section 4.3.1, the releases have had varied success in managing algal blooms depending on the volume of water released. The most recent fill event in November/December 2015 provided almost a 25% increase in lake volume which resulted in dilution rates of up to 75% in North Lake. From the monitoring results it appears that fills of this magnitude could be used to manage algal bloom conditions. Bakker and Hilt (2015) present a review of the use of water-level fluctuations on cyanobacterial blooms for water quality management. Their review concluded:

- A summer water-level drawdown will only reduce cyanobacteria blooms when accompanied by a strong increase in macrophyte abundance (which compete for the nutrients), or leads to a complete drying out.
- The more eutrophic the system the more chance that cyanobacteria will dominate.
- Water level rises as a response to flooding/infills were found to have contrasting effects on the abundance of cyanobacteria in shallow lakes. Filling events can have a direct dilution effect, however the overall impacts is strongly dependent on the water nutrient concentrations and transparency.

This would indicate that to be successful, fill events at Lake Wyangan should target late spring and summer periods where drawdown through evaporation starts to occur. The fill water volume should be at least 25% of total lake volume and water quality should be monitored to ensure it has low levels of suspended sediment and nutrients.

Discussions are on-going as to the feasibility and costs of options for hydrologic manipulation, which include:

1. Environmental water allocations – provided through the existing MI network,

Environmental water is water that is allocated and managed specifically to improve the health of rivers, wetlands and floodplains. Environmental water is managed consistent with a range of NSW and Commonwealth legislative and policy initiatives, including:

- The Water Management Act 2000
- Water Sharing Plans
- Commonwealth Water Act 2007
- The Basin Plan

For further information, refer to:

http://www.environment.nsw.gov.au/environmentalwater/policy.htm

Environmental water is managed to protect or restore environmental assets. Environmental assets are defined as water-dependent ecosystems and services and sites of ecological significance, must be present. Water-dependent ecosystems include wetlands, streams, floodplains, lakes and other bodies of water, salt marshes, karst and underground systems (Commonwealth Environmental Water Office, 2013). In NSW, the Office of Environment and Heritage (OEH) manages the delivery of environmental water in collaboration with stakeholder and other agencies. OEH also delivers environmental water held by the Commonwealth Environmental Water Holder.

At present environmental water is delivered through the MI network to both Campbell's Swamp and Nericon Swamp. Both these swamps meet several criteria for assessing the importance of wetlands for waterbirds at local, state, national and international levels (Taylor et al, 2000). In NSW decisions on environmental water management are based on annual and long-term watering plans, managed by OEH.

Lake Wyangan forms part of the Important Bird and Biodiversity Areas (IBA's) listing. This Griffith Wetlands IBA listing includes Lake Wyangan, Campbells, Nericon and Barren Box Swamps. Both North Lake Wyangan and South Lake Wyangan are stated in the IBA description to have permanent water storage capabilities with areas of Cumbungi suitable for Bittens. Australiasian Bittern is an IBA trigger species, endangered species and has been sighted in 2006-08 during the breeding season.

The nearby Nericon and Campbells swamps provide habitat for a number of bird species listed in the Threatened Species Conservation Act 1995, the Japan, Australia Migratory Birds Agreement and China Australia Migratory Birds Agreement. Consequently these two swamp areas are valuable local and regional assets, with international importance for threatened and migratory birds (Umwelt 2004). It is probable that some bird species, where habitat conditions prevail, relocate from Nericon and Campbells swamps to Lake Wyangan during drier periods.

Within the Murrumbidgee catchment the Murrumbidgee Environmental Water Allowance Reference Group advises on both planned and adaptive environmental water. At present

Lake Wyangan is not included within the watering priorities or watering plans within the Murrumbidgee catchment.

2. Council "fills" – provided through the existing MI network,

As detailed in Section 4.3.1 and Section 5.2.2, GCC holds a Water Access License. It is able to trade this water on the open market at a value determined year to year by the open market (in 2015 this water was worth up to $230/ML). GCC can utilise this license for the purpose of filling North Lake Wyangan, foregoing the temporary Water Market opportunities, and subsequent income. This water is supplied to the lake via the existing drainage network. No long term funding is allocated to the purchase of water for the lake within the GCC budget and no cost share arrangement is currently in place.

A possible funding mechanism for future lake filling could be the establishment of a Lake Wyangan Community Water Fund. This would be community investment in water sourcing and securing water for flows into the lake. The fund could also be used to pay for water infrastructure works for improvement of water quality within the lake. Further investigation is required to determine the feasibility of such a fund.

3. Modification of existing extraction licenses from the lake to allow North Lake to operate as an irrigation storage.

It was identified in discussions with stakeholders during the project that there are existing extraction licenses associated with Lake Wyangan. At present these licenses are only triggered under high lake levels typically associated with flood events. However, the question was asked as to whether these licenses could be modified to enable extraction from North Lake Wyangan in particular under non-flood conditions if the supply water was provided via the drainage network and stored in the lake.

4. Changes to existing MI/Council infrastructure to facilitate enhanced delivery or extraction of water from the lake either for environmental allocations, Council fills, or irrigation water delivery.

Murrumbidgee Irrigation provided an indication of the possible flow routes and volumes that could be implemented for North and South Lake Wyangan to improve circulation and mixing conditions. This is shown in Figure 5-1 and consists of supply of water into South Lake, extraction of water from South Lake, and then redistribution of this water into North Lake via the supply and drainage network. An initial test of these options has been undertaken using the hydraulic model described in Section 4. Figure 5-2 presents the results from modelling this proposed scenario. It can be seen that there is a relatively consistent level of mixing throughout the North and South Lake. These results can be compared to the existing event results shown in Figure 4-6. The proposed mixing regime shows better mixing than for the fill event only conditions (shown in Figure 4-6), with an approximate 10% increase in dilution in the North Lake compared to the November 2015 fill event. Previously the South Lake had no dilution during all fill events, but this scenario allows for a 25 – 30% dilution. This appears to be a viable short-term option in increasing fresh water circulation in the lake.

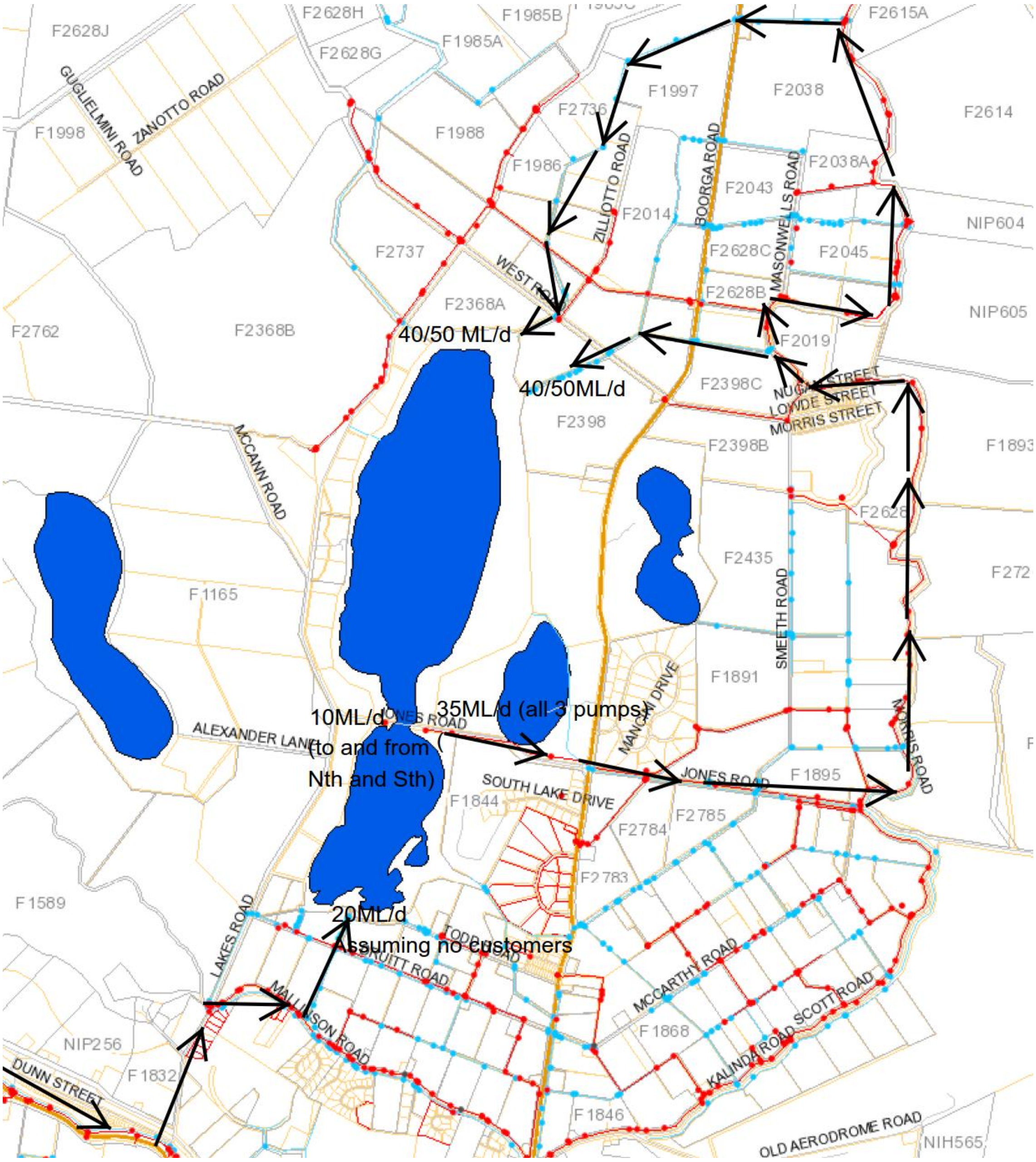

Figure 5-1 *Lake Wyangan Water Circulation Options, provided by Murrumbidgee Irrigation*

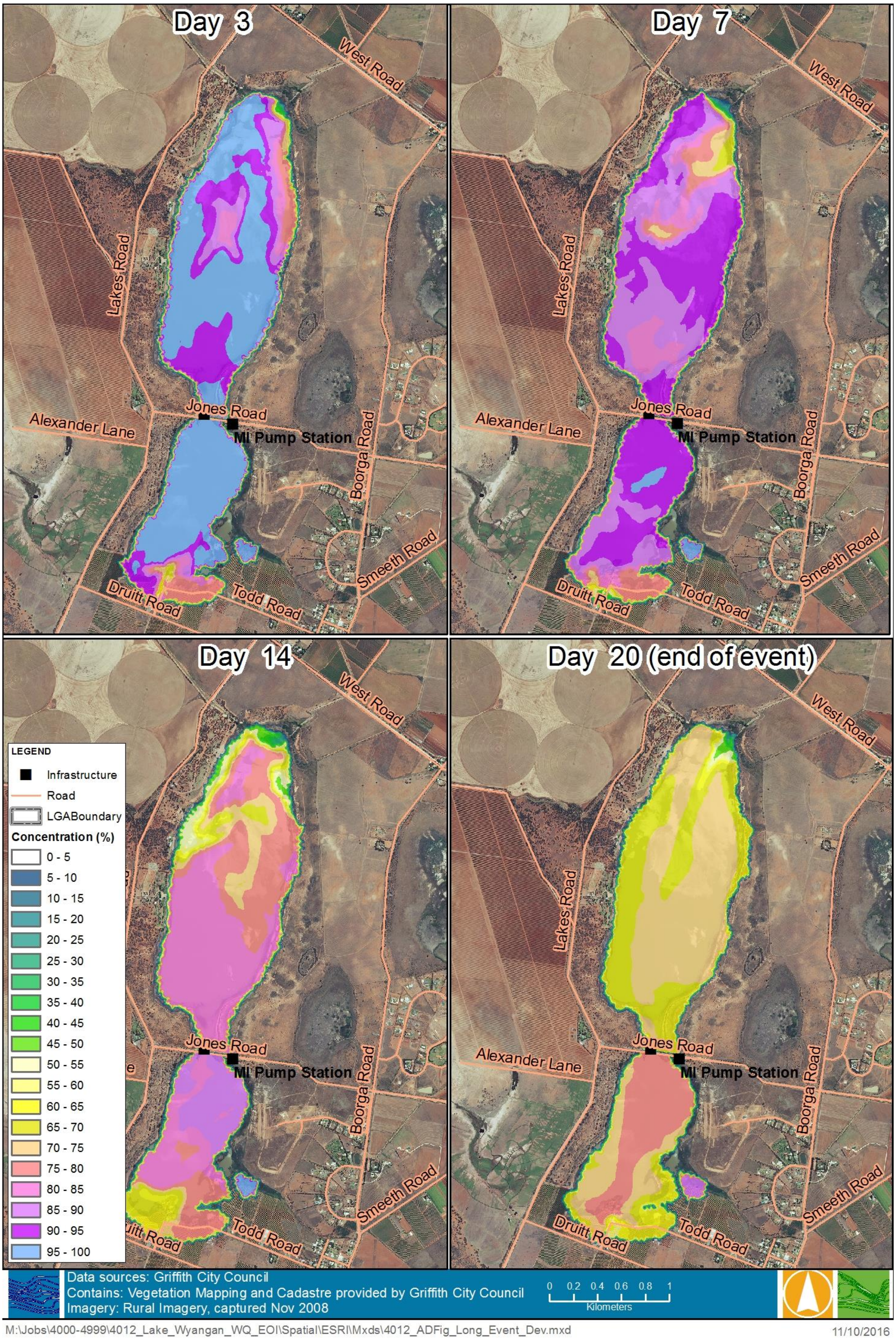

Figure 5-2 Mixing Processes for a Large Inflows Utilising the Proposed Changes to Delivery System

Nutrient Inactivation (Phoslock)

A quotation was requested from Phoslock, a manufacturer of a proprietary product for nutrient inactivation in lake systems. Based on the phosphorus loads in the lake, as detailed in Section 2, there is a total combined (water column and sediment) of 4.7 tonnes of Phosphorus in South Lake and 6.0 tonnes of Phosphorus in North Lake. The dose ratio of the product is 100 to 1 (Phoslock to Phosphorus) which therefore indicates a required volume of 1,000 tonnes is required. The total cost for this would be $3,000,000.

To treat the water column only, the dose required is 124 tonnes, for approximately $370,000.

Given the on-going load of phosphorus entering the lake system there would also be a need to treat the lake in the future as phosphorus loads increase.

5.2.3 Long Term In-Lake Options

The review detailed in Table 5-1 has identified 20 potential management option for managing algal blooms in Lake Wyangan. Apart from surface skimming and algaecides many of these options, while not highly effective individually, could provide long term benefits as part of a suite of management actions.

Further details of recommended in-lake long term management options are provided below. Note that the “short term” options of aeration/mixing and hydrologic manipulation are also considered within the scope of “long term” management options but are not repeated here. Any long term in-lake options should be coupled with catchment management options (discussed in the following section) to ensure effectiveness.

Macrophyte Restoration

During the community consultation, it was noted by several attendees that there has been a significant reduction in emergent and submerged marcrophytes in the Lake Wyangan system. This could be due to many factors including changing hydrological regime, increased levels of algal growth (as a result of increased levels of available nutrient) on the macro-plant leaves, and levels of suspended sediment in inflows and re-suspension, limiting light available to the plants, presence of carp, and recreational boat use. Reducing nutrient and suspended sediment levels in the lakes opens the possibility of re-establishing the macrophyte habitats although other factors such as the presence of carp and impacts from boat use may also need to be managed in conjunction with this management option.

This management option would involve the re-establishment of emergent and submerged macroplants.

Local resident and wetland specialist, Geoff Sainty, has provided the following options for restoring submerged aquatic plants and green algae to **South Lake Wyangan**:

1. Substantially (>1m) drawdown of South Lake at or near the close of the 2016 irrigation season, when counts of cynobacteria are reduced to “green or amber”
2. The drawdown of the South Lake will expose the ring of *Phagmites Australia* and *Typha spp*. currently surrounding South Lake, and allow it to dry out to the extent that levels can be exposed with a controlled burn in July/August.
3. Survey the sedge of South Lake adjacent to the three main drainage inflows so that an appropriate water management option (likely to be a sediment pond and shallow wetland system) can be designed to reduce the inflowing nutrient loads. This design should consider the results of the monitoring program and any additional nutrient load data collected subsequent to this study.

4. Sediment ponds and wetlands constructed and seeded with submerged aquatic plants with the longer term aim of introducing native species into the lake. Species include *Vallisneria gigantean, Najas marina, Stuckenia pectinate and Myriophyllum verrucosum*. Filamentous algae is also a significant competitor to blue green algae and should be encouraged. A check of the available seedbank in the lake would provide some idea of the ability for macrophytes to return naturally once an appropriate watering regime is established. Costs would be reduced if seeding and planting isn't required.

As noted in Lawrence (2012) for Lake Burley Griffin, the re-establishment of macrophyte habitats in lakes and reservoirs has had a mixed success rate. In a number of cases, this is the result of elevated suspended sediments post the loss of macrophytes, limiting light necessary for their re-establishment. Hence a staged or phased approach to a "macrophyte restoration" program is recommended in order to assess this risk. Bakker and Hilt (2015) note that growth of macrophytes in shallow lake systems is important for the control of cyanobacteria blooms and changing water levels can both enhance or inhibit the required conditions for growth.

Carp Management

Carp are a pest animal in the lake and the wider catchment. Carp have significant effects on native aquatic plants both through direct grazing and through uprooting plants while feeding, leading to a reduction in plant density and biomass. Soft-leaved, shallow-rooted and submerged plants are most likely to be affected. Their disturbance of the lake bottom whilst feeding reduces light penetration, which can make it difficult for native fish that rely on sight to feed. Reduced light can also decrease plant growth, and suspended sediments can smother plants and clog fishes' gills.

Anecdotal information provided by residents indicates that carp numbers and their impact on lake water quality may be significant.

The following actions are recommended as part of a carp management option:

- Confirm fish numbers in Lake Wyangan including carp,
- Identification of hotspots where the fish congregate for spawning or where water temperatures are favourable,
- Carp fishing or targeted removal

Targeted carp removal could be undertaken in identified hotspots where the fish congregate for spawning or where water temperatures are favourable.

5.3 Catchment Management Options

Catchment options for managing algal blooms focus on reducing the levels of nutrients entering the lake via the drains or overland flow paths. For the Lake Wyangan catchment the focus is on management of inflows associated with:

- **Agriculture** – excess fertiliser wash-off from the land. Different land uses have different levels of fertiliser application and farm practises can impact the level of excess fertiliser wash-off.
- **Rural and Peri-Urban Water Management** – runoff from roads and peri-urban developments. Most runoff enters Lake Wyangan via the MI drainage network.
- **Wastewater** – there is currently no reticulated wastewater system for the area and aging septic tanks (and other older systems).

Management options associated with each of these aspects are discussed in the following sections.

5.3.1 Agricultural Land Management Practices

The majority of the Lake Wyangan catchment is productive farming land. The dominant land uses on horticultural farms are viticulture and citrus and on larger broad acre farms almonds, melons, winter cropping, rice and livestock grazing including some pasture production.

Reducing nutrients inputs to Lake Wyangan from agricultural runoff can be managed through the various changes to farm practices including:

- Maintaining healthy vegetation in and around drains (discussed further under the drain water quality treatments in Section 5.3.2)
- Capturing and reusing runoff
- Covering or enclosing fertiliser
- Reducing fertiliser use through better targeting
- Upgrading to more efficient irrigation systems

Examples include the Hawkesbury-Nepean River Recover Program initiative (http://www.water.nsw.gov.au/__data/assets/pdf_file/0006/548619/recovery_hn-nutrient-export-monitoring-farm-runoff-managing-nutrient-pollution.pdf).

Other resources include:

Australian Soil Resource Information System (ASRIS):
http://www.asris.csiro.au/themes/nutrient.html

The period between the implementation of improved management practices and subsequent improvements in water quality varies, but it is generally accepted to be in the order of years to decades for agricultural nutrients (Meals et al, 2010).

Specific on-farm measures to reduce nutrient inputs associated with agricultural runoff are beyond the scope of the present study, however reductions in fertiliser wash-off from the horticultural and broadacre farms is likely to result in the greatest reductions to nutrient levels in agricultural runoff. As the runoff is predominantly delivered to Lake Wyangan through the MI drainage network it is recommended that management actions focus on maintaining healthy vegetation in and around drains across the catchment. This is discussed further under the following section.

5.3.2 Rural and Urban Water Management

Rural and urban water management can be achieved through a large range of features. These features focus on integrating water cycle management into planning and design and must therefore work well with several variables. The selection of the preferred type is dependent on a number of factors, such as:

- The treatment objectives – regulatory requirements to meet best practice standards;
- Catchment characteristics and land use – factors such as catchment size, slopes, soil conditions etc.;
- Amount of land available – often space is a constraint, particularly in retrofit situations;
- System maintenance – whether or not GCC has the experience, equipment and funding available and in place to effectively maintain the systems; and

- Site specific constraints – other services such as gas or sewer, existing vegetation, areas of heritage or environmental significance, flood prone areas, social considerations etc.

Rural and urban water management features can be implemented across various types of developments or across different landuses within a catchment and at various scales – from small residential extentions or minor local road upgrades to new large subdivisions, or drainage network upgrades and changes to the use of the drainage system. The most common installations apply to collection of runoff along linear features such as the MI drains or roads, upgrades to existing peri-urban areas, new peri-urban developments, commerical or industrial properties and large carparks. Within the Lake Wyangan catchment we have idenitified that the existing MI drainage network could be upgraded to incorporate water management features.

Two approaches can be taken in terms of the distribution of water management assets – a single-site treatment, most commonly applied at the system outlet, or a distributed approach. In the single-site treatment approach, a single large-scale treatment is installed around the catchment outlet. This approach does offer maintainance advantages, however it requires for large volumes of water to be treated at one location, quite often far away from the original pollutant source. It may be an option in areas where land contraints are an issue.

In the distributed approach, smaller treatments are applied throughout the catchment. The types of treatments differ, and because of this, there are a number of advantages over the single-site treatment method. These include localised treatment, improved removal efficiencies, distributed risk, staged implementation, overall improved waterway health and greater community benefits.

Water management features fall into three treatment categories: primary, secondary and tertiary. Using a selection of features in this order will provide the most effective treatment train – a sequence of treatments that have been designed to meet water treatment needs of a particular environment.

Some pollutants, for example nutrients and fine sediments, require several measures used in sequence for treatment to be most effective. Wetland systems ideally require gross pollutant traps upstream of them to make sure that litter and other debris does not enter the wetland system. The treatment train approach is therefore particularly important when a treatment measure requires pre-treatments to remove pollutants that would otherwise impact on its performance. Figure 5-3 presents a schematic of the application of the treatment train.

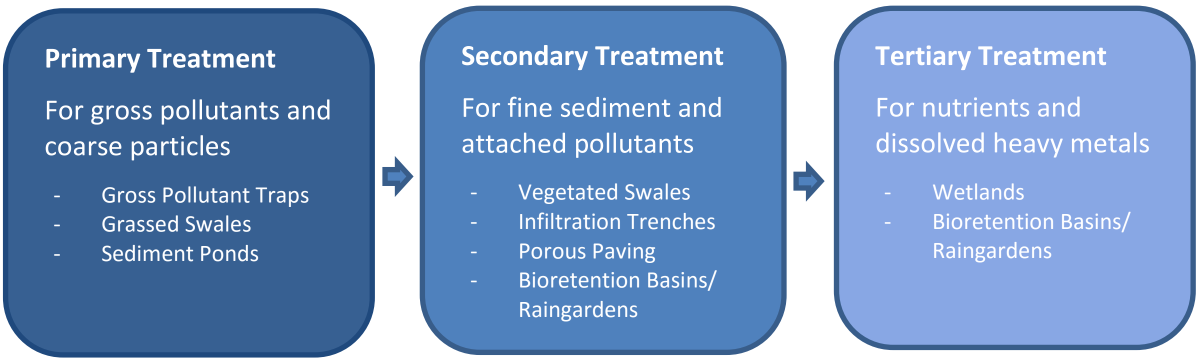

Figure 5-3 Treatment Train schematic

These systems can be located on individual properties, along roadways and in open space areas, and along or within the existing MI drainage network. Table 5-3 presents a summary of typical water management features that are suitable for application to Lake Wyangan and catchment. A more extensive list of water management features and their key opportunities and constraints that are connected to each of these features is provided in Appendix E.

Table 5-3 Review of Rural and Urban Runoff Water Treatment Options

Water Treatment Method	Description	Benefits/Effectiveness	Limitations	Advantages for Lake Wyangan	Constraints for Lake Wyangan
Sediment Basin	Detention systems slow water runoff and allow the sediments to settle and deposit.	Provides opportunities for sediment settlement. It has been identified that there are significant inflows of sediment to the lake via the MI drainage network. Refer Appendix B.	They require significant maintenance every 5 years with potential prescribed waste removal costs.	Would also be suitable at each of the inlets to both North and South Lake Wyangan. Also suitable for re-development areas - they can be temporarily used during construction activities as they assist in controlling and removing elevated sediment levels.	They often do not provide best practice treatment unless they are combined with other systems.
Wetlands	Wetlands usually have a series of planted ponds that help to filter water through physical and biological processes.	Provides secondary treatment to remove fine particles and dissolved pollutants like nutrients and heavy metals. Provides amenity/recreational value for the community.	Size of the system required to achieve nutrient reduction targets can be significant.	Provides habitat for animals and plants. Removes high levels of nutrients from the inflowing water. As noted in Section 5.2.3, a sediment basin and wetland treatment system could be implemented on the inflowing drains to South Lake. A similar system would also be applied to the North Lake inflows.	Requires significant available land. Slow process (large detention time).

Water Treatment Method	Description	Benefits/Effectiveness	Limitations	Advantages for Lake Wyangan	Constraints for Lake Wyangan
Buffer Strips and Vegetated Swale	Swales are linear grassed or vegetated channels which collect and transport stormwater.	They have the ability to combine flow conveyance and water quality treatment within one system.	They are only suitable for gentle slopes of less than 5% gradient.	They are a relatively simple and inexpensive to construct. Potential applications along roadways, along margins of MI drains, and along the margins of the lakes. These systems could be implemented as part of the management of agricultural runoff (see section 5.3.1).	Changes to vegetation management in the Drains would be required to ensure appropriate vegetation is retained. Consideration to impacts on drain capacity and flooding should also be incorporated into any design. Unless associated with bioretention, swales provide limited removal of fine sediment and dissolved pollutants.
Raingarden/ Bioretention	They treat water through vegetation and a soil filtration media. Stormwater is collected and allowed to pond to a certain depth above the filter medium, until it seeps through the soil media and into the perforated underdrain.	Provide high levels of treatment in a relatively small surface footprint - very efficient removal of nutrients for the treatment size.	Bioretention system can easily become clogged with pollutants and sediment unless regularly maintained. Vegetation needs to be sustained throughout the dry period via irrigation with (preferable) non-potable water.	They are a scalable system that can be used at the lot, street and regional levels and can be easily retrofitted into existing roadways. Provide quick filtration systems. Good option for new peri-urban development areas around the lake.	Internal training would be encouraged to enable the effective construction and maintenance of these systems.

Considerations when choosing a treatment

The selection of different water management features should be carefully considered as systems can perform in a different manner within various geographical regions. For example, systems developed and designed to work well within a specific region, should not be simply adopted in different locations without a system redesign and good consideration of local rainfall and soil conditions.

Raising awareness of integrated water management techniques and practices within the local community and also within GCC itself is a key element in the long-term success of any assets (i.e. wetlands, sediment basins etc). When choosing a system, attention must be paid to how the feature will fit in with the local community, more specifically if it will be well received and accepted by the local residents, whether it requires any maintenance or supervision from adjacent landowners and also whether it improves the local amenity and creates a pleasant green environment. All of these are key to the long-term success of the assets.

Special considerations must be given to existing agricultural, rural or residential areas where retrofitting of such systems occurs. Water management features may not be, at least initially, easily accepted by local residents who are familiar with their current nature strip or drain maintenance practices. Education of residents needs to occur, informing them of the feature purposes, benefits and maintenance requirements. It is also good if the local residents are aware of what a well performing asset should look like and therefore if they are able to report an underperforming or damaged asset to GCC for immediate attention. Forming "friends of" groups or giving residents a sense of ownership through education on how to maintain and identify issues with their local asset have proven to be highly successful in other Local Government Areas.

In terms of new developments, current best practice encourages the implementation of water management systems within all new developments in order to achieve best practice water treatment. These features should be designed into all new subdivisions within the Lake Wyangan catchment.

Selected treatment systems

It is proposed that the opportunity of a range of water management systems should be explored particularly to improve the quality of water entering Lake Wyangan through the MI drainage network. The most suitable systems were presented in Table 5-3 are discussed in more detail in the following section. The selected systems and their suggested scale of application are summarised in Figure 5-4.

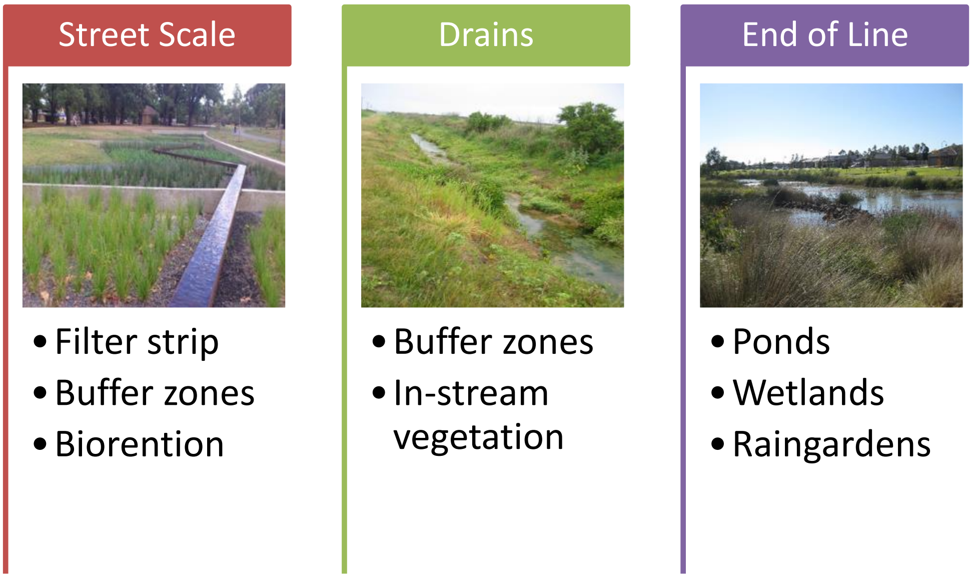

Figure 5-4 Water Quality Treatment Options Cascade

Drain and Street systems. Water management features could be implemented along streets as well as the MI or GCC drains throughout the catchment. The MI drainage network conveys the majority of inflows to Lake Wyangan and as such the quality of water in the drains is integral to the lake water quality. The drains would be an ideal place for implementation of vegetated swales, based on the following:

- The drains are linear in nature and currently many of them have vegetation in their base or sides.
- Many of the drains are experiencing erosion which contributes to sediment loads to the lake. This could be managed through appropriate vegetation within the drains.
- The agricultural practices provide significant sediment loads – which the vegetated swales can help minimise.

GCC owned roadside reserves would also be a good place for the implementation of vegetated swales, based on the following:

- The roadside reserves are linear in nature – vegetated swales can fit in with this easily;
- Very limited pipe infrastructure exists in the region – therefore it will not impact or be impacted by the vegetated swales; and
- As for the drains, the agricultural practices provide significant sediment loads – which the vegetated swales can help minimise.

The longevity of the system would be quite highly dependent on education of the local community. It must be ensured that farming machinery is not driven over the vegetated swales and channels and does not damage the features.

GCC could develop a communication program to educate and inform the broader local community. This could consist of individual household correspondence to introduce key stormwater management principals and their benefits to the resident. This could be in the form of a brochure.

In addition to this, each implemented system could have its own signage, explaining the reasons and benefits of having such a system in place as well as providing information about its maintenance and protection. It could also emphasise the importance of vegetation for the desired treatment performance of the system. These processes would help in improving community awareness and help in making sure that these systems function properly for a long duration of time. A fitting asset inspection and maintenance schedule would also need to be put in place.

Features such as bioretention basins/raingardens would help in the removal of nutrients, however these would most likely get overwhelmed by the high sediment loads coming off of the agricultural areas and are therefore not recommended in this instance except for more urban sites. The same goes for gross pollutant traps (GPTs), which would not be the best option for this area. All of these could clog quite easily from the high sediment loads and would become ineffective. Nevertheless, these features might have potential to be implemented in the future if a portion of the existing sediment is reduced upstream.

End of the line systems. End of the line systems involve implementing larger water management features at or just before the (sub-) catchment outlet. This would involve the placement of sedimentation ponds, wetlands and large scale bioretention systems to address the high sediment loads and nutrients within the water. As noted in Section 5.2.3 the drain outlets in both the North and South Lake would be appropriate locations for these features. However, land availability will be a major constraint for this approach. Very high sediment loads could also damage and ultimately shorten the life span of the systems. A description of these systems has been previously presented in Table 5-3.

Wetlands are usually preferred by the community as they provide aesthetic and amenity benefits. In addition, they provide downstream waterway health and significant temperature cooling benefits. Research carried out by the CRC for Water Sensitive Cities showed that sampled communities surveyed in Victoria and New South Wales are willing to pay more (whether it be tax or increased property prices) to have cooler temperatures during hot summer days (CRC for Water Sensitive Cities, 2014).

Potential Outcomes

Table 5-4 presents some indicative levels of pollutant retention for different water treatment measures (Source: NSW DEC 2006).

Table 5-4 Indicative levels of pollutant retention for different stormwater treatment measures (Source: NSW DEC 2006)

Water Treatment Measure	Suspended solids	Total phosphorus	Total nitrogen
Swale	55–75%	25–35%	5–10%
Bioretention/Raingarden	70–90%	50–80%	30–50%
Pond	50–75%	25–45%	10–20%
Sediment Pond + Wetland	50–90%	35–65%	15–30%

Potential Locations

Where drainage channels already exist, the system could be widened and vegetation could be planted to help treat the water. Care would need to be taken to ensure the capacity of the system is maintained. This could potentially be a very cost effective solution for sediment removal as it makes use of existing features.

It was noted during the site visit that flow impediment is a concern with regard to vegetation within the drains. The choice of vegetation and good vegetation management can mitigate this issue. For instance, the presence of Cumbungi within drains should be controlled while leaving Common Reed. Cumbungi is quite robust and resistant to flows, whereas Common Reed will lay down in high flow conditions.

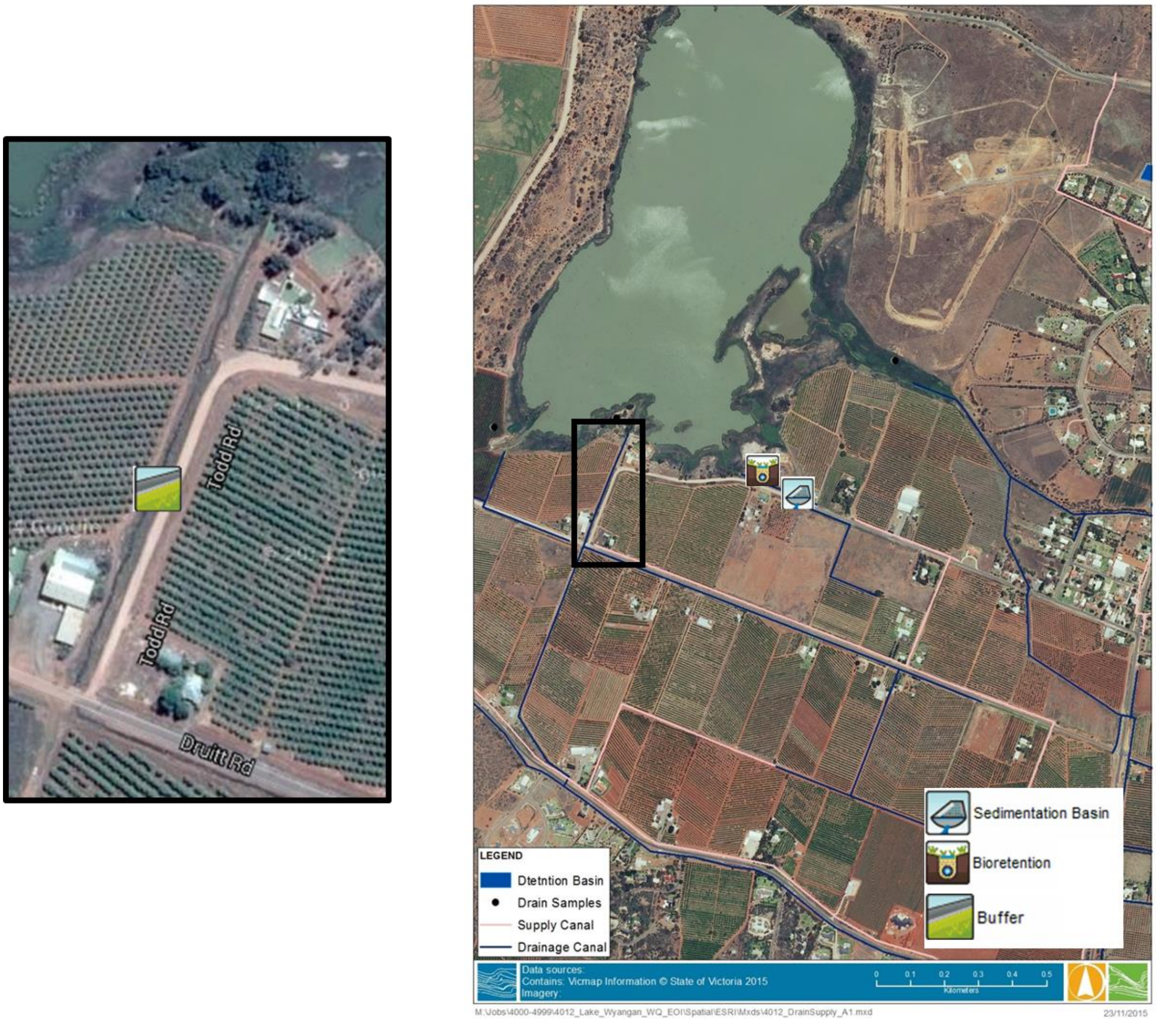

Figure 5-5 *Examples of Potential Location for Treatment Systems*

As mentioned previously, drain or street scale features and end of the line systems should be implemented together to achieve maximum nutrient removal efficiencies. This also allows the size required for the end of line systems to be reduced. For example, if a portion of the runoff is treated via vegetated swales, the wetland downstream will potentially be smaller. This option is appealing, mainly when the land availability is a major constraint for the end of the line features.

5.3.3 Wastewater Treatment Systems

There is currently no reticulated wastewater system for the area and wastewater from individual lots is currently managed through a network of aging septic tanks (and other older systems).

Short Term Options

The following short term options for managing wastewater runoff into Lake Wyangan include the following:

- Audit of existing systems to confirm locations, type of system and current condition.
- Site specific monitoring if point source discharges identified.

Medium Term Options

- Development of maintenance guidelines for existing systems and communication/education with existing landowners.
- Working with landowners on gradual upgrading of existing systems. Will require development of guidelines for new systems within the catchment including types of suitable systems, locations, lot or development scale systems.

Long Term Options

- Implementation of a reticulated wastewater system.

5.4 Additional Management Options

Potential additional management options to be considered as part of the overall Lake and Catchment Management Strategy include:

- An improved "algal bloom" risk forecasting capacity (i.e. improved forecasting of blue-green algal bloom event).
- User education and awareness programs for user groups and the broader community - Both the NHMRC Drinking Water Guidelines and the NHMRC Managing Risks in Recreational Waters Guidelines place major focus on management of risk, with the application of both "a duty of care" on the part of the agencies, and on the part of the consumers or users of services. This requires a much stronger focus on provision of the information and knowledge necessary for users to take decisions appropriate to their well-being and enjoyment of recreational activities.
- A long term monitoring program providing the scope of information supporting appropriate management and risk assessment decisions, both on the part of the management authority and user groups. This will be based on the outcomes of the current monitoring work.

6. SUMMARY

Lake Wyangan is situated 6 km's northwest of the Griffith CBD and is the epi-centre for a diverse range of land uses and recreational uses. The immediate area surrounding Lake Wyangan comprises the villages of Lake Wyangan and Nericon, several Rural Residential developments, intensive horticultural farms, grazing land and recreational areas. The North Lake is a very popular recreational facility with several clubs using the area for boating, water-skiing, sailing, rowing, fishing, picnicking, barbequing, and wildlife observation. Rural Residential developments are becoming increasingly popular due to their proximity to these facilities and the aesthetics of lakes.

This diverse land use mix now presents significant water management challenges, particularly as community expectations in regard to both water quantity and quality have risen significantly. Of particular concern is the reoccurring incidence of Blue-Green Algae (B-GA) in the lakes. Lake Wyangan regularly attains the NHMRC 2008 Recreational Guideline 'Red Alert' status with biovolume reading ≥10mm^3/L subsequently restricting all access to the lake.

The overall objectives of this study were to:

- Describe the North and South Lake Wyangan receiving water bodies,
- Identify the major potential threat to North and South Lake Wyangan environmental and use value,
- Assess 'in-lake' and 'catchment' water quality and ecological condition and determine what are the 'in-lake' physical, chemical and biological processes, stressors/drivers and modifiers enhancing B-GA dominance in both lakes,
- Determine what are the 'in-lake' and 'catchment' management intervention options available to restore North and South Lake Wyangan 'environmental' and 'use' values, and
- Determine an ongoing program of water quality monitoring for the North and South Lakes to support the understanding of the lake and catchment system and impacts on water quality as well as underpin any modelling and assessment of management interventions.

6.1 System Description

The catchment within which Lake Wyangan is located covers an area of approximately 121 km^2, and incorporates the townships of Lake Wyangan and Nericon. There is no natural outlet from the catchment, with all runoff and irrigation overflows draining to Tharbogang Swamp, Nericon Swamp, Campbell Swamp, and Lake Wyangan (north and south). Lake Wyangan itself was formed in the 1950's out of a former gypsum mine at the northern end and a low lying swamp area to the south. Although currently permanent water bodies, they previously would have been considered ephemeral wetlands.

Natural inflows to the lakes are limited, with the majority of inflows occurring as a result of surplus irrigation water and irrigation escape flows (prior to the recent upgrade by Murrumbidgee Irrigation of the Lake Wyangan irrigation supply system). In recent years there has been a noticeable reduction in water levels in North and South Lake Wyangan. This has been the catalyst for Council undertaking lake filling events.

Without inflows and outflows to generate currents within the lakes, circulation of the water is driven predominantly by wind, however wind speeds are typically low, and wind mixing is limited. Therefore, the residence time of any flows entering either North or South Lake

Wyangan is considered excessive in terms of circulation and mixing as it is predominantly dependent on evaporation

6.2 Lake and Drain Water Quality

For this project, an expanded water quality monitoring has been developed for Lake Wyangan. This information has provided a comprehensive dataset for understanding the lake system, and particularly the processes, drivers and stressors.

Key findings are:

- Given the high nitrogen to phosphorus ratio in the lake waters, it is likely that phosphorus is the limiting nutrient in terms of blue-green algal blooms,
- Within the lake sediment there is a significant store of phosphorus, which has the potential to be released into the water column under low oxygen condition which can occur as a result of temperature stratification.
- The lack of circulation or flushing of the lake water means phosphorus will continue to build up over time and can encourage stratification to occur.
- Following rainfall events, high suspended sediment loads were observed in the drains which flow into the lake and there was a corresponding increase in phosphorus concentration in the water samples in North Lake.

On-going monitoring as well as further refinements to the monitoring program are described in Section 6.4.

6.3 Management Options

Managing the frequency and duration of algal blooms within Lake Wyangan focuses on the three main contributing factors: residence time, light and nutrients. Options available to manage these factors were reviewed in terms of **in-lake** options and **catchment** based options.

6.3.1 In-Lake Options

For the in-lake options assessment over 20 short and long term options were considered with many of the long term options linked to catchment management actions. A detailed summary of all the in-lake options assessed and their relevance to Lake Wyangan is provided in Table 5-1. Based on the outcomes of the review, the recommended short- and long-term options were:

- **Aeration/Mixing Systems** - The monitoring to date has indicated that the release of phosphorus stored in the sediment into the water column is likely an important factor in blue-green algae bloom generation. This happens when temperature stratification occurs. Although not confirmed by monitoring to date, this is thought likely to occur diurnally with conditions most conducive to stratification in late Spring through to late Summer. Further monitoring is recommended to confirm these conditions. The lack of mixing of the lake waters in turn exacerbates this process. Mixing and/or aeration of the bottom waters, significantly reduces the energy required to work against the temperature - density differential through the water column. Mixing of the surface water would promote cycling and growth of the Green (Chlorophyta) group of algae in preference to the blue-green (cyanobacteria) algae.

The option of mixing/aeration within the bottom waters **does not directly manage the summer surface water algal growth**. It will, however, reduce the risk of algal blooms following autumn mixing of the bottom and surface waters, and the amount of phosphorus available at the commencement of the next growing season.

Mixing within the surface water, is primarily focused on providing the turbulence necessary to cycle the Green algal cells through the light (euphotic) zone, promoting their growth in preference to blue-green algal growth. However, in shallow systems like Lake Wyangan this approach will also promote oxidation of sediments, reducing the release of sediment phosphorus in shallow waters.

As with all “mixer” options, there are also risks with this arrangement – turning on a mixer post de-oxygenation of the sediments, may result in the mixing of bottom phosphorus throughout the surface waters, thereby enhancing algal growth (Lawrence, 2012).

A possible mixer solution has been costed (Aquago) which could be implemented to treat “hot spots” for algal growth in the lake. As a preliminary attempt to identify “hot spots”, satellite imagery analysis of B-GA was undertaken for the lake. The analysis was able to identify spatial variability in B-GA potential across the lake. The analysis showed that in combination with on-going water quality monitoring it could be used to identify “hot spots”.

A mixer treatment option for the whole lake is likely to be cost prohibitive and difficult to implement for a recreational system such as Lake Wyangan.

- **Hydrologic Manipulation** – this is the enhancement of the inflow, outflow and mixing regime within the lakes. The aim is to reduce the residence time of the waters and therefore the phosphorus concentrations in the water column. Discussions are on-going as to the feasibility and costs of options for hydrologic manipulation, which include:
    - Environmental flow allocations – provided through the existing MI network,
    - Council “fills” – provided through the existing MI network,
    - Modification of existing extraction licenses from the lake to allow North Lake to operate as an irrigation storage for MI customers.
    - Changes to existing MI/Council infrastructure to facilitate enhanced delivery or extraction of water from the lake.

  In the short-term, Council “fills” are likely to be the most feasible option. The fill event in November/December 2015 resulted in high levels of dilution of the B-GA and indicates that fill volumes of around 25% of the total lake volume can be effective in short term management of algal bloom. The best timing for such inflows is late spring to summer and the inflow water quality is particularly important to ensure a successful result.

  Enhanced mixing that could be achieved through changes to the MI network should also be investigated further.

- **Nutrient Inactivation** – this is the use of products to bind the available phosphorus (water column or sediment) so that is cannot be used by the B-GA to promote growth. The costs of this option are likely to be prohibitive.

Other recommended in-lake options were:

- **Macrophyte Restoration** - This management option would involve the re-establishment of emergent and submerged macrophytes. It could be undertaken in conjunction with all of the short-term options and it likely to be necessary for the success of any long term solution for the lake.

- **Carp Management** - Targeted carp removal could be undertaken in identified hotspots where the fish congregate for spawning or where water temperatures are favourable. Hotspots would be identified through a fish monitoring program.

6.3.2 Catchment Options

Catchment options for managing algal blooms focus on reducing the levels of nutrients entering the lake via the drains or overland flow paths. For the Lake Wyangan catchment the focus is on management of inflows associated with:

- **Agriculture** – excess fertiliser wash-off from the land. Different land uses have different levels of fertiliser application and farm practises can impact the level of excess fertiliser wash-off. This wash-off water is then transferred to the lake via the MI drainage network.
- **Rural and Peri-Urban Water Management** – runoff from roads and peri-urban developments. Most runoff enters Lake Wyangan via the MI drainage network.
- **Wastewater** – there is currently no reticulated wastewater system for the area and aging septic tanks (and other older systems).

Management actions for each of these aspects are described further in Section 5.3. Recommended physical works actions include the following:

- **Modification to the vegetation and vegetation management of the MI and GCC drains** in the catchment to incorporate stormwater management principals of sediment and nutrient reduction. This may also assist in reducing erosion within the drains themselves.
- **Creation of vegetated buffers or changes to land management practises along the drains**. This would reduce the surface runoff from the agricultural land and reduce the fine sediment load into the drains from these areas.
- **Construction of sediment basins and wetland features** prior to water from the drains entering the lake to reduce further sediment and nutrient loads.

There are also a number of non-physical works options associated with catchment management which are described further in the Management Strategy document.

6.4 Monitoring program

Based on the analysis of all previous and current monitoring data the following recommendations are made for the future monitoring at Lake Wyangan:

In-Lake Sampling

- The existing GCC monitoring sites (Red Dots) should be maintained. Existing frequency of sampling to be maintained.
- Existing analysis parameters should continue to be analysed.
- Genetic analysis of the B-GA samples should be incorporated into the sampling to further understand the potential toxicity of the taxa present in Lake Wyangan.
- Installation of a fixed temperature/dissolved oxygen logger in both North and South Lake Wyangan recording temperature and DO concentrations at the surface and in the bottom waters at 15 minute intervals (or less). Ideally this would be telemetered. This could be used as a reference site for the satellite imagery analysis calibration.

In-Drain Sampling

- Continued sampling at the in-drain sampling sites (Green Dot sites NLW-1, NLW-2, NLW-3, SLW-1, SLW-2, SLW-3).
- Weekly sampling frequency of TSS, N, P, EC and Temperature sampling at these site (to occur during/after significant rainfall >15mm when possible)
- Inclusion of (preferably) telemetered continuous flow measurement of all inflowing drains (NLW-1, NLW-2, NLW-3, SLW-1, SLW-2, SLW-3)

To supplement, and possibly reduce the extent of the field monitoring program in the future, it is recommended that the use of satellite imagery analysis continued to be explored. Further calibration of the analysis with field measurements would allow for further calibration and validation of the results. To do this, the following recommendations are made:

- Schedule further in-situ sampling on the days of a relevant satellite overpass. Overpass days and exact times are known in advance, and if the day is cloud free, the sampling would yield very useful coincident information. This will provide data for further calibration of the HAB (and turbidity) algorithms, as well as for validating the results to a higher degree of confidence, gradually fine tuning the system to be more sensitive to local variations in these particular lakes. For an example of how to determine overpass times and dates see https://publiclab.org/notes/nedhorning/08-02-2013/determining-landsat-8-overpass-times . EOMAP could provide guidance on suitable dates.
- Conduct the in-situ sampling at a minimum the equivalent of 2-3 satellite image pixels (30-90m depending on the satellite) from the lake shore, in order to avoid having to offset the corresponding satellite-measurement location. This would be possible using the proposed fixed in-lake sampling sites or by moving the existing GCC Red Dot sampling away from the shoreline.
- Once the HAB algorithms have been fine-tuned it is likely the frequency of in-situ sampling can be reduced, and/or better targeted in terms of timing and locations.

The outcomes from this report are incorporated in the accompanying Lake Wyangan and Catchment Management Strategy document (Water Technology, 2016b).

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APPENDICES

Appendix A – Sediment, Water Quality, & Bathymetric Data Capture & Analysis

Lake Wyangan nutrient study technical report

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Executive summary
This study undertook a preliminary assessment of the nutrient sources in Lake Wyangan with the view to reducing the current blooms of blue-green algae (cyanobacteria). Sediment samples as well as water samples were taken from the Lake and return drains feeding the lake. The N:P ratio in both the north and south lakes is high (>16:1) reflecting both a high ratio of input from the catchment as well as the presence of N_2 fixing blue green algae in the lake. This high ratio suggests phosphorus is most likely the limiting nutrient, especially given the presence of N_2 fixing cyanobacteria. The role of N_2-fixing cyanobacteria is supported by the fact that suspended particulate matter in the water column had very low $\delta^{15}N$ values compared to catchment inputs. Stores of phosphorus within the sediment associated with iron-bound phosphorus equated to ~9 tonnes, compared to a standing stock of ~1.2 tonnes in the water column. There was weak stratification in August, suggesting that strong stratification and anoxia would develop over spring-summer leading to significant release of phosphorus from the sediment. Destratification, recirculation of the lake and phoslock are suggested as possible means to reduce the concentration of phosphorus, and thus cyanobacteria, within the water of the lake.

Background
This study was undertaken as part of the broader Lake Wyangan Catchment Strategy being led by Water Technology in 2015. Of key importance to managing water quality within Lake Wyangan is the identification of the relative importance of nitrogen and phosphorus in driving current cyanobacterial blooms as well as elucidating the relative importance of catchment and internal sources of nutrients (derived from the sediment). This study collected 6 cores from the North and South Lakes and analysed them for different forms of nitrogen and phosphorus. In addition, samples were also taken from the Lake itself and 3 return drains to compliment sampling programs being undertaken locally.

Methods
Six intact sediment cores were collected from a boat in Lakes North and South Wyangan as shown in Figure 1. Cores were aerated and stored at *in situ* temperature (~48 hrs) before being sectioned in the lab. Sediment sections were subsampled for centrifugation to collect porewater and sequential extraction for phosphorus (Ruttenberg 1992). Water samples were also collected within the lake at the same sites as cores as well as at 3 inlet drains (north drain ND, and 2 south drains SD1 and SD2) for later analysis of total nitrogen (TN), total phosphorus (TP) as well as samples for ammonium, phosphorus and nitrate (filtered through a 0.2 □m filter) and frozen until analysed. All field work was carried out on August 11 2015. Samples for nutrients were analysed at the Water Studies Centre using standard methods in a NATA accredited laboratory within three weeks of collection. Solid samples for stable isotopes were analysed on Hydra 20–22 isotope ratio mass-spectrometer and coupled ANCA-GSL2 elemental analyser (Sercon Ltd., UK). Samples of dissolved nitrate were analysed for □^{15}N using the method of (McIlvin and Altabet 2005). Isotope values are reported in the □ notation relative to ambient air with precision = 0.1%.

Figure 1 shows the sampling locations for sediment cores and water quality within North and South Lake Wyangan (blue markers) as well as three return drains sampled (red markers).

Results and discussion

Temperature and dissolved oxygen

The physic-chemical data show that the north lake was slightly temperature stratified and that this caused dissolved oxygen concentrations to drop to <80% saturation at depths >1 m (Figure 2). The south lake was slightly stratified, although this was not reflected in the dissolved oxygen profiles, which showed super saturation at all depths.

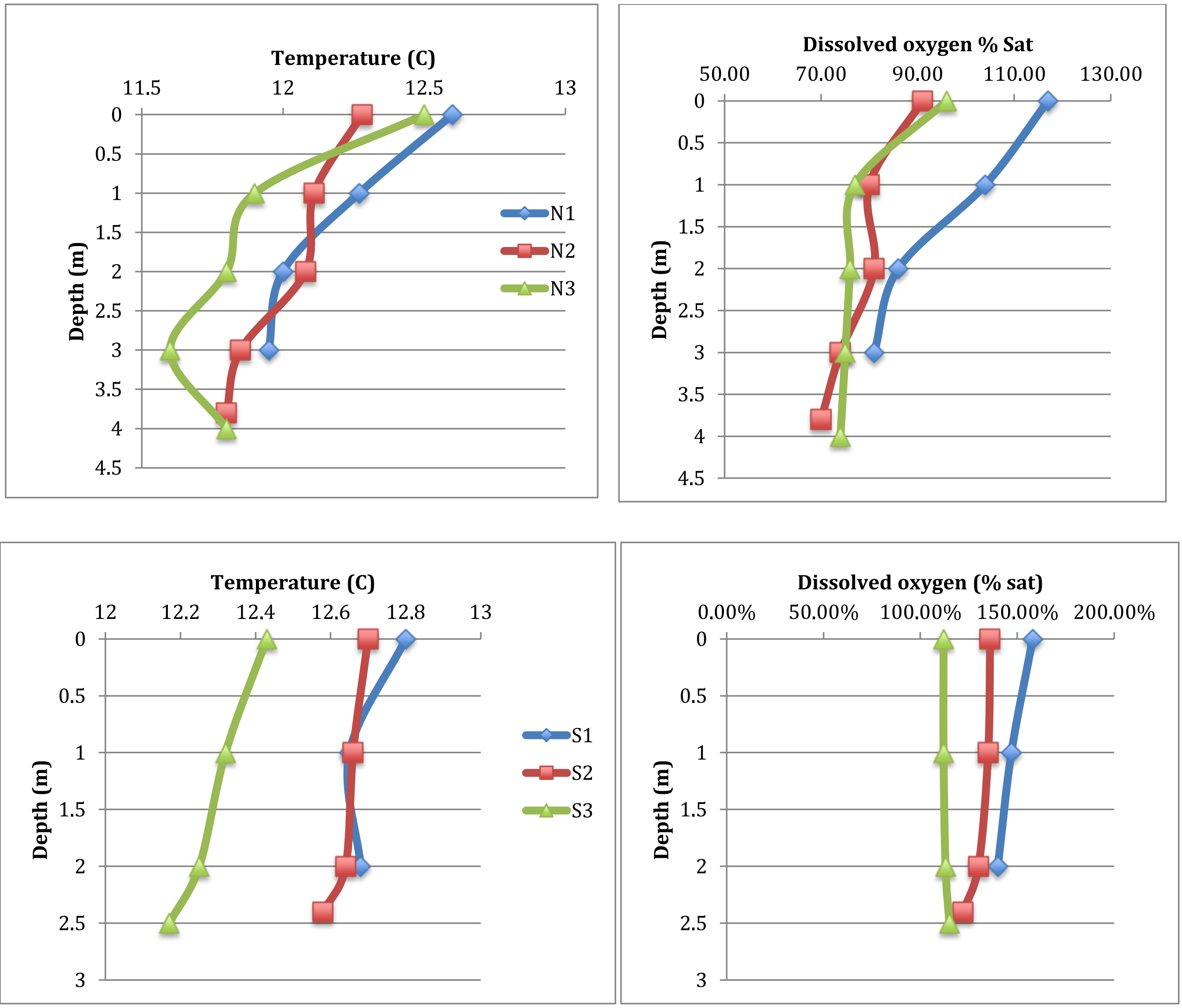

Figure 2. Shows temperature and dissolved oxygen profiles at the north lake (top panel) and south lake (bottom panel) on August 11 2015. The lowest datum point is within 0.5m of the bottom.

Water column nutrient concentrations

Concentrations of all forms of nutrients were consistent within the north and south lakes, with average concentrations of 0.38 and 4.1 mg/L for TP and TN respectively in the south lake and 0.04 and 1.8 mg/L for TP and TN respectively in the north lake. Concentrations of total nutrients were much higher than those for dissolved ammonium, nitrate+nitrite and filterable reactive phosphorus (FRP) suggesting all nutrients are bound up in biomass, consistent with the very high chlorophyll *a* concentrations. The TN:TP ratios averaged 24 and 94 in the south and north lakes respectively.

This is well above the Redfield ratio (the ratio required for balanced phytoplankton growth) of 16, suggesting that the phytoplankton are phosphorus limited (Guildford and Hecky 2000). Phosphorus concentrations within the drains were very low, consistent with the high water clarity observed. Nitrogen was dominated by nitrite+nitrate, which is to be expected from water draining agricultural sources, although the concentrations were not very high for this land use. Chlorophyll *a* concentrations were highest in the south lake, falling in the range 85-100 μg/L and 5-8 μg/L for the north lake. For reference > 20 μg/L is regarded as hypereutrophic and 6-20 μg/L is regarded as eutrophic (Hakanson et al. 2007). The $\delta^{15}N$ values fell in the range 1.9-2.8 ‰ for the north lake and 3.6-4.2 ‰ in the south lake. Isotopic analysis of the nitrate entering from the drains showed the values were much higher – with $\delta^{15}N$ values in the range of 6.9 – 14.8 ‰. The lower isotope values of algae in the lake than the source nitrogen entering from the catchment are consistent with algae deriving the majority of their nitrogen requirements from N_2 fixation (Woodland et al. 2013) as well as the large number of cyanobacteria species capable of nitrogen fixation within the lake (see end of report for species list).

Table 1 shows the concentrations of total phosphorus (TP), total nitrogen (TN), ammonium (NH_4^+), filterable reactive phosphorus (FRP) and nitrate + nitrite (NOx) collected from Lake Wyangan and 3 major drains. All sites are shown in Figure 1 and all concentrations are given in mg/L (as N or P) except chlorophyll a, which is given in μg/L and $\delta^{15}N$ in ‰. The $\delta^{15}N$ values in the lakes are given for suspended particulate material and the values in the drains are given for NO_3^-.

Site	TP	TN	NH_4^+	FRP	NOx	Chlorophyll *a*	Turb NTU	$\delta^{15}N$ ‰	TN:TP (molar)
S1	0.37	4.2	0.002	0.003	0.003	110	172	4.2	25
S2	0.37	4.0	0.001	0.003	0.002	79	155	3.8	24
S3	0.39	4.0	0.002	0.003	0.002	83	156	3.6	23
N1	0.05	1.9	0.10	0.003	0.041	5.3	18	2.8	84
N2	0.04	1.8	0.11	0.003	0.042	8.9	16	2.2	100
N3	0.04	1.8	0.11	0.003	0.043	8	17	1.9	100
SD1	0.06	2.3	0.029	0.013	1.8	-		11.5	85
SD2	0.06	5.6	0.006	0.008	3.2	-		14.8	207
ND1	0.04	1.5	0.011	0.002	0.87	-		6.9	83

Sediment nutrient profiles

A typical depth profile of the different phosphorus fractions extracted from the sediment is shown in Figure 3. Easily exchangeable (free) phosphorus comprised a negligible fraction of the total phosphorus. Iron-bound phosphorus (Asc P) typically comprised the largest fraction of phosphorus extracted, with the highest concentrations occurring at the sediment surface. During water column anoxia, this phase of phosphorus is most easily released from the sediments (Scicluna et al. Accepted 11 Aug 2015). HCl P is likely to represent a variety of phases including various forms of apatite and vivianite as well as P sorbed onto clay surfaces. This form of P typically increases with depth and is considered to be relatively stable within the sediment. Organic P (org P) is most likely associated with phytoplankton and plant detritus. This fraction of P typically decreased with depth in the sediment. This fraction of P is only likely to be available over month-year timescales.

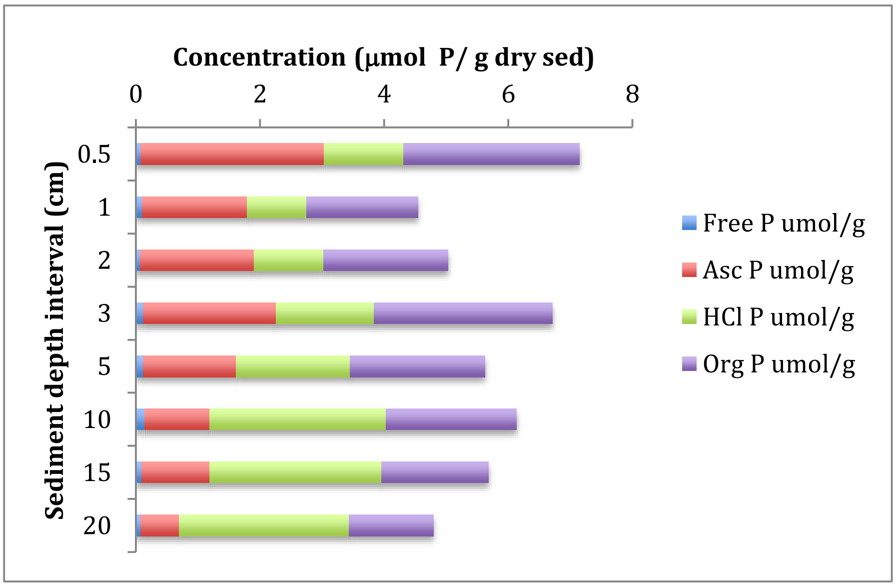

Figure 3. Shows the different fractions of P extracted from the sediment at site N1 including easily extractable P (Free P), Iron bound P (Asc P), mineral associated P (HCl P) and organic P (Org P).

Within the context of water quality, the iron-bound phosphorus is of greatest relevance because it can be rapidly released during stratification, and the profiles of this fraction are shown at all sites (Figure 4). All profiles showed a characteristic peak at the surface reflecting the highest concentration of available iron oxides in this region of the sediment. Consistent with the water quality data, sediment phosphorus concentrations were highest at South Lake Wyangan. Below 15 cm, concentrations decreased to ~2 µmol P/g dry sed in South Lake Wyangan and 1 µmol P/g dry sed in North Lake Wyangan. Assuming that concentrations of iron-bound P above these background concentrations can be released during anoxia, then this conservatively equates to a releasable concentration of 1.7 and 1.07 µmol P/g dry sed in the south and north lakes respectively. Scaling this to the porosity (0.84), density (2.65) and volume per square meter (0.2 m^3) over the area of the north (2.1 km^2) and south lakes (0.9 km^2) gives a total mass of 3.9 and 5.5 tonnes of P in the south and north lakes respectively. This compares to a standing mass of 0.76 and 0.48 tonnes of P in the water column of the south and north lakes respectively.

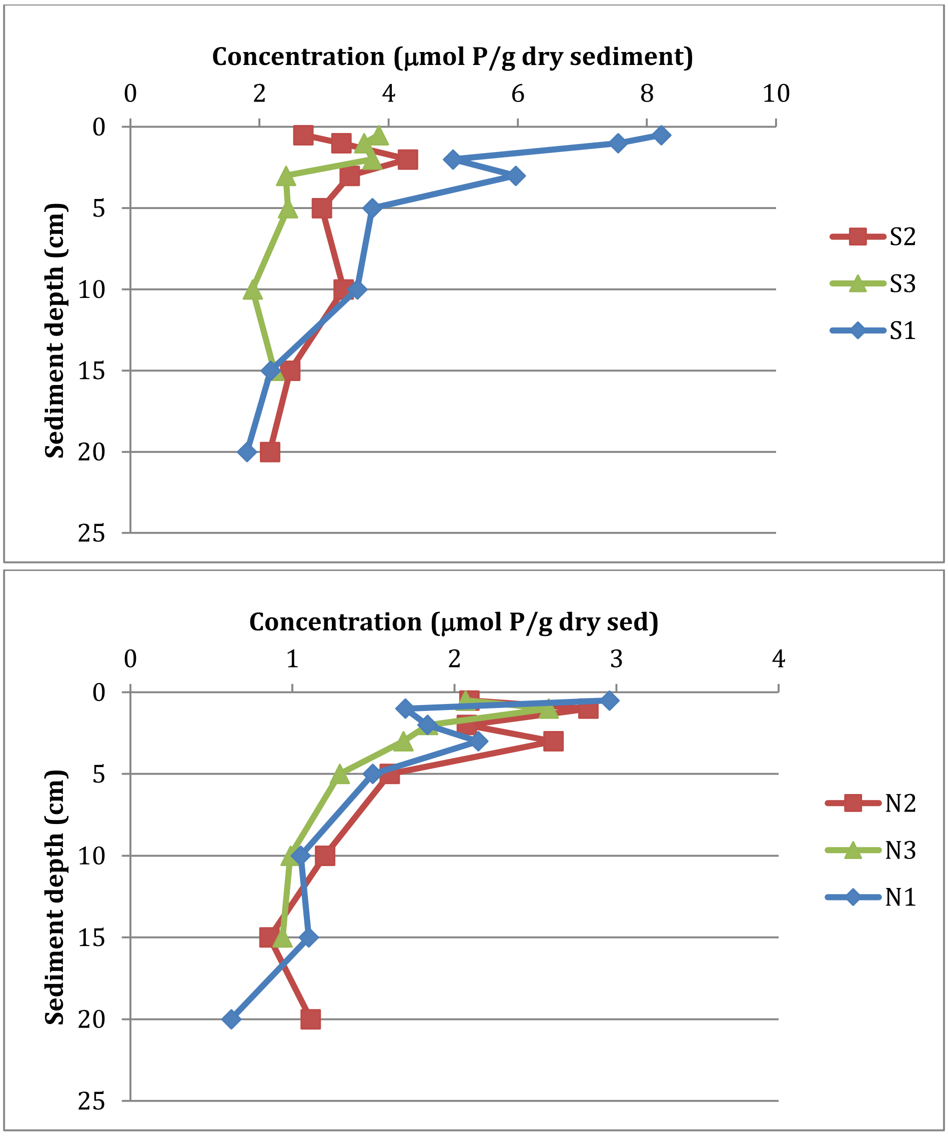

Figure 4. Profiles of iron bound (ascorbate extractable) phosphorus in Lake Wyangan South (top) and North (bottom).

Implications and options for management

Within the context of these results 4 possible management strategies are briefly discussed below.

1 Recirculation of water through the lake

At present the lakes are a terminal system and evaporation is the only means of water loss. In this situation phosphorus will continue to build up in the lakes over time. Recirculation of water through the lakes will reduce phosphorus concentrations in the lakes. Any plan to recycle water through the lakes would need to occur during periods of stratification to ensure that phosphorus released from the sediment was flushed out of the lakes.

2. Destratification

The iron to phosphorus ratio in these sediments is consistently > 10, and iron oxides are known to bind phosphorus down to a ratio of 6:1. The sediment therefore has very high capacity to bind iron if the water column remains oxic. Therefore measures to enhance mixing processes in the lake to minimize the potential for periods of stratification to occur should be investigated. Destratification and water mixing is also used in some circumstances to help reduce cyanobacterial blooms by direct impacts on their growth (Webster et al. 2000)

3. Phoslock

Phoslock is a commercially available product that will bind phosphorus within the sediment at a rate of 11kg P/ tonne of phoslock. Based on the mass of free P calculated in the lake above which totals ~10 tonnes, then ~1000 tonnes of phoslock will be needed to bind this P.

4. Reduction of external catchment loads.

Considering that the water in the return drains is derived from agricultural land, the water quality is of a relatively high standard at baseflow based on the limited data set here. TP and FRP are both within or close to the Anzecc guidelines for lowland rivers (see appendix 1). TN and NOx, are well above the guidelines. Given that the vast majority of phosphorus transport is likely to occur during stormflow, when particles are moblised, reducing catchment inflows is unlikely to be cost effective. The low $\delta^{15}N$ values of the phytoplankton combined with the fact that there are many nitrogen fixing species of cyanobacteria present in the lake suggests managing nitrogen loads to the lake is of second order importance. The importance of the catchment inflows should be reviewed after the current catchment monitoring program is completed.

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List of nitrogen fixing cyanobacteria identified in Lake Wyangan from previous monitoring

Aphanizomenon gracile, Cylindrospermospsis racibororskii, Gleocapsa (now called *Gloeothece*; can fix N_2 in darkness), *Pseudanabaena, Planktolyngbya minor, Planktolyngbya microspira, Anabaena bergii, Anabaena, Aphanothece spp*. (some strains fix N_2), *Pseudanabaena Limnectica, Anabaena aphanizomenioides, Anabaenopsis elekinii, Aphanizomenon ovalisporum, Phormidium* (some species might be N_2 fixers), *Anabaena torulosa, Oscilliatoria, Aphizomenon issatchenkoi, Cylindrospermopsis*, Nostocaceae, *Anabaenopsis*

Appendix 1. Anzecc guidelines for slightly disturbed systems in South East Australia

Table 3.3.2 Default trigger values for physical and chemical stressors for south-east Australia for slightly disturbed ecosystems. Trigger values are used to assess risk of adverse effects due to nutrients, biodegradable organic matter and pH in various ecosystem types. Data derived from trigger values supplied by Australian states and territories. Chl *a* = chlorophyll *a*, TP = total phosphorus, FRP = filterable reactive phosphate, TN = total nitrogen, NO_x = oxides of nitrogen, NH_4^+ = ammonium, DO = dissolved oxygen.

Ecosystem type	Chl *a*	TP	FRP	TN	NO_x	NH_4^+	DO (% saturation)[l]		pH	
	($\mu g\ L^{-1}$)	($\mu g\ P\ L^{-1}$)	($\mu g\ P\ L^{-1}$)	($\mu g\ N\ L^{-1}$)	($\mu g\ N\ L^{-1}$)	($\mu g\ N\ L^{-1}$)	Lower limit	Upper limit	Lower limit	Upper limit
Upland river	na[a]	20[b]	15[g]	250[c]	15[h]	13[i]	90	110	6.5	7.5[m]
Lowland river[d]	5	50	20	500	40[o]	20	85	110	6.5	8.0
Freshwater lakes & Reservoirs	5[e]	10	5	350	10	10	90	110	6.5	8.0[m]
Wetlands	no data	no data	no data	no data	no data	no data	no data	no data	no data	no data
Estuaries[p]	4[f]	30	5[j]	300	15	15	80	110	7.0	8.5
Marine[p]	1[n]	25[n]	10	120	5[k]	15[k]	90	110	8.0	8.4

na = not applicable;
a = monitoring of periphyton and not phytoplankton biomass is recommended in upland rivers — values for periphyton biomass (mg Chl *a* m^{-2}) to be developed;
b = values are 30 μgL^{-1} for Qld rivers, 10 μgL^{-1} for Vic. alpine streams and 13 μgL^{-1} for Tas. rivers;
c = values are 100 μgL^{-1} for Vic. alpine streams and 480 μgL^{-1} for Tas. rivers;
d = values are 3 μgL^{-1} for Chl *a*, 25 μgL^{-1} for TP and 350 μgL^{-1} for TN for NSW & Vic. east flowing coastal rivers;
e = values are 3 μgL^{-1} for Tas. lakes;
f = value is 5 μgL^{-1} for Qld estuaries;
g = value is 5 μgL^{-1} for Vic. alpine streams and Tas. rivers;
h = value is 190 μgL^{-1} for Tas. rivers;
i = value is 10 μgL^{-1} for Qld. rivers;
j = value is 15 μgL^{-1} for Qld. estuaries;
k = values of 25 μgL^{-1} for NO_x and 20 μgL^{-1} for NH_4^+ for NSW are elevated due to frequent upwelling events;
l = dissolved oxygen values were derived from daytime measurements. Dissolved oxygen concentrations may vary diurnally and with depth. Monitoring programs should assess this potential variability (see Section 3.3.3.2);
m = values for NSW upland rivers are 6.5–8.0, for NSW lowland rivers 6.5–8.5, for humic rich Tas. lakes and rivers 4.0-6.5;
n = values are 20 μgL^{-1} for TP for offshore waters and 1.5 μgL^{-1} for Chl *a* for Qld inshore waters;
o = value is 60 μgL^{-1} for Qld rivers;
p = no data available for Tasmanian estuarine and marine waters. A precautionary approach should be adopted when applying default trigger values to these systems.

In addition to the sediment and water quality sampling the following information was gathered on the storage capacity of North and South Lake Wyangan.

LAKE STORAGE

The water storage volume of the lakes is important for understanding the in-lake processes and potential impacts associated with inflows from the surrounding catchment. The volume of the lakes will impact on the cost associated with implementation of some potential water quality improvement options. The available estimate of lake storage volumes was based on estimates of the average depth of the lakes and the area calculated from aerial imagery. The volume of water below of the 0 m mark on the water level gauges was classified as dead storage.

Therefore, to add the current study a limited water depth survey was taken during the water quality sampling program using a Lowrance HST-WSBL 83/200kHz T/M shallow water transducer, which was mounted 0.2 m below the water surface at the back of the sampling boat. The water depth was recorded by the Lowrance HDS 5 Fishfinder Plotter. The water depth data was then converted into AHD elevations based on the water level gauge readings recorded on same day. The adjusted survey was then imported into 12D for further processing. An updated volume estimate for the lakes was then derived.

The figure shows the previous and updated level-storage relationship for Lake Wyangan. The new data indicates that the volume below 0 m gauge level (assumed to be 105.5m AHD) which is currently treated as dead storage equates to about half of the total volume of the lakes.

Figure A1 *Water level gauges reading: 1.0m for the Northern Lake (left) and 0.8m for Southern Lake (right) at time of survey*

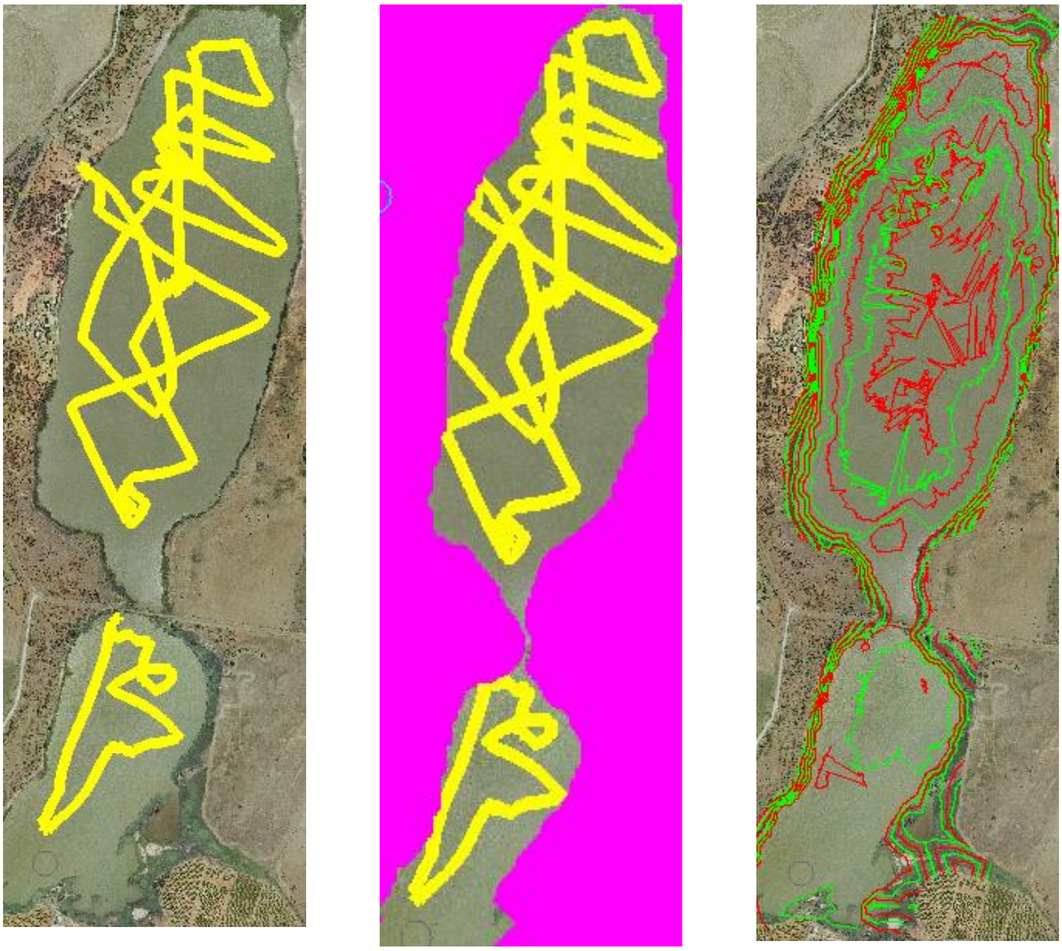

Figure A2 *Bathymetry survey track (left), DEM (middle) and interpolated contour (right)*

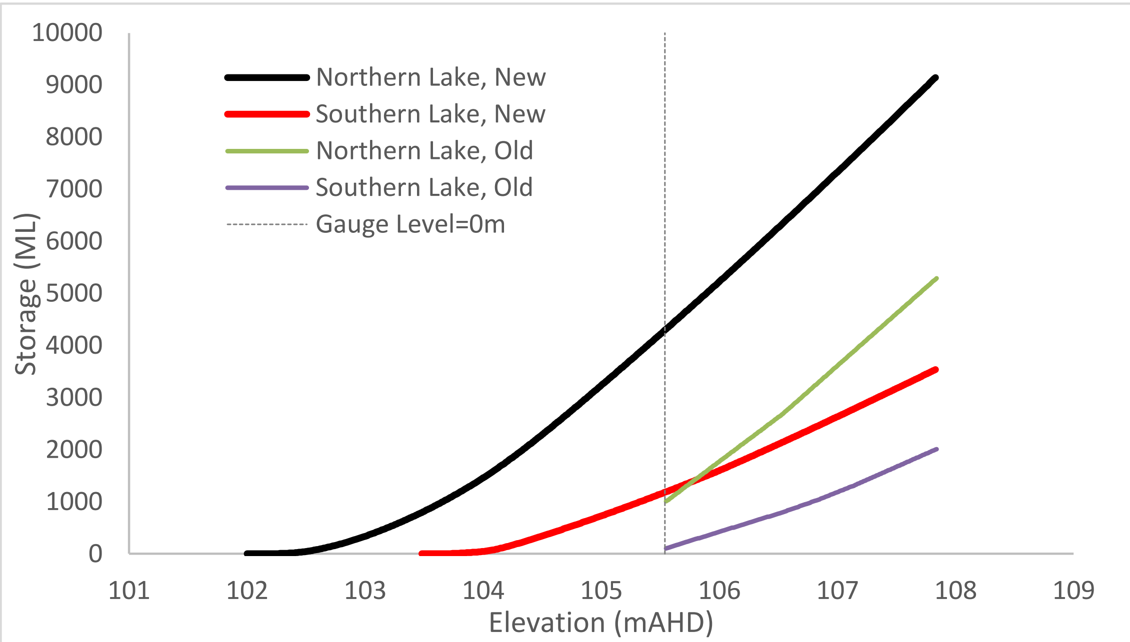

Figure A3 *Level-Storage Relationship for Lake Wyangan*

Appendix B – Field Monitoring & Observations

Lake Wyanagan & Catchment Management Strategy (LW&CMS)

Drain & In-Lake Sampling Schedule, 2015-2016 - Final

Project Start Date	1/06/2015

Activity	Sampling Status	Sep-05																					
		1	2	3	4	7	8	9	10	11	14	15	16	17	18	21	22	23	24	25	28	29	30
		S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
2015 - 2016 Public Holidays																							
1. In-Drain & In-Lake Sampling -GCC																							
(Water samples to be taken In-Drains and In-Lake) * # - Weekly																							
Water samples to be taken In-Drains (5 x sites) and In-Lake (2 x sites)	Weekly		✓					✓						✓			✓						✓
(NB: Weekly sampling to occur during/after significant rainfall (> 15mm) when possible)																							
2. In-Lake Sampling - GCC																							
(Water samples to be taken In-Lake) ● - Continuing																							
Water samples to be taken In-Lake at existing GCC sites/frequency (6 x sites)	Continuing																✓						
(NB: GCC to commence additional sampling for Total Phosphorous)																							
3. In-Lake Sampling (Boat) - MI																							
(Water Samples to be taken in main body of Nth LW & Sth LW) ** ✘ - Monthly																							
Monthly boat sampling (2 x sites) (NB: Sampling to occur more frequently if possible)	Monthly													✓									

Activity	Oct-15																					
	1	2	5	6	7	8	9	12	13	14	15	16	19	20	21	22	23	26	27	28	29	30
	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O
2015 - 2016 Public Holidays			■																			
1. In-Drain & In-Lake Sampling -GCC																						
(Water samples to be taken In-Drains and In-Lake) * # - Weekly																						
Water samples to be taken In-Drains (5 x sites) and In-Lake (2 x sites)					✓					✓					✓				✓			
(NB: Weekly sampling to occur during/after significant rainfall (> 15mm) when possible)																						
2. In-Lake Sampling - GCC																						
(Water samples to be taken In-Lake) ● - Continuing																						
Water samples to be taken In-Lake at existing GCC sites/frequency (6 x sites)										✓									✓			
(NB: GCC to commence additional sampling for Total Phosphorous)																						
3. In-Lake Sampling (Boat) - MI																						
(Water Samples to be taken in main body of Nth LW & Sth LW) ** ✘ - Monthly																						
Monthly boat sampling (2 x sites) (NB: Sampling to occur more frequently if possible)																	✓					

Activity	Nov-15																				
	2	3	4	5	6	9	10	11	12	13	16	17	18	19	20	23	24	25	26	27	30
	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
2015 - 2016 Public Holidays																					
1. In-Drain & In-Lake Sampling -GCC																					
(Water samples to be taken In-Drains and In-Lake) * # - Weekly																					
Water samples to be taken In-Drains (5 x sites) and In-Lake (2 x sites)				✓				✓					✓				✓				
(NB: Weekly sampling to occur during/after significant rainfall (> 15mm) when possible)				E																	
2. In-Lake Sampling - GCC																					
(Water samples to be taken In-Lake) ● - Continuing																					
Water samples to be taken In-Lake at existing GCC sites/frequency (6 x sites)								✓					✓				✓				
(NB: GCC to commence additional sampling for Total Phosphorous)													A								
3. In-Lake Sampling (Boat) - MI																					
(Water Samples to be taken in main body of Nth LW & Sth LW) ** ✘ - Monthly																					
Monthly boat sampling (2 x sites) (NB: Sampling to occur more frequently if possible)											✓										

Activity	Dec-15																							
	1	2	3	4	7	8	9	10	11	14	15	16	17	18	21	22	23	24	25	28	29	30	31	1
	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	D	J
2015 - 2016 Public Holidays																			■	■				■
1. In-Drain & In-Lake Sampling -GCC																								
(Water samples to be taken In-Drains and In-Lake) * # - Weekly																								
Water samples to be taken In-Drains (5 x sites) and In-Lake (2 x sites)		✓						✓			✓													
(NB: Weekly sampling to occur during/after significant rainfall (> 15mm) when possible)																								
2. In-Lake Sampling - GCC																								
(Water samples to be taken In-Lake) ● - Continuing																								
Water samples to be taken In-Lake at existing GCC sites/frequency (6 x sites)		✓									✓													
(NB: GCC to commence additional sampling for Total Phosphorous)		A																						
3. In-Lake Sampling (Boat) - MI																								
(Water Samples to be taken in main body of Nth LW & Sth LW) ** ✘ - Monthly																								
Monthly boat sampling (2 x sites) (NB: Sampling to occur more frequently if possible)																✓								

*** Parameters to be analysed (where possible)**
Total Suspended Solids
Total Nitrogen
Total Phosphorous
Ammonia
Phosphate
Nitrate + Nitrate as N
EC
Temperature
Dissolved Oxygen

**** Parameters to be analysed (where possible)**
Total Suspended Solids
Total Nitrogen
Total Phosphorous
Ammonia
Phosphate
Nitrate + Nitrate as N
Phytoplankton Cell Counts/Biovolumes

✓	Task Completed
E	Event Sample (>15mm of rain)
A	Only Algae Sample Taken
NA	No Algae Sample Taken
U	Sampled upstream of bridge at NLW-1, not downstream of bridge

1. In-Drain & In-Lake Sampling - GCC #	**Site**	
Weekly	NLW-1	In-Drain
Refer Map for Site Locations	NLW-2	In-Drain
	NLW-3	**In-Lake**
	LW6	**In-Lake**
	SLW-1	In-Drain
	SLW-2	In-Drain
	SLW-3	In-Drain

2. In-Lake Sampling - GCC ●	**Site**	
Continuing	LW-N	In-Lake
NB. Using current GCC Site Naming	LW-RA	In-Lake
Refer Map for Site Locations	LW-CA	In-Lake
	LW-BC	In-Lake
	LW-E	In-Lake
	LW-S	In-Lake

2. In-Lake Sampling (Boat) - MI ✘	**Site**	
Monthly	NLW-4	In-Lake
Refer Map for Site Locations	SLW-4	In-Lake

Proposed Monitoring Program as per Water Technology P/L request as of Mon. 17th Aug. 2015.
This Proposed In-Drain & In-Lake Sampling Schedule 2015 - 2016. Updated **25 July 2016**.

Jan-16																			
4	5	6	7	8	11	12	13	14	15	18	19	20	21	22	25	26	27	28	29
J	J	J	J	J	J	J	J	J	J	J	J	J	J	J	J	J	J	J	J
																■			
		✓					✓					✓						✓	
							U					U						E	
		✓										✓							

Feb-16																				
1	2	3	4	5	8	9	10	11	12	15	16	17	18	19	22	23	24	25	26	29
F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
✓						✓						✓					✓			
																	U			
✓												✓								

Mar-16																						
1	2	3	4	7	8	9	10	11	14	15	16	17	18	21	22	23	24	25	28	29	30	31
M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
																		■	■			
✓				✓					✓					✓							✓	
U				U					U					U							U	
✓									✓												✓	

Apr-06																				
1	4	5	6	7	8	11	12	13	14	15	18	19	20	21	22	25	26	27	28	29
A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
																■				
						✓												✓		
																		NA		

May-16																					
2	3	4	5	6	9	10	11	12	13	16	17	18	19	20	23	24	25	26	27	30	31
M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
	✓															✓					
	A																				

Jun-16																					
1	2	3	6	7	8	9	10	13	14	15	16	17	20	21	22	23	24	27	28	29	30
J	J	J	J	J	J	J	J	J	J	J	J	J	J	J	J	J	J	J	J	J	J
								■													
			✓											✓							
			E											E							
																			✓		

NORTH LAKE WYANGAN

Field Monitoring Observations, 2015/16
Drain No. D2LVDR030E,
High Rainfall Events (>15mm) and Turbidity Sampling

1. Introduction

As part of the delivery of the Lake Wyangan Catchment Management Strategy (LW&CMS), Water Technology Pty Ltd requested Griffith City Council (GCC) undertake, as part of its weekly Lake Wyangan 'In-drain & In-Lake Sampling – GCC' water sampling schedule, targeted sampling of High Rainfall Events (> 15mm). Four High Rainfall Events (> 15mm) occurred during the period September 2015 to June 2016, specifically:

- 5th November 2015 (Rainfall Event #1);
- 28th January 2016 (Rainfall Event #2);
- 6th June 2016 (Rainfall Event #3); and
- 21st June 2016 (Rainfall Event #4).

This paper briefly reports on two of these four High Rainfall Events (>15mm) targeting the following 'In-drain & In-Lake Sampling – GCC' and 'In-Lake Sampling – GCC' water quality sampling sites:

- NLW-1;
- LW-N; and
- NLW-3.

(Refer LW&CMS – Technical Report, August 2016, Page11, Figure 3-2 and Page 20, Figure 3-10 for water quality sampling site locations.)

Discussion within this paper reports on the following two High Rainfall Events (>15mm):

- 28th January 2016 (Rainfall Event #2); and
- 21st June 2016 (Rainfall Event #4)

2. 2016 Seasonal Conditions

These two rainfall events are significant as they occurred under seasonally different climatic conditions, 28th January 2016 (Summer) and 21st June 2016 (Winter), reflective of differing seasonality in rainfall patterns and subsequent overland surface flow conditions.

Both these High Rainfall Events (>15mm) resulted in significant, both visual and measured turbid, drainage flows entering North Lake Wyangan. Both rainfall events were sampled immediately the morning after each rain event had ceased. During the sampling a number of photographs were captured, turbidity samples taken and turbidity readings recorded by GCC's Environmental Health Officer assigned to this project.

Both months, January 2016 and June 2016 received higher than average rainfall, with 73mm received in January 2016, compared to an average of 34.3mm and 127.4mm in June 2016, compared with an average of 36mm. This 2016 year to date (1st January - 31st July 2016), Griffith had received 319.6mm of rain, approximately 80% of the average annual rainfall of 396.4mm as presented in (Figure 1).

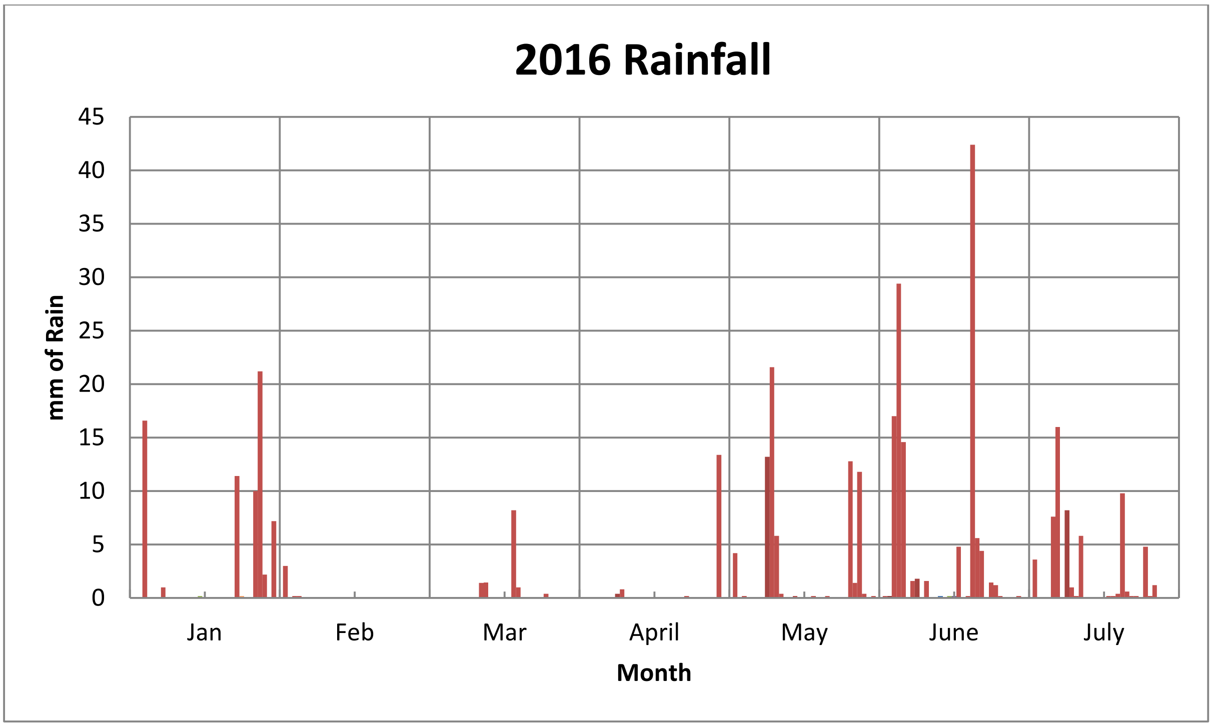

Figure 1 - 2016 Rainfall, 1st Jan. – 31st July 2016

3. Observations and Discussion

28th January 2016 (Rainfall Event #2)

On the 27th & 28th January 2016 Griffith received a total of 31.2mm of rainfall. As a result of this rain, a decision was made to undertake an 'In-drain & In-Lake Sampling – GCC' water quality sample collection on the morning of 28th January 2016. On this morning, there was a high volume water flow observed at sampling site NLW-1 on Drain No. D2LVDR030E (Figures 2 and Figure 3). The water flowing through sampling site NLW-1 was visually a very distinct ochre orange brown colour, characteristic of a high sediment and turbid flow.

Figure 2 – NLW-1, Eastern side of Bridge (Over Drain No. D2LVDR030E), 28th January 2016

As observed on the 28th January 2016 (Figure 3) turbid flows are visually contrasting in sediment loading compared to a previous 'In-drain & In-Lake Sampling – GCC' sample collection taken on the 13th January 2016 (Figure 4).

Figure 3 - Upstream of NLW- 1, 28th January 2016

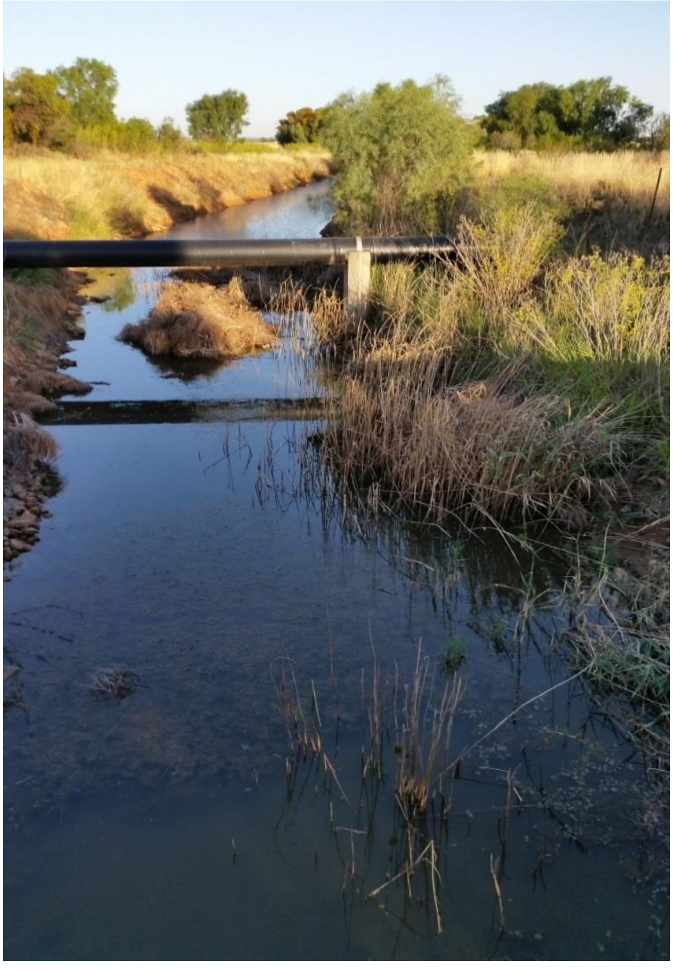

Figure 4 - Upstream of NLW-1, 13th January 2016.

The reduced 'in channel' vegetation condition between Figure 3 and Figure 4 also suggests this drain received significantly higher flows during and straight after the 31.2 mm rainfall event of the 27th and 28th January 2016.

In addition, late on the afternoon of the 28th January 2016 two GCC Environment Health & Sustainability (EH&S) staff members went out and undertook a site inspection of the Northern extent of North Lake Wyangan and thereafter completed a 5km (approx.) drive upstream from sampling site NLW-1 along Drain D2LVDR030E, crossing Lakes & West Road up to Lee Lane (Refer to Figure 10).

This site inspection commenced in the Recreational Area of North Lake Wyangan. A substantial turbid plume had been observed at sampling site NLW-3 during the morning of the 28th January 2016, during the afternoon of the 28th January 2016 this turbid plume was still present but was now observed dispersing around the outer perimeter and out into the Northern end of North Lake Wyangan (Figure 5 and Figure 6).

Figure 5 – North Lake Wyangan looking North East from NLW-3, 28th January 2016

Figure 6 - Lake Wyangan looking North East from NLW-3, 28th January 2016

Further, (Figure 7 and Figure 8) were taken at sampling site LW-N (which is downstream of sampling site NLW-1). This site is close to where Drain No. D2LVDR030E exists the Murrumbidgee Irrigation drainage system and enters North Lake Wyangan. The water flow was again observed as a very distinct ochre orange brown colour as was also observed at sampling site NLW-1 earlier in the day.

Figure 7 – LW-N (Downstream of NLW-1), 28th January 2016

Figure 8 – LW-N (Downstream of NLW-1), 28th January 2016

Figure 9 - Area upstream of LW-N & downstream of NLW-1, 28th January 2016

(Figure 9) view upstream of sampling site LW-N & downstream from sampling site NLW-1 which also directly flows into North Lake Wyangan.

Throughout the 5km (approx.) site inspection and drive upstream from sampling site NLW-1 along Drain No. D2LVDR030E, Turbidity readings were taken at 5 locations (Figure 10) using a calibrated hand held Turbidity Meter (HACH 2100Q Turbidimeter). Each sample was tested three times. The results are presented in Table 1 as follows.

Table 1 – Sites and Turbidity Readings taken along Drain D2LVDR030E during the afternoon of 28th January 2016

Site	Reading 1	Reading 2	Reading 3
NLW-3 (Orange Dot)	55.3 NTU	56.8 NTU	57.3 NTU
LWN (Green Dot)	354 NTU	352 NTU	352 NTU
NLW-1 (Purple Dot)	357 NTU	357 NTU	358 NTU
Cnr West Road & Lee Lane (Red Dot)	246 NTU	244 NTU	244 NTU
End of Lee Lane (Blue Dot)	114 NTU	113 NTU	112 NTU

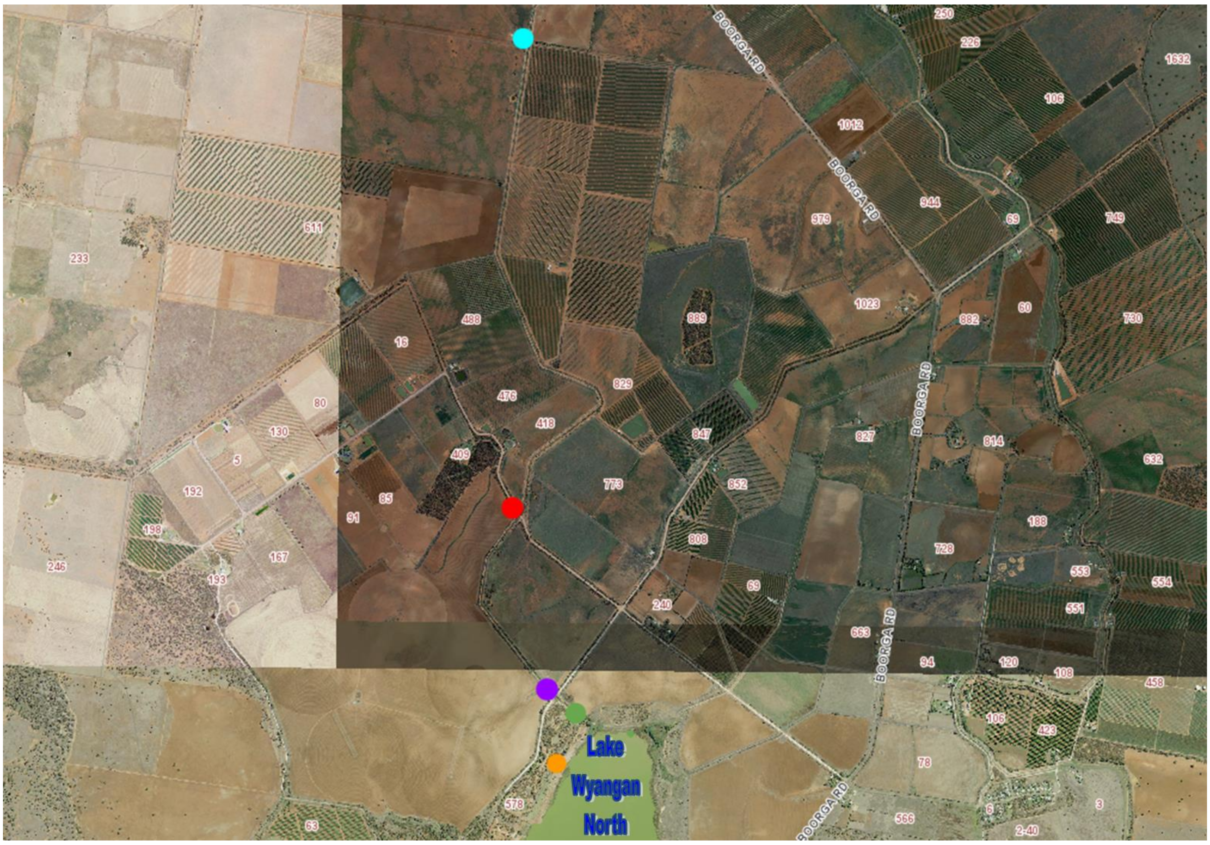

Figure 10 - Map of Turbidity Reading sites taken during the afternoon of the 28th January 2016

21st June 2016 (Rainfall Event #4)

On the 20th June 2016, 42.4mm of rain was received in Griffith and a site inspection was carried out that afternoon where large turbid flows were again observed flowing into North Lake Wyangan. Photographs were taken during this site inspection and a decision was made by GCC EH&S staff to undertake an 'In-drain & In-Lake Sampling – GCC' water quality sample collection the following morning.

A plume of sediment was observed on 20th June 2016 in North Lake Wyangan, however this plume was mainly concentrated to the northern extend of North Lake Wyangan (Figure 11). By the time a turbidity sample was taken on 21st June 2016, the plume of sediment could only be observed along the eastern side of North Lake Wyangan (Figure 12).

Figure 11 – North Lake Wyangan, High Drainage and Turbid Inflows, 20th June 2016

Figure 12 - North Lake Wyangan, Turbid Inflows Fringing Eastern Lake Edge, 21st June 2016

High volume turbid flows were observed flowing into North Lake Wyangan at sampling site NLW-N on 20th June 2016 (Figure 13). This flow had decreased by 21st June 2016, however the colour of the inflowing water was much the same as observed the day prior (Figure 14).

Figure 13 – High Volume Drainage Flows through LW-N, 20th June 2016

Figure 14 - High Volume Drainage Flows through LW-N, 21st June 2016

Turbid flows were also observed at sampling site NLW-1 on 21st June 2016. (Figure 15) is looking upstream of sampling site NLW-1.

Figure 15 - Looking upstream from NLW-1, 21st June 2106

During the 'In-drain & In-Lake Sampling – GCC' water quality sample collection on 21st June 2016, additional water samples were collected and taken back to GCC Offices for Turbidity testing, again using a handheld Turbidity Meter (HACH 2100Q Turbidimeter). These samples collected on the 21st June 2016 were sampled on both the 21st June 2016 and the 28th June 2016. The Turbidity readings results are illustrated in Table 2 and Table 3 following.

Table 2 - Turbidity Readings taken 21st June 2016

Site	Reading 1	Reading 2	Reading 3
NLW–1	172 NTU	172 NTU	173 NTU
LWN	174 NTU	174 NTU	175 NTU
NLW–2	62.4 NTU	62.9 NTU	62.5 NTU
NLW–3	37.3 NTU	37.7 NTU	37.7 NTU
LW6	63.4 NTU	67.4 NTU	65.7 NTU
SLW–2	73.7 NTU	74.1 NTU	72.4 NTU

Table 3 - Turbidity Readings taken 28th June 2016

Site	Reading 1	Reading 2	Reading 3
NLW-1	21.5 NTU	21.4 NTU	21.5 NTU
LWN	21.6 NTU	21.6 NTU	21.6 NTU
NLW-2	32.4 NTU	32.3 NTU	32.3 NTU
NLW–3	7.36 NTU	7.54 NTU	7.50 NTU
LW6	17.7 NTU	17.6 NTU	18.0 NTU
SLW–2	4.01 NTU	3.97 NTU	3.96 NTU

Water samples bottles collected on the 21st June 2016 were subsequently photographed on the 21st June 2016 (Figure 16), 22nd June 2016 (Figure 17) and again on the 28th June 2016 (Figure 18). As visually evidenced in these photographs, it was clear to see all water sample sediments settling out over a period of one week.

Figure 16 - Sample Bottles, 21st June 2016

Figure 17 - Sample Bottles, 22nd June 2016

Figure 18 - Sample Bottles, 28th June 2016

4. Conclusions

Based on the 'Australian and New Zealand Guidelines for Fresh and Marine Waters 2000', ranges for default trigger values for turbidity within Lakes and Reservoirs of south-east Australia range from 1-20 NTU's. North Lake Wyangan, as a receiving aquatic lake ecosystem, and as evidenced within this paper, is receiving inflow waters significantly higher than the 'Australian and New Zealand Guidelines for Fresh and Marine Waters 2000' identified defaults trigger values.

All sampled turbidity readings from the 28th January 2016 (Rainfall Event #2) exceeded the ANZFM default trigger values with results ranging from **53-358 NTU's** whilst the sampled turbidity readings of the 21st June 2016 (Rainfall Event #4) also exceeded the ANSFM default trigger values with results ranging from **37.3-175 NTU's**. The extent of these very high turbidity values and flows into North Lake Wyangan had not previously been identified.

The reduction in overland sediment movement from within the Lake Wyangan catchment into Lake Wyangan should now underpin future strategic management actions directed at reducing sediment loss, flows and deposition into Lake Wyangan.

Prepared by:

Griffith City Council
Environment, Health & Sustainability Unit
August 2016.

Appendix C – Satellite Analysis Report

Satellite-based Water Quality Monitoring

Lake Wyangan, New South Wales, Australia

-

Data analysis, comparison with survey data, interpretation, and recommendations

Lake Wyangan, Landsat 8 true color RGB, 2016-03-31

Order number: 1498
Project name: 1498_Water-Technology_WQ_Lake-Wyangan
Delivery number: 1498_Delivery_EOMAP2Water-Technology_vs03_20160610

Version	Date
3.0	2016/06/10

Date of delivery: 2016/06/09
Contact person: Philip Klinger
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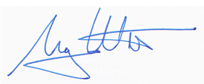
Australia

Service Provider:
EOMAP GmbH & Co. KG
Schloss Seefeld
Schlosshof 4a
82229 Seefeld, Germany

Reporting:

Signature:
Full name: Philip Klinger
Date: 2016/06/08

Review:



Full name: Dr. Magnus Wettle
Date: 2016/06/10

Content

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Abbreviations

Abbreviation	Description
ABS	Total absorption of water constituents (excluding pure water absorption)
ALG	Floating algae bloom indicator
AOI	Area of interest
AOT	Aerosol optical thickness
CAB	Chlorophyll Algae Bloom indicator
CDM	CDOM, Yellow substances
CHL	Chlorophyll a
DIV	Ratio between organic absorption and TSM scattering
FLG	Flags
HAB	Harmful Algae Bloom Indicator
LCM	Land Cover Mapping
OWD	Optical water depth
QUC	EOMAP quality coding
QUT	Total retrieval quality of each pixel
RGB	Red-Green-Blue true color composite
SDB	Satellite derived bathymetry
SDD	Secchi disc depth
SFC	Seafloor classification
SFR	Sea floor reflectance
SIA	Sum of inorganic absorbers
SOA	Sum of organic absorbers
SST	Sea surface temperature
TSM	Total suspended matter
TUR	Turbidity
Z90	Penetration depth from which 90% of the reflected light is measured

Sensors

Abbreviation	Description
LSAT5	LANDSAT5
LSAT7	LANDSAT 7
LSAT8	LANDSAT8
SENT2	SENTINEL2
SENT3	SENTINEL3
MERIS	MERIS
MODAQ	MODIS_AQUA
MODTE	MODIS_TERRA
REYE1	RAPIDEYE1
REYE2	RAPIDEYE2
REYE3	RAPIDEYE3
REYE4	RAPIDEYE4
REYE5	RAPIDEYE5
SPOT4	SPOT4
SPOT5	SPOT5
THEOS	THEOS
WVIE2	WORLDVIEW2
WVIE3	WORLDVIEW3

Naming of the product files

The naming of EOMAP product files follows a sequence of mandatory and optional elements.

<product>_<region>_<subregion>_<optional_ path/row(Landsat)>_<serviceprovider>_<date>_<time> _<sensor>_<resolution>_<other_information>.<ext>

Example:

<TUR>_<id>-<Sumatra><127060>_<EOMAP>_<20140409>_<032930>_<LSAT8>_<m0030>.<tif>

Executive Summary

This work investigated the ability of satellite-based mapping to complement and augment the ongoing water quality monitoring program at Lake Wyangan, New South Wales. Detecting and monitoring harmful algal blooms was of particular interest, while turbidity and chlorophyll-a concentrations were also tracked. These three water quality parameters were derived from satellite sensor image data for ten dates between September 2015 and April 2016, and the results were compared with in situ measurements over the same period.

Overall trend of the satellite and in situ measurements relating to harmful algal bloom detection is in agreement: harmful algal blooms were detected lake-wide by the satellite-based approach towards February-March 2016, which coincides with in situ sampling of higher levels of algal bio-volume and total algal biomass. An exception to this trend occurred in the southern lake Wyangan during the time period of September 2015, where remotely-sensed values indicate a moderately increased risk of algal bloom presence which was not reflected in the situ measurements.

The in situ sampling program was not designed for comparison with satellite-based measurements, and hence there were challenges in comparing the two data sets. The most important limitation here was the time lag between satellite and in situ measurements. Extensive experience has shown that time differences of one day can have a significant impact on matching up aquatic measurements, particularly at the localised pixel scale.

Overall, it is assessed the satellite-based monitoring can play a cost-effective role in synoptic coverage, near-real-time monitoring of algal blooms (and turbidity) for these two lakes. The satellite-derived algal bloom signal would firstly be considered on a lake-wide basis, signalling when the blooms are beginning to occur and in which general location. This would function as a near real time early warning system, giving a birds eye view of the status of the lakes that in situ sampling cannot achieve without significantly more resources. A set of recommendations are provided for developing higher confidence in this approach at a more detailed spatial scale. If successful, it is likely that the frequency of in situ sampling can be reduced and/or better targeted, with the potential associated cost savings and improved understanding of the lake system.

1.Overview and objective

Mapping and monitoring of water quality related parameters such as sediment dynamics, chlorophyll concentrations and harmful algae blooms can support environmental assessments of potential impacts from agricultural, recreational and industrial activities on coastal and inland water bodies. Using image data captured from earth-orbiting satellite sensors offers a cost-effective solution to deploying such monitoring services.

This report describes the methods and data used - together with the results obtained - for the satellite-based water quality monitoring study of Lake Wyangan (the area of interest), New South Wales, Australia (Figure 1).

Figure 1: AOI of Lake Wyangan, New South Wales, Australia

The area of interest (AOI), Lake Wyangan, is situated northwest of Griffith in southern New South Wales. As a part of the Murrumbigee irrigation area, the surrounding landscape is characterized by farming and viticulture, and fruit-growing. The agricultural and recreational use, together with high temperatures during the summer months and relatively low precipitation (slow rates of water exchange) can lead to an increased susceptibility to (harmful) algae blooms in Lake Wyangan. Hence, ongoing monitoring is needed to track trends in the lake's water quality development.

In this study, the key water quality parameters of turbiditiy (TUR), chlorophyll-a (CHL) and harmful algae blooms (HAB) are mapped using satellite imagery from ten (10) historical dates, ranging from September 2015 to the end of April 2016. The methods and data used are described in Chapters 2 through 4. The satellite derived water parameter values obtained are described in chapter 6 "Results", which also includes comparison with in-situ survey data collected by the client. The final chapter 7 summarises and discusses the results, and offers a set of recommendations for future satellite-based water quality surveys, based on the findings of this study.

2. Methods and Products

2.1. Modular Inversion and Processing System MIP

For the retrieval of satellite-derived water quality data, the physics-based Modular Inversion and Processing System (MIP), developed by EOMAP, has been applied to Landsat 7 and 8 data. This sensor-independent approach includes all the relevant processing steps to guarantee a robust, standardised and operational retrieval of water quality parameters from various satellite data sources. The advantage of physics-based methods is that they do not require a priori information about the study area and can therefore be applied independently of satellite type and study area.

MIP is the first sensor-independent processing system that takes into account adjacency and terrain altitude impacts. The system integrates a fully coupled and bidirectional atmospheric and in-water retrieval of harmonized water quality properties, allowing for the full range of scattering and absorption in natural waters (Kiselev et al. 2014, Heege et al. 2014, Richter et al. 2014, Heege & Fischer 2000 & 2004). The MIP architecture systematically handles the independent properties of sensor parameters and specific optical properties as well as the radiative transfer relationships (at 1nm spectral resolution). The different workflow steps from satellite raw imagery import to value added water quality retrieval are displayed in Figure 2. MIP is the most established, sensor-independent and operational aquatic remote sensing processing system for the full range of high, medium and low resolution satellite sensors. Fully-automated water monitoring processors are installed in satellite ground segments worldwide (Europe, Australia, Asia and America), to ensure fast and efficient access to a wide range of satellite sensors. The data processing and orchestration software, the EOMAP Workflow System (EWS), ensures continuous, daily production.

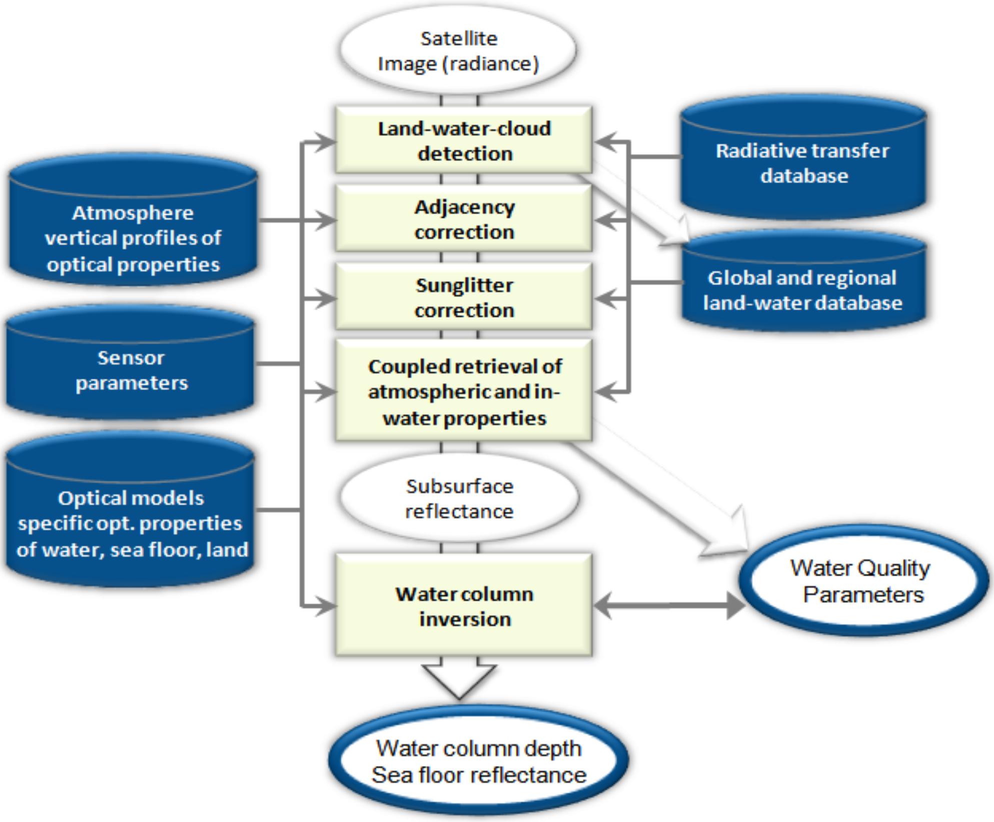


Figure 2: EOMAP's physics-based MIP workflow

2.2. Satellite derived water quality parameters

The following satellite derived water quality parameters have been delivered with this project.

2.2.1 Turbidity

Turbidity (TUR) is a key parameter of water quality and is linearly related to the backward scattering of light of organic and inorganic particles in water. It is linearly related to TSM (Total Suspended Matter) at low to moderate turbidity values. The measurement unit is Earth Observation Turbidity Unit (ETU), which is similar to Formazine Turbidity Unit (FTU) or Nephelometric Turbidity Unit (NTU). Turbidity is determined by the backward scattering of light between 450 to 800nm, physically retrieved using satellite data. The geometrical properties of in situ measurement devices and wavelengths used may differ in comparison to the satellite product. For example, the standard FTU determination is based on the measurement of light scattered within a 90° angle from a beam directed at the water sample. Typical values vary over several magnitudes: for marine waters or clear lakes typical concentrations are between 0.01 to 1 ETU, whereas for turbid lakes and rivers concentrations can reach 100 ETU and even significantly more. The Turbidity product calculated here from the 2016-03-31data is shown as an example in Figure 3.

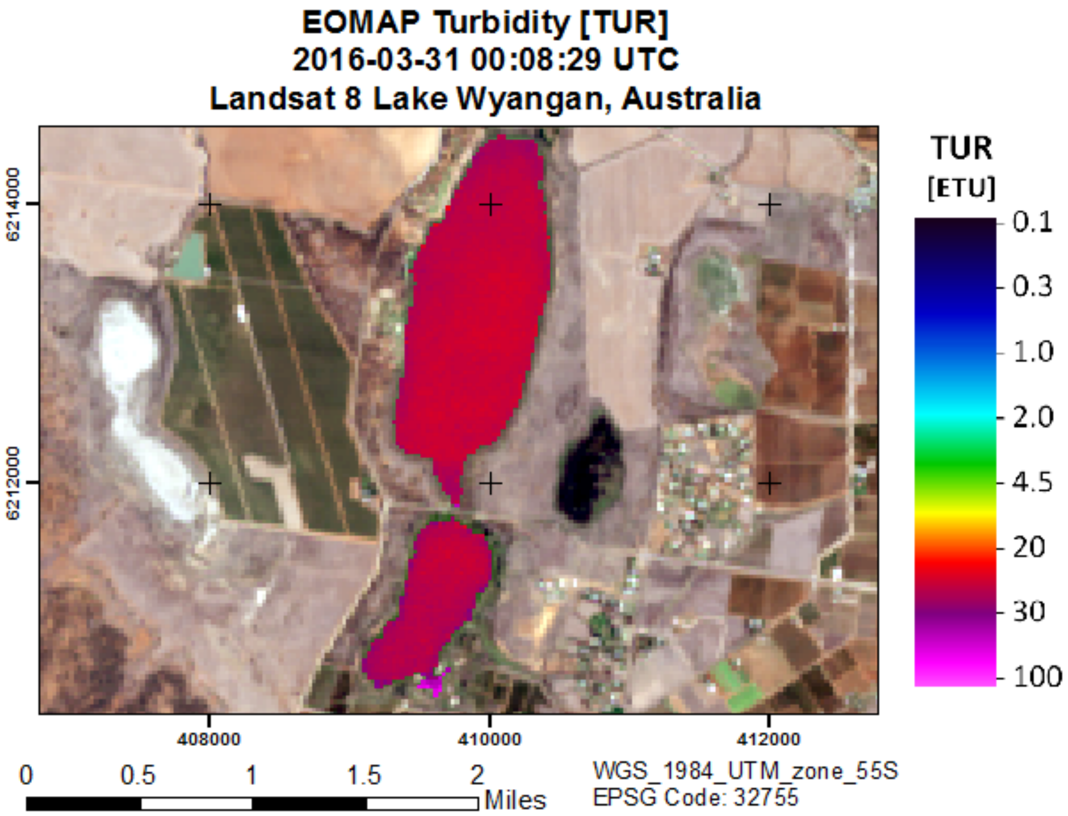


Figure 3: EOMAP Turbidity product from 2016-03-31

2.2.2 Chlorophyll-a

Chlorophyll-a (CHL) in [µg/l]: EOMAP offers a standardized Chlorophyll-a measure for a range of sensors. It is based on the derived information of in-water organic absorption, in-water turbidity and the spectral characteristics of Chlorophyll absorption. Chlorophyll values vary over several magnitudes: for marine waters or clear lakes these are typically between 0.01to10 µg/l, whereas for eutrophic lakes concentrations can reach 100 µg/l and more. EOMAP's Chlorophyll products are typically reliable within a range of 10 – 50 % in comparison to in situ measures (Broszeit, 2015). The Chlorophyll absorption is part of the organic absorption parameter. 1 µg/l CHL is equivalent to a*CHL_440 = 0.035 1/m at 440nm. For clear water conditions (low chlorophyll and total suspended matter), the specific absorption of chlorophyll increases significantly (Bricaud et al. 1995). The Chlorophyll-a product calculated here from the 2016-03-31data is shown as an example in Figure 4.

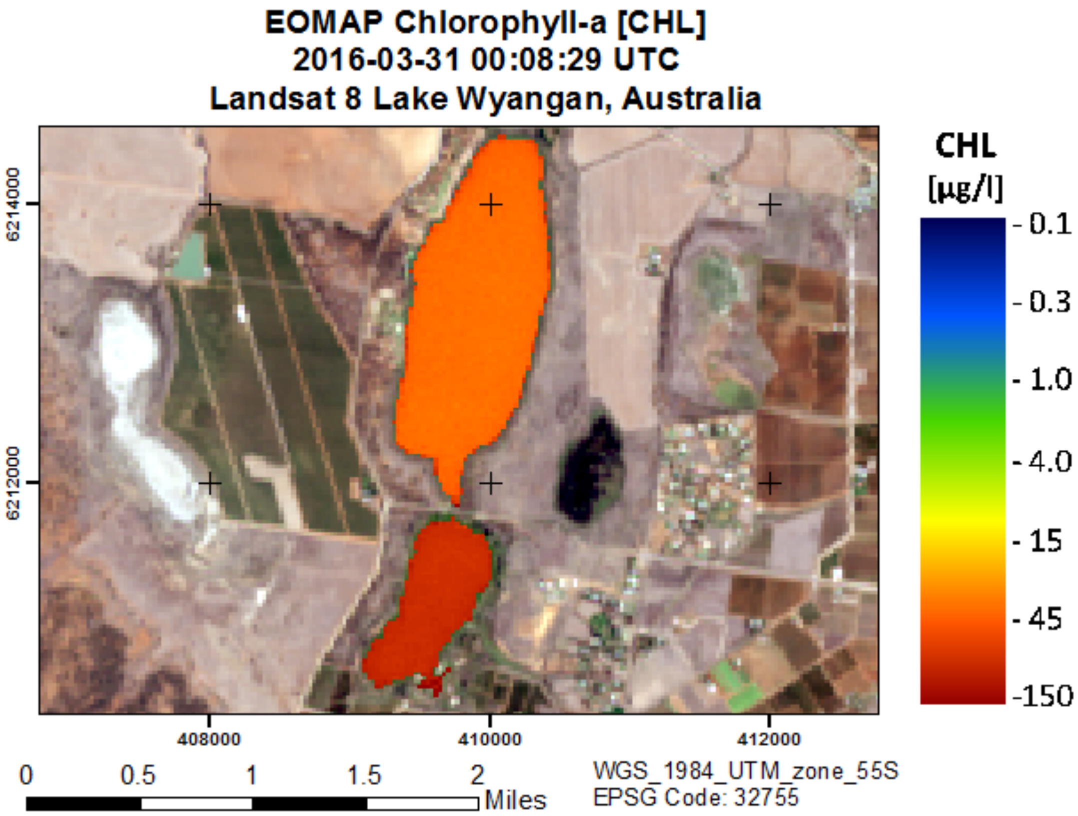


Figure 4: EOMAP Chlorophyll-a product from 2013-03-31

2.2.3 Harmful Algae Bloom indicator

EOMAP's **Harmful Algae Bloom indicator (HAB)** detects areas likely affected by harmful algae blooms formed by cyanobacteria containing phycocyanin as pigment. The classification is based on the investigation of spectral trends in the green-red wavelength channels of the modelled and measured spectra. It is worth noting that this is not a quantitative measure, e.g. a unit of concentration measure. Instead, it uses spectral analysis to infer the intensity of a harmful algal bloom signal. Red algae blooms are not detected by the algorithm. The Harmful Algae Bloom indicator product calculated here from the 2016-03-31 image data is shown as an example in Figure 5.

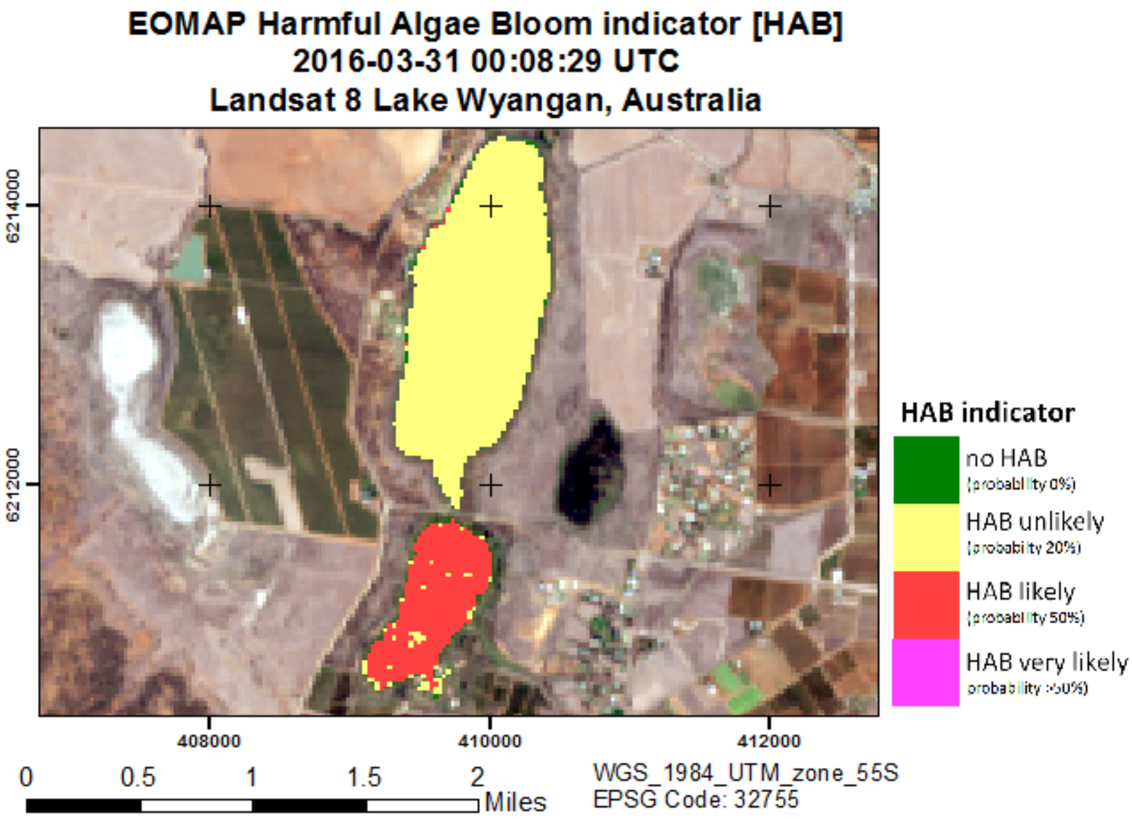


Figure 5: EOMAP Harmful Algae Bloom indicator product from 2013-03-31

3. Data sources

The image data used are from US Geological Survey (USGS) Landsat 7 (three scenes) and 8 (seven scenes) satellites sensors. The data have been downloaded from USGS "Glovis" portal and processed with MIP-EWS. The full list of processed and delivered satellite scenes is shown in Table 1.

Table 1: Full list of processed and delivered scenes.

Sensor	Time of record
Landsat 8	2015-09-05 00:08:40 UTC
Landsat 8	2015-09-30 00:02:40 UTC
Landsat 8	2015-10-23 00:08:54 UTC
Landsat 8	2015-11-17 00:02:47 UTC
Landsat 7	2015-12-18 00:10:03 UTC
Landsat 7	2016-01-19 00:10:31 UTC
Landsat 7	2016-02-04 00:10:39 UTC
Landsat 8	2016-03-08 00:02:32 UTC
Landsat 8	2016-03-31 00:08:29 UTC
Landsat 8	2016-04-25 00:02:09 UTC

As a result of the failure of the Scan Line Corrector (SLC) on board Landsat 7, data acquired by this sensor suffers from increasing data gaps towards the image borders since 2003. As the AOI of Lake Wyangan is located quite close to the image border of the Landsat scenes, Landsat 7 data shows significant data gaps above the lake (see Figure 6). The SLC instrument originally was designed to compensate for these gaps which are caused by the sensor architecture and forward movement of the satellite during data recording. EOMAP has developed a filtering algorithm to fill these data gaps with adjacent, valid data as displays in Figure 7. Subsequently, horizontal displacements can occur to some degree, towards the image borders in affected areas.

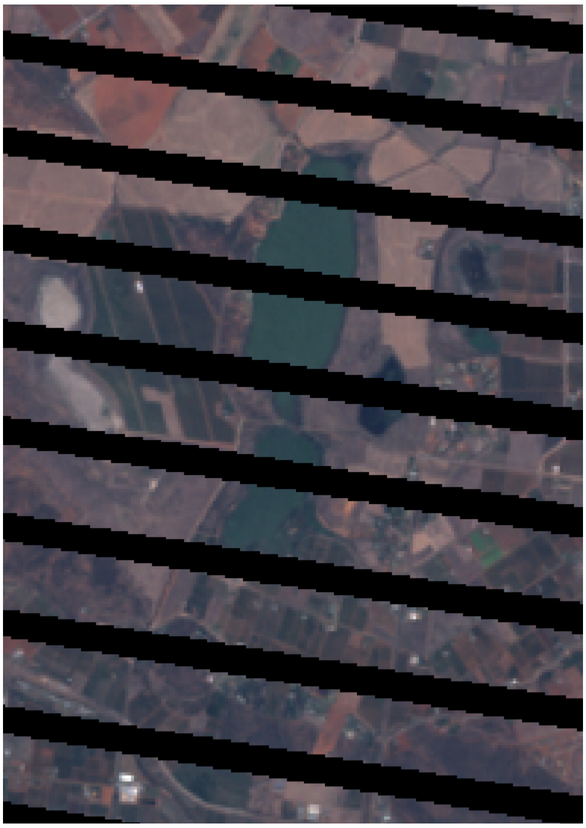


Figure 6: Landsat 7 scene from 2016-01-19 with SLC gaps

Figure 7: Same scene with EOMAP SLC filtering

4. Data formats

The water quality data is delivered as 32bit real value GeoTIFF, as well as 8bit scaled and colored GeoTIFF for an easier visualisation. The color palettes of the 8bit GeoTIFFs currently used are EOMAP standard but can be changed based on client-specific request. For image analyses, we recommend using GIS applications like QGIS or ESRI ArcGIS, which can load the geo-referenced raster grid data and interrogate (water constituent) image values. Metadata (projection, image extent, etc.) for each set of raster data is stored in the corresponding .xml metadata and .pdf overview files.

5. Quality Control and Masking

5.1 Quality Information

As a standard part of the processing, an accuracy or quality indicator is calculated for each retrieved parameter and for each detected water area pixel. This measure comprises a comprehensive range of factors that can impact the derived product quality, including:

- the geometry between sun, target, and sensor,
- the estimated sun glint probability,
- the retrieved aerosol optical depth,
- residuals of the measured and modelled sensor radiances and subsurface reflectances,
- the comparison of retrieved water species concentrations to extreme values as defined in the configuration files,
- pixels affected by cloud shadows and
- shallow water areas.

The quality information is part of each standard geodata delivery and is visualized by two different 8bit GeoTIFFs:

- QUT - Total Quality quantifying the overall quality of each pixel from low to high
- QUC – EOMAP Quality coding, revealing the processor's internal quality check split into the defined indicators (e.g. sunglint, shallow water risk, etc.). These are classified into 'no quality concerns',' quality warning' and 'bad quality' (flag).

Figure 8 and Figure 9 show the quality indicator products for the scene of 2016-03-31.

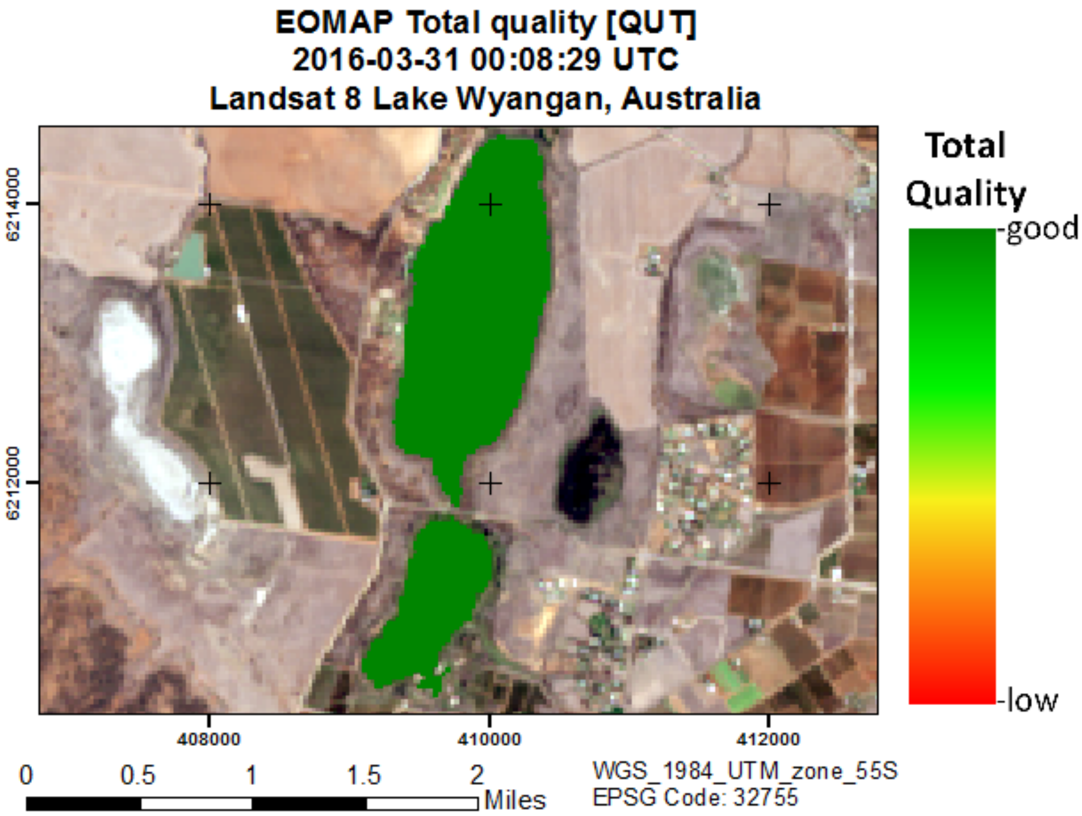
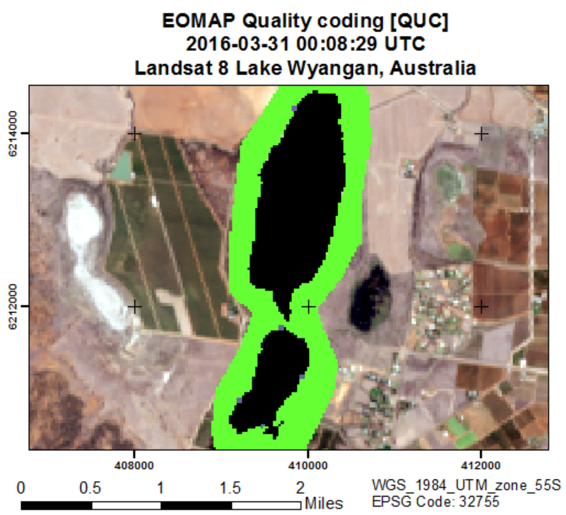


Figure 8: EOMAP Total Quality (QUT) product from 2016-03-31



Color	Flag Description
	No risk identified
	sunglint risk
	large solar zenith angle
	large spacecraft zenith angle
	Aerosol above limit or Cirrus risk
	Cloud Shadow
	Shallow water risk
	Mixed pixel risk
	Retrieved concentration at configuration limit
	Retrieval / processor warning
	sunglint risk
	large solar zenith angle
	large spacecraft zenith angle
	Aerosol above limit or Cirrus risk
	Cloud Shadow
	Shallow water risk
	Mixed pixel risk
	Retrieved concentration at configuration limit
	Retrieval / processor warning
	Shallow water automatically
	Shallow water manually
	Land/Transition zone
	Invalid pixel manually
	Cloud
	Cloud Shadow manually
	Processor failed / corrupt input data

Figure 9: EOMAP Quality Coding (QUC) product from 2016-03-31

5.2 Flagging

EOMAP's water quality products are accompanied by the processor's internal quality control mechanisms, resulting in pixel flagging in case of unreliable values. Moreover, a manual quality check and -if required - additional masking is applied to each product.

The QUC file indicates the main quality influencing parameter using a specific EOMAP quality coding classification scheme with corresponding grey values (GV), shown in Figure 10.

Professional version allow combination of the two most relevant flags:

First number = most relevant flag
1-digit-number refer to second relevant flag, e.g. 1 for sunglint risk, 2 for large solar zenith angle

Examples: 25 Warning flag for large zenit solar angle and Whitecaps
114 Critical flag for sunglint, plus warning for aerosol above limits

GV	GV range	Flag status	Flag description	Color code	Color
0	0	Water	No risk identified	0 0 0	
10	10 - 19	Warning	sunglint risk	148 138 84	
20	20 - 29	Warning	large solar zenith angle	83 141 213	
30	30 - 39	Warning	large spacecraft zenith angle	218 150 148	
40	40 - 49	Warning	Aerosol above limit or Cirrus risk	196 215 155	
50	50 - 59	Warning	Cloud Shadow	177 160 199	
60	60 - 69	Warning	Shallow water risk	146 205 220	
70	70 - 79	Warning	Mixed pixel risk	250 191 143	
80	80 - 89	Warning	Retrieved concentration at configuration limit	190 190 190	
90	90 - 99	Warning	Retrieval / processor warning	210 210 210	
110	110 - 119	Critical	sunglint risk	73 69 41	
120	120 - 129	Critical	large solar zenith angle	22 54 92	
130	130 - 139	Critical	large spacecraft zenith angle	150 54 52	
140	140 - 149	Critical	Aerosol above limit or Cirrus risk	118 147 60	
150	150 - 159	Critical	Cloud Shadow	96 73 122	
160	160 - 169	Critical	Shallow water risk	49 134 155	
170	170 - 179	Critical	Mixed pixel risk	226 107 10	
180	180 - 189	Critical	Retrieved concentration at configuration limit	120 120 120	
190	190 - 199	Critical	Retrieval / processor warning	130 130 130	
220	220	No value	Transition Zone	102 255 51	
221	221	Unreliable	Shallow water automatically	146 205 220	
222	222	Unreliable	Shallow water manually	60 159 186	
230	230	No water	Land	102 255 51	
232	232	Unreliable	Invalid pixel manually	102 102 152	
240	240	No water	Cloud	255 255 255	
242	242	Unreliable	Cloud Shadow manually	180 180 180	
250	250	No retrieval	No retrieval / out of AOI or image extend	255 0 0	

Figure 10: Description of EOMAP QUC product with corresponding GV classification

As an example, cloud shadow effects can occur in the vicinity of clouds, resulting in unrealistically low water parameter values. To detect and flag (mask) these areas, EOMAP has developed a specific algorithm based on geometric models, taking into account the sun angle and sensor viewing geometry, the retrieved aerosol properties, the height of the clouds, an analysis of the blue channel radiances and a statistical anomaly detection of the water species concentrations. When applying this cloud shadow detection algorithm, approximately ~85% of the cloud shadows are detected and masked. Remaining cloud shadows have been manually flagged and can be identified in the EOMAP Quality Coding (QUC) file by GV 242.

Due to the spatial extent of single pixels (30x30m in the case of Landsat), it is likely that spectral mixing of signals from land and water can occur in the pixels along the edge of the water body, leading to unreliable retrieval of values. Such pixels are labelled with the quality flag "transition zone". EOMAP uses a high resolution land-water-mask database to determine the land-water-boundary, which is then filtered to create a transition zone, which in turn is automatically masked out during processing. In the 8bit water constituent products the transition zone has GV 251, in the QUC product it is marked with GV 220.

6. Results and comparison with in situ data

In-situ algal and water parameter sampling surveys have been carried out during the period of satellite monitoring. Figure 11 shows the in-situ measurement locations. For analysis and comparison, all available and useable data of table *4012- LW&CMS, Sampling Program_copy to EOMAP 02.06.16.xls*, have been used. In order to compare trends of water parameter concentrations of Lake Wyangan, virtual stations located at or near the in situ stations are used to interrogate values in the remote sensing outputs for both parts of the lake: NLW-3 and NLW-4 for northern Lake Wyangan, SLW-4 and LW6 for southern Lake Wyangan.

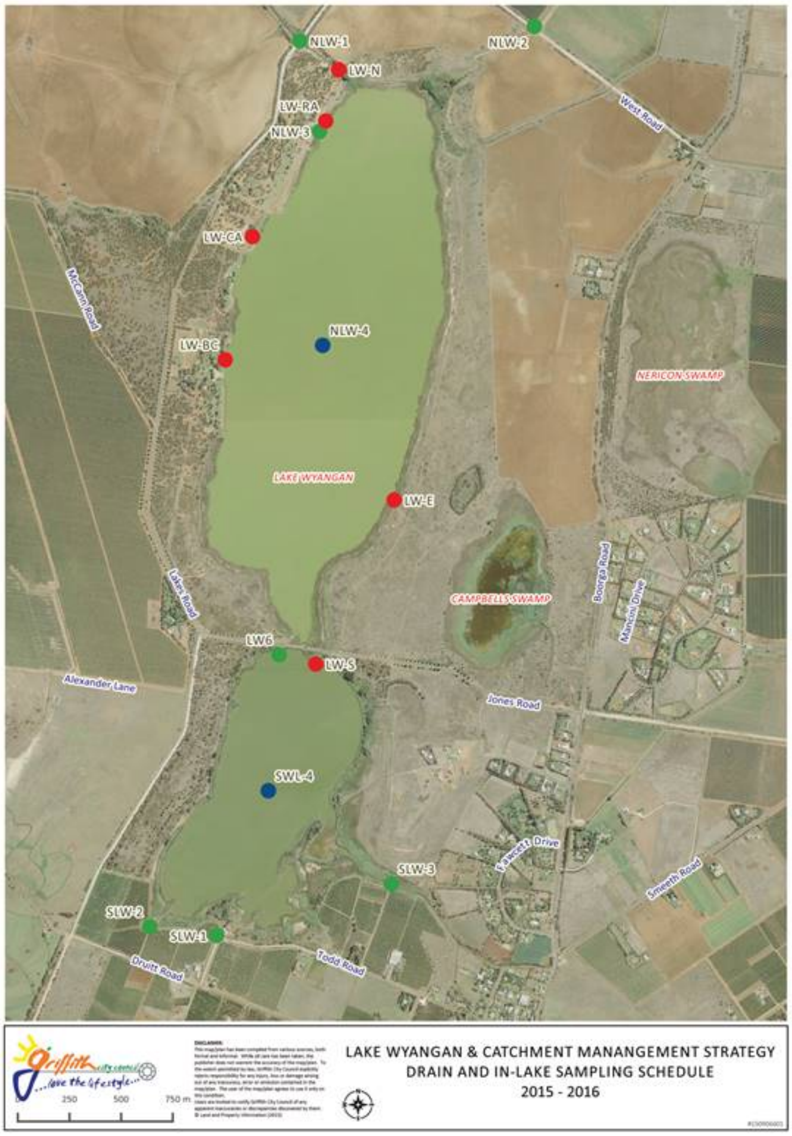


Figure 11: Location of the in situ stations

Figure 11 reveals that all in-situ measurement stations except NLW-4 and SWL-4 are more or less directly at the edge of the lake. As explained previously, satellite pixels for such locations may contain a mixed signal from both aquatic and terrestrial origin. In order to obtain more reliable values for satellite vs. in situ comparison here, the virtual stations for satellite data have been positioned slightly further from the lake shore than the in-situ locations (see Figure 12). Although both lakes are relatively quite homogeneous in water parameter concentrations, this spatial offset needs to be considered when interpreting the comparison results. Stations NLW-1, NLW-2, LW-N, SLW-1, SLW-2 and SLW-3 are located in drains around the lakes, and these water bodies are too small to be reliable measured using the spatial resolution of the Landsat image data (30m pixels).

Figure 12: Location of virtual stations used for time trend analysis

The data file *1498_Delivery_EOMAP2Water-Technology_vs02_20160609_validation.xlsx*, attached to this report, lists the stations, the UTM/geographical coordinates, the sensor date of image acquisition and statistical measures (mean, median, min, max, SD) of chlorophyll-a and turbidity for a 3x3 pixel matrix at the given station coordinate. As a measure of statistical significance, the columns CHL_ip and TUR_ip provide information on the number of pixels the values are calculated from (with a maximum of nine pixels). Furthermore, the Total Quality indicator (QUT) as described above in section 5.1 is included in these tables, with values of 100 indicating good retrieval quality and lower values reflecting decreasing retrieval quality.' No data' fields indicate flagging, for instance due to haze/clouds.

The following two concepts need to be considered when comparing satellite-derived and in-situ measurements:

- Temporal offsets between in-situ and satellite derived measurements can lead to significantly diverging results. Experiences from multi-year freshwater monitoring projects[1,2] with extensive in situ validation programs reveal that several hours are enough to cause divergences between the two data sets, where comparisons of water quality measurements taken one or more days apart need to be treated with care. This is essentially due to the inherently dynamic environment of a water bodies, where hydrodynamic processes can influence composition and distribution of water parameters at relatively rapid time scales. Table 2 lists the minimum time differences between dates of remote sensing and in situ measurements. These measurements are complemented by additional in situ measurements, in between these dates, for stations NLW-3, NLW-4, SLW-4 and LW6.
- While in-situ measurements are typically point measurements (horizontally and vertically), an inherent feature of satellite data sampling is that the measurement is integrated over an area equivalent to the pixel size, in this case 30m x 30m. In addition, there is also an element of averaging the signal vertically, where the depth of this is a function of water column visibility. This differences in sampling technique may also cause significant divergences when comparing remotely sensed and in situ water quality data. (Depending on the application, it can be argued that the satellite-derived measurement can under certain circumstances be more representative of the aquatic environment, since a point measurement can be more sensitive to (non-) mixing in the water column.)

For some further background, EOMAP's water quality products have been successfully validated and compared to in-situ data in numerous commercial and R&D projects worldwide, covering a wide range of different types of water bodies such as highly turbid rivers and estuaries, chlorophyll-driven, eutrophic inland waters or clear lakes. Further information on this can be obtained in the EOMAP online validation report[1] or from reports of different R&D projects such as from the EU-FP7 GLaSS[2] project.

[1] http://www.eomap.com/exchange/pdf/EOMAP_Validation_Examples_Water_Quality.pdf
[2] http://www.glass-project.eu/assets/Deliverables/GLaSS-D4.2.pdf

Table 2: Time differences between satellite and closest in situ measurements

sat date	closest In situ date	difference (days)	stations	parameters	figures
2015-09-05	2015-09-09	4	NLW-3, LW6	HAB, TUR	Figure , Figure
2015-09-30	2015-09-30	0	NLW-3, LW6	HAB, TUR	Figure , Figure
2015-10-23	2015-10-21	2	NLW-3, LW6	HAB, TUR	Figure , Figure
2015-11-17	2015-11-18	1	NLW-3, LW6	HAB, TUR	Figure , Figure
2015-12-18	2015-12-15	3	NLW-3, LW6	HAB, TUR	Figure , Figure
2016-01-19	2016-01-20	1	NLW-3, LW6	HAB, TUR	Figure , Figure
2016-02-04	2016-02-01	3	NLW-3, LW6	HAB, TUR	Figure , Figure
2016-03-08	2016-03-07	1	NLW-3, LW6	HAB, TUR	Figure , Figure
2016-03-31	2016-03-21	10	NLW-3, LW6	HAB, TUR	Figure , Figure
2016-04-25	2016-03-21	35	NLW-3, LW6	HAB, TUR	Figure , Figure

6.1 Turbidity

Figure 13 displays the trend in remotely-sensed mean turbidity values (3x3 pixel matrix) during the period under investigation for Lake Wyangan north (black) and south (red). The overall mean TUR value for northern and southern Lake Wyangan is 29.97 ETU and 37.7 ETU, respectively. This is characterized by a higher amplitude of TUR values variations for the southern lake which has standard deviation of 20.61 ETU compared to the northern lake standard deviation of 7.2 ETU. Both northern and southern parts of the lake show trends of decreasing TUR values during the period under investigation, as indicated by the dashed, linear fitted lines. This decrease is considerably less significant for northern Lake Wyangan.

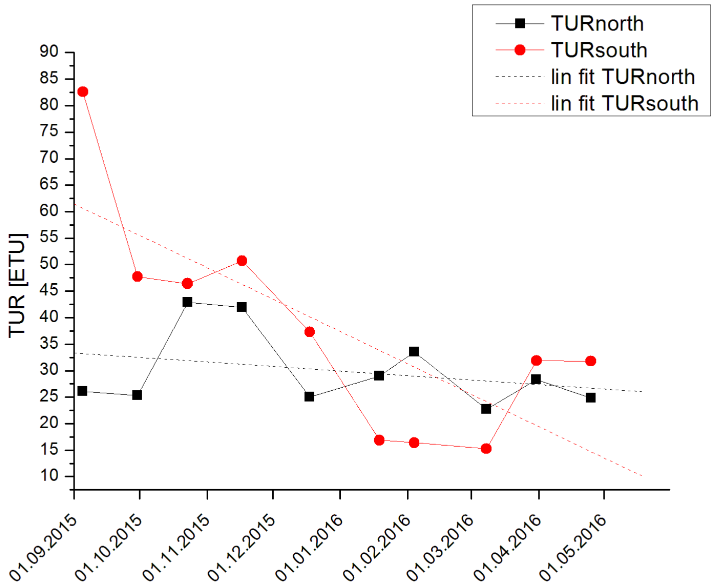


Figure 13: Remotely-sensed turbidity timeseries for Lake Wyangan at stations NLW-4 and SLW-4

The following four plots display in situ vs. remotely-sensed turbidity comparisons for the four stations available for analysis. The remaining stations could not be analysed, either due to lack of comparable in situ data or due to resolution limits of the applied satellite sensors (e.g. drain stations).

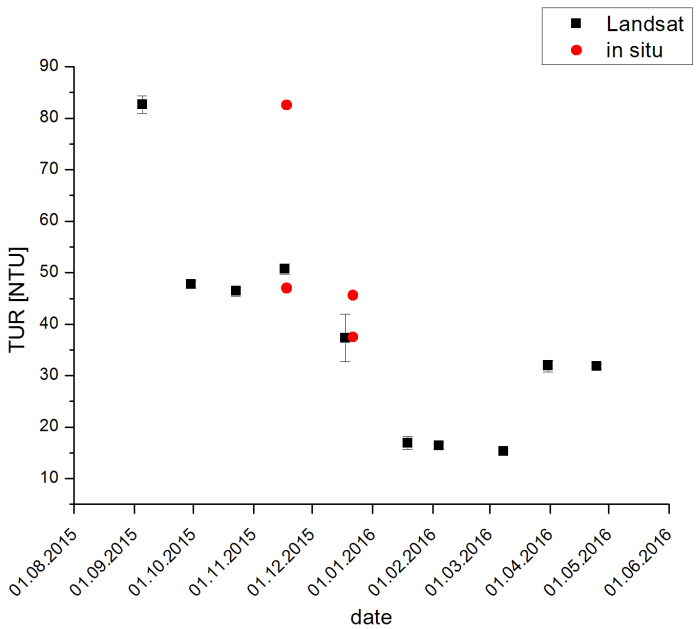


Figure 14: Remotely-sensed vs. in situ turbidity comparison for station SLW-4 (southern lake)

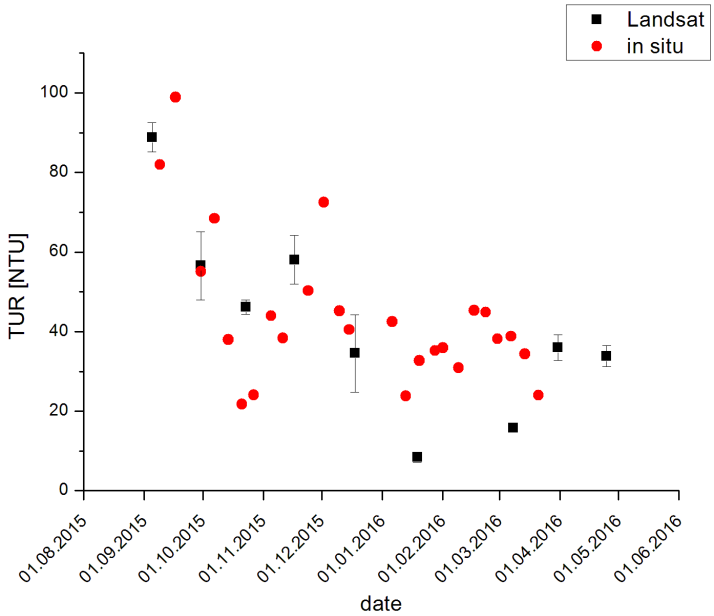


Figure 15: Remotely-sensed vs. in situ turbidity comparison for station LW6 (southern lake)

The results for remotely-sensed turbidity values at the southern Lake Wyangan stations SLW4 and LW6 are in good alignment with in situ measurements (Figure 14 and Figure 15). The trend of decreasing turbidity for this part of the lake as indicated by the satellite measurements (Figure 13) is confirmed by the in situ measurements of station LW6. This station furthermore has a suitable density of in situ measurements through time, and indeed reveals the best match between in situ and remote sensing turbidity for the two lakes during this time period. It is worth noting that the single in situ sampling instance that occurred on the same day as the satellite image capture for this station (September 30, 2015, see Table 2) has a very good match up: essentially perfect.

Station SLW4 does not offer a sufficient number of in situ values to allow for further statements on trends, but the single measurements are in good accordance with the remotely-sensed values.

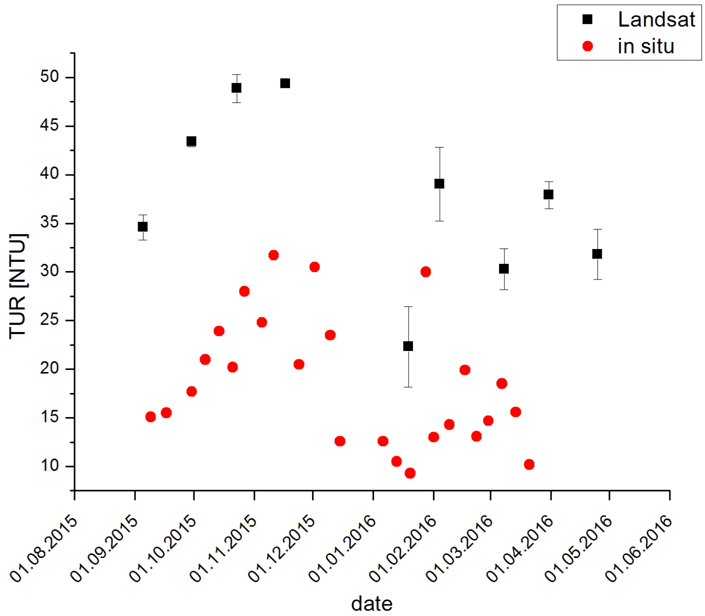


Figure 166: Remotely-sensed vs. in situ turbidity comparison for station NLW-3 (northern lake)

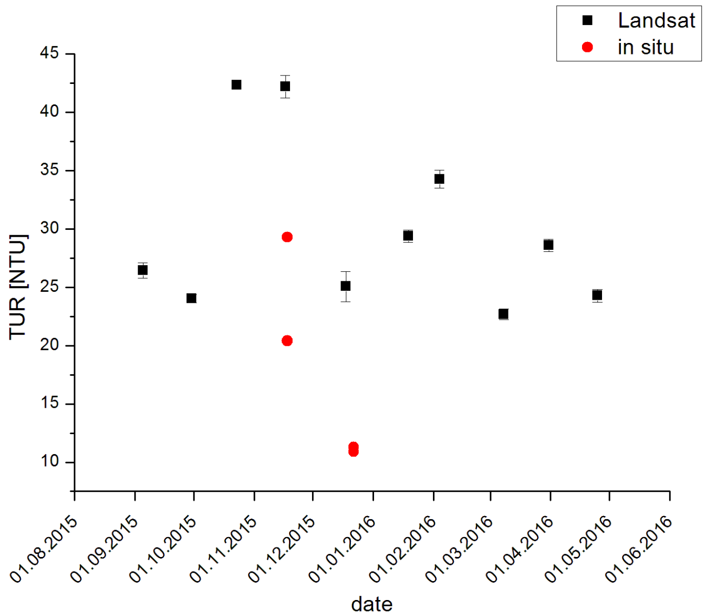


Figure 177: Remotely-sensed vs. in situ turbidity comparison for station NLW-4 (northern lake)

For northern Lake Wyangan, the in situ and Landsat turbidity measurements do not have a close match in absolute terms, (Figure 166 and Figure 177). However, for station NLW-3 (Figure 16) there is a generally good agreement in the trend (e.g. an increase in turbidity at station NLW-3 from September 2015 to November 2015, and then a drop in values around

January 2016), where the two data sets give an appearance of having a systematic offset. For station NLW-4, there are only 3 in situ measurements, and even if two (2) of these are in line with the overall average of Landsat values for this station, it is considered that there are not enough data points for a useful comparison at this station.

6.2 Chlorophyll-a

Figure 18 displays the trend in remotely-sensed mean chlorophyll-a values (3x3 pixel matrix) during the period under investigation for Lake Wyangan north (black) and south (red). The overall mean CHL value for northern and southern Lake Wyangan is 32 µg/l and 64.37 µg/l, respectively. Similar to the results from TUR measurements, southern Lake Wyangan is characterized by a higher amplitude of CHL value variations, indicated by a standard deviation of 26.07 µg/l, where the northern lakes has a CHL standard deviation of 8.11 µg/l during this time period. The trend for northern part of the lake reveals relatively stable conditions with possibly a weak increase through time, whereas the southern Lake Wyangan exhibits a decrease in CHL concentrations through time. There are no chlorophyll-a in situ measurements available for comparison in the data table.

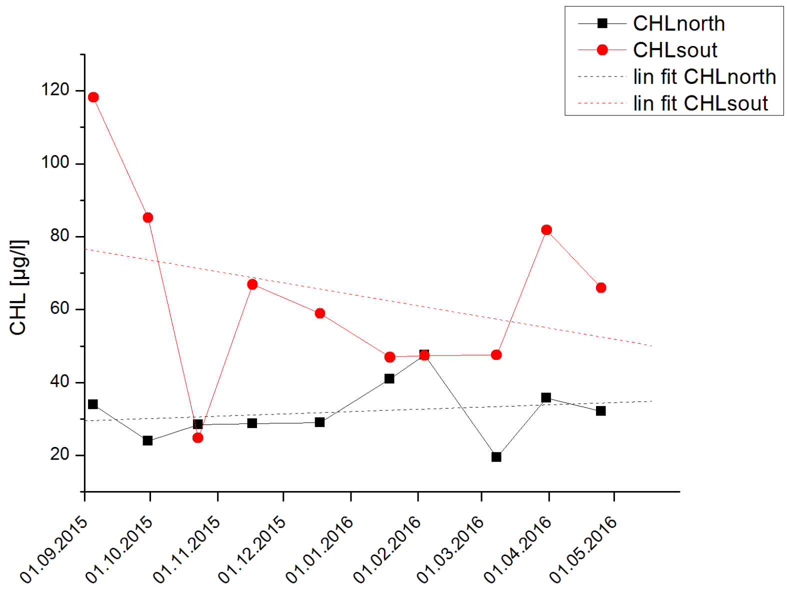


Figure 18: Remotely-sensed chlorophyll-a timeseries for Lake Wyangan at stations NLW-4 and SLW-

6.3 Harmful algae blooms

The following Figure 19 displays the Harmful Algae Bloom (HAB) maps generated for the period under investigation. These are based on the apparent presence of the phycocyanin pigment, contained in the cyanobacteria, and have been classified into four categories of HAB presence: 'none', 'not likely', 'likely' and 'very likely'.

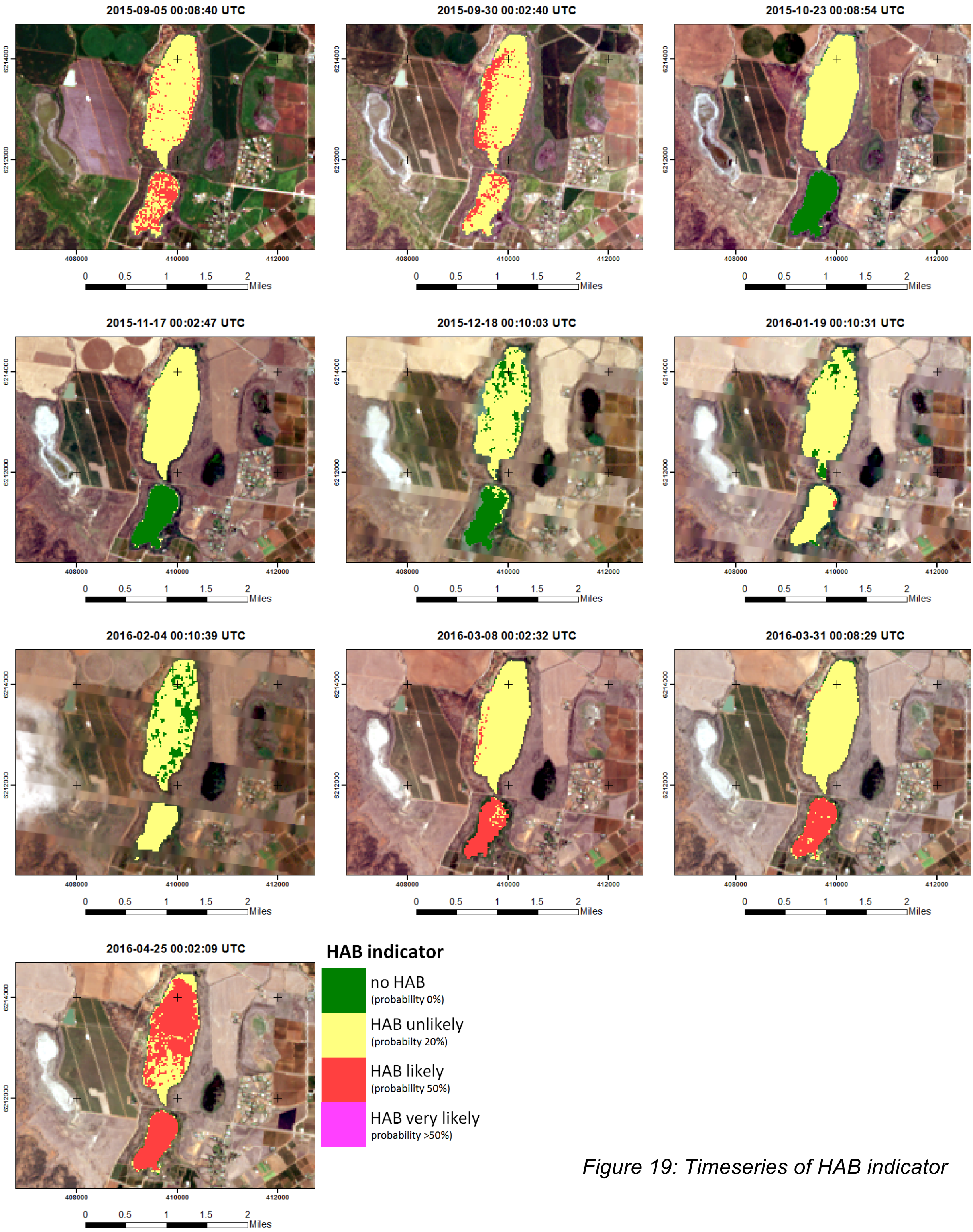


Figure 19: Timeseries of HAB indicator

Indications of a likely harmful algae bloom can be observed particularly towards the end of the period under investigation, around March 2016 in southern Lake Wyangan. By the end of April 2016, also the northern part of the lake shows area-wide, significantly increased likelihood for the presence of a cyanobacteria bloom. During the early stage of the monitoring period, in September 2015, there's also slightly increased evidence for blooms in parts of the lakes: area-wide in early September for southern Lake Wyangan and at the western shore of northern Lake Wyangan by the end of September. Between October 2015 and February 2016, the HAB detection algorithm shows no signs of increased cyanobacteria bloom risk for either lake.

These overall trends, captured by the satellite sensor, compare favourably with the trends derived from the in situ sampling of algal biomass, as shown for stations NLW-3 and LW6 for the northern and southern lakes respectively (Figure 20). A trend of increased algal biomass towards March 2016 is clearly visible in the in situ data, in alignment with the Landsat-derived HAB indicator as shown in the time series of Figure 19 above. Broadly, this would be expected due to high water temperatures towards the end of the summer, which offer favourable environmental conditions for (harmful) algae growth The localised increased likelihood of HAB in September 2015, as shown in the satellite data, is not reflected in the in situ algal biomass data

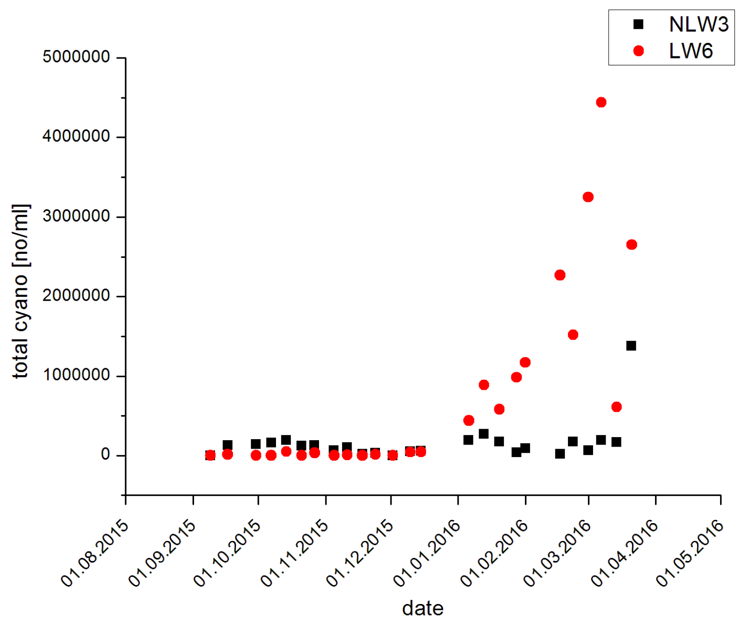


Figure 20: In situ measured total algal biomass for in-lake stations NLW-3 (northern lake) and LW6 (southern lake)

For comparison with in situ algal sampling results, only stations NLW3 and LW6 can be used. Though there are continuous measurements for stations NLW-1, NLW-2, SLW-1, SLW-2 and SLW-3, all these stations are located in drains below the resolution capacity of the sensors (Figures 11 and 12). However, correlations between blooming cyanobacteria in both the lakes and the adjacent drains are likely, hence the in situ measurements of the drains will also be taken into account further below.

Figure 21 and Figure 2 show the algal bio-volume results of the in situ sampling for stations NLW-3 (northern lake) and LW6 (southern lake) in units of mm³/l. Both stations show an increase in algal bio-volume towards the end of December 2015 and beginning of January 2016, which continues to rise towards March 2016.. Another but significantly weaker peak can be observed in northern Lake Wyangan around October 2015, whereas in situ data from southern Lake Wyangang does not show a rise in algal bio-volume at that time.

These graphs also feature the output of the HAB algorithm (from Figure 19 above) as bar graphs. The fill colour of the bars indicates the HAB classification pixel value at the exact station coordinate. The border colour displays the trend of the surrounding pixels and the whole lake, respectively. For instance, the pixel at NLW-3 on 25th of April 2016 is classified HAB unlikely (yellow) whereas most of the adjacent pixels and surrounding wider areas of the lake are classified as HAB likely (red). Since both remote sensing stations, NLW-3 and LW6, have been moved away from the original coordinates of the in situ stations, as described above, it is important to incorporate the trends of the neighbouring pixels and the larger-scale water body in the interpretation of the results. (As with all the other comparisons here, there's also a temporal shift, due to the offsets in situ and satellite measurement dates.)

Please note that where the infill color of a bar is grey, this indicates that the measurement from this pixel has been flagged as not reliable by the EOMAP processor. The outline of such a grey bar will still indicate the general value of surrounding pixels. An example of this are the December and January HAB measurements in Figure 21.

The trends observed in the in situ bio-volume data are present in the satellite derived HAB indicators. In particular, the increase in algal bio-volume towards late summer is clearly described for southern Lake Wyangan (LW6). This trend is also indicated for the northern lake, although there are fewer number of in situ measurements during apparent time of increase blooms (March 2016 onwards) and only one satelite measurement shows elevated HAB risk for this particular location. Again, the synoptic view given in Figure 19 reveals a pattern of increased HAB likelihood beginning in early March 2016, whereas this is not seen to be occurring until late April in the northern lake. This appears to be confirmed by the in situ measurements graphed in Figures 21 and 22. Overall, the data points where the in situ and satellite measurements appear least in agreement correspond to when the measurements were furthest apart in time (i.e.where in situ data points are in between the bar graphs).

Note that the single instance of same-day measurement for the satellite capture and in situ sampling, April 25, 2015, show a good correlation for the northern lake (Figure 21) but the moderately elevated HAB signal in the southern lake was not confirmed by the adjacent (slightly closer to shore) in situ same-day sampling (Figure 22). Apart from this, the same trend of less agreement between in situ and satellite measurements seem to occur when they are furthest apart in time (in situ data points in between the bar graphs).

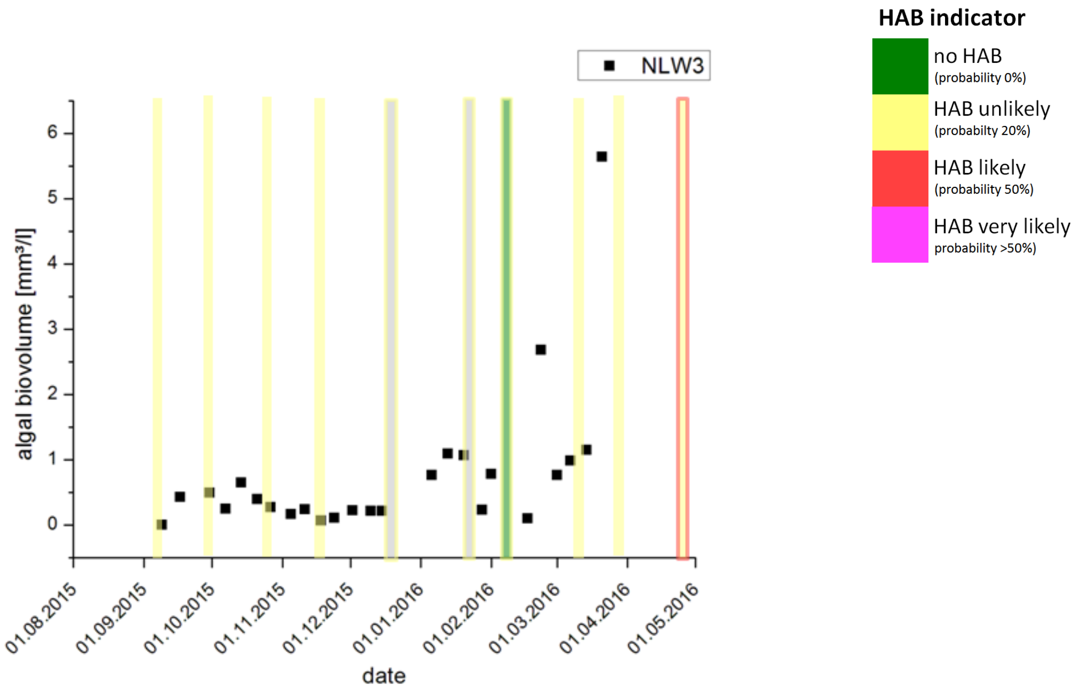


Figure 21: Comparison of in situ measured algal biovolume and HAB classification for station NLW-3 (northern lake)

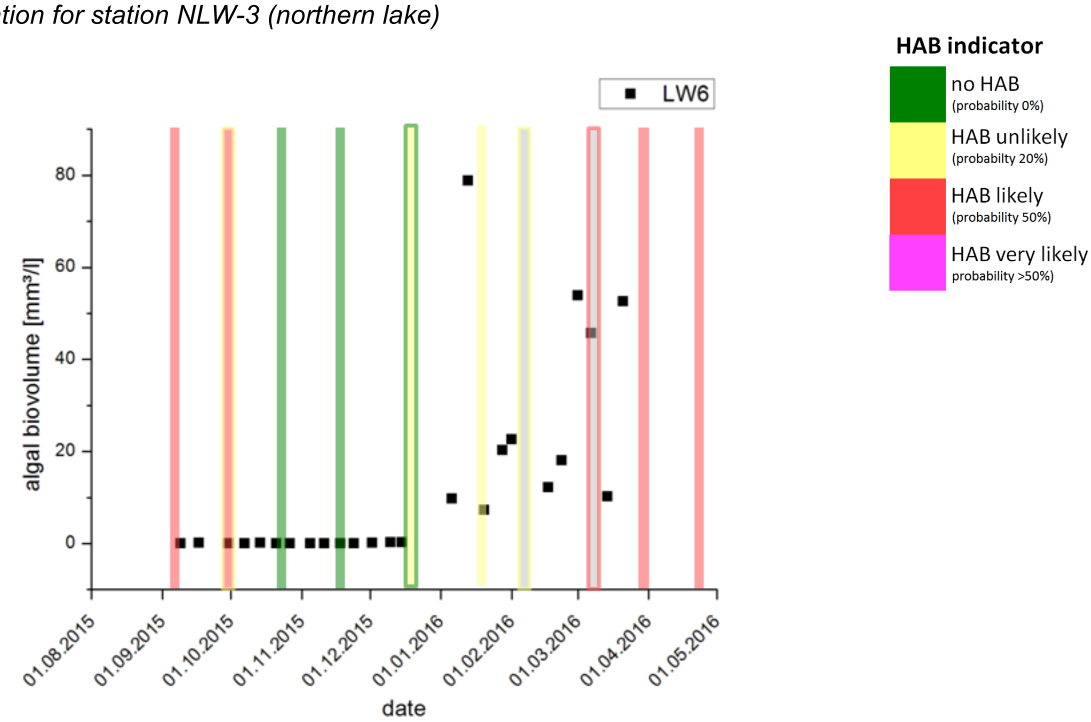


Figure 22: Comparison of in situ measured algal biovolume and HAB classification for station LW6 (southern lake)

Similar trends of increasing algal bio-volume towards late summer are also visible at the other stations located in the drains around northern and southern Lake Wyangan as illustrated in Figure 213.

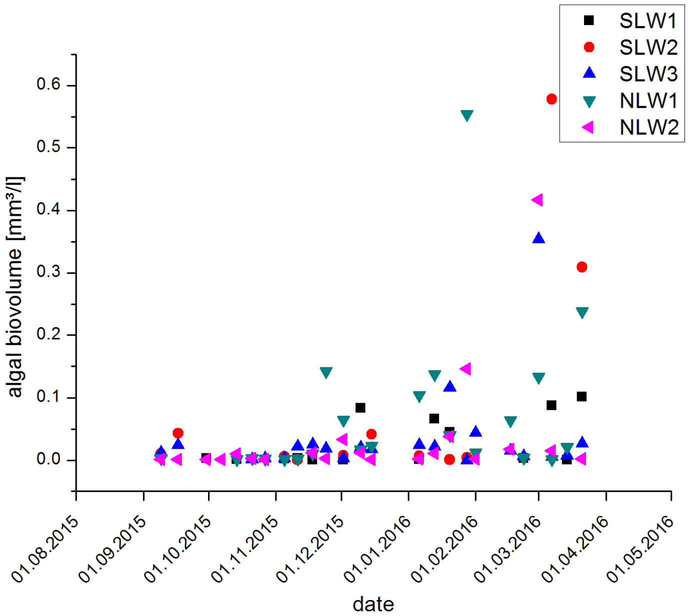


Figure 213: Trends in algal bio-volume at in situ measurement stations within the drains

In agreement with the results above are the in situ measurements of total algal biomass in [no./ml] with a distinct rise towards April 2016, as sampled near the drain stations (Figure 22).

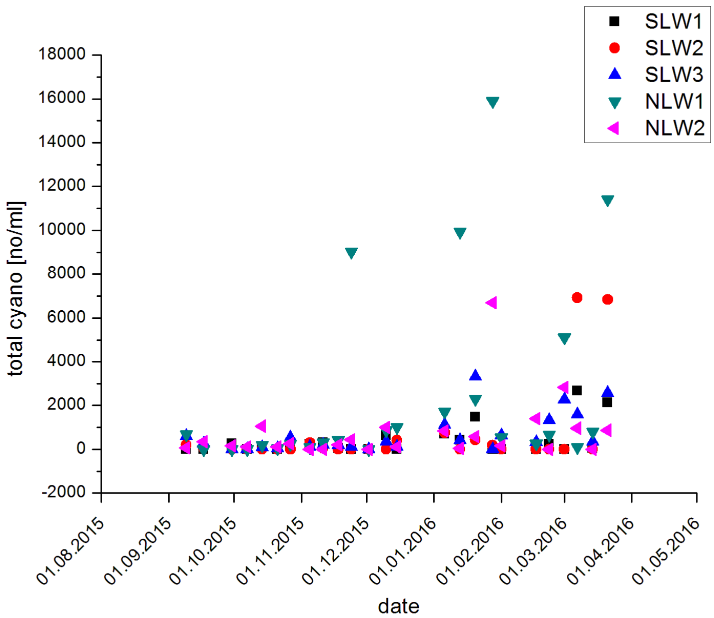


Figure 22: In situ measured total algal biomass for drain stations

7. Discussion, Conclusions and Recommendations

In summary, northern Lake Wyangan is characterized by relative stability and continuity in terms of the key water quality parameters of turbidity and chlorophyll-a, with lower overall mean concentrations and variability, in comparison to southern Lake Wyangan. For southern Lake Wyangan, a decreasing trend in both turbidity and chlorophyll-a values through time can be observed, together with a larger amplitude in variations.

Harmful algal blooms are detected lake-wide by the satellite-based approach towards February-March 2016, which coincides with in situ sampling of higher levels of algal bio-volume and total algal biomass. Diverging results have been obtained for HABs in southern Lake Wyangan at the beginning of the period under investigation (September 2015), where remotely-sensed values indicate a moderately increased risk of algal bloom presence which is not reflected in the situ measurements.

The overall trend of the satellite and in situ measurements relating to harmful algal bloom detection is in agreement; this is illustrated in Figures 19 and 20, notably. Comparing the outputs from the two methods on a per-station basis is less straightforward, where differences in location, method and most importantly timing, influence the ability to compare measurements in a dynamic aquatic environment. For this study there was one instance of same day measurement from both satellite and in situ sampling, april 25, 2015. This coincident measurement gave very good results for turbidity, but inconclusive results for HAB: it provided a good HAB match-up for the Northern lake (Figure 21) but the elevated HAB signal in the southern lake was not confirmed by the adjacent (slightly closer to shore) in situ sampling (Figure 22) in this time period.

The satellite-derived Turbidity, Chlorophyll-a and HAB trends do not appear correlated, which is considered a positive indicator that the various remote sensing algorithms are detecting bio-optically distinct parameters in the Lake Wyangan water column.

Overall, it is assessed the satellite-based monitoring can play a cost-effective role in synoptic coverage, near-real-time monitoring of algal blooms for these two lakes (3 water quality parameters were mapped across both lakes for 10 separate dates at a cost of ~ 5,000 AUD). Based on the findings here, it would firstly be applied on a lake-wide basis, signalling when the blooms are beginning to occur and in which general location. In order to develop higher confidence in this approach at a more detailed spatial scale, further same-day in situ match ups are likely required, where all the in situ sampling is at a minimum the equivalent of 2-3 satellite image pixels from the shore.

For deploying an on-going, satellite-based HAB monitoring for Lake Wyangan, the following recommendations are made:

1. (Also) use Sentinel 2a imagery: this is a new satellite from the European Space agency, which up until now has had only intermittent imaging of Australia. This is sparse coverage is now being rectified through political channels at the national level, and a Geoscience Australia is likely to be providing a cost-free direct feed of Sentinel data which could be as frequent as several times per week. Sentinel 2a has similar spectral characteristics to

Landsat 8, however the pixel resolution is 10m instead of 30m, which is a very important consideration for applications in these relatively small lakes.

2. Schedule further in situ sampling on the days of a relevant satellite overpass. Overpass days and exact times are known in advance, and if the day is cloud free, the sampling would yield very useful coincident information. This will provide data for further calibrating the HAB (and turbidity) algorithms, as well as for validating the results to a higher degree of confidence, gradually fine tuning the system to be more sensitive to local variation in these particular lakes.

3. Conduct the in situ sampling at a minimum the equivalent of 2-3 satellite image pixels from the lake shore, in order to avoid having to offset the corresponding satellite-measurement location.

From this further development of the system, it is likely that the frequency of in situ sampling can be reduced, and/or be better targeted in terms of timing and locations, with the potential associated cost savings.

Additional Information

In response to queries from the project steering committee, EOMAP have provided the following information on their satellite imagery analysis approach.

Analysis Algorithm

The algorithm used for the analysis of HAB is based on the assumption that Cyanobacteria can be characterized by the presence of the accessory pigments phycocyanin and phycoerythrin (Stal 2007, Glazer, 1989, Brient et al 2008). In connection with Chlorophyll, these pigments cause the characteristic blue-green appearance of Cyanobacteria. Chlorophyll and Pheophytin pigments are present also in other algae, and show a distinct absorption in the blue region up to 500nm and beyond 650nm, while phycocyanin and phycoerythrin have a rather broad absorption in the green region (Figure C1). The absorption band of phycocyanin between 550nm and 650nm is spectrally well captured by the green band of many satellites (e.g. Landsat 7, 8), while the satellite red bands are largely insensitive here (with a spectral response maximum around 670nm).

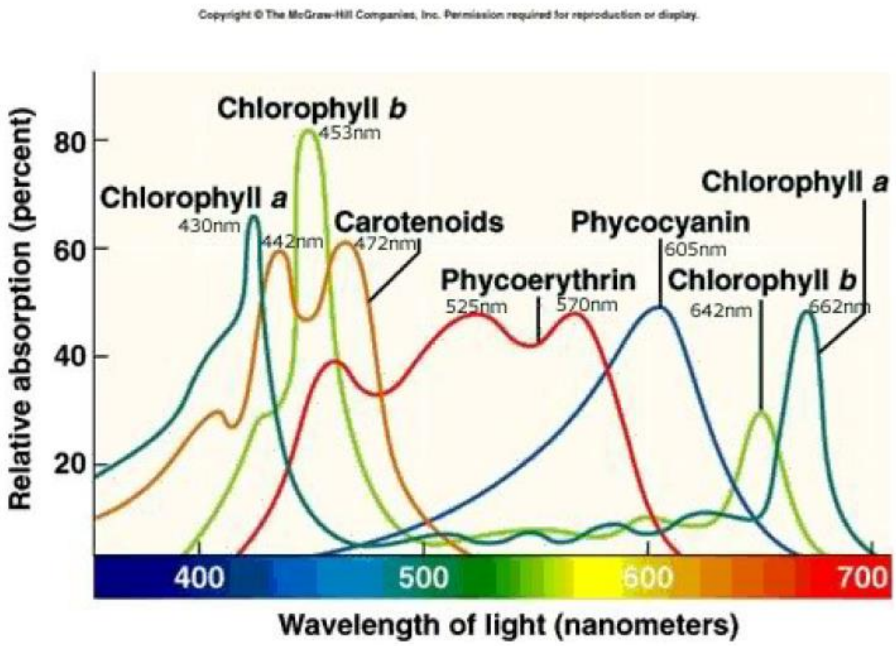


Figure C1 Absorption Spectra

The EOMAP algorithm compares, after atmospheric correction, the absorption properties (calculated together with the in-water scattering properties) with model-based assumptions of in-water absorption, where the algae pigments, humic and particle absorption are represented by standard spectra. These model spectra do not contain increased phycocyanin and phycoerithrin absorption. The algorithm detects the difference between the physically retrieved and modelled absorption slope from the green to the red band. The output is therefore completely independent on the Chlorophyll product, which is calculated using all satellite bands (in the visible/NIR range), thereby distinguishing organic and anorganic components and further separating the Chlorophyll-a specific absorption.

As phycoerytrhin is present also in Red algae, the algorithm might be sensitive to these as well. We also cannot preclude that other impacts such as floating biomass and any remaining errors from the atmospheric- and adjacency corrections might also influence (albeit slightly if at all) the HAB indicator level.

References

Stal, L.J. (2007) Cyanobacteria: Diversity and versatility, Clues to Life in Extreme Environments. In: Algae and Cyanobacteria in Extreme Environments. ed. / J. Seckbach. Dordrecht : Springer, 2007. p. 659-680

Brient L, Lengronne M, Bertrand E, Rolland D, Sipel A, Steinmann D, Baudin I, Legeas M, Le Rouzic B, Bormans M. (2008): A phycocyanin probe as a tool for monitoring cyanobacteria in freshwater bodies., J Environ Monit. 2008 Feb;10(2):248-55. doi: 10.1039/b714238b. Epub 2007 Dec 10.

Glazer, A.N., 1989. Light guides. Directional energy transfer in a photosynthetic antenna. J. Biol. Chem. 264:1-4

Other Applications

Below are a couple of links to existing application of the HAB indicator tool. Note that the 'free' HAB monitoring eoApp for the Great Lakes is using free 500m pixel resolution data, which is easy for us to do inexpensively, but this resolution is not applicable to Lake Wyangan. However, the eoApp as a delivery platform (for 30m data) could be applied for on-going monitoring at the lake.

http://www.eomap.com/featured-image-blooming-baltic-sea/

http://www.eomap.com/daily-satellite-tracking-of-harmful-algae-blooms-for-the-great-lakes-now-online/

EOMAP also have three projects about to start in Germany with local water authorities, all three are for monitoring water quality, and these will include the HAB indicator. We will be provided with in situ validation data for this. The three clients are the state agencies of Berlin, Brandenburg and Mecklenburg-Western-Pomerania.

Appendix D – Aquago Proposal

Lake Wyangan

Solutions for water quality improvement

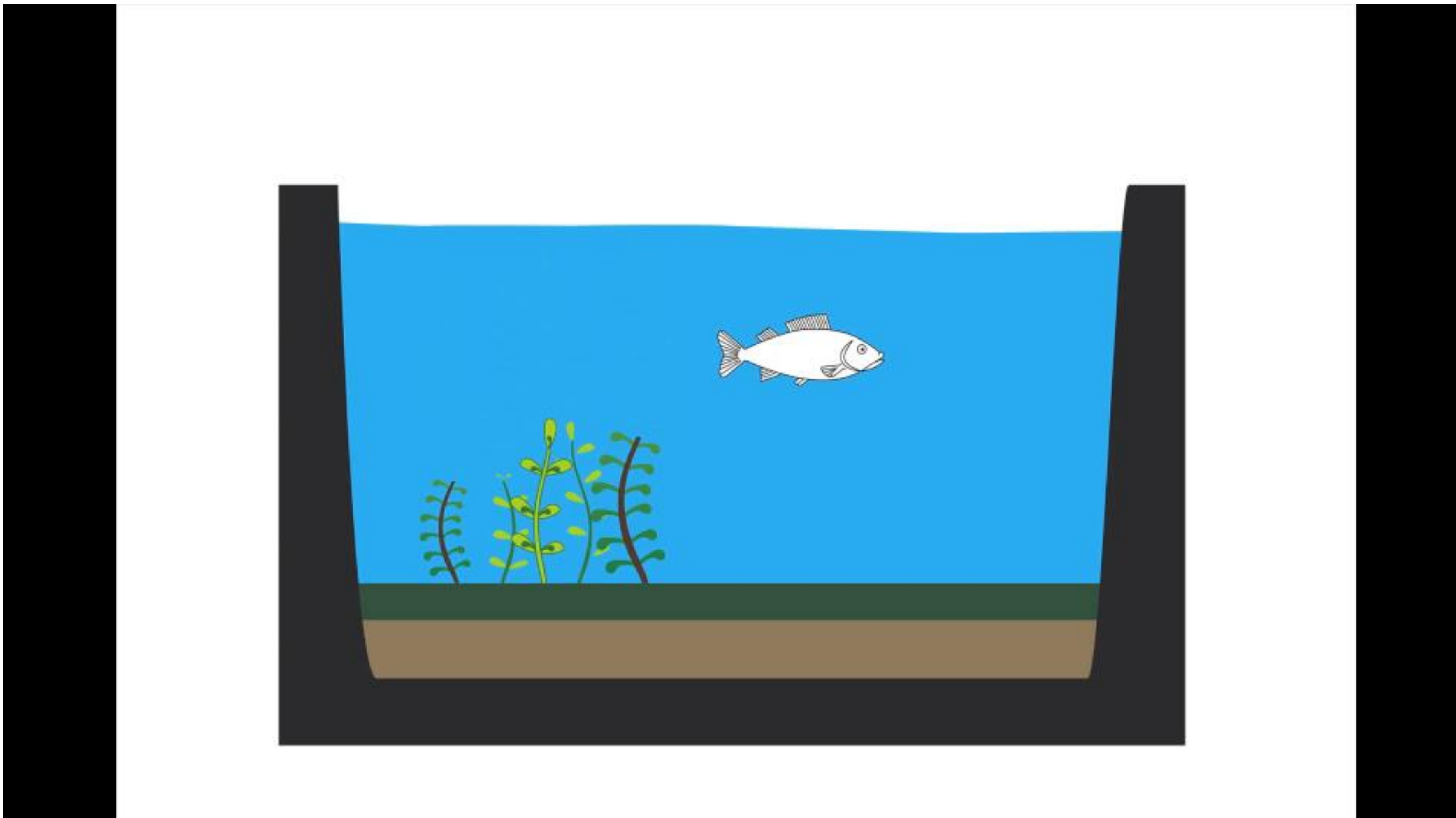
Who we are ?

Created in 1995 for wastewater plants interventions by divers, we specialized in waterbodies aeration, and created AQUAGO.

After more than 15 years experience with lakes, AQUAGO, offers to her clients energy-effective solutions for water treatment.

The patented solar aerator-circulator system SUNGO offers an environmentally friendly, highly efficient solution to oxygenate and clean up all types of water bodies.

solar powered mixers : operating principle in eutrophicated lakes



Our advantages :

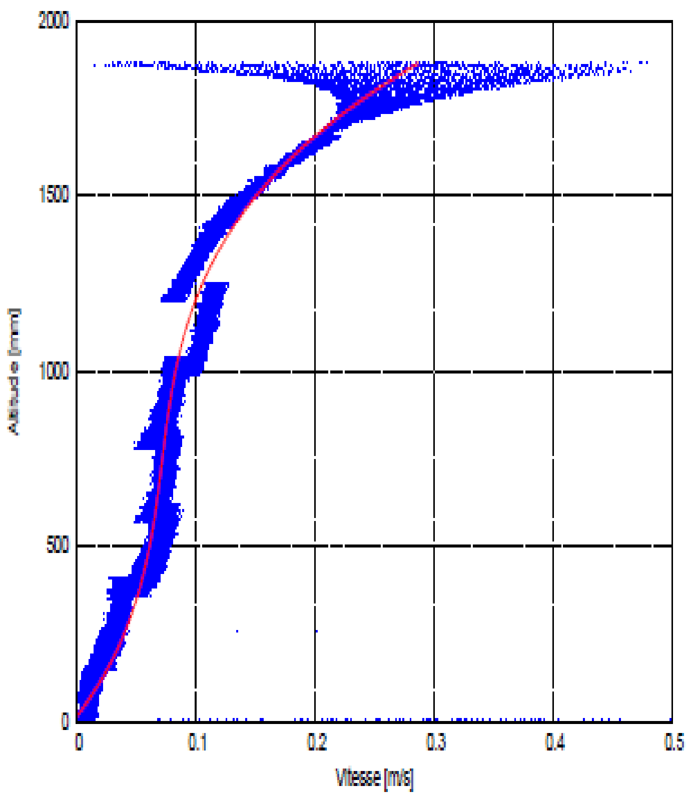
- No infrastructure works
- No connection to the grid
- Easy to install and operate
- Eco-friendly solutions
- Visible results
- Measurable results
- Possibility to change the location of the units easily

solar powered aerators :advantages

With SUNGO: No infra works

- No infra works
- No connection to the grid
- Easy to install and operate
- Possibility to change the location of the units easily

solar powered aerators :advantages



Efficient up to 7 m., SUNGO mixers control algae growth, without putting the sediments in suspension.

Phosphorus remain trapped in the sediments.

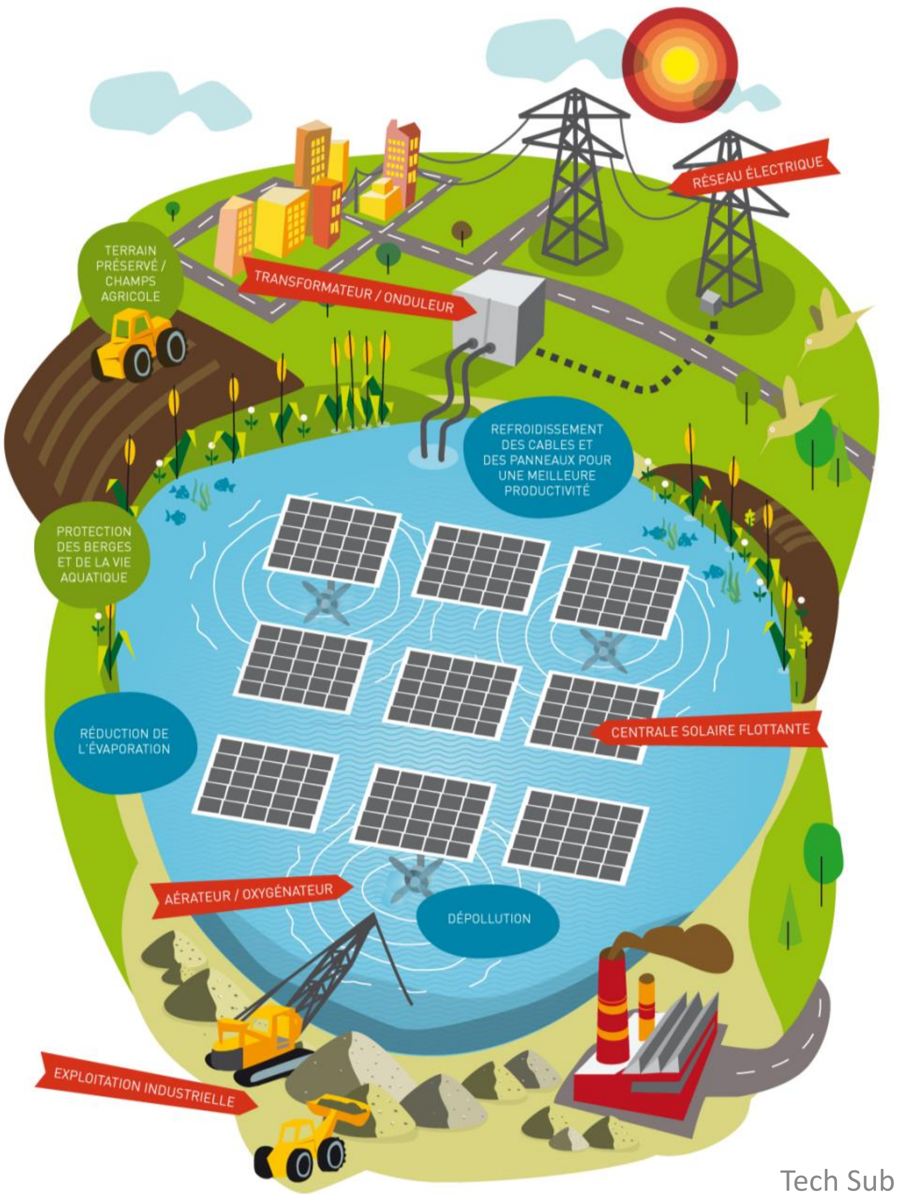
No turbidity augmentation

Homogeneization of the water quality

Creates turbulences that control algae growth

the impeller turns at a maximum of 125 rpm, it generates a slow flow. The velocity at -2 meters is low enough to prevent any agitation of the sediments. (IFREMER study 2012)

Ciel et terre and Aquago offer floating solar energy from small to large scale projects :



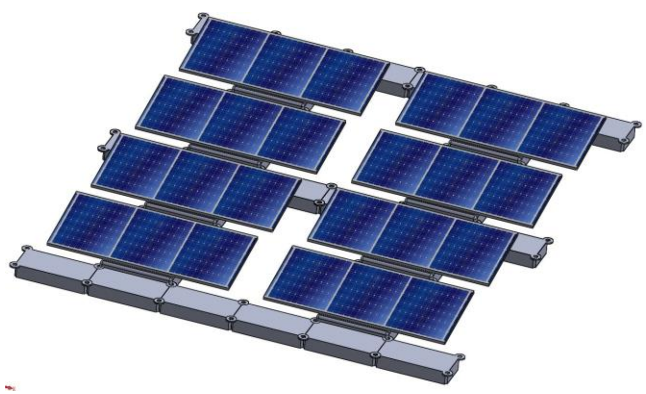
Aquago and Ciel & Terre combine their solution of solar energy production and water treatment

- **PRODUCE ENERGY FROM WATERBODIES**
- **ENERGY-POSITIVE WASTEWATER TREATMENT PLANTS**

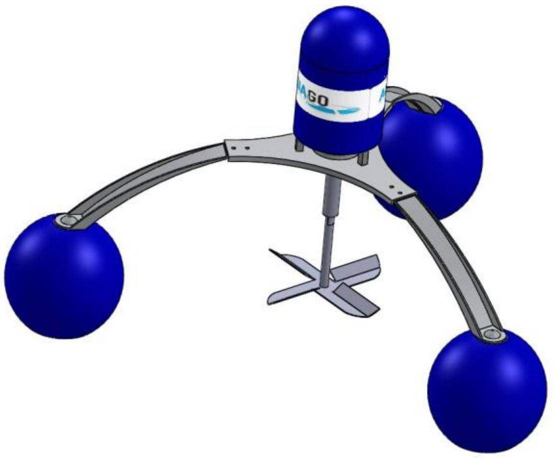
Our proposal : 100 solar powered aerators

- 100 units
- 1 unit every 5000 m2
- Total surface covered : 50 ha

Total : 100 kW



25 2 kw HYDRELIO solar platforms



100 SUNGO units

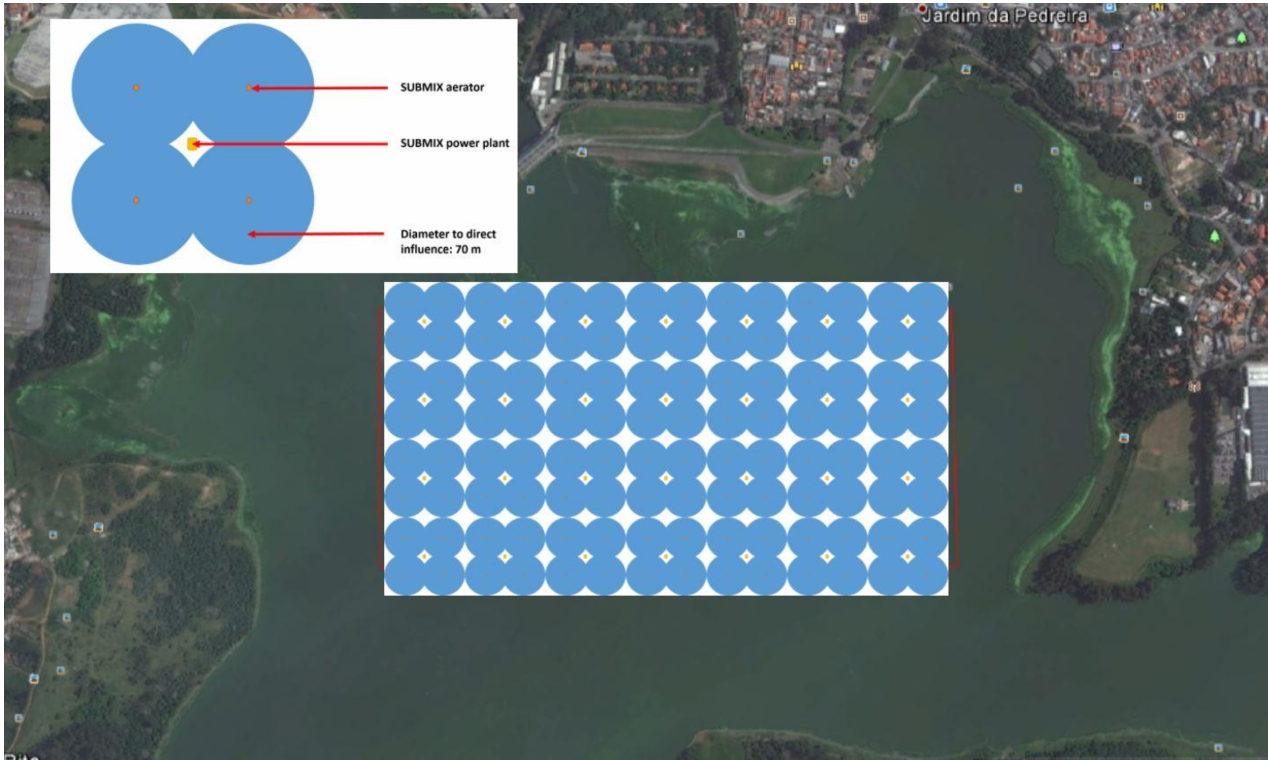
Our proposal : 100 solar powered aerators

- 100 units installed
- 1 unit every 5000 m2
- Total surface covered : 50 ha

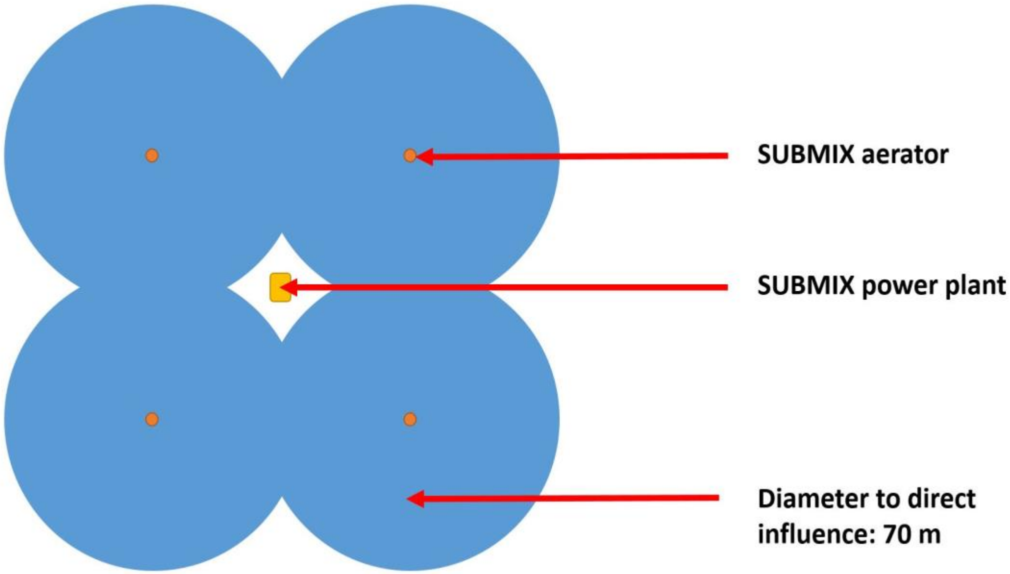
Total : 100 kW
25 x 2 kw solar platform

Best location :
- Upstream area
- Dead zones
- Main algae blooms areas

The mixers can be installed on 1 or several areas, the ratio should be respected for effect optimization.



Our proposal : 100 solar powered aerators for 50 ha



Visual result for 2 ha area

Total : 100 kW
25 2 kw solar platform

Pricing

	Price per unit	Qty	discount	Total
Provision of solar SUNGO mixers including : - Delivery on site - Warranty 2 years - 25 years free energy warranty	20 000	100	20%	1 600 000

If installation service is needed, a quotation will be designed according to the final project details, not representing more than 5% of the pricing.

Maintenance contract can be proposed in addition of the provision.

Appendix E – Rural and Urban Runoff Water Treatment Options

System Type	Description	Opportunities Benefits/Effectiveness	Limitations	Photograph
Gross Pollutant Trap (GPT)	Gross Pollutant Traps (GPTs) are structures that trap solid waste such as litter and coarse sediment. GPT treatment includes physical screening, rapid sedimentation and separation processes. Items trapped by GPTs are most commonly all litter, plastic bags and bottles, larger sediments, organics such as grass and cigarette butts. There are many different types of GPTs (litter collection baskets, flexible booms/floating traps, netting trash traps, trash racks), many of them perform a similar function – trapping litter (some also sediment above 5 mm in size) and removing them from the water system.	• GPTs fit in with the conventional street drainage system. • They have a relatively small footprint. • Can be hidden from view. • There is no vegetation associated with GPTs, therefore no vegetation to maintain. • Clean out of GPTs can be easily outsourced to contractors. • Most often used as the first treatment feature in a treatment train, providing pre-treatment of small to medium sized systems.	• They provide very limited removal of fine sediment and dissolved pollutants. • High build costs. • Complex to install, specialist needed. • GPTs require regular cleaning. • Unsuitable for very large sites over 100 ha, better suited to small/medium catchments. • If they are poorly maintained it will not only impact on the downstream water quality but may also become a flood hazard or a source of pollution.	 **Source: Rocla, 2015**

Raingarden / Bioretention	Bioretention systems are also more commonly referred to as raingardens. They treat stormwater through vegetation and a soil filtration media. Stormwater is collected and allowed to pond to a certain depth above the filter medium, until it seeps through the soil media and into the perforated underdrain. Typical retained contaminants include gross pollutants, coarse sediment, nutrients and heavy metals.	• They provide high levels of treatment in a relatively small surface footprint - very efficient removal of nutrients for the treatment size. • They are a scalable system that can be used at the lot, street and regional levels and can be easily retrofitted into existing roadways. • Well suited to flat terrain. • Can incorporate a submerged saturated zone which is a simple modification to the system and will help retain moisture (and provide a source of water for the vegetation). • Have aesthetic benefits.	• Bioretention system can easily become clogged with pollutants and sediment unless regularly maintained. • If the system fails it often requires a full reset. • The establishment period of a raingarden is particularly important to ensure long term success. • Unsuitable for steep terrain. • Unsuitable for areas with a high groundwater table. • Dry climatic conditions require further consideration to ensure the system does not regularly dry out. • Need to thoughtfully consider how much of the flow will bypass and how much can be treated as these system only treat overland flows rather than pipe flow. • Internal training will be required to be able to effectively build and maintain these systems. • Vegetation will need to be sustained throughout the dry period via irrigation with	 *Source: Melbourne Water, 2005*

			(preferable) non-potable water.	
Pond	Ponds and lakes are open water bodies that treat stormwater by providing extended detention and allowing for sediments to settle. They also encourage UV disinfection. Lakes and ponds often combined with wetlands and other WSUD elements to provide pre-treatment.	• Provides opportunities for stormwater sediment settlement. • Provides amenity/recreational value for the community. • Provides habitat for animals and plants. • Well suited to flat terrain. • Provides heat island effect benefits.	• Provides minimal water quality treatment compared to other options with similar land take. • Potential stratification issues if water body is too deep. • Potential for algal blooms. • Requires significant available land.	 *Source: Melbourne Water, 2005*.
Wetland	Constructed wetlands are large, man-made, significantly vegetated ponds that regularly fill and drain. They provide a natural way to reduce velocities, treat stormwater and remove sediment and contaminants before discharging stormwater downstream. Wetlands usually have a series of planted ponds that help to filter water through physical and biological processes. Wetlands	• Provides secondary treatment to remove fine particles and dissolved pollutants like nutrients and heavy metals. • Provides amenity/recreational value for the community. • Provides habitat for animals and plants. • Well suited to flat terrain.	• Operation and health of the wetland is dependent on good design of the outlet structure. • Wetland vegetation must be protected from high flow velocities and being frequently inundated with water for extended periods of time. • Not well suited for steep terrain.	 *Source: Melbourne Water, 2005*

	contain an inlet zone (which removes coarse sediment), a macrophyte zone (which removes fine particles and dissolved pollutants) and a high flow bypass (which lets out flood flows such as to not damage the wetland and its plants). Wetlands are almost always part of a treatment train with treatments added upstream. Gross pollutant traps and sediment ponds in the inlet zone protect the wetland by providing a primary treatment to remove coarse sediment and rubbish.	• There is potential to include flood protection in the system. • Provides heat island effect benefits.	• Requires significant available land.	
Sediment Basin	Sediment ponds (or sediment basins) are detention systems which slow stormwater runoff and allow the sediments to settle and deposit. By keeping the stormwater in the pond for an extended period of time, much of the medium and large sediment in the stormwater is removed. Sediment ponds are often temporarily used during construction activities as they assist in controlling and removing	• Provides opportunities for stormwater sediment settlement. • Protects the downstream systems from high sediment loads and therefore increases the longevity of the downstream system. • Provides amenity/recreational	• Sediment ponds generally tend to create issues within the community during clean out periods. Education through (for example) posters surrounding the sediment drying area during the cleanout period are a good way of addressing this issue and minimising community complaints. • They require significant maintenance every 5 years	 *Source: Melbourne Water, 2005*

	elevated sediment levels. They are also generally incorporated into wetland designs upstream of the wetland systems.	value for the community. • Well suited to flat terrain. • Relatively simplistic systems.	with potential prescribed waste removal costs. • Sediment drying areas are required and should be sited close to the pond but outside the flood extent to avoid reanimation of sediment in higher flows. Drying is required as transportation of wet sediment is expensive and difficult to manage.	
Buffer Strips and Vegetated Swale	Swales are linear grassed or vegetated channels which collect and transport stormwater. The vegetation in a swale treats stormwater and reduces pollutant loads while removing coarse and medium sediments. Swales are typically constructed with a low grade in order to reduce the velocity of stormwater flows. A vegetated swale can be combined with a bioretention system (i.e. bioswale), in which case the bioretention can be installed in a portion of the swale or along its full length. In urban areas, swales may be used as an alternative to the conventional street nature strip or centre	• Swales reduce and delay stormwater runoff. • They have the ability to combine flow conveyance and water quality treatment within one system. • Are aesthetically pleasing. • They are a relatively simple and inexpensive to construct. • They are an easy system to maintain. • Bioswales with trees can create street	• Unless associated with a bioretention, swales have limited removal of fine sediment and dissolved pollutants. • They take up more land area than traditional kerb and gutter and can restrict certain activities such as car parking. • They are only suitable for gentle slopes of less than 5% gradient. • Ponding can occur if very flat grades are present. Very high grades on the other hand can lead to scour. • Require regular inspections. • They often do not provide best practice treatment	 *Source: Melbourne Water, 2005* .  *Source: Melbourne Water, 2005*

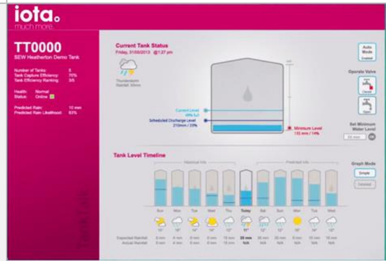
	median strip of roads, as well as run-off collection points in car park areas.	green corridors offering a range of environmental benefits.	unless they are combined with other systems.	
Permeable Pavement	Permeable paving is an alternative to conventional paving which allows for water to pass through it and enter a sub-surface layer from where it either infiltrates into the soil or is filtered back into the drainage system. Permeable paving offers physical screening and sedimentation processes and is retains gross pollutants and coarse sediment.	• It reduces peak stormwater discharge from paved urban areas in lower intensity rainfall events. • It contains pollutants close to source. • It can appear more aesthetically pleasant than conventional drainage channels. • It has the option of increasing groundwater recharge. • Often applied in city centres to reduce the impervious areas directly connected into the drainage network.	• Permeable pavements can ideally only support light traffic loads and are therefore best applied to car parks or residential areas. • Permeable paving can be applied on heavier traffic loads, however then clogging becomes an issue and they are therefore unadvisable. • They are prone to pavement clogging, which can reduce their effectiveness. • They carry with them a risk of possible groundwater contamination. • They are only suitable for mildly sloped sites.	 *Source: Outdoor Design, 2010*

Tree Pit	Tree pits collect stormwater runoff most commonly from paved sidewalks, roads or small carparks. Runoff filters through the tree roots and the surrounding soil, trapping sediments and pollutants before flowing into a piped drainage system. They resemble traditional street trees above ground but include a filtration layer underground.	• Tree pits can be easily incorporated into retrofitted dense urban areas. • They make use of the existing kerb and channel infrastructure. • They are a simple technology that is easy to implement. • Trees provide heat island effect benefits.	• Tree pits have a very limited treatment area. • All existing services in the area must be considered prior to installation. • They can be difficult to maintain due to constrained access to the pit and do require regular maintenance due to the accumulation of litter and other pollutants within the tree pit. • Need to consider pedestrian safety and disabled access when installed on narrow footpaths.	 *Source: IPWEA, 2015*
Green Roof	A green roof is built on a roof structure, new or existing, which is protected by high quality waterproofing. The area of the green roof is then either partially or completely covered with vegetation. Green roofs can be extensive or intensive. Extensive green roofs are lightweight and require minimal maintenance. They generally have lower water	• Green roofs aid in reducing urban runoff and delaying it entering the urban drainage system. • They improve water quality. • Appropriate for commercial/industrial buildings as well as residential. • They provide community benefits	• More complex design and installation. • Green roofs need to be designed to be able to carry the total load of the saturated substrate and hence may not be suitable for all existing buildings. • Lower profile and educational opportunities if the green roof cannot be viewed by the public or does	 *Source: Econews, 2013*

	requirements and use small, low growing specie such as succulents. Intensive green roofs are heavier and support a wider variety of plants. They require more irrigation and maintenance but also provide more benefits.	though the provision of communal green spaces and the opportunity for urban roof agriculture. If well irrigated, green roofs provide heat island effect benefits.	not have easy common access.	
Green Wall	A green wall is a wall partially or completely covered by vegetation that includes a growing medium (soil). Green walls can be implemented both indoors and outside and they usually feature their own water delivery system. Green walls differ from green facades in that they incorporate multiple containers of plants to create the vegetation cover, as opposed to Green facades which rely on plants based on the ground to climb and cover the wall.	• Green walls have very high aesthetic value. • Can be used to grow vegetables. • Can act as a sound barrier reducing noise pollution. • If well irrigated, green walls provide heat island effect benefits.	• Limited water treatment potential. • Plant species would need to take into account local weather conditions. • Green walls needs to be designed to be able to carry the total load of the saturated substrate and hence may not be suitable for all existing buildings.	 *Source: Econews, 2013*

Rainwater Tanks	Rainwater tanks collect stormwater from rooftops or other paved surfaces in order to reuse the water for either irrigation or indoor reuse purposes. By storing stormwater runoff from rooftops and gutters, rainwater tanks provide an ideal substitute for potable water in a household. Uses can include irrigation of gardens, car washing, toilets, laundry, and within the hot water service. There are a variety of commercial rainwater tank products available but all essentially provide the same function. Rainwater tanks can be above or below ground, circular, bladder or slimline. Rainwater tanks help reduce the total volume of stormwater runoff (and associated pollutants) from a site from reaching the downstream waterways.	• Rainwater tanks retain water at its source. • They significantly reduce site runoff and can help attenuate peak floods. • In areas with high soil permeability, a leaky rainwater tank could be considered which would allow for some of the captured water to gradually infiltrate into the soil.	• Only provides real benefits when the tank water is used frequently allowing each rain event to be captured. • Requires some user maintenance. • Will often be located on private property which restricts access for maintenance.	 *Source: Polymaster, 2014*

Floating Wetlands	Floating wetlands are plant cells that float on the water surface and are anchored within a pond. The floating vegetation provides a biological filtration system for the removal of nutrients and other pollutants from water bodies.	• Can be easily used for existing underperforming ponds or lakes and be retrofitted straight onto the exiting asset. • The system is self-cleansing, essentially requiring no maintenance. • Can be constructed with high aesthetic value. • Designs are flexible and can therefore fit into any space.	• Limited Australian experience with the usage of the feature.	 *Source: SPEL, 2015*
Proprietary Products	There are a numerous amount of proprietary products currently available on the market such as: • Cartridge filters which allow for targeting of specific pollutants such as sediments and debris, heavy metals, hydrocarbons, pathogens/bacteria and nutrients. • Storm Water Quality Improvement Devices (SQUIDs)	• Proprietary products tend to come with a known maintenance schedule to allow future budgeting.	• Often locked into maintenance contracts with the proprietary owner. • Not natural self-sustaining features. • No recreational or habitat values of the systems. • Exact details on long term performance have not yet been determined.	 *Source: SPEL, 2015*

	that have the ability to retain and reduce suspended solids, nutrients, heavy metals and hydrocarbons. • Biofilta is a proprietary product that increases the treatment performance of a raingarden by storing the outflow water and recycling this though the system using a pump.		• Located within confined spaces which would require specialist equipment and technique to maintain, not to mention the risks associated with the safety measures that needs to be put in place for safe access and maintenance. • Limited educational opportunities.	
Smart systems	Iota’s Tank Talk technology aims at limiting stormwater overflows and flooding impacts. These systems are operated remotely via the internet and enable monitoring of water levels in rainwater tanks to provide storage capacity information. This information can then be used to determine the timing and volume of releasing excess water from the tank.	• Talking Tanks and similar products can have a broader benefit of managing peaks across the networks through scheduling of excess flow releases.	• Maintenance can be a challenge. • System is automated but still requires human assessment and supervision. • Costlier than a standard tank.	 *Source: Iota, 2015*

Appendix F – Community Survey

COMMUNITY SURVEY

A community information session was held at the Lake Wyangan School in November 2015 followed by a Community Forum at the Regional Theatre in Griffith on the 16th December. At both events those attending were asked to complete a questionnaire to obtain feedback on how the community uses Lake Wyangan, what is important to the community about Lake Wyangan, and their opinions on activities to manage the lake in the future including specific management options. The results of the survey are discussed below.

There were 40 attendees at the first meeting, and 14 of those attendees completed the survey. A further 13 responses were received following the second meeting. Questions 1, 2 and 3 related to community values, questions 4, 5 and 6 related to management options, while question 7 asked for methods for future communications.

The outcomes from this survey have been used to inform the accompanying Lake Wyangan and Catchment Management document.

Values of Lake Wyangan

Question 1 - What do you personally value most about Lake Wyangan (North and South)?

Recreational uses, particularly boating (22) and swimming (15) had the highest rating. The aesthetic value of the lake was also of value to half (15) of those surveyed.

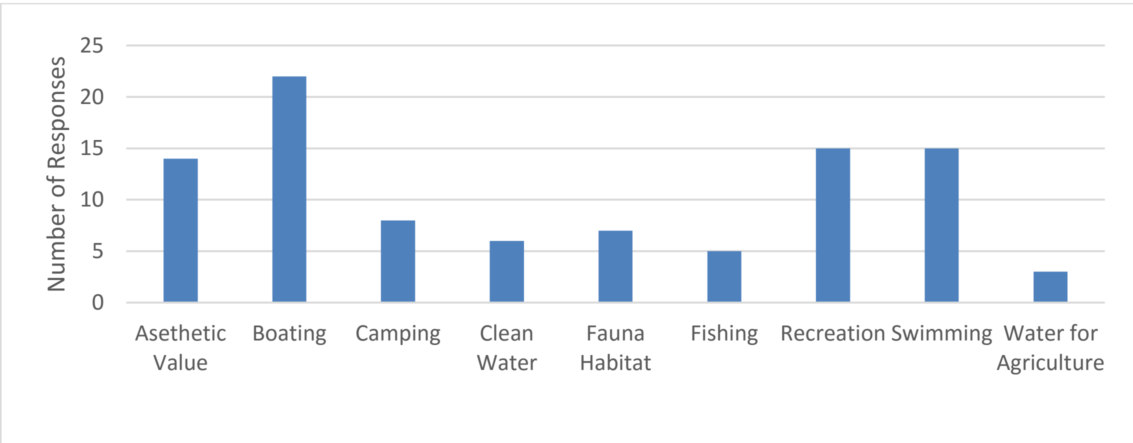


Figure E1 Values of Lake Wyangan (North and South)

Question 2 - How often do you visit Lake Wyangan?

21 of the 27 respondents surveyed indicated they visit Lake Wyangan weekly. Of those who indicated daily use some specified that this was limited to summer months with weekly usage in winter.

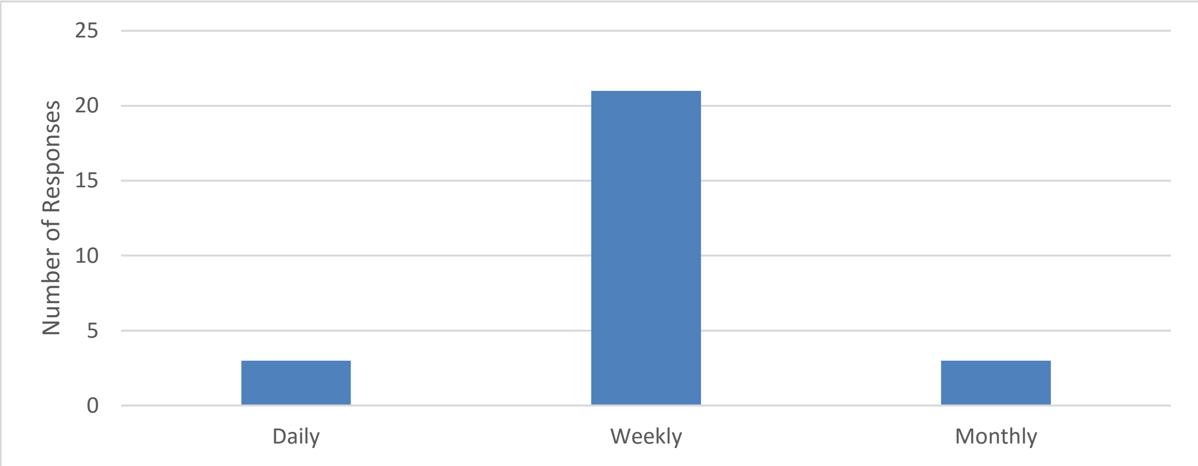


Figure E2 Frequency of Visitation

Question 3 - Are you aware of recent lake closures as a result of BGA? And if so, how has this affected you?

The responses indicated that all residents at the meeting were aware of the lake closure due to BGA outbreak. The majority of responses indicated that they were no longer able to use the lake for recreational purposes particularly boating (sailing, kayaking, rowing and water skiing) and swimming. Several responses mentioned that financially worse off by the closure due to costs associated with boat club fees and boating equipment.

One respondent expressed concern for the link between BGA and health issues (i.e. motor neuron disease), noting that they thought the lake should be monitored more frequently to help reduce the risk for swimmers.

Activities to Improve Lake Health

Questions 4 and 5 aimed to understand what activities the community believe will be effective in improving the health of Lake Wyangan.

Question 4 - In your opinion, which of the following activities are effective in improving the health of the lake?

This question had a series of options presented, and responses to each are detailed below. Overall, improved lake management practices and improvement of water levels were considered the most effective ways to improve lake health with at least half of those surveyed choosing 'Very Effective'. Reducing agricultural nutrient and waste runoff and improving land and catchment management practises were also considered to be effective by the majority of residents. Zoning of land by Council to prevent inappropriate development near the lake was considered the least effective method.

- *Decreasing nutrient and waste runoff from urban areas*

  Most residents (13 of 25 responses) believe reducing urban nutrient and runoff will have at least some effect on improving the health of the lake.

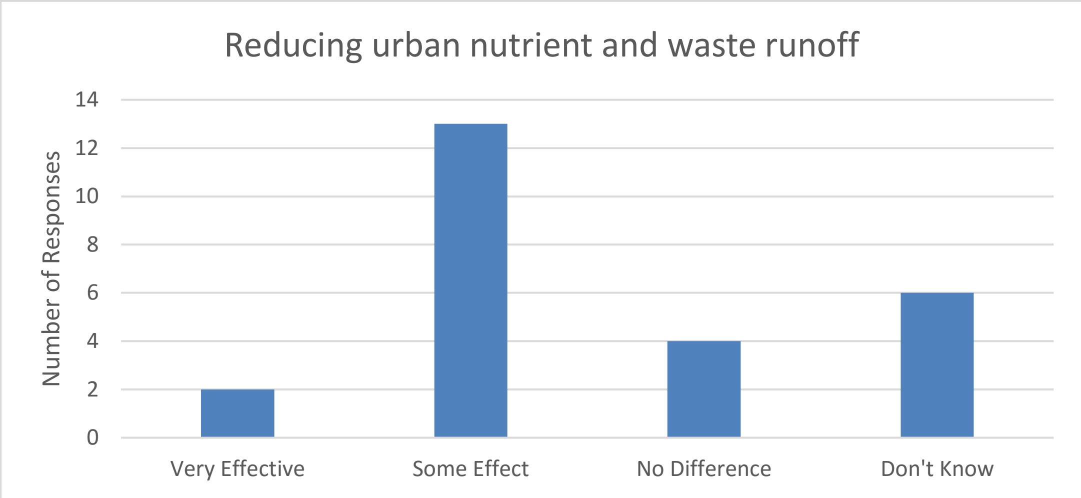


Figure E3 ***Effectiveness of reducing urban nutrient and water runoff***

- *Decreasing nutrient & waste runoff from agricultural areas*

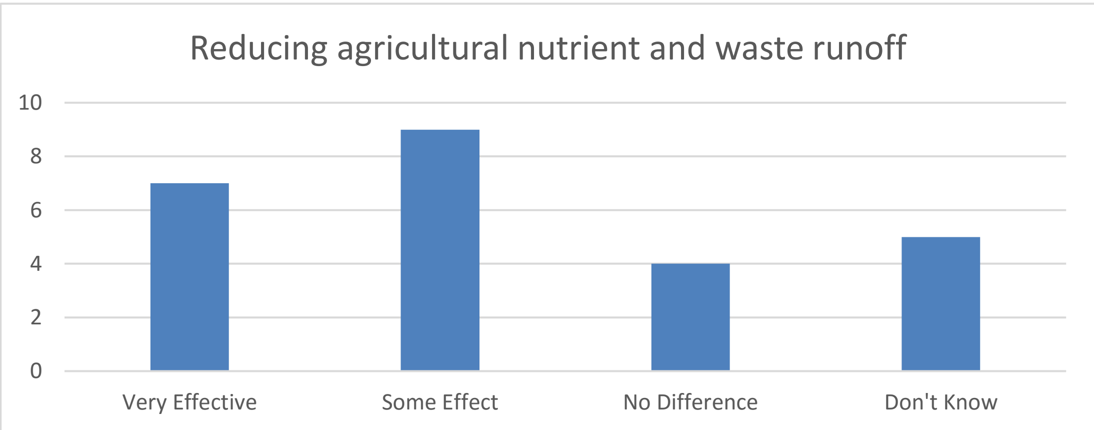


Figure E4 ***Effectiveness of reducing agricultural nutrient and waste runoff***

* *Zoning of land by Council to prevent inappropriate development near the lakes*

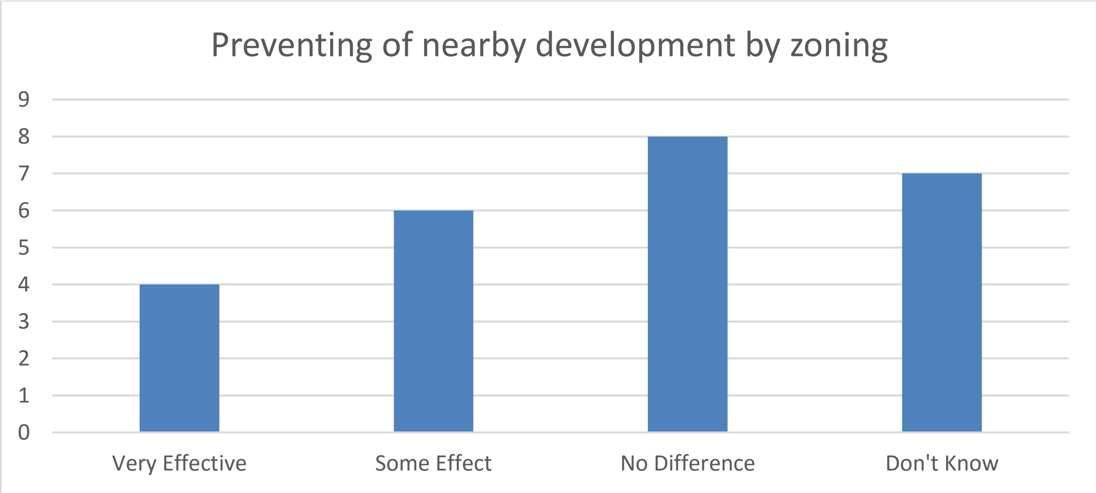


Figure E5 ***Effectiveness of managing nearby development by zoning***

* *Maintaining water levels*

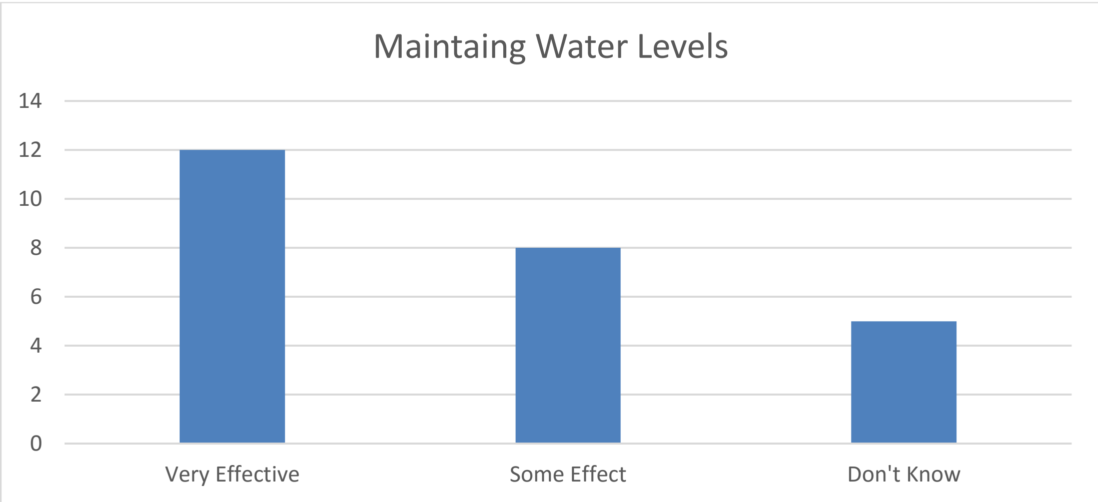


Figure E6 ***Maintaining water levels***

- *Improved land/catchment management practises*

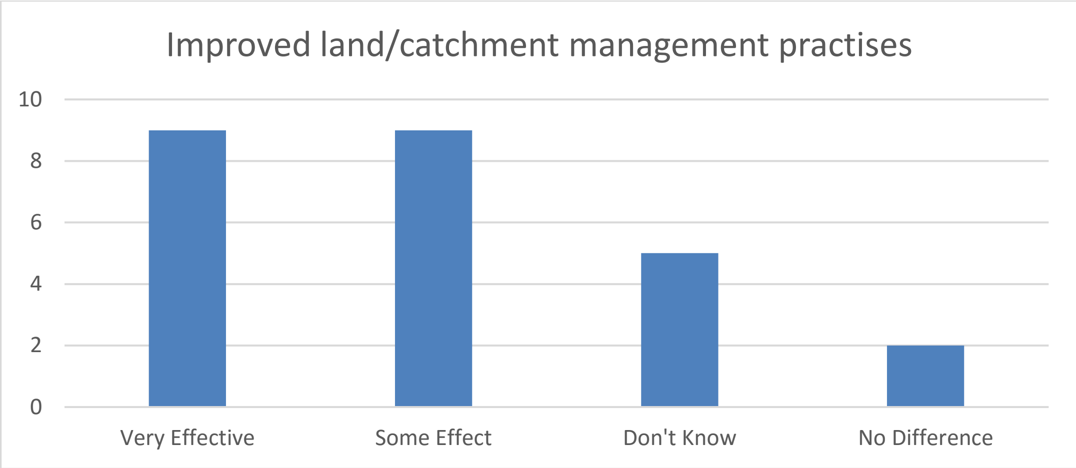


Figure E7 Improved land/catchment management practises

- *Improved lake management practises*

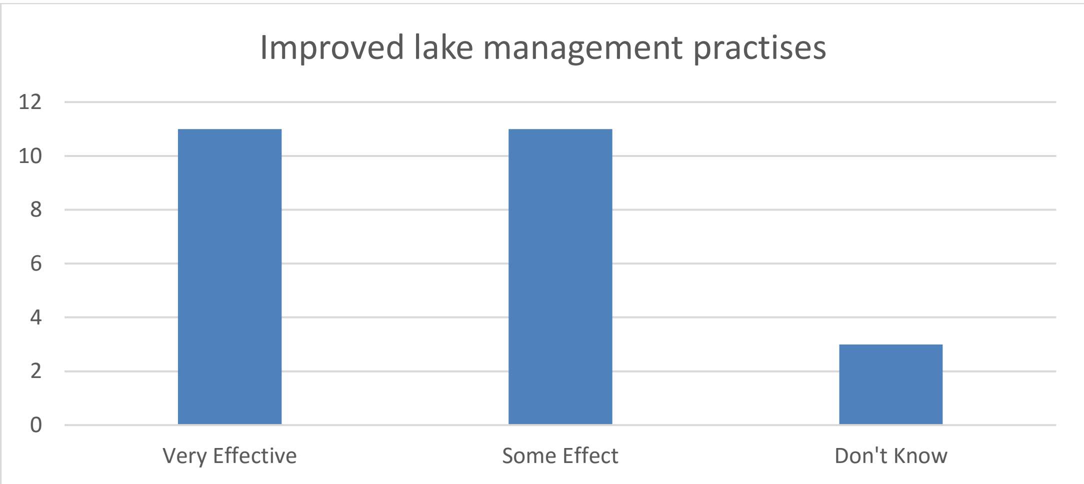


Figure E8 Improved lake management practises

Question 5 - Are there any other activities for improving the health of the lake you would like investigated?

There were several reoccurring responses to this question:

- Trial ultra-sonic technology.
- Dredging of the lake to reduce high nutrient sediment.
- Introduce vegetation to uptake nutrients either at the lake or in its catchments.
- Alter the inflows and outflows to the lake.
- Maintain water levels within the lake.

- Recirculate water around the lake.

Some residents believe that more frequent monitoring of the lake is required.

Other activities suggested included:

- Phoslock for phosphorus removal
- Harvesting of cumbungi
- Removal of carp
- Introduction of beneficial flora that may be able to offset the Algal Blooms
- Dredging of the sediments to remove the load in the sediment
- Revisit utilising the lake as a storage to pump out of for Irrigation. Dredge the lake to reduce nutrient levels.
- Aeration of water

Question 6 - Do you know enough about what is being done to manage BGA outbreaks in the Lake?

20 of the 27 survey participants were interested in learning more about the management of BGA outbreaks in the lake and in being kept up to date about the management of BGA in the lake in the future.

Question 7 - What is the best way of getting information to you on the health of Lake Wyangan?

Local media forms including updates in the local newspaper (15), a local newsletter (7) or information page on the local council website (8) were the most popular responses. Despite not being an option on the survey a large portion of residents (9) indicated they'd like to receive information about Lake Wyangan via email. A number of residents (6) were in favour of an information site being provided at the lake.

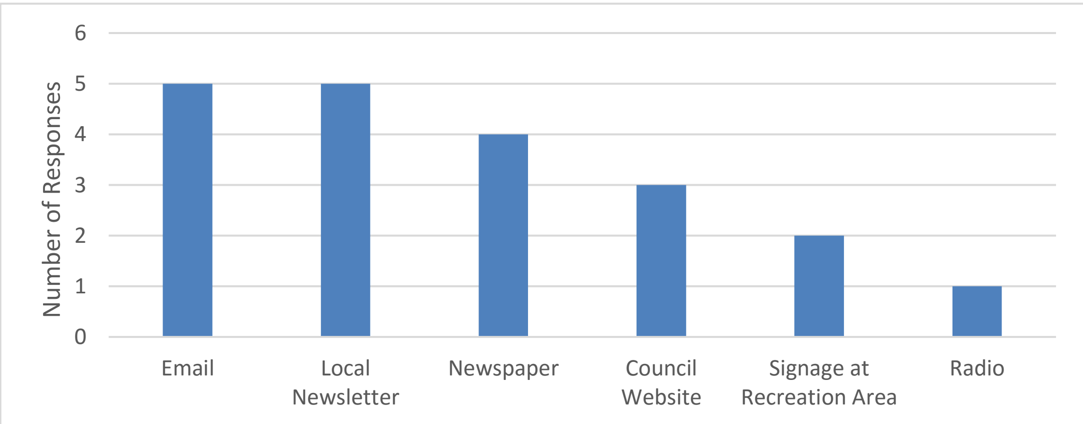


Figure E9 Methods of Communication

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