» Lake Ainsworth water quality snapshot

February 2017

prepared by Ballina Shire Council

Contents

Executive Summary

In summary the aims of this report include:

- provide water quality snapshot of Lake Ainsworth
- identify current and future issues associated with the water quality of Lake Ainsworth
- analyse available water quality data and calculate trigger values
- represent water quality data using tables and graphs
- collate and organise current and historic data
- determine whether available data are sufficient to analyse impact of development and traffic on the Lake's water quality.

An evaluation of water quality results from monitoring undertaken over the past 12 months at Lake Ainsworth indicates:

- Lake Ainsworth may be considered a dystrophic Lake which displays eutrophic characteristics in the warmer months
- physico-chemical parameters such as dissolved oxygen, pH, turbidity and electrical conductivity are within the expected range of values and will not affect the integrity of the Lake and will remain suitable for primary recreational contact
- there is considerable seasonal variation with some of the parameters monitored in this report and as a result it is necessary to calculate average (and/or median) values relative to each season
- variation of the parameters within each season also reinforces the notion that Lake Ainsworth is a dynamic system and as yet unpredictable
- the results of *Enterococci* abundance suggest there may be a slight risk of faecal contamination occurring in Lake Ainsworth, however, this is generally typical of ecosystems with no or limited ocean flushing
- *Enterococci* levels are usually under the guidelines set by The Australian and New Zealand Environment Conservation Council (ANZECC, 2000)
- the Office of Environment and Heritage (OEH) gave Lake Ainsworth a poor water quality grade using The National Health and Medical Research Council (NHMRC, 2008) guidelines and determined that after moderate to heavy rainfall, Lake Ainsworth may be unsuitable to swim
- sample site LA4 (Lake Ainsworth West) exhibited statistically higher amounts of *Enterococci* which may disproportionally contribute to a poor water quality grade given by the OEH
- the results from the nutrient sampling suggest that Lake Ainsworth has significantly high levels of nutrients in comparison to the guidelines set by ANZECC (2000) and NHMRC (2008) and also in comparison to recorded 1995 levels
- mean total phosphorous (TP) levels peak in the summer months which is typical of eutrophic systems
- high TP levels indicate that blue-green algal blooms are likely to continue to persist in favourable weather conditions (i.e. light wind, warm temperatures and extended dry periods)
- the results from the blue-green algal analysis are inconclusive due to the nature of the data sets and a data organisational plan is required.

- hydrocarbons, pesticides and heavy metals generally showed significantly low levels. As these parameters were usually below the lowest detectable limit, they were not included in this report.

A Coastal Management Program (CMP) as defined under the Coastal Management Act (2016) should be prepared to update the understanding of water quality processes in Lake Ainsworth and to determine on going management actions required to maintain the Lake in a healthy state.

Cyanobacterial (blue-green algae) blooms occur frequently in Lake Ainsworth and an aerator was installed in 1997 to reduce blooms by destratifying the water column. Stratification usually occurs between October and March and is characterised by a warm oxygen rich surface layer that is separated from a cold oxygen poor bottom layer. The oxygen poor bottom waters accelerate nutrient release from the sediments and into the water column allowing various species of undesirable cyanobacteria to thrive.

Given the potential human health and ecological risks associated with excessive algal growth, Ballina Shire Council (BSC) regularly monitors algal levels, particularly during the warmer months. Elevated nutrient levels (as well as other factors) often contribute to an increased abundance of cyanobacteria and hence are also to be sampled in the monitoring program to assist in a better understanding of specific algal bloom triggers in Lake Ainsworth. Additional parameters such as: *Enterococci*, dissolved oxygen, pH, turbidity, electrical conductivity, hydrocarbons, heavy metals and pesticides are also closely monitored across five sample sites (**Fig. 1**) as they may directly and/or indirectly affect the health of recreational users and Lake Ainsworth. These are outlined in **Table 1** below.

Table 1. Summary of the water quality monitoring program in Lake Ainsworth.

Component	Parameters	Sampling period	Sampling frequency	Sampling locations
Algae	Species, density (cells/100mL), biovolume (mm^3/L)	October – April	Weekly	Composite samples (LA1 + LA2 and LA3 + LA4)
Microbiological	*Enterococci* (cfu/100mL)	All year (trial period)	Weekly (additional samples taken once a month between December and February)	LA1, LA2, LA3 and LA4
Nutrients	Total nitrogen, nitrite, nitrate, ammonium, total phosphorous, phosphate, dissolved organic and inorganic carbon (mg/L), true colour	All year (trial period)	Weekly	LA1, LA2, LA3, LA4 and LA5
Physico-chemical parameters	pH, electrical conductivity (µs/cm), turbidity (NTU), dissolved oxygen (mg/L), temperature (^{0}C)	All year (trial period)	Weekly (5 times/month between December and February)	LA1, LA2, LA3, LA4 and LA5
Hydrocarbons, heavy metals and pesticides	Oils, petroleum, heavy metals, pesticides	All year (trial period)	3 – 4 times/year	LA1, LA2, LA3, LA4 and LA5

There is community concern regarding the negative impact paved roads have on the water quality of Lake Ainsworth. The relationship between the eastern road and the Lake's water quality is undetermined in this report.

Another issue gaining community attention is the foreshore erosion, particularly in the south eastern corner (Fig. 2 and Fig. 3) where it is suggested that high pedestrian activity, gaps in vegetation, and impervious surfaces contribute to the erosion and steep incline of the Lake's shores. Excessive erosion can increase sedimentation loads and turbidity, which in some cases has the potential to shorten the lifespan of a Lake system. High turbidity levels have the potential to become a nuisance to recreational users and can also increase water temperatures through enhanced solar absorption. The effect of erosion on the water quality of Lake Ainsworth is undetermined in this report.

Compared with previous years, the data is becoming more organised and readily available and will provide useful information to environmental managers regarding the state of particular systems. It is recommended to keep the current sampling regime with continued organisation of obtained data. For the development of a Coastal Management Program (CMP), it is imperative to update understanding of water quality processes in Lake Ainsworth and to determine appropriate management actions required to maintain the health of Lake Ainsworth. The data that have been collected in this report will assist Council in the development of a CMP.

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Figure 1. Sample locations in Lake Ainsworth, NSW. (Copied from LAWQMP (2015).

Figure 2. The south eastern corner of Lake Ainsworth on 26 September 1995.

Figure 3. The south eastern corner of Lake Ainsworth on 18 October 2016.

1. Introduction

1.1 Aims of Report

In summary the aims of this report include:

- provide water quality snapshot of Lake Ainsworth
- identify current and future issues associated with the water quality of Lake Ainsworth
- analyse available water quality data and calculate trigger values
- represent water quality data using tables and graphs
- collate and organise current and historic data
- determine whether available data are sufficient to analyse impact of development and traffic on the Lake's water quality.

To provide a water quality snapshot of Lake Ainsworth, data have primarily been collected over the past 12 month period. From these data Council can also evaluate the outcome of the enhanced trial monitoring program. There are only limited historic data to compare with current data and these evaluations will be included in this report. This will assist in providing some context to data collected at Lake Ainsworth over the past 12 months.

The evaluation of water quality results from monitoring undertaken to date at Lake Ainsworth indicates:

- Lake Ainsworth may be considered a dystrophic Lake which displays eutrophic characteristics in the warmer months
- physico-chemical parameters such as dissolved oxygen, pH, turbidity and electrical conductivity are within the expected range of values and will not affect the integrity of the Lake and will remain suitable for primary recreational contact
- there is considerable seasonal variation with some of the parameters monitored in this report and as a result it is necessary to calculate average (and/or median) values relative to each season
- variation of the parameters within each season also reinforces the notion that Lake Ainsworth is a dynamic system and as yet unpredictable
- the results of *Enterococci* abundance suggest there may be a slight risk of faecal contamination occurring in Lake Ainsworth, however, this is generally typical of ecosystems with no or limited ocean flushing
- sample site LA4 (Lake Ainsworth West) exhibited statistically higher amounts of *Enterococci* which may disproportionally contribute to a poor water quality grade given by the Office of Environment and Heritage (OEH)
- the results from the nutrient sampling suggest that Lake Ainsworth has significantly high levels of nutrients in comparison to the guidelines set by ANZECC (2000) and NHMRC (2008) and also in comparison to recorded 1995 levels
- mean total phosphorous (TP) levels peak in the summer months which is typical of eutrophic systems

- High TP levels indicate that blue-green algal blooms are likely to continue to persist in favourable weather conditions (i.e. light wind, warm temperatures and extended dry periods)
- the results from the blue-green algal analysis are inconclusive due to the nature of the data sets and a data organisational plan is required
- hydrocarbons, pesticides and heavy metals generally showed significantly low levels. As these parameters were usually below the lowest detectable limit, they were not included in this report.

This report includes limited detail on remediation actions and is mainly concerned with identifying matters to be further investigated. Various methods (such as sand dredging) to reduce nutrient levels have been proposed in the Lake Ainsworth Management Plan (LAMP, 2002). These may be somewhat out dated and may need revision before implementation. A Coastal Management Program (CMP) as defined under the Coastal Management Act (2016) should be prepared to update the understanding of water quality processes in Lake Ainsworth and to determine on going management actions required to maintain the Lake in a healthy state.

The Office of Environment and Heritage has confirmed that a CMP would be the approach to identifying appropriate future management aims for Lake Ainsworth. It will be important that the CMP addresses aspects such as:

- sea level rise (and associated saline groundwater intrusions)
- the current and future status of the Lake’s flora and fauna
- increased sand dune erosion and potential for Lake reopening
- problems associated with increased visitor rates
- water level fluctuations associated with urban development and flooding
- foreshore erosion
- high nutrient levels
- appropriate stormwater management.

The CMP should detail the cost benefit analysis of various management actions that it proposes.

1.2 Background

Lake Ainsworth is located in Lennox Head on the Far North Coast of NSW. It is categorised as a typical acidic freshwater coastal Lake that was originally denied ocean access through the formation of sand dunes immediately to the east. The tea colour occurs as a result of tannins and humic acids leached from surrounding heathlands and melaleuca wetlands and transported via subsurface flows. Covering an area of 12.4 ha, the Lake is considered to be an important recreational and environmental asset and is managed by NSW Crown Lands leaving the southern end reserve to be managed by Ballina Shire Council. The deepest section of the Lake is 8.4 metres and depending on the time of year may exhibit relatively low temperatures and contain little to no oxygen compared with the surface layers. During periods of increased temperatures (i.e. October to March) the top layer of water heats up more rapidly than the bottom layer and this difference in temperature creates chemically and thermally distinguished layers of water. This process is known as stratification and is responsible for restricting the vertical mixing capabilities of waterbodies. This affects dissolved oxygen concentrations throughout the water body and as a result oxygen concentrations may be significantly higher in surface waters and virtually non-existent in deeper waters. Sometimes, significant rainfall events and strong winds can achieve partial destratification.

1.3 Formation History and Classification

Lake Ainsworth is an acidic coastal dune Lake formed on perched water tables, where organic matter has accumulated on top of porous sand. Therefore, Lake Ainsworth generally has a surface level above the mean sea level. As Lake Ainsworth experiences high organic loading activity from allochthonous sources, the Lake could be categorised as a dystrophic Lake which displays eutrophic characteristics in the summer. Due to dissolved tannins and humic substances the water of Lake Ainsworth is stained a brown tea colour and exhibits low pH levels which may limit the growth of many phytoplankton species. The eutrophic characteristics of the Lake are related to the high levels of nutrients (i.e. total phosphorous), the high levels of chlorophyll-a, and the persistence of blue-green algal blooms (Table 2; Table 3) (Perkins *et al*. 2015; Twiggs, 1996). The Lake is generally dystrophic in the cooler months and shifts into a eutrophic state in the summer when the waterbody starts to stratify (Perkins *et al*. 2015; Twiggs, 1996). It is important to note that due to the high levels of dissolved humic acids there are large amounts of naturally bound nitrogen which contribute to high levels of total nitrogen (TN) that are not, however, available for plant uptake. Therefore, TN may not be a reliable indicator of nutrient enrichment occurring in Lake Ainsworth.

Using various reference guidelines (see **Appendix:** Calculations for Lake Ainsworth trophic category) and data from **Table 2** and **Table 3** Lake Ainsworth falls into the eutrophic category and as such will continue to be characterised by:

- a large presence of cyanobacteria and phytoplankton of only a few limited dominant species
- a large number of aquatic plants
- low oxygen levels in the bottom waters
- low water clarity.

There is debate as to whether the Lake once had a saline composition, with some papers suggesting it has never been saline (Timms, 1982; van Senden *et al*. 1996) and others suggesting it had a saline phase (Tibby *et al*., 2007). It has been suggested that the saline phase ended in the 1930s and the authors support these claims using marine diatoms found in sediment cores, old parish maps from 1908 and satellite images from 1947 that suggest a possible opening to the sea (Tibby *et al*., 2007). However, other papers claim there was never a saline phase and based the argument on the presence and persistence of freshwater fauna (Timms, 1982). Another study which was to form a significant basis for the current Lake Ainsworth Management Plan (LAMP) also repeated this notion (van Senden *et al*. 1996). If these claims are true then it may be necessary to prepare for reopening of Lake Ainsworth to the sea and adjust the management of Lake Ainsworth accordingly to prevent this from occurring. At this point surface measurements of electrical conductivity (EC) indicate that the top layer is fresh water.

Table 2. Table shows the mean and range of critical parameters in determining the trophic state of urban Lakes (Copied from Brown and Simpson (2001).

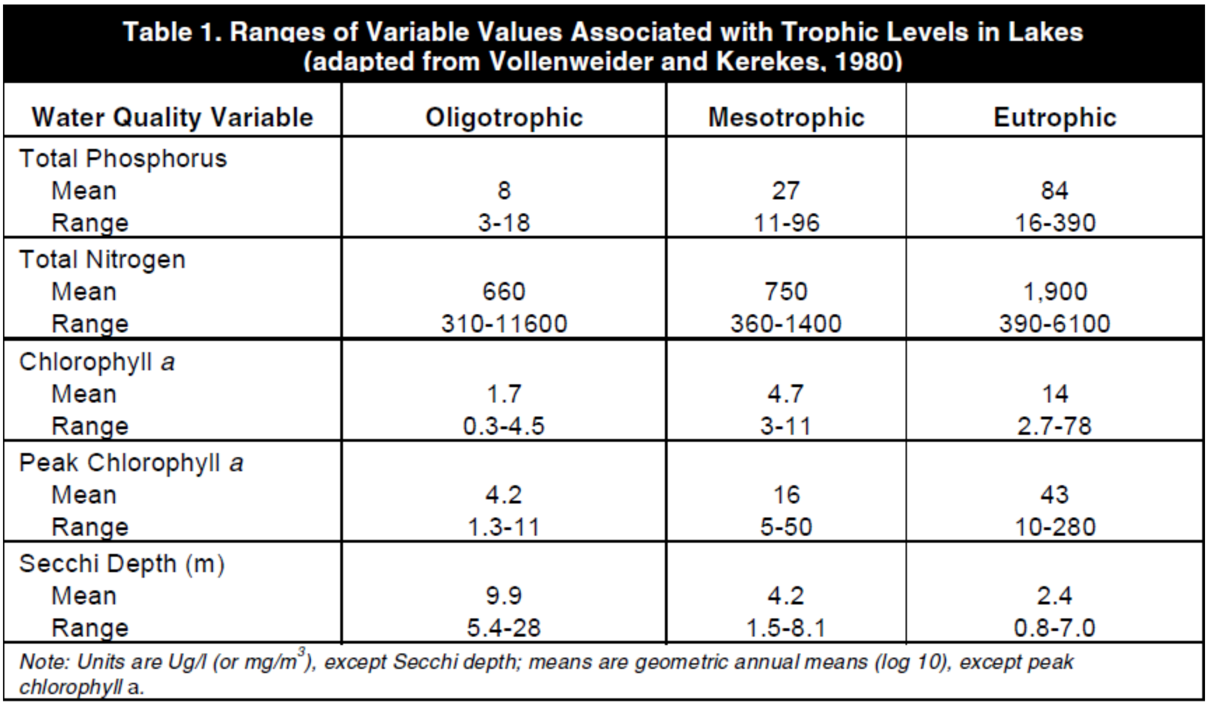


Table 1. Ranges of Variable Values Associated with Trophic Levels in Lakes (adapted from Vollenweider and Kerekes, 1980)

Water Quality Variable	Oligotrophic	Mesotrophic	Eutrophic
Total Phosphorus			
Mean	8	27	84
Range	3-18	11-96	16-390
Total Nitrogen			
Mean	660	750	1,900
Range	310-11600	360-1400	390-6100
Chlorophyll *a*			
Mean	1.7	4.7	14
Range	0.3-4.5	3-11	2.7-78
Peak Chlorophyll *a*			
Mean	4.2	16	43
Range	1.3-11	5-50	10-280
Secchi Depth (m)			
Mean	9.9	4.2	2.4
Range	5.4-28	1.5-8.1	0.8-7.0

Note: Units are Ug/l (or mg/m^3), except Secchi depth; means are geometric annual means (log 10), except peak chlorophyll a.

Table 3. The mean and range values calculated from collected samples at Lake Ainsworth, NSW. TP (n = 270); TN (n = 210); Chl- *a* (n = 8). Values are in ug/L. N = number of replicate samples.

Water quality variable	Lake Ainsworth (mean + range)
Total phosphorous (TP)	123.4 27 – 350
Total nitrogen (TN)	779.8 124 – 2797
Chlorophyll *a* (Chl-*a*)	34.375 18 – 59
Secchi Depth (m)	N/A

Note: Secchi depth not measured by Ballina Shire Council staff. Instead, turbidity (NTU) levels are measured.

1.4 Catchment and Hydrology

The catchment area for Lake Ainsworth is relatively small (**Fig. 4**) and there is a small amount of urban development immediately adjacent to Lake Ainsworth including; sealed and unsealed roads, the sport and recreational centre, the Lennox Head Surf Club and the Lake Ainsworth Caravan Park (**Fig. 1**). The catchment area surrounding Lake Ainsworth mainly consists of undisturbed native vegetation including but not limited to, coastal heath, Melaleuca swamps, and various types of native dunal vegetation. The eastern road shown in **Figure 1** is an informal road and was not subject to the same regulations as a formal state road. Due to the close proximity of the road to the Lake and a lack of vegetation buffer zone there is some community concern regarding untreated runoff and its impact on water quality. The stormwater runoff around Lake Ainsworth is documented in **Figure 5** and shows there are two formal stormwater pipes in the north end in the Sport and Recreation Camp and predominantly surface runoff around the rest of the Lake. The impervious surfaces surrounding Lake Ainsworth act as a stormwater conveyance system and may contribute to erosion. It is important to note, however, that the diagram does not include surface flows entering Lake Ainsworth from the east.

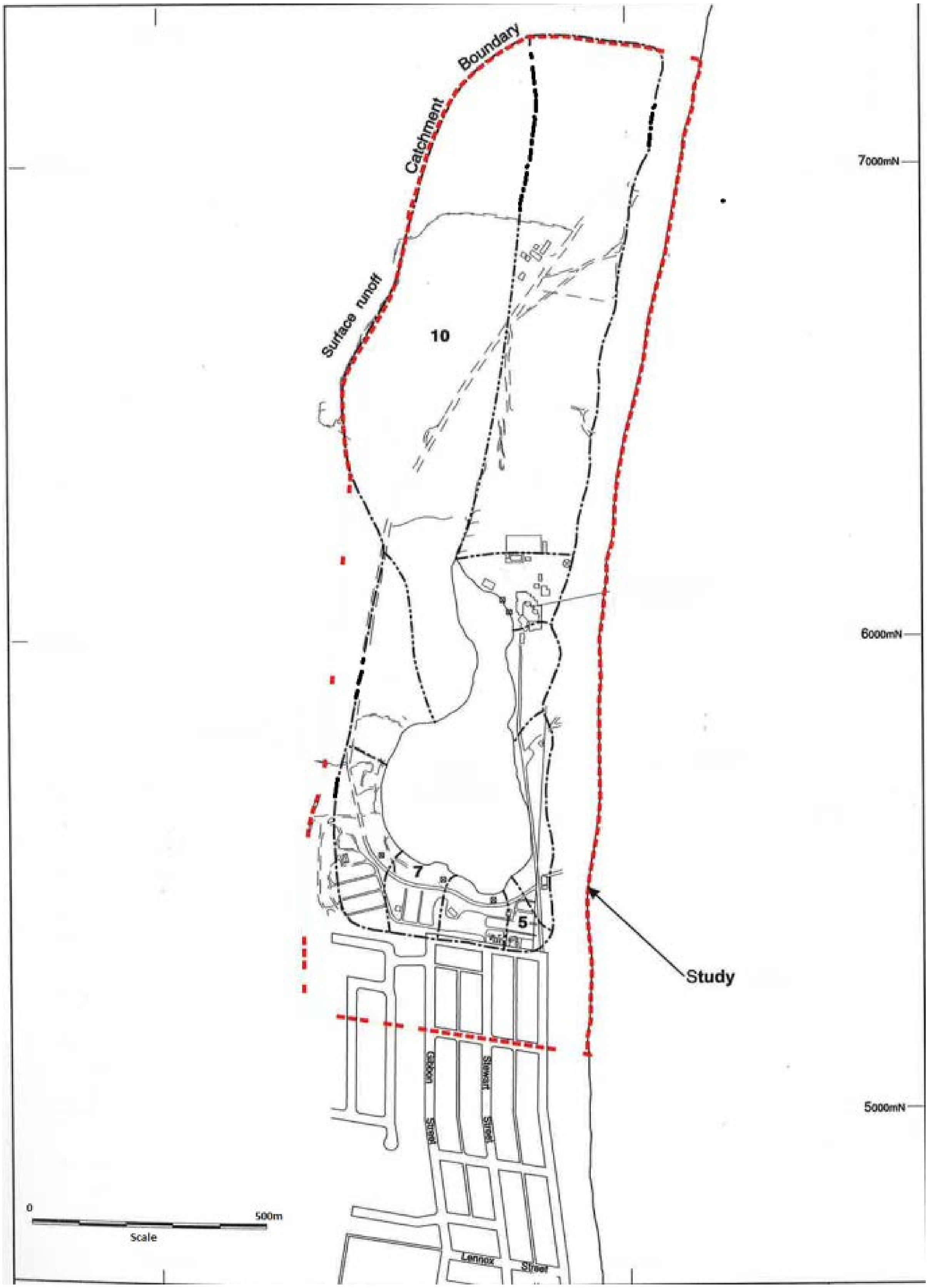


Figure 4. The Catchment boundary and surface runoff of Lake Ainsworth, northern NSW (in broken black line). Study area is encompassed by a broken red line (picture source: LAMS, 2000).

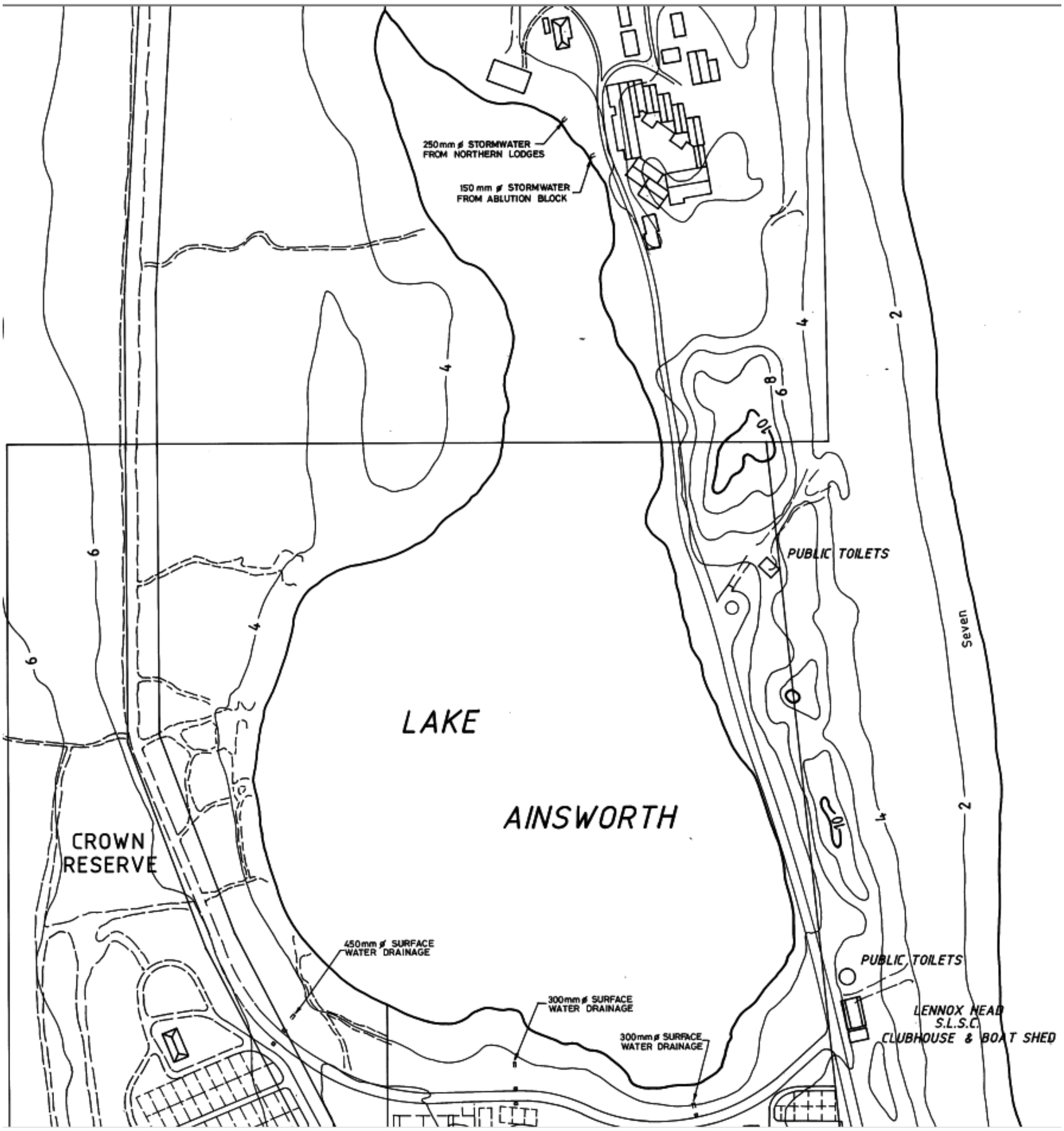


Figure 5. A diagram of Lake Ainsworth detailing the surface water drainage (in the southern end) and stormwater pipes (in the northern end). *Note: Diagram does not include surface water runoff from the east to the west.*

2. Water Quality Criteria

2.1 Public Usage

Lake Ainsworth is an important recreational and environmental asset and remains a key tourist destination within the Ballina Shire. The Lake is primarily used for swimming activities by local residents and tourists and is used extensively by the Lake Ainsworth Sport and Recreation Centre. Some of these activities include:

- swimming
- sailing/sailboarding
- canoeing/kayaking/ski paddling/stand-up paddle boarding.

Therefore the continued protection of the water quality at Lake Ainsworth is imperative for the benefit all stakeholders and the environment.

2.2 History of Water Quality Issues

2.2.1 Algae

Lake Ainsworth has a history of high nutrient levels (TP and TN) and as a result the Lake has experienced relatively frequent algal blooms (Lake Ainsworth Management Plan, 2002) which can compromise the stability of the Lake, negatively affecting recreational users and also the endemic flora and fauna. Light winds, warm temperatures (approximately 25^{O}C), and limited water circulation also contribute to the persistence of blue-green algal blooms. Algal blooms are natural occurrences in marine and aquatic ecosystems. Some species of cyanobacteria can produce toxins in large concentrations that can cause adverse effects on humans, flora and fauna. Species of potentially toxic cyanobacteria that have occurred in Lake Ainsworth include: *Dolichospermum circinale* (formally known as *Anabaena*), *Lyngbya* spp., *Microcystis* spp., and *Oscillatoria* spp. Most algal outbreaks occur in spring and summer as the water temperature starts to rise and before the water becomes too warm. The optimum water temperature for toxin production by cyanobacteria is suggested to be between 20-25^{0}C (Dadheech *et al*. 2014) and the optimal growth rate is thought to be approximately 25^{0}C (Bowling, 2014). *D. circinale* is responsible for approximately 70% of outbreaks in NSW and was last seen in high concentrations in May 2016 and September/October and January in 2015 and also in spring and summer of 1995 and 1996. There have been numerous other undocumented outbreaks in between. Potentially toxic cyanobacteria of the genus *Microcystis* was also found in the spring and summer of 1995 and 1996. In January 1994 outbreaks of *Oscillatoria* occurred which are also known to produce harmful toxins. Interestingly, in the winter periods of 2015 and 2016, there were significant outbreaks of blue-green algal blooms.

Depending on the species of cyanobacteria in question there are several main toxins that cause concern. These are:

- Hepatotoxins and cytotoxins – cause breakdown of tissues in liver and other internal organs, leading to internal haemorrhaging and gastroenteritis
- neurotoxins – attack nervous system, can lead to respiratory failure
- BMAA (neurotoxin, saxitoxin) – chronic environmental exposure may be a risk factor leading to neurodegenerative disease

- contact irritants – skin rashes, gastrointestinal upsets, throat, ear and eye irritation, mild respiratoire effects & hay fever – like symptons
- some toxins and contact irritants are known tumour promoters and some are possibly carcinogenic (Source: Bowling, 2014).

Therefore, the waters of Lake Ainsworth must be closely monitored for the above algal blooms. In the event of an outbreak all relevant stakeholders are currently informed via personal communications from health officers, emails, appropriate signage around the Lake, media releases and by updating the Council's website.

The listing of cyanobacteria as potentially toxic indicates the ability for a particular species to produce harmful toxins. The situation is, however, complicated because potentially toxic species do not necessarily produce harmful toxins and may be present in large numbers without producing neurotoxins and other toxins (Dadheech *et al*. 2014). All species, however, are known to produce irritants.

It is possible that a non-toxin producing genetic variation of a known potentially toxic species may exist. However, genetic drift may occur and cause a transition into a toxin producing variation. To detect genetic drift toward harmful variations of algae it is recommended that genetic testing be conducted once or twice a season.

It has been suggested that in some cases the harmful toxins causing the most damage can be produced by species with the lowest biovolume but without molecular testing it may be impossible to determine the origin of the toxins. Although some species of cyanobacteria may not be listed as potentially toxic, they may induce allergic reactions to humans and animals and thus when present in high biovolumes special care must be taken. It is also important to consider other ramifications of blue-green algal blooms which include, dissolved oxygen deprivation (and associated odours), reduced aesthetics and the potential for foul tasting water. Results from genetic testing conducted by Tweed Laboratories on 20 November 2014 indicate that there were no genes present that produce harmful toxins in blooms of *D. circinale* in Lake Ainsworth. More recent testing undertaken on January 19 2017 indicates that the MycE gene is present in recent blooms of *Microcystis aeruginosa,* indicating that it is likely that toxins are being produced.

2.2.2 Stratification

It is believed the Lake is chemically and thermally stratified between October and March and thus provides favourable conditions for cyanobacterial blooms within this period (Perkins *et al*. 2015). To reduce the frequency of bloom events, an aerator was installed in late 1997 and began operating on November 7 in the deep section of the Lake. The aerator operates 12 hours a day in the night time between September and April. The intended goal for the operation of the aerator is that the bottom waters, as well as the sediments, become oxygenated and partial destratification occurs. It has been documented that the aerator has achieved at least partial destratification (LAMS, 2000) with depth profiles indicating minimal deviation in parameters such as temperature, pH and dissolved oxygen. More recent data collected by Perkins *et al*. 2015 reinforces this notion (Fig. 6). Whether this is sufficient to effectively reduce blue-green algal blooms is unknown and warrants further investigation. The aerator is bar-shaped, 75m long and consists of 25 bubble fountains separated at 3m intervals (Perkins *et al*. 2015). With the increasing threat of climate change it may be necessary to alter the months in which the aerator is running as the optimum temperatures (around 25^0C) may occur earlier in the season and may continue for an extended period into the autumn and winter months. To determine the optimum period throughout the year in which to operate the aerator it may be beneficial to record physico-chemical parameters year round for a designated number of years. Closely monitoring surface pH, temperature and DO levels in bottom waters throughout the year will help determine stratification processes and when the aerator needs to be utilised. To determine the extent of current stratification in Lake Ainsworth it would be useful to measure dissolved oxygen (as well as other physico-chemical parameters) at varying depths (every 0.5 – 1 m up to 8 m) at different times in the year over an extended period of time (e.g. **Fig. 6**). This, in conjunction with other analyses, would provide a good basis as to the water quality of the Lake.

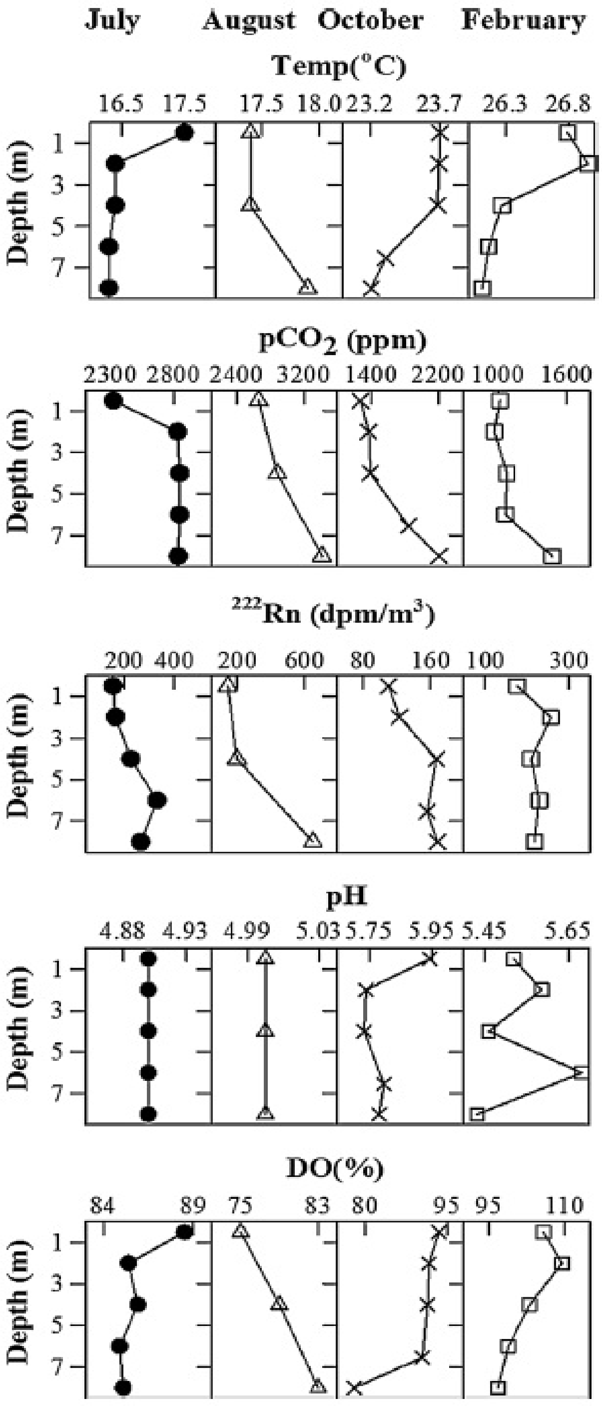


Fig. 4 Depth profiles of temperature, pCO_2, ^{222}Rn, pH and DO in the deepest section of the lake throughout the study

Figure 6. Copied from Perkins *et al*. (2015). “Depth profiles of temperature, pCO_2, ^{222}Rn, pH and DO in the deepest section of the Lake throughout the study”.

2.2.3 Faecal Contamination

Faecal contamination in freshwater and marine ecosystems poses a risk to human health and where bacteria levels exceed the guidelines it is recommended that an analysis of the available data be conducted. After >10mm of rain in less than 72 hours there is increased risk of faecal contamination and it is recommended to avoid primary recreational contact in Lake Ainsworth during and for up to 3 days afterward. The abundance and distribution of *Enterococci* was analysed at Lake Ainsworth across three sample sites (LA2 - east, LA3 - south and LA4 – west) to determine patterns of contamination from 2013 to September, 2016. In closed off aquatic and marine systems there generally tends to be a larger abundance of *Enterococci* due to the limited flushing and dilution effect and therefore greater risk of recreational users becoming ill. The risk is amplified during busy holiday periods, where dense congregations of recreational users can contribute to the spread of illnesses. Therefore, in closed-off coastal ecosystems such as Lake Ainsworth, increased surveillance is needed to ensure that public safety and ecosystem values are maintained simultaneously.

2.3 Water Quality Guidelines

2.3.1 Algae/nutrients/pH

Various sources of data (i.e. ANZECC Guidelines, 2000; NHRMC Guidelines for Managing Risks in Recreational Water, 2008) indicate that Lake Ainsworth drastically exceeds nutrient guidelines (Table 2; Table 3; Table 4; Table 5) for concentrations of total nitrogen (TN), total phosphorous (TP) and chlorophyll-a (chl-a) (*it is important to note difference between ug/L and mg/L*). These established guidelines assist environmental managers to recognise the susceptibility of a particular water body to promote the growth of undesirable species of blue-green algae. The guidelines also provide information which can be inferred to describe the biological activity that may be occurring in a water body. Water bodies with high biological activity (as a result of high nutrient levels) can have negative consequences for a system and high productivity can lead to a water body becoming over exhausted and barren (as a result of oxygen deprivation, reduced light availability, increased temperatures, etc.). It is important to manage nutrient levels to ensure the health of Lake Ainsworth is maintained. Methods of managing and determining the source of nutrient levels are discussed in more detail below (see; 5.2 sediment cores and 7.2 recommendations).

As numerous water bodies around Australia have naturally high nutrient levels it may be important to determine whether the nutrient levels in Lake Ainsworth are of a natural or anthropogenic origin. The guidelines mentioned above are generic values for the south-eastern region of Australia and may not be applicable to all water bodies within this region and must be used in conjunction with the expertise of local environmental managers. More information regarding the values obtained at Lake Ainsworth can be seen in the Appendix. Council also engages Symbio Alliance Laboratories to analyse ammonia, nitrite, nitrate, dissolved organic carbon, dissolved inorganic carbon, true colour and dissolved phosphorous (as PO_4) at Lake Ainsworth.

As this report is focused on providing a succinct water quality snapshot, various components of analysis have been left out and will be addressed at a later stage. The calculation of trigger values will help management determine unusual readings and may indicate an ecosystem in distress whereby appropriate protocols can be established to minimise or prevent particular incidents. Where there are no ecological effects data from the ANZECC guidelines recommend using the 80th and 20th percentiles.

ANZECC guidelines (2000) recommend pH values should be between 5.0 and 9.0 for primary recreational contact. As the lacrimal fluid in the human eye has a pH of 7.4, it is ideal to have pH levels close to this value in recreational waters. The lacrimal fluid has a buffering capacity and can withstand pH levels between 5.0 and 9.0.

As the Lake transitions between various trophic states throughout the year (Fig. 6; Fig. 7), it is important to adjust the trigger values so that they are representative of the current state of the system. Therefore, due to stratification and destratification processes it may be necessary to establish trigger values for each season. This will require all year round monitoring of water quality in Lake Ainsworth.

The National Health and Medical Research Council (NHMRC) has developed guidelines specific to blue-green algae and primary recreational contact (information below copied from: http://www.water.nsw.gov.au/water-management/water-quality/algal-information/guidelines-for-algae).

NHMRC has three alert levels relating to the abundance of blue-green algae and these are described below:

- Green level – "Green Level occurs above 500 cells/mL of *Microcystis aeruginosa* or >0.04 mm^3/L of total cyanobacterial biovolume but below the Amber alert level. At this level routine sampling for algae should be undertaken"
- Amber level – "Amber Level Alert Mode is triggered when *Microcystis aeruginosa* concentrations are between 5000 and 50,000 cells/mL or the biovolume of all cyanobacteria is between 0.4 and 4 mm^3/L. At this alert level investigations into the causes and increased sampling of algae should be undertaken"
- Red alert – "A Red Level Action Mode is in place when >50,000 cells of *Microcystis aeruginosa* are present or a biovolume of all toxin producing cyanobacteria exceeds 4 mm^3/L. Red Level is also triggered if the total of all cyanobacteria (toxic and non-toxic) exceeds 10 mm^3/L or scums are present for long periods. At Red Mode, Local Health Authorities should be contacted to assess risks to recreational users and appropriate measures should be taken to warn water users. Water should not be used for primary recreation."

2.3.2 Faecal Contamination

For faecal contamination in primary contact aquatic systems, ANZECC (2000) recommends that the median bacterial content in samples taken over the bathing season should not exceed 35 *Enterococci* organisms/100mL (maximum number in any one sample: 60-100 organisms/100mL).

Lake Ainsworth received a poor water quality grade for 2014 – 2015, in relation to the high abundance of *Enterococci* by the Office of Environment & Heritage (OEH) based on guidelines provided by the NHMRC (2008). The guidelines provided by ANZECC (2000) and the NHMRC (2008) offer different methodologies in measuring the abundance of *Enterococci* and thus provide different assessments of public health risk. As the guidelines provided by NHMRC (2008) are more recent they may be considered more relevant. The relationship between the microbial results and the national guidelines is discussed in 4.3 Water Quality Results and Discussion - Bacteriological.

Table 4. Table copied from the ANZECC (2000) water quality guidelines for South Eastern Australia.

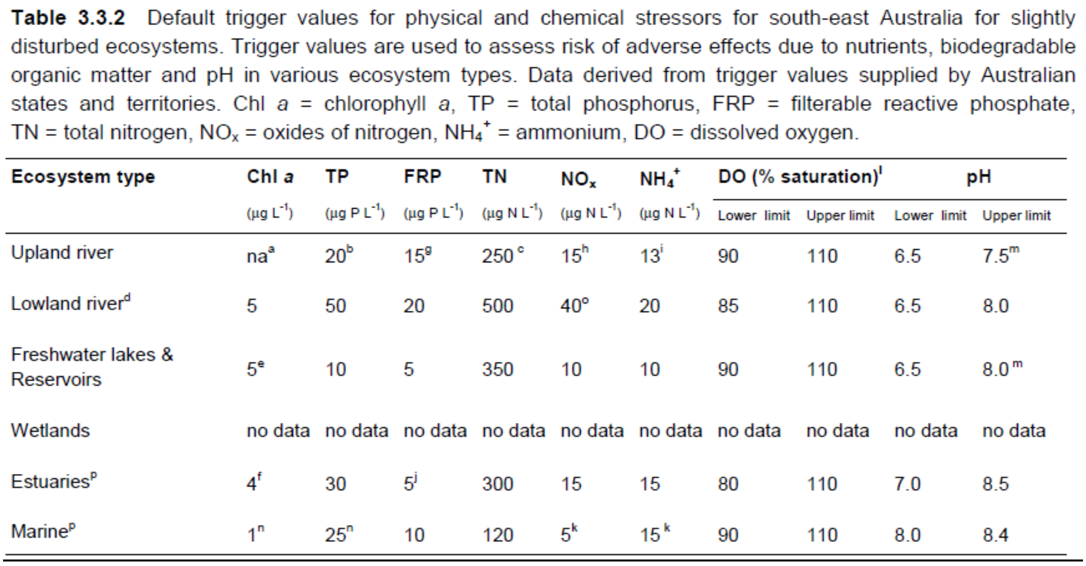
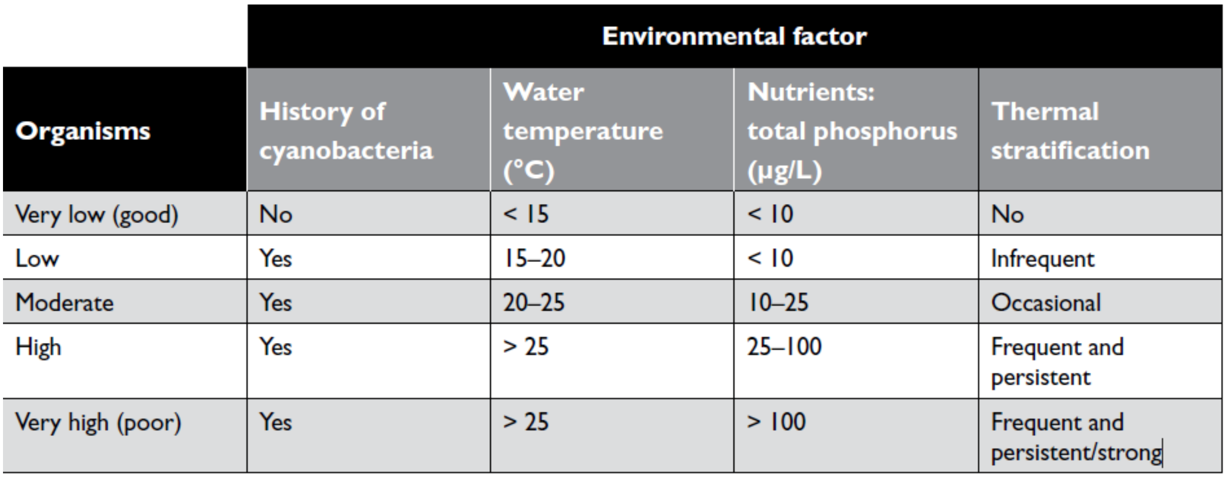


Table 3.3.2 Default trigger values for physical and chemical stressors for south-east Australia for slightly disturbed ecosystems. Trigger values are used to assess risk of adverse effects due to nutrients, biodegradable organic matter and pH in various ecosystem types. Data derived from trigger values 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**	
	(µg L^{-1})	(µg P L^{-1})	(µg P L^{-1})	(µg N L^{-1})	(µg N L^{-1})	(µg 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

(Copied from ANZECC Guidelines (2000)

Table 5. Table copied from the NHMRC (2008) guidelines showing the criteria for the susceptibility of a waterbody to harbouring species of blue-green algae.



	Environmental factor			
Organisms	**History of cyanobacteria**	**Water temperature (°C)**	**Nutrients: total phosphorus (µg/L)**	**Thermal stratification**
Very low (good)	No	< 15	< 10	No
Low	Yes	15–20	< 10	Infrequent
Moderate	Yes	20–25	10–25	Occasional
High	Yes	> 25	25–100	Frequent and persistent
Very high (poor)	Yes	> 25	> 100	Frequent and persistent/strong

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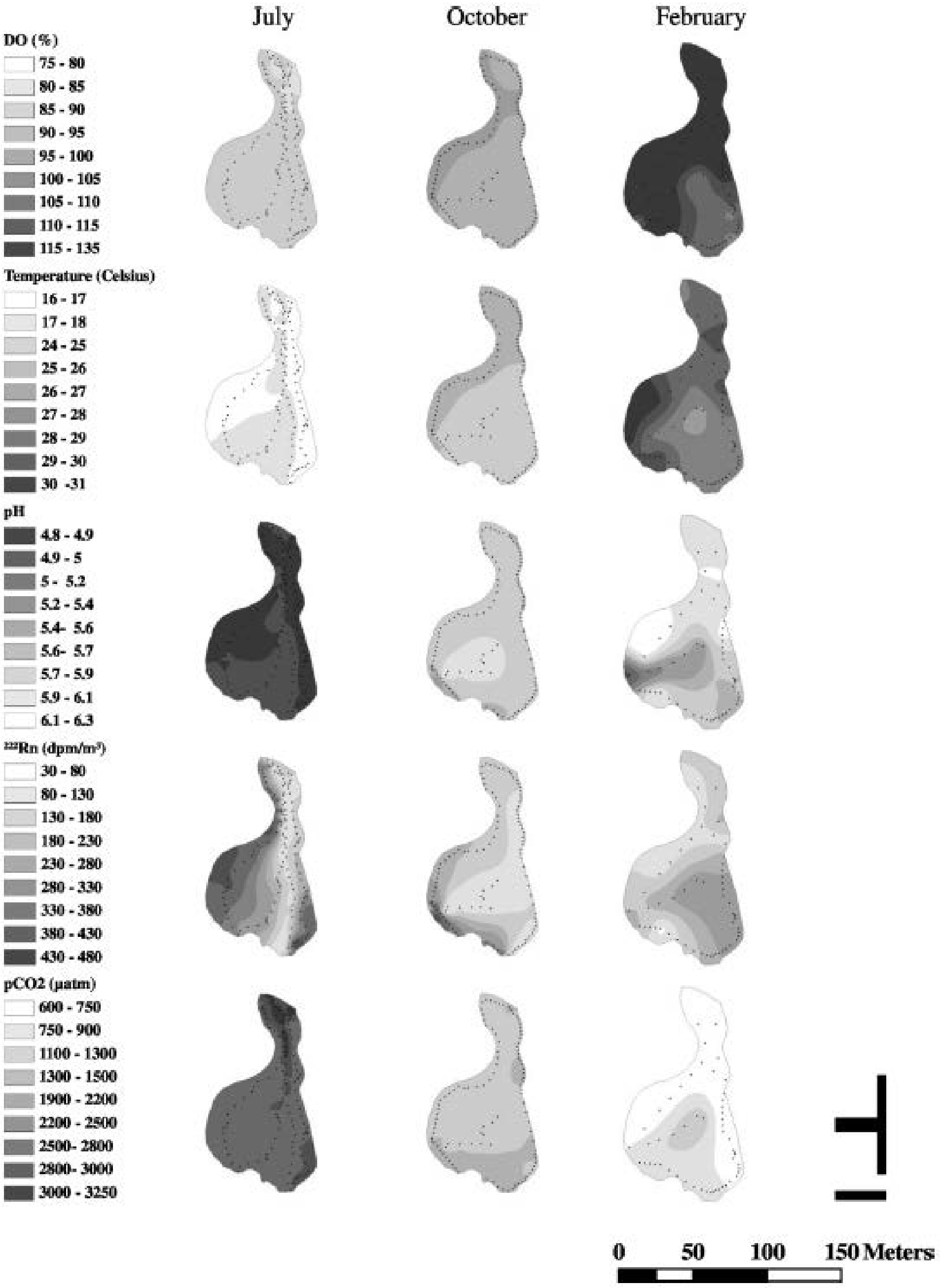

Fig. 3 Interpolated maps from the spatial kayak surveys. Each *dot* represents sample location

Figure 7. Copied from Perkins *et al*. (2015). “Interpolated maps [of Lake Ainsworth] from the spatial kayak surveys. Each *dot* represents sample location”.

3. Monitoring Program

3.1 History of Monitoring Programs

3.1.1 Algae

Blue-green algae was monitored inconsistently since the early 90s until 1995 when blue-green algal sampling was conducted on a weekly basis between September and May. From 1995 until about 2004 blue-green algal samples were also collected approximately once a month (sometimes more frequently) in the winter months. From 2002 onwards the blue-green algal data was reported in Microsoft Excel.

3.1.2 Faecal Contamination and the Beachwatch Monitoring Program

E. coli and faecal coliforms have also been monitored since 1991 on a monthly basis in the swimming season (October to March). Ballina Shire Council received a grant of $19,625 in September, 2002 from the Environmental Protection Authority (EPA) to participate in the Beachwatch Partnership Pilot Program (BPPP). The BPPP was conducted during October 2002 to April 2003. Fifteen samples from three sample sites were collected each month (three samples a week each week and six samples for one of those weeks) from Lake Ainsworth so a geometric mean for the number of *Enterococci* could be calculated.

In January 2005, Ballina Shire Council initiated a partnership with the Environmental Protection Authority (now known as the Office of Environment and Heritage (OEH) and commenced the Beachwatch Monitoring Program and based on recommendations from the EPA and the World Health Organisation (WHO, 2003), *Enterococci* was monitored across three sample sites in Lake Ainsworth on a weekly basis between November and February the geometric mean was calculated to report the pollution levels. From the WHO (2003) recommendations, *E. coli* was no longer deemed the most suitable bacterial indicator for faecal pollution in recreational waterways. The abundance and distribution of harmful bacteria is inferred by the presence of *Enterococci* and is monitored closely to determine the risk of recreational users becoming ill. One limitation however, is that they may not be able to distinguish between human and animal faecal contamination. There are various methods available to determine the origin of a particular contamination event and the risk associated with these events will depend on where the bacteria have originated (i.e. humans, birds, livestock, horses).

3.1.3 Physico-chemical

Physico-chemical parameters (i.e. pH, electrical conductivity, dissolved oxygen, turbidity and temperature) were recorded on a weekly basis at one sample site between December and February from 2006 onwards. From January 2016, physico-chemical parameters were recorded at five sample sites around Lake Ainsworth for the full year trial period (**Fig. 1:** LA1, LA2, LA3, LA4 and LA5). Between 1993 and 1996, 67 nutrient samples were collected on an ad hoc basis and parameters such as total phosphorous, ammonia and nitrate were analysed. Due to the uncertainty of data collection, limited data management and the storage of raw data in different formats at different locations it presents key challenges in the appropriate and reliable analysis of historic data. Despite this, some parts of historically collected data have been analysed and current data management is adequate to ensure that collected data can be reliably analysed and compared in the future.

3.2 Current Monitoring Program

Regular water quality monitoring is undertaken by Ballina Shire Council across five samples sites (**Fig. 1**) and depending on the type of samples being collected there are different sampling schedules. These are outlined in **Table 1** below.

Table 1. Summary of the water quality monitoring program in Lake Ainsworth.

Component	Parameters	Sampling period	Sampling frequency	Sampling locations
Algae	Species, density (cells/100mL), biovolume (mm^3/L)	October – April	Weekly	Composite samples (LA1 + LA2 and LA3 + LA4)
Microbiological	*Enterococci* (cfu/100mL)	All year (trial period)	Weekly (5 times/month between December and February)	LA1, LA2, LA3 and LA4
Nutrients	Total nitrogen, nitrite, nitrate, ammonium, total phosphorous, phosphate, dissolved organic and inorganic carbon (mg/L), true colour	All year (trial period)	Weekly	LA1, LA2, LA3, LA4 and LA5
Physico-chemical parameters	pH, electrical conductivity (µs/cm), turbidity (NTU), dissolved oxygen (mg/L), temperature (^{0}C)	All year (trial period)	Weekly (5 times/month between December and February)	LA1, LA2, LA3, LA4 and LA5
Hydrocarbons, heavy metals and pesticides	Oils, petroleum, heavy metals, pesticides	All year (trial period)	3 – 4 times/year	LA1, LA2, LA3, LA4 and LA5

Physico-chemical parameters such as pH, electrical conductivity (EC), turbidity, dissolved oxygen (DO) and temperature are monitored by Council on a weekly basis in the swimming season (November – February). Once a month an additional set of data are recorded to ensure the guidelines set by Beachwatch Program are met. To gain a further understanding of the processes occurring in Lake Ainsworth, Council has recorded these parameters in the non-swimming season.

3.3 Aims of monitoring

Monitoring the selected parameters listed in **Table 1** above assists in determining the health of the Lake and whether or not the water is suitable for primary recreational contact. To determine the suitability of the Lake's water for primary recreational contact parameters such as pH, turbidity, dissolved oxygen, temperature and *Enterococci* and blue-green algae levels are monitored closely as they may directly or indirectly affect the health of recreational users and/or the aesthetics of the Lake.

Nutrient concentrations, heavy metals, pesticides and hydrocarbons are also monitored by Council and are considered to be important chemicals as they have the potential to cause significant damage when concentrations become too high. National guidelines (e.g. ANZECC, 2000; NHMRC, 2008) are referred to when analysing data in order to gain context and understanding of the measured values. This enables Council to determine the health of Lake Ainsworth within an established framework and this has been discussed in more detail in section **2.3 Water Quality Guidelines.** During bloom conditions dissolved oxygen levels can raise signifying an increase in photosynthesis of blue-green algae. This can also be accompanied by a rise in pH. In post-bloom conditions dissolved oxygen levels can drop dramatically and further jeopardise the health of the Lake. Temperature can also provide a good indication of the favourable conditions for blue-green algae. Hence, it is important to measure physico-chemical parameters such as pH, conductivity, turbidity, dissolved oxygen (DO) and temperature to determine, at the earliest possible stage, the likelihood of bloom events and also whether large bloom events are going to significantly affect the health of the Lake in the long or short term for recreational users, flora and fauna. Collecting these data will also assist Council in optimising the period in which the aerator is utilised.

As destratification occurs, acidic bottom waters mix with more alkaline top waters and the pH of the Lake may start to decrease. Periods of destratification are also associated with a reduction in aquatic plants and algae and as a result, a build-up of carbon dioxide (CO_2) can create a more acidic environment. As such, pH may be considered a useful parameter in measuring the trophic state of the Lake (**Fig. 6; Fig. 7**). Furthermore, as bottom waters become oxygen-poor in stratified periods, DO levels are also considered an important parameter to determine the extent of mixing in the Lake. Declining pH levels and increasing bottom water DO levels may indicate the initiation of destratification which is usually characteristic of the autumn and winter months. pH values and DO levels provide useful insight into the state of the system. This is highlighted by Perkins *et al*. (2015) where they found considerable seasonal and depth variation with different physico-chemical parameters (**Fig. 6; Fig. 7**). Until recently, there were limited sampling efforts in the non-swimming period and therefore a lack of physico-chemical data. Emerging data recently collected by Council indicates interesting seasonal fluctuations (See section **4. Water Quality Results and Discussion**).

4. Water Quality Results and Discussion

4.1 Coastal Management Program (CMP)

For the development of a Coastal Management Program (CMP), it is imperative to update understanding of water quality processes in Lake Ainsworth and to determine the on going management actions required to maintain the Lake in a healthy state. The data that have been collected below will assist Council in the development of a CMP.

4.2 Physico-chemical

In 2016, Council recorded physico-chemical data from Lake Ainsworth year round and as a result trigger values for each season can now be calculated based on mean, median (50th percentile), 80th percentile and the 20th percentile. A summary of the physico-chemical data can be seen in **Table 6** and includes the following data:

- dissolved oxygen
- pH
- turbidity
- electrical conductivity (salinity)
- total phosphorous (TP)
- total nitrogen (TN)
- ammonia.

Across the various parameters there are different degrees of seasonal variation which may indicate complicated processes specific to each season. There is also considerable variation within each season for some of the parameters which reinforces the notion that Lake Ainsworth is a dynamic environment and as yet unpredictable.

Sources of Ammonia may increase in the warmer months in response to increased waste produced by bacteria in the decomposition of algal material (**Fig. 8**). Fluctuations in pH in various seasons may be associated with levels of dissolved carbon dioxide and/or stratification processes (**Fig. 9**). There appears to be larger variation of pH values in the autumn and winter months. Dissolved oxygen (DO) levels recorded at the surface appear to deviate with each season and the results are consistent with stratified freshwater lakes. The deviation of surface DO may indicate how well the water body is mixing between surface and bottom layers of water and the results suggest that most mixing may occur in the winter and spring (**Fig. 10**), which is usually typical of these ecosystems. Alternatively, the DO results may represent the Lake’s ability to hold dissolved oxygen in differing water temperature. It is important to note, however, that the percentage saturation of DO was not included in the analyses and may provide more information regarding seasonal fluctuations of DO. TP concentrations showed some seasonal variation and the highest values were recorded in the summer with values starting to rise in spring (**Fig. 11**). As there appears to be no correlation between rainfall and TP concentrations in 2016 and 1995 (**Fig. 12**; **Fig. 13; Fig. 14**), it may be possible to rule out stormwater as a significant source of TP. Therefore, the contribution of impervious surfaces in the catchment area to an increase in TP is likely to be insignificant. Furthermore, there appears to be no trend between proximity to road and TP concentrations (**Fig. 15**) and the highest average concentrations of TP occur at sample site LA5, which is the only sample site with surrounding intact vegetation and no immediately adjacent urban development. As visitor numbers increase in the summer months so does the production of waste and if a sewerage leak was present we could also expect similar results. To rule this out Council have engaged the water and wastewater team to ensure sewerage leaks are not occurring and confirmation has been made regarding this issue. The *Enterococci* results also suggest there is no connection between potential sewerage leaks and nutrient concentrations. If a sewerage leak was responsible for high *Enterococci* abundance at site LA4 we could also expect to see high values of TP and TN. **Figure 15 and Figure 16** show that there are no statistically unusual TP or TN values for LA4. Interestingly, studies have revealed that the use of sunscreen may contribute to TP levels. If sunscreen significantly contributed to TP levels we could expect larger TP values in the summer – which is consistent with our findings. There are no current data available to pinpoint the exact source of the elevated TP levels. Avian bird faeces have also shown in some cases to contribute to TP levels, however, usually there is no net-positive effect of avian faeces on TP levels.

Table 6. Physico-chemical parameters recorded at Lake Ainsworth from December 2015 to October 2016. Summary statistics have been calculated for each season.

	Summer				
Variable	**Mean**	**Median**	**80th percentile**	**20th percentile**	**Standard deviation**
Dissolved oxygen (mg/L)	6.82	6.58	7.49	6.18	0.89
Turbidty (NTU)	2.44	2	3	1.2	2.02
pH	5.83	5.80	5.98	5.65	0.24
Total phosphorous (mg/L)	0.13	0.13	0.15	0.12	0.02
Total nitrogen (mg/L)	0.86	0.85	0.92	0.791	0.10
Ammonia (mg/L)	0.06	0.07	0.08	0.04	0.03
Electrical Conductivity (uS/cm)	219.99	218	224	214	9.16
	Autumn				
Dissolved oxygen (mg/L)	6.92	6.78	7.60	6.29	1.54
Turbidty (NTU)	2.38	2	3	2	1.18
pH	5.81	5.78	6.16	5.52	0.77
Total phosphorous (mg/L)	0.11	0.11	0.12	0.10	0.03
Total nitrogen (mg/L)	0.77	0.73	0.88	0.68	0.33
Ammonia (mg/L)	0.05	0.04	0.06	0.03	0.02
Electrical Conductivity (uS/cm)	217.77	216	224	212	7.82
	Winter				
Dissolved oxygen (mg/L)	9.40	9.06	10.96	8.11	1.55
Turbidty (NTU)	2.56	3	4	1	1.67
pH	5.86	5.80	6.04	5.60	0.37
Total phosphorous (mg/L)	0.11	0.11	0.12	0.10	0.02
Total nitrogen (mg/L)	0.66	0.65	0.76	0.53	0.14
Ammonia (mg/L)	0.04	0.04	0.05	0.03	0.02
Electrical Conductivity (uS/cm)	213.42	212	220	208	7.65
	Spring				
Dissolved oxygen (mg/L)	8.49	8.36	9.08	7.70	0.82
Turbidty (NTU)	1.95	1.9	3.08	0.48	1.34
pH	5.95	5.83	6.1	5.768	0.26
Total phosphorous (mg/L)	0.12	0.12	0.13	0.11	0.03
Total nitrogen (mg/L)	0.72	0.66	0.78	0.60	0.20
Ammonia (mg/L)	0.04	0.04	0.05	0.02	0.01
Electrical Conductivity (uS/cm)	217.15	217.50	220.20	213	3.98

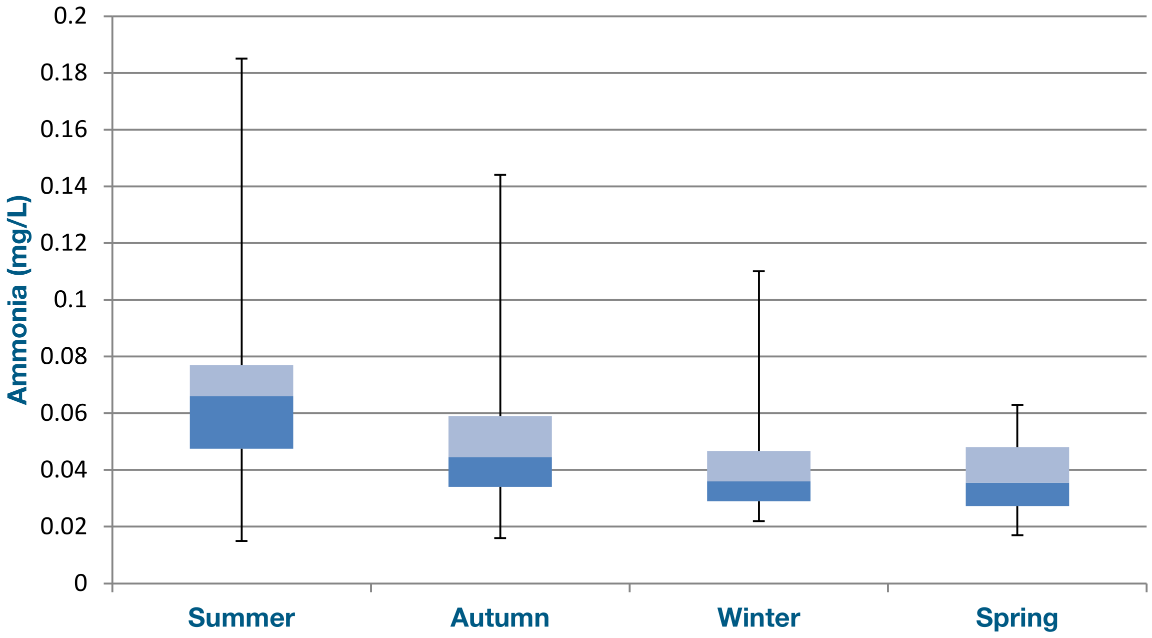

Figure 8. Box plot showing ammonia values calculated for each season from December, 2015 to October, 2016 in Lake Ainsworth. *Note:* The point of colour change denotes median value.

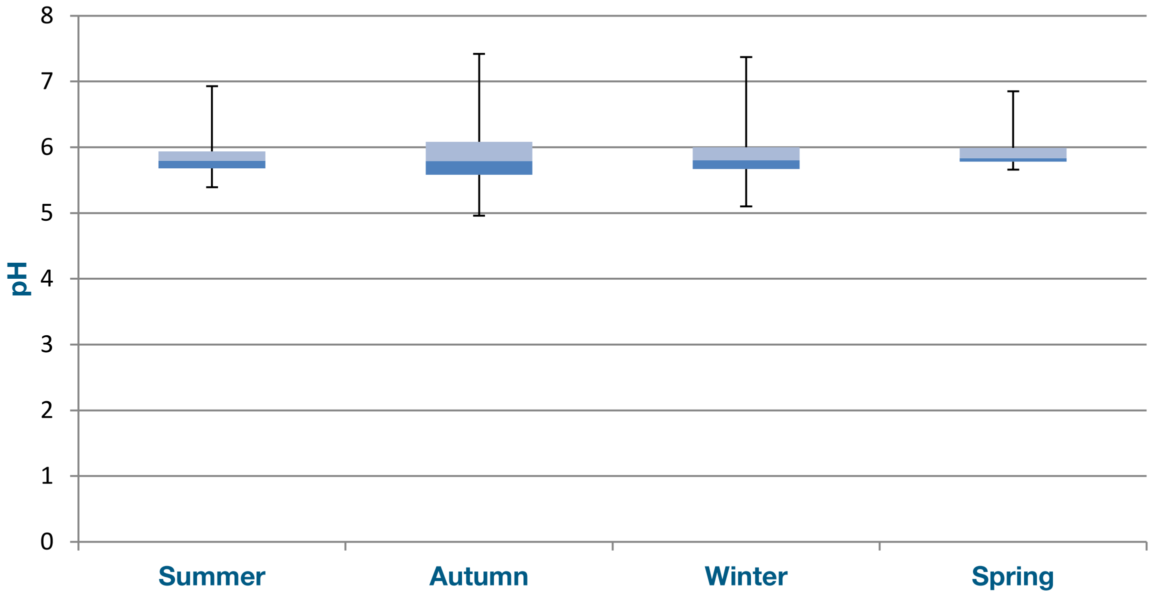

Figure 9. Box plot showing pH values calculated for each season from December, 2015 to October, 2016 in Lake Ainsworth. *Note:* The point of colour change denotes median value.

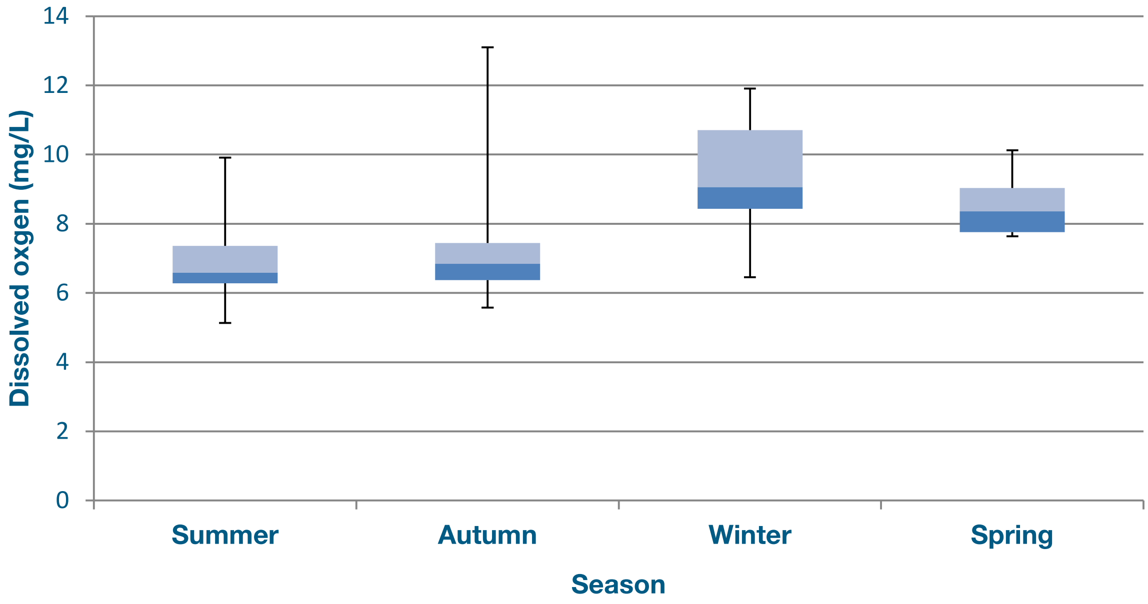

Figure 10. Box plot showing dissolved oxygen values calculated for each season from December, 2015 to October, 2016 in Lake Ainsworth. *Note:* The point of colour change denotes median value.

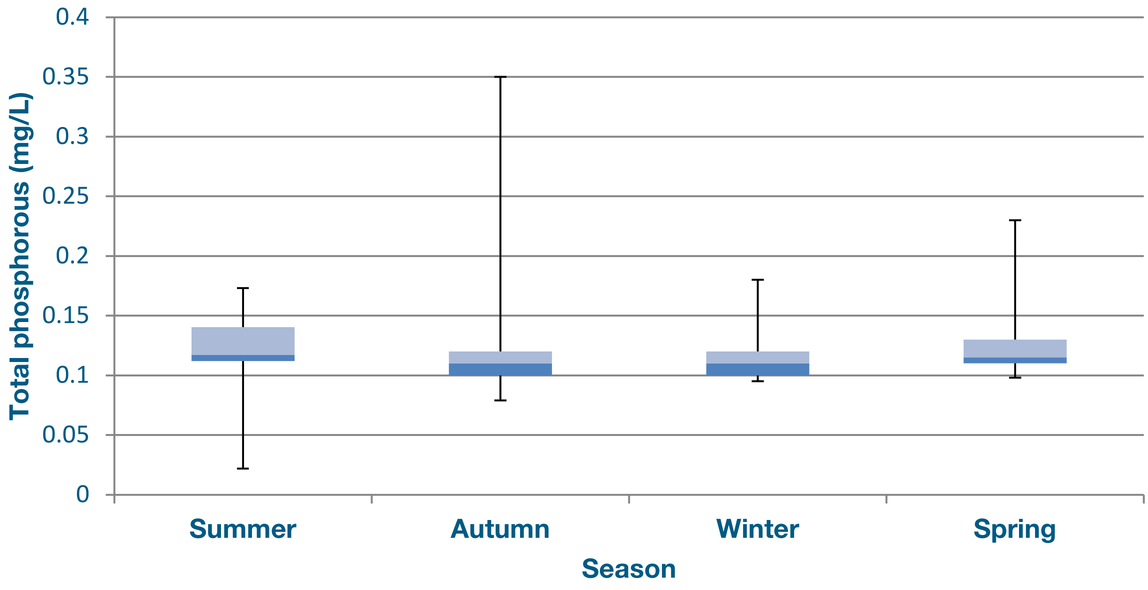

Figure 11. Box plot showing total phosphorous values calculated for each season from December, 2015 to October, 2016 in Lake Ainsworth. *Note:* The point of colour change denotes median value.

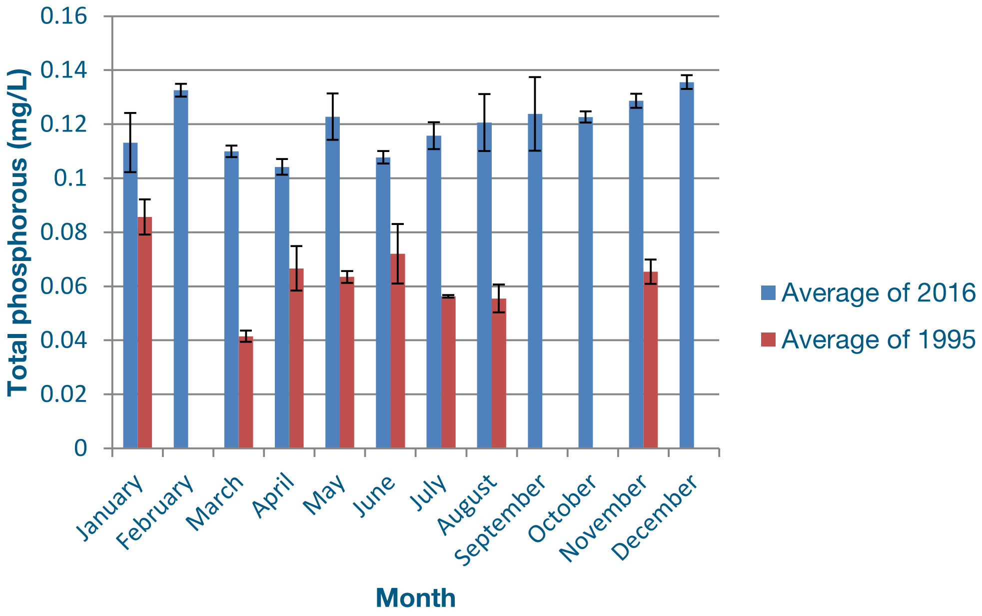

Figure 12. Mean (+/-SE) monthly total phosphorous levels in Lake Ainsworth, Lennox Head in 1995 (red) and 2016 (blue). Data are from December 2015 – November 2016. N= 50 (1995); N = 270 (2016). *Note:* +/- SE = +/– 1 standard error. N = number of replicate samples.

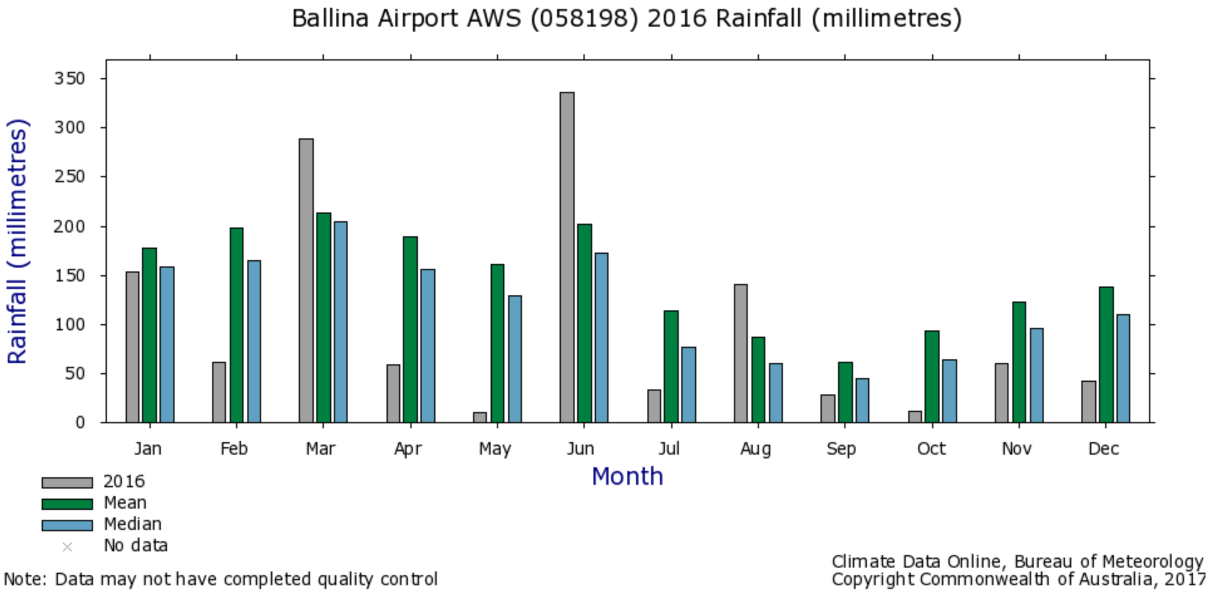

Figure 13. The total mean, median and 2016 rainfall. Figure provided by Bureau of Meteorology.

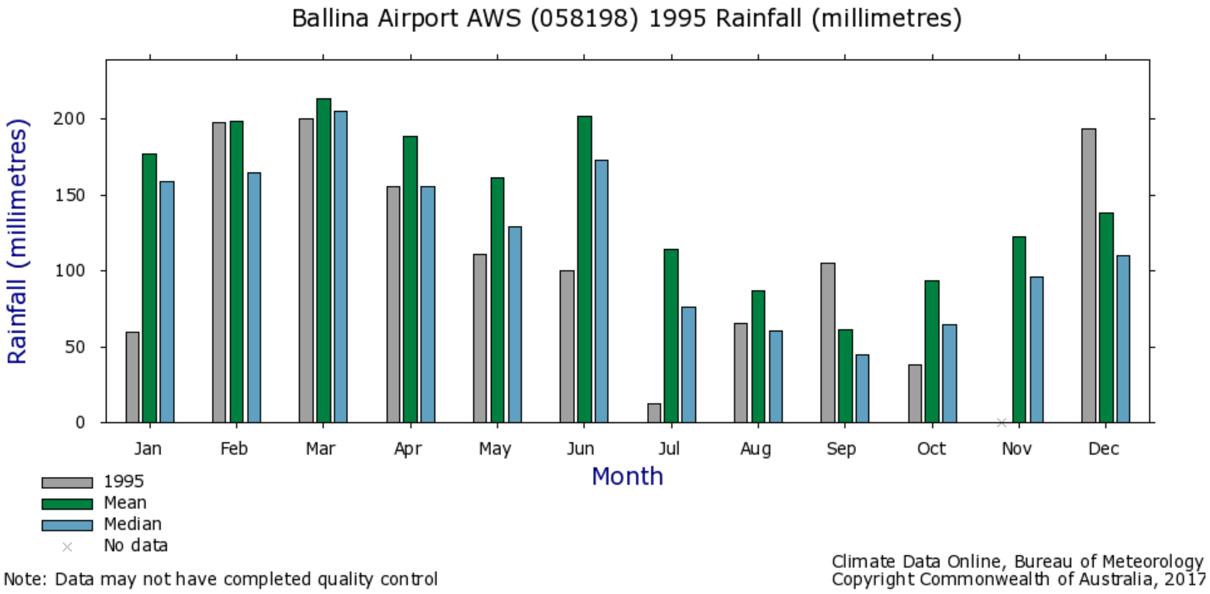

Figure 14. The total mean, median and 1995 rainfall. Figure provided by Bureau of Meteorology.

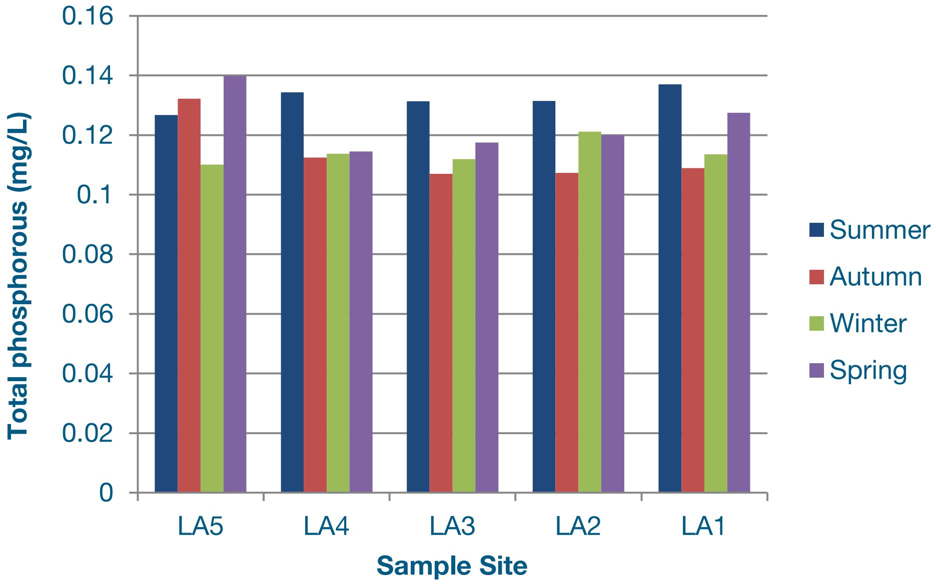

Figure 15. Mean total phosphorous concentrations (mg/L) at each sample site in Lake Ainsworth across each season from December 2015 to October 2016. N = 54 per sample site. N = number of replicate samples.

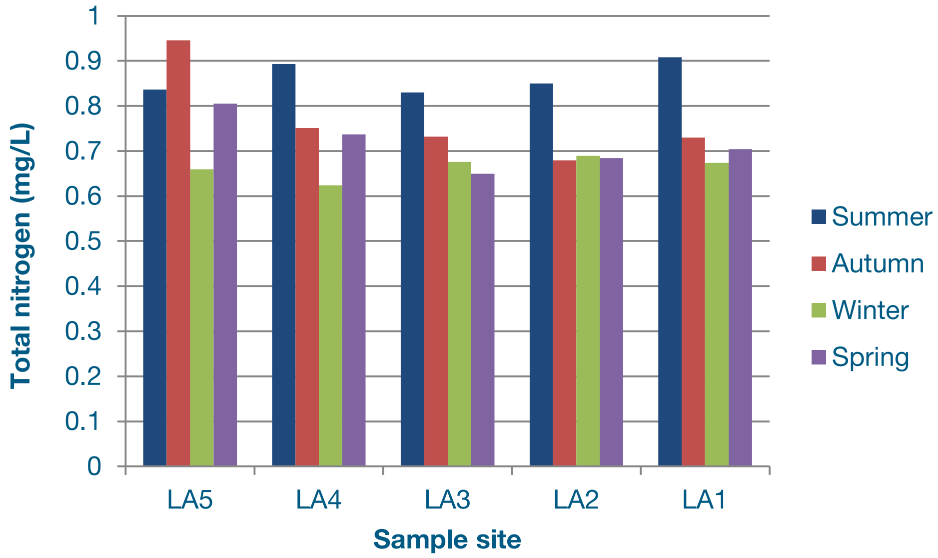

Figure 16. Mean total nitrogen concentrations (mg/L) at each sample site in Lake Ainsworth across each season from December 2015 to October 2016. N = 54 per sample site. N = number of replicate samples.

A comparison between TP levels in 1995 and 2016 can be analysed in **Figure 12** There appears to be a significant increase in TP between 1995 and 2016 which is of concern particularly if this trend continues over the next 20 years. Rainfall graphs in 1995 and 2016 are included above (**Fig. 13**; **Fig. 14**) to determine whether differences in monthly and annual rainfall may contribute to the differences in monthly TP between 1995 and 2016. A preliminary assessment of the relationship between total phosphorous and rainfall in 1995 and 2016 shows no obvious relationship between these two variables. It is likely that there are numerous underlying mechanisms responsible for fluctuations in total phosphorous. According to the Lake Ainsworth Management Study (2000) nutrient samples collected in the 1995 period were collected on an ad hoc basis and may be biased toward higher than normal concentrations. If this is the case, then the 2016 TP levels may be significantly higher than previously thought. As the release of nutrients from the sediments is facilitated by low-oxygen conditions, it could be expected that the installation of the aerator would contribute to a reduction in nutrients. This does not seem to be the case and warrants further investigation. Due to uneven data sets (n= 50; 1995; n = 270; 2016) and unknown methodologies in sample collection and analysis, conclusions drawn from these data may be limited in their scope.

4.3 Bacteriological

A total of 280 microbial samples were collected and analysed from the beginning of 2013 to August, 2016. There were 89 samples collected at each site (LA4, LA3 and LA2) and with the introduction of microbiological sampling at site LA1 there have been 13 samples collected at this site. The average abundance of *Enterococci* at LA4 was 66 cfu/100ml. The average abundance of *Enterococci* at LA3 was 35 cfu/100ml and the average abundance of *Enterococci* at LA2 was 30 cfu/100ml (**Fig. 17**). The average *Enterococci* abundance at each sample site from 2013 to September 2016 is shown in **Figure 18.** According to the ANZECC (2000) guidelines the median count of *Enterococci* at Lake Ainsworth is below the recommended levels indicating the suitability of the Lake for primary recreational contact (**Fig. 19; Fig. 20**). **Figure 19** shows exceedance of the *Enterococci* count at LA4 in 2014 and 2013.

However when the data are combined (**Fig. 20**) there is no exceedance of the recommended enterococc*i* guidelines between 2013 and 2016. As the latter graph encompasses more samples it could be considered more reliable and probably contains values closer to the true median. The high *Enterococci* counts that occur at LA4 (Lake Ainsworth West) and the *Enterococci* counts at the remaining sample sites are shown in **Figure 19 and Figure 21. Table 7** shows the frequency and ratio of microbial exceedance as per the ANZECC (2000) guidelines.

Median values for *Enterococci* abundance between 2013 and 2016 were calculated and presented below (**Fig. 20**) and show a decrease in abundance from 2013 to 2016. Low values recorded in 2016 may be due to year-round sampling which may represent lower *Enterococci* values occurring in the winter. Alternatively these results may suggest that there is less faecal contamination occurring in 2016 than previous years and may be due to a variety of reasons. The median *Enterococci* abundance was also calculated between 2013 and 2016 as per the recommendations of the ANZECC (2000) guidelines. At site LA4 the median count of *Enterococci* was 31; for site LA3 it was 19; and for site LA2 the median count was 17 (**Fig. 19**). Over the past four years all sample sites contained a median score lower than the poor water quality guidelines of 35 cfu/100mL as recommended by ANZECC (2000) and as a result the Lake is usually suitable for primary recreational contact. The ANZECC (2000) guidelines also state that the maximum number of *Enterococci* in any one sample should not exceed 60-100 cfu/100mL. The ratio of microbial exceedance was calculated and presented in **Table 7**. Samples exceeded the threshold on a small number of occasions suggesting that sometimes it is unsuitable to swim in Lake Ainsworth (particularly at site LA4). The Office of Environment and Heritage (OEH) have summarised the *Enterococci* results in Lake Ainsworth using the National Health and Medical Research Council (NHMRC, 2008) guidelines and can be accessed here: http://www.environment.nsw.gov.au/beach/Reportann.html.

To summarise, in 2014 and 2015 Lake Ainsworth received a poor water quality grade by the OEH and is occasionally unsuitable for primary recreational contact (particularly after moderate - high rainfall). Consistent with the findings from Council, Lake Ainsworth may be considered to be the most vulnerable recreational swimming area that is sampled by Council in relation to microbial levels in the water column.

To determine the significance of the results, various statistical tests have been employed and the calculations and results are available in the **Appendix**. To summarise, Council found that site LA4 on average contained significantly more *Enterococci* than site LA3 and site LA2. A further investigation will need to be conducted to determine why site LA4 harbours more *Enterococci* than site LA3 and LA2 (**See the Appendix:** Statistical Analyses). These findings are an interesting discovery and may represent a combination of factors causing an apparent increase in *Enterococci* at site LA4. Additional microbial samples have been taken at site LA1 (Lake Ainsworth North) to assist in identifying the source of contamination. The continued occurrence of ducks in large numbers at site LA4 may contribute to the observed abundance of *Enterococci.* An important limitation of this indicator species (*Enterococci*) is that it may also occur in areas contaminated by warm-blooded animal faeces. It is often observed that there is a considerable amount of duck faeces present at site LA1 similar to observations at site LA4 and by taking another sample at site LA1 it may be possible to determine the influence of duck faeces on the abundance of *Enterococci*.

The abundance of *Enterococci* at LA1 appears to be at similar levels to sites LA2 and LA3. Data from LA1 were not included in this report due to the low number of replicates and thus a lack of comparative scope. To determine whether the faecal contamination is of human or animal origin it may be necessary to perform microbial source tracking on water samples. The origin of the contamination will dictate the level of management response. For example, if contamination is of human origin more measures will need to be taken as the public health risks are substantially higher than if the contamination is of animal origin. It has been noted in the LAMP (2002) and LAPS (Senden *et al*. 1996) that stormwater outlets at the southern end of the Lake harboured more *Enterococci* than the other outlets and stormwater flow at the southern end may be more prominent in comparison to other locations around the Lake. This is consistent with our findings where Council found a significantly higher abundance of *Enterococci* in the south western end (LA4) compared with the eastern side (LA2) and the southern side (LA3) (Fig. 17; Fig. 18). Therefore the differences in microbial abundance may be due to stormwater flow which has been documented to predominantly travel from the south of Lake Ainsworth to the north. An investigation into this issue would need to be undertaken to determine whether treatment of stormwater flow is needed to reduce microbial levels.

To update the organisation of *Enterococci* abundance data, it would be recommended to add these data to Hydstra to ensure that the data are described accurately and efficiently. This in conjunction with updating the Beachwatch sample sites to iPad configuration will ensure the Beachwatch monitoring program is run as effectively and efficiently as possible. It is also recommended to include surface water temperature in the Hydstra software to ensure the water temperature can be monitored over the course of a year. At this point, temperature is not accessible in Hydstra due to operational technicalities. The feasibility of the above recommendations can be further investigated when required.

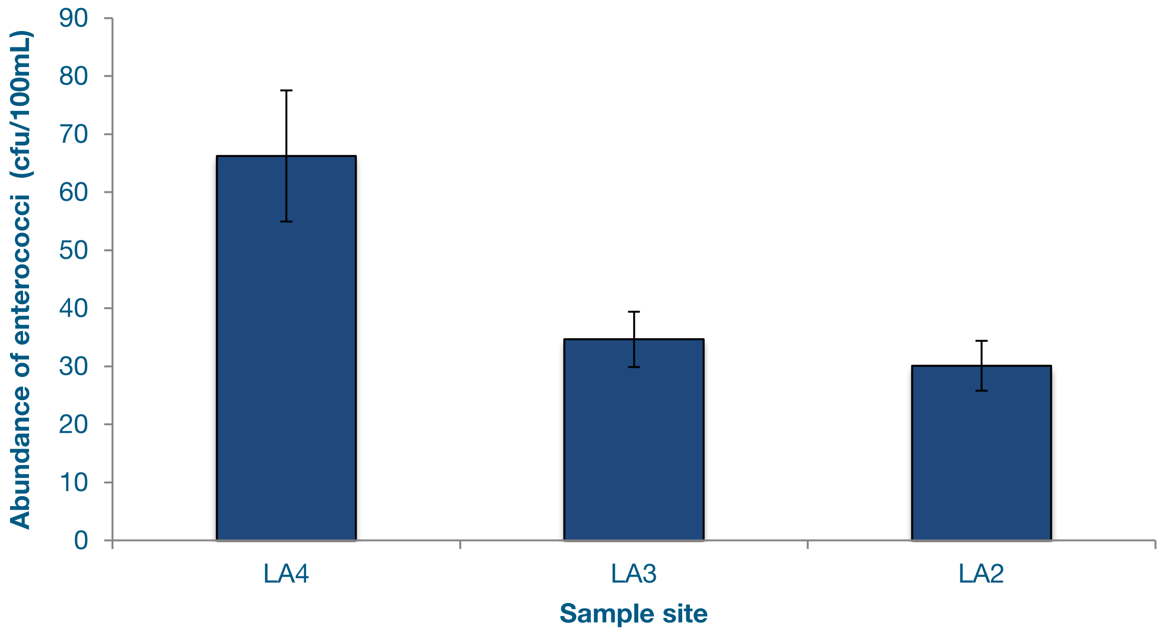

Figure 17. The mean (+/- SE) abundance of *Enterococci* at Lake Ainsworth, Lennox Head, NSW. Data have been collected across three sample sites; LA4 (Lake Ainsworth West); LA3 (Lake Ainsworth South); and LA2 (Lake Ainsworth East), from 2013 – September, 2016. N= 89. *Note:* +/- SE = +/– 1 standard error. N = number of replicate samples.

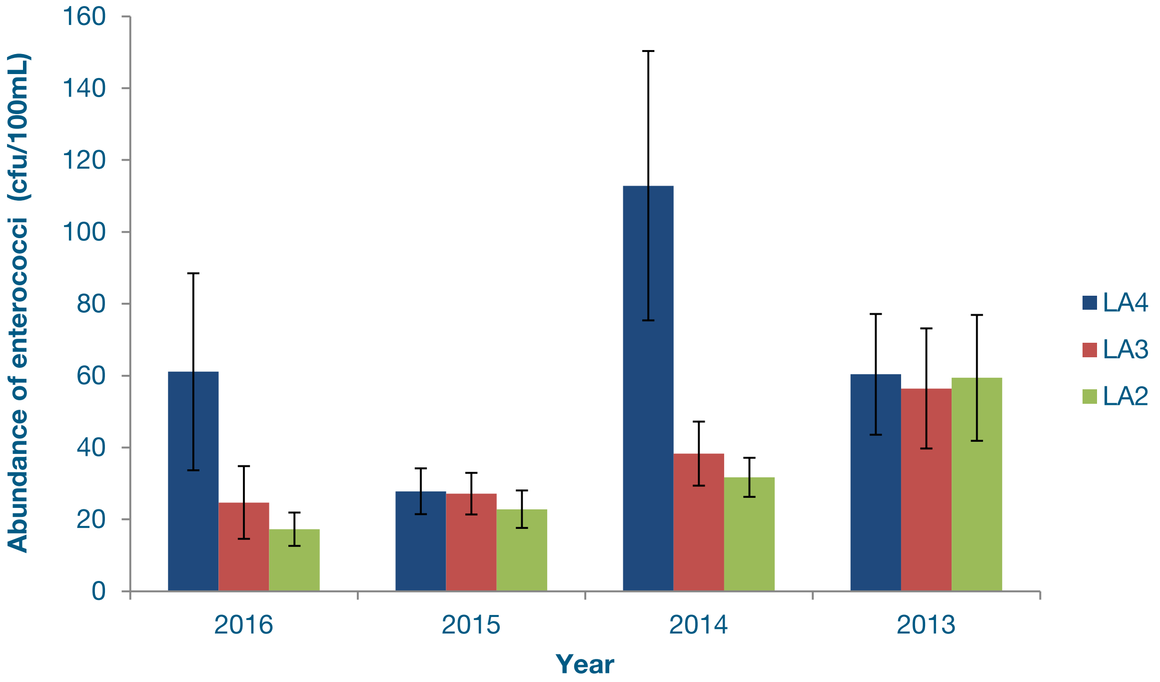

Figure 18. The mean (+/- SE) abundance of *Enterococci* at Lake Ainsworth, Lennox Head, NSW. Data have been collected across three sample sites; LA4 (Lake Ainsworth West); LA3 (Lake Ainsworth South); and LA2 (Lake Ainsworth East), from 2013 – September, 2016. N= 34 (2016); n = 17 (2015); n = 20 (2014); n = 18 (2013). *Note:* +/- SE = +/– 1 standard error. N = number of replicate samples.

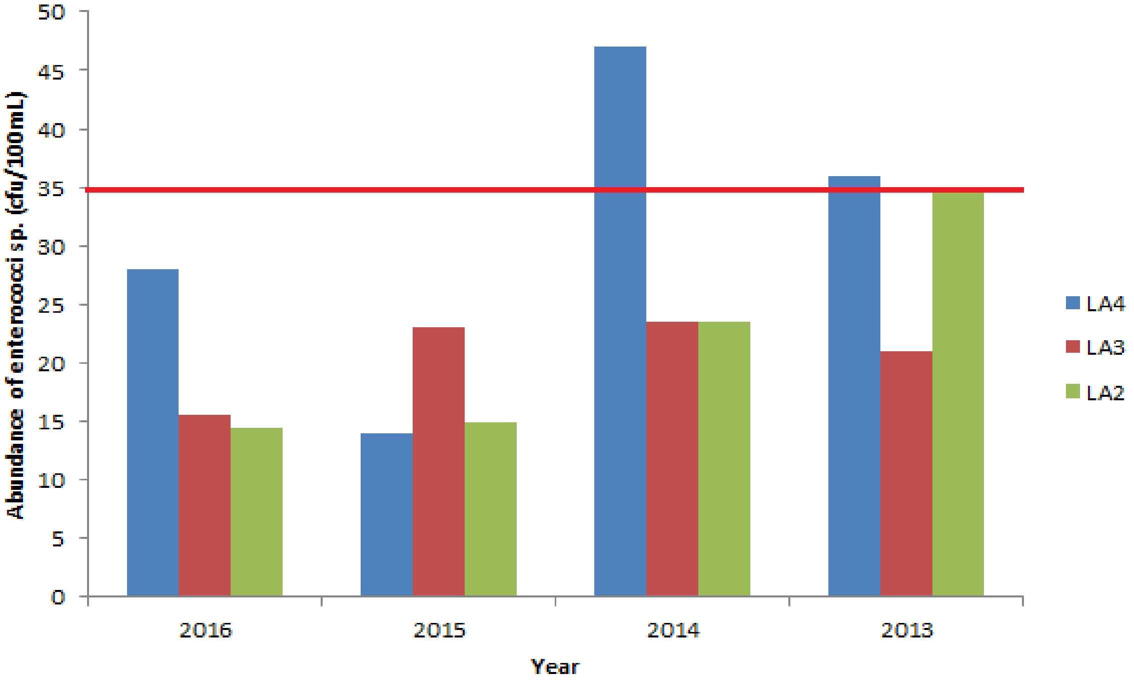

Figure 19. The median abundance of *Enterococci* at Lake Ainsworth, Lennox Head, NSW. Data have been collected across three sample sites; LA4 (Lake Ainsworth West); LA3 (Lake Ainsworth South); and LA2 (Lake Ainsworth East), from 2013 – September, 2016. N= 34 (2016); n = 17 (2015); n = 20 (2014); n = 18 (2013). Red line indicates ANZECC (2000) guidelines for poor water quality as indicated by median *Enterococci* count (35 cfu/100mL). N = number of replicate samples.

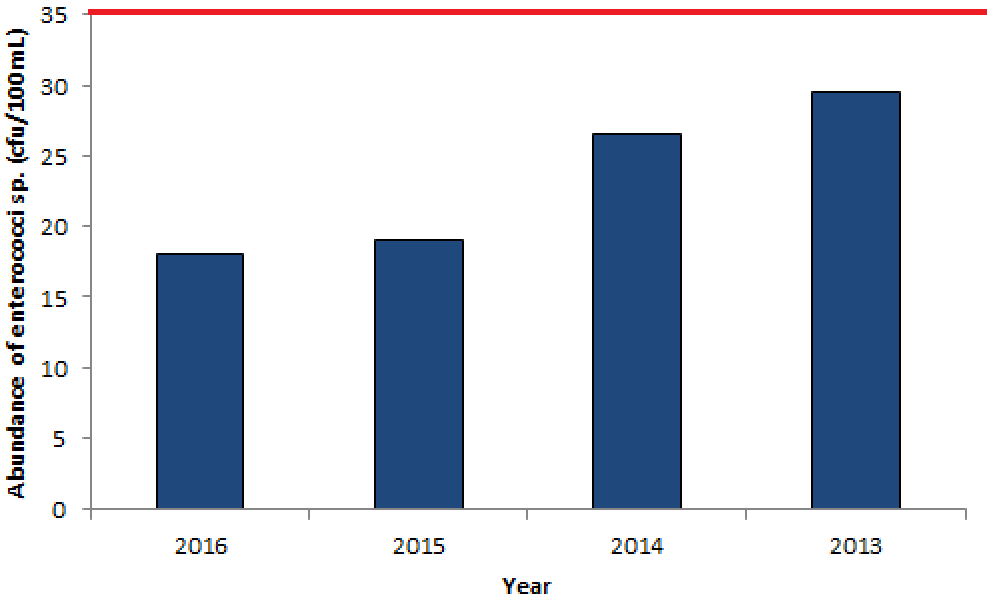

Figure 20. The median abundance of *Enterococci* at Lake Ainsworth, Lennox Head, northern NSW. Data have been collected across three sample sites; LA4 (Lake Ainsworth West); LA3 (Lake Ainsworth South); and LA2 (Lake Ainsworth East) and combined, from 2013 – September, 2016. N= 102 (2016); n = 51 (2015); n = 60 (2014); n = 54 (2013). Red line indicates the ANZECC (2000) guidelines for poor water quality as indicated by median *Enterococci* count (35 cfu/100mL). N = number of replicate samples.

Table 7. The occurrence of single samples with >60 cfu/100mL of *Enterococci* as per the ANZECC (2000) guidelines in Lake Ainsworth Northern NSW, between 2013 and 2016.

# of samples > 60 cfu/100mL	2016	2015	2014	2013
LA4	6	2	9	5
LA3	3	1	4	5
LA2	2	1	4	4
Total	11	4	17	14
Total n (number of replicate samples)	102	51	60	54
Ratio of exceedance	0.11	0.08	0.28	0.26

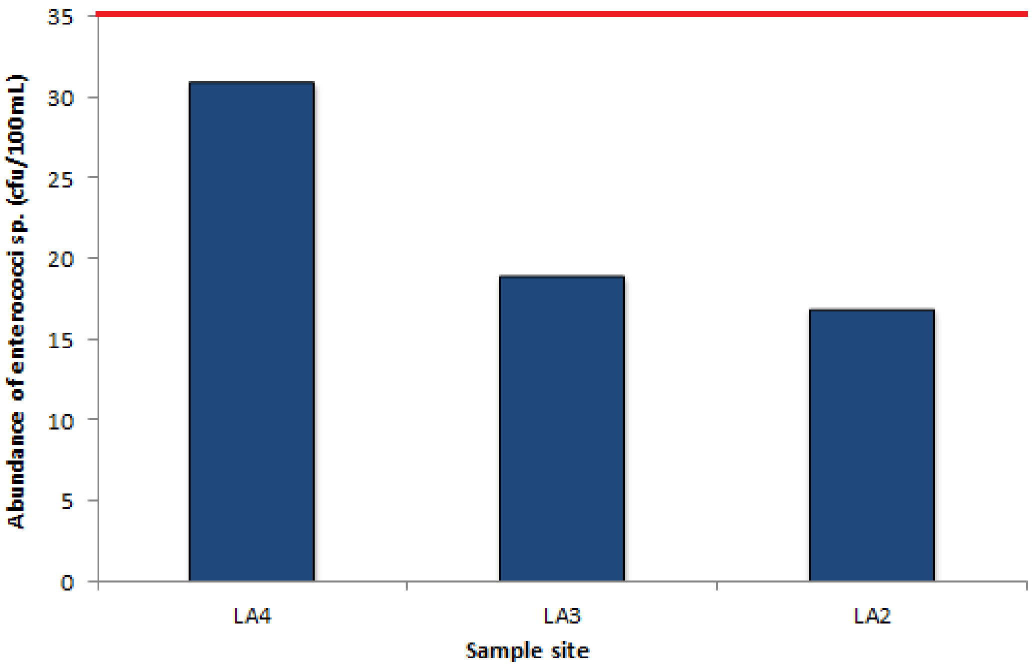

Figure 21. The median abundance of *Enterococci* at Lake Ainsworth, Lennox Head, NSW. Data have been collected across three sample sites; LA4 (Lake Ainsworth West); LA3 (Lake Ainsworth South); and LA2 (Lake Ainsworth East), from 2013 – September, 2016. N= 89. Red-line indicates the poor water quality guidelines as recommended by ANZECC (2000). N = number of replicate samples.

4.4 Nutrients and the Facilitation of Blue-Green Algae and Aquatic Plants

As ecosystems progressively shift from a dystrophic to a eutrophic state accelerated by development, climate change, and other anthropogenic pressures, it can be expected to see a rise in algal blooms and aquatic plant growth (with a limited number of dominant species). The current data suggest that Lake Ainsworth is in a eutrophic state (particularly in the warmer months) and a further analysis of historic data would need to be performed to determine whether there has been a significant shift driven by anthropogenic pressures.

There appears to be substantial phosphorous levels (often the limiting nutrient for blue-green algae) in Lake Ainsworth to support phytoplankton and blue-green algae blooms. Generally speaking, through the process of denitrification, nitrogen is released to the atmosphere. As the main mechanism of phosphorous removal is typically through burial, low sedimentation rates and porous sediments in Lake Ainsworth promote phosphorous storage and release. Historical sewage/sullage contamination has likely partly contributed to higher levels of phosphorous which is released from the sediments via oxygen-poor conditions under stratification. Aquatic plants and blue-green algae require phosphorous (as well as nitrogen and other trace elements) throughout their lifecycle and when algal and plant material die-off and decompose phosphorous is released back into the system. As plant material decomposes this also contributes to a reduction in dissolved oxygen which enhances phosphorous release. These processes are responsible for a continual storage and recycling of phosphorous in the system while nitrogen cycles may display different characteristics.

The ideal nitrogen and phosphorous ratio for phytoplankton and blue-green algal communities to thrive has been documented as the Redfield Ratio and the respective numbers are 16:1. As blue-green algae are able to fix nitrogen from the atmosphere there is now a build-up of nitrogen as well as phosphorous in the water column which contributes to the eutrophication of a system. Due to the nature of these cycles a positive feedback loop is generated and the water quality has the potential to deteriorate rapidly.

Lake Ainsworth has been historically defined as a dystrophic Lake and as such, it is likely the system originally exhibited low nutrient availability.

The high nutrient levels found in Lake Ainsworth may also be a significant contributing factor to the presence and persistence of the noxious aquatic weed - water hyacinth.

Water hyacinth is considered to be one of the most destructive aquatic weeds in the world on account of its ability to spread quickly and completely suffocate rivers, dams, lakes and irrigation channels. There have been numerous observations of this noxious weed in Lake Ainsworth, with Lennox Head Land Care frequently reporting sightings of the plant. A major removal effort conducted by Lennox Head Land Care in April 2015 and more recent efforts in 2016, saw a large reduction in the biomass of water hyacinth, however, due to its ability to spread quickly and produce seeds which may be viable for up to 20 years, it is likely the problem will continue to persist into the future. This situation needs to be monitored carefully if the invasion of this species is to be controlled. There has been recent discussion about the potential of water hyacinth to remove nutrients from the water column and this can be seen in more detail here: *Striking a deal with the weed from hell*, http://conservationmagazine.org/2014/03/water-hyacinth-in-kings-bay/ . **Figure 22** shows a small patch of water hyacinth on the eastern shore of the Sport and Recreation Centre.

Figure 22. Water hyacinth (*Eichhornia crassipes*) at the Lake Ainsworth Sport and Recreation Centre along the eastern shore.

This report has not analysed the relationship between nutrients and the growth of blue-green algae, however, numerous studies have shown a positive correlation between these two variables sometimes with certain lag times. A preliminary assessment of blue-green algal abundance can be seen in **Figure 23** and **Figure 24**.

The analysis of total cyanophyta (as well as potentially toxic cyanobacteria) has also been included, as non-toxic species can cause allergic reactions and thus pose a threat to the recreational value of the Lake. Algae samples are taken at four different sites in the Lake and these are combined into two composite samples with one composite sample (LA1 and LA2) at the north end and another composite sample at the southern end (LA3 and LA4).

There appeared to be on average a larger number of 'total cyanophyta' and 'potentially toxic cyanophyta' at the southern end (LA4 and LA3) than the northern end (LA1 and LA2) in 2015 and part of 2016 (**Fig. 23**; **Fig. 24**). However, due to significant variation in the data and very small data sets, it is very unlikely there will be any statistical significance to the findings. Further, due to the time consuming nature of extracting and analysing algae data, there are limited amounts of data that are represented by graphs and tables. A historic analysis of cyanobacteria abundance would provide useful information regarding the health of the Lake and the effectiveness of the aerator. One issue, however, would be how to quantify the highly variant abundance of cyanobacteria. A discussion on quantifying blue-green algae can be seen in the **Appendix.** The blue-green algal analysis presented in this report is not comprehensive enough to draw any conclusions from and as such, it is vital that more extensive analyses are conducted in the future.

To determine the public health risk of algal blooms, the abundance of blue-green algae is measured in accordance with the NHRMC (2008) guidelines previously mentioned in **2.3 Water Quality Guidelines** and the results are then relayed to the public using a variety of mechanisms mentioned in **2.2 History of Water Quality Issues**. Additional sampling for Chlorophyll-*a* (Chl-*a*) conducted every 6-8 weeks may provide useful insights into the relationship between the abundance of blue-green algae and Chl-*a* on a yearly basis. Chl-*a* is a photosynthetic pigment found in photosynthesising organisms and is often a good indicator for estimating the biomass of phytoplankton and blue-green algae in a system. It has been suggested in numerous studies that there is a positive correlation between Chl-*a* and blue green algae abundance. However, as Chl-*a* is also associated with phytoplankton, the relationship between blue-green algae and Chl-a can be complex and unpredictable.

With the increasing threat of climate change, it has been suggested that extended periods of warm surface waters of at least 20^{0}C may be linked to increasing biomass of *Dolichospermum* spp. in Lake Stechlin, in temperate Germany (Dadheech *et al*. 2014). If these findings are true then it could be expected to see significant algal blooms earlier in the season in Lake Ainsworth, subsequently followed by algal 'die-offs' when water temperature exceeds the threshold and increasing algal blooms in the autumn and winter seasons.

Overall there has been a significant improvement in data collection and storage across a wider range of variables. This will contribute to a better understanding of Lake Ainsworth and how best to manage this natural resource. The foundation for this will allow for the implementation of a Coastal Management Program (CMP) designed to promote the sustainable use of Lake Ainsworth for the benefit of all stakeholders and the environment.

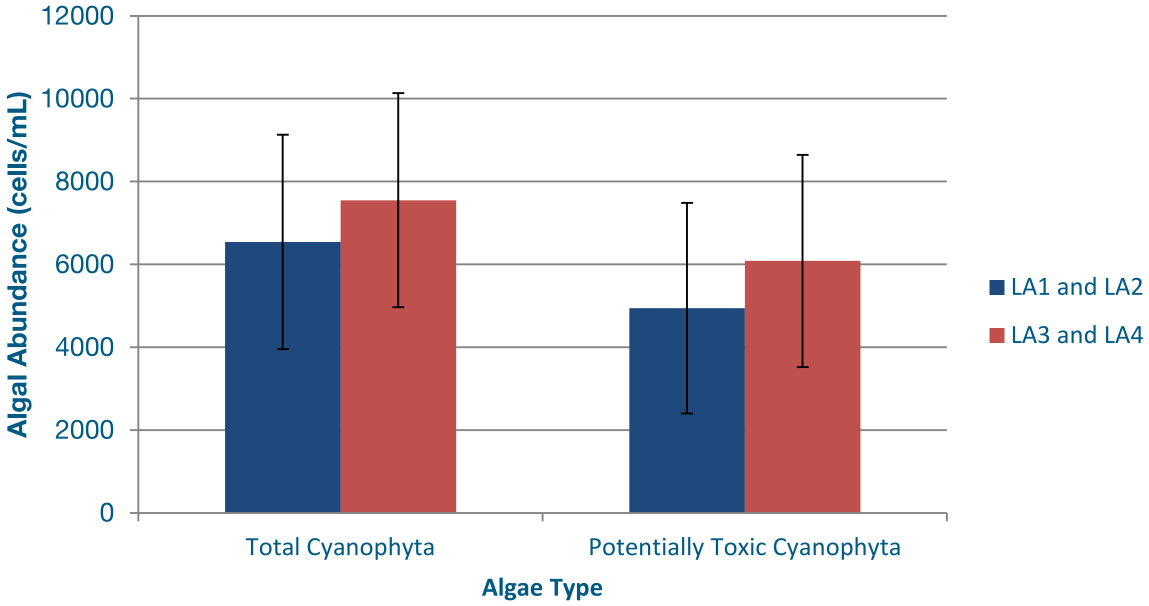

Figure 23. The mean (+/- SE) abundance of all cyanophyta and potentially toxic cyanophyta at Lake Ainsworth, Lennox Head, NSW in 2015 (n=26). Collected data are composite samples of LA1 and LA2 (Lake Ainsworth North and Lake Ainsworth East (blue)) and LA3 and LA4 (Lake Ainsworth South and Lake Ainsworth West (red)). *Note:* +/- SE = +/– 1 standard error. N = number of replicate samples.

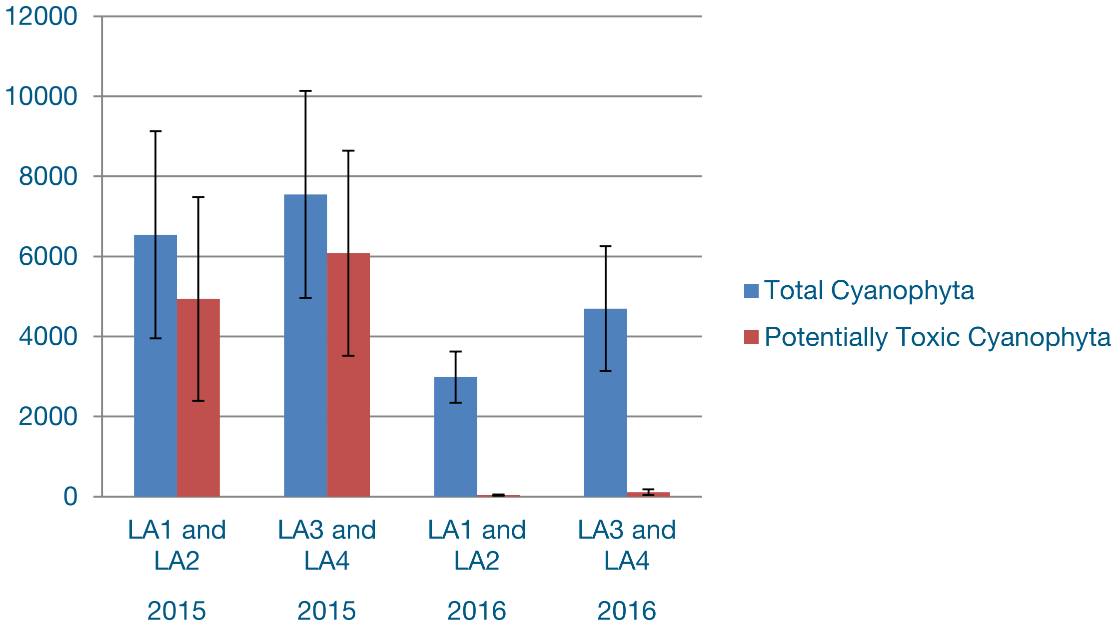

Figure 24. The mean (+/- SE) abundance of all cyanophyta (blue) and potentially toxic cyanophyta (red) at Lake Ainsworth, Lennox Head, NSW in 2015 (n=26) and 2016 (n=10). Collected data are composite samples of LA1 and LA2 (Lake Ainsworth North and Lake Ainsworth East) and LA3 and LA4 (Lake Ainsworth South and Lake Ainsworth West). *Note:* +/- SE = +/– 1 standard error. N = number of replicate samples.

5. Management Issues and Information Gaps

5.1 Impervious Surfaces and Water Quality

It is well recognised that impervious surfaces in the catchment area of a particular water body can negatively influence the water quality. In a natural undisturbed ecosystem stormwater runoff is absorbed through porous soils and vegetation and as a consequence, stormwater runoff may take an extended period of time to reach the receiving water body as the water is constantly being filtered and interrupted by naturally occurring materials. The introduction of impervious surfaces not only reduces the amount of porous soils and vegetation but also provides a non-porous surface which inhibits the absorption of stormwater into the ground. As a result, there may be a larger volume of water entering the receiving water body in a shorter period of time and due to the loss of filtration processes the stormwater may contain pollutants such as faecal matter, hydrocarbons, heavy metals, pesticides, nutrients, additional sediments, litter and more. In addition, the increased speed and volume at which the stormwater enters the water body also influences water currents and circulation patterns, erosion, temperature and may contribute to flash flooding (Trombulak & Frissell, 2000; Brown & Simpson, 2001; Alberti *et al*. 2007; Kim *et al*. 2016).

The construction, maintenance and use of roads have led to various contaminants that find their way into the aquatic environment. These include heavy metals, organic compounds, and nutrients (Trombulak & Frissell, 2000). In a study performed by Alberti *et al*. (2007) investigating the impact of four main variables ("land use intensity, land cover composition, landscape configuration, and connectivity of the impervious area") on 42 sub-basins in Washington, related to urban development, they found that the extent and percentage (i.e. ratio) of impervious surfaces to non-impervious surfaces as well as the connectivity of impervious surfaces were key stressors to the ecological integrity of aquatic ecosystems. It was further reinforced that as the number of roads increases there is an increase in the rate of runoff to associated basins (Alberti *et al*. 2007). In a study performed by Kim *et al*. (2016), they found that decreased water quality in watersheds in Korea were characterised by catchment areas containing more than 10% of impervious surfaces.

In a global perspective, the population density in the Lennox Head region as well as the extent of urban development (i.e. impervious surfaces) is relatively insignificant (<10%). The ratio between impervious surfaces and non-impervious surfaces in the Lake Ainsworth catchment area may be considerably less than the threshold suggested in this study (Fig. 1; Fig. 4; Fig. 5).

Many other studies have also highlighted the negative impacts impervious surfaces have on water quality. Some of these impacts include:

- increased sedimentation which leads to warmer temperatures and reduced light availability allowing undesirable species of cyanobacteria to thrive
- increased nutrient loading
- increase in hydrocarbons and heavy metals
- changes in hydrodynamics
- increased erosion.

Heavy metals and pesticides are also of concern and if levels exceed the national guidelines there is serious risk to humans, flora and fauna. Heavy metal contamination occurs in four ways:

- amount of contamination is related to the amount of traffic
- contamination generally drops exponentially from source (some studies say up to 20m, however, elevated levels can be found up to 200m away and can be determined by prevailing wind patterns (NE in summer))
- accumulates in soils to be released at a later stage
- bioaccumulates in tissues of plants and animals and may enter the food chain.

The discontinued use of leaded petrol has led to a decline in heavy metals found in the environment.

The proposed redevelopment plan for Lake Ainsworth involves the removal of the eastern road to make way for more grassy areas in an attempt to reduce overcrowding issues and improve amenity. This will create more space for community recreation around Lake Ainsworth and may improve water quality. The use of the eastern road began in the 1940s and proposed plans to redevelop the road have not proceeded without community objection. On the other hand, there has also been community concern regarding the negative impact of the eastern road on the quality of water in regards to untreated stormwater runoff. The relationship between the eastern road and an apparent deterioration of water quality is undetermined in this report. The redevelopment plan also involves the introduction of a water sensitive urban design which can be used to capture and treat stormwater runoff prior to discharge into the Lake.

Stage one of the proposed redevelopment works are due to proceed in 2017. The actions in Stage one include:

- closure of the eastern road to vehicular traffic (excluding emergency access)
- construction of 3m wide concrete path
- landscaping/open space improvements
- rehabilitation/erosion control to embankment of Lake.

Various sources (Senden *et al*. 1996; LAMS, 2002) have indicated that the Lake's sediments release 10 times more phosphorous than groundwater and runoff combined. Therefore, excessively high nutrient loads in Lake Ainsworth may partly be a result of unregulated and unrestricted past practices which have resulted in a mass storage of nutrients in the sediments which are released especially during times of stratification.

5.2 Sediment Nutrients

It may be feasible to collect sediment cores and analyse nutrient levels over an extended period of time (paleolimnology) to see whether nutrient levels are stabilising or increasing. Logan *et al*. (2011) analysed nutrient tolerant species of diatoms found in sediment cores to infer the past and present nutrient status of the Richmond River. They found that despite significant land clearing and development, there were no significant changes in TP levels. Observed trends of TP levels were suggested to be positively correlated with rainfall (and perhaps Indian Ocean Dipole and El Niño Southern Oscillation events) and the extent of land clearing and development appeared to have no effect on TP influx (Logan *et al*. 2011). These are important findings and suggest that despite perceived conceptions there may be little or no influence. Therefore, it is possible that analysing a sediment core taken from Lake Ainsworth may produce no conclusive results. **Figure 25** shows a hypothetical example of the results of a sediment core taken in the deepest part of the Lake can produce. The timeline interface of nutrient influx could provide links between historic events and the introduction of nutrients. For example, it may be possible to determine whether the restriction of sewage and sullage release had a significant effect on the reduction of nutrients.

It has been recommended in the Lake Ainsworth Water Quality Monitoring Program (LAQMP, 2015) to collect sediment samples at various locations around the perimeter of the Lake and at different depths, in order to gain a better understanding of the ability for sediments to store heavy metals, hydrocarbons and nutrients. This is supported by Trombulak & Frissell (2000) where they found that sediments play an important role in the storage of these chemicals.

In another study performed by Tibby *et al*. (2007), it was suggested that due to the presence of saline diatoms in a sediment core there was a period of time when Lake Ainsworth was saline. Using ^{210}Pb, measured by alpha spectrometry, to measure sediment age the authors determined that there was a saline phase in Lake Ainsworth which probably ended in the 1930s (Tibby *et al*. 2007). The collection of sediment cores is currently being discussed between Council and Professor Bradley Eyre (Southern Cross University).

Nutrient influx may be considered one of the most important factors regarding cyanobacteria blooms. If nutrient levels are increasing over time then appropriate management action will need to be taken before further damage occurs. Excessive blue-green algal blooms will severely degrade the recreational quality of the Lake and will also compromise the status of native flora and fauna. A historic analysis of cyanobacteria blooms would provide useful insights into the performance of the aerator and also the general condition of the Lake. As past studies have revealed, the instalment of native riparian vegetation could increase buffer zone, decrease nutrient loads, decrease runoff velocity, decrease the abundance of blue-green algae, water hyacinth and other noxious weeds and filter potential contaminants. Another way to potentially reduce nutrient levels may involve sand dredging as discussed in the Lake Ainsworth Management Plan (2000). Due to the complicated nature of a sand dredging project, there would need to be careful consideration before implementation.

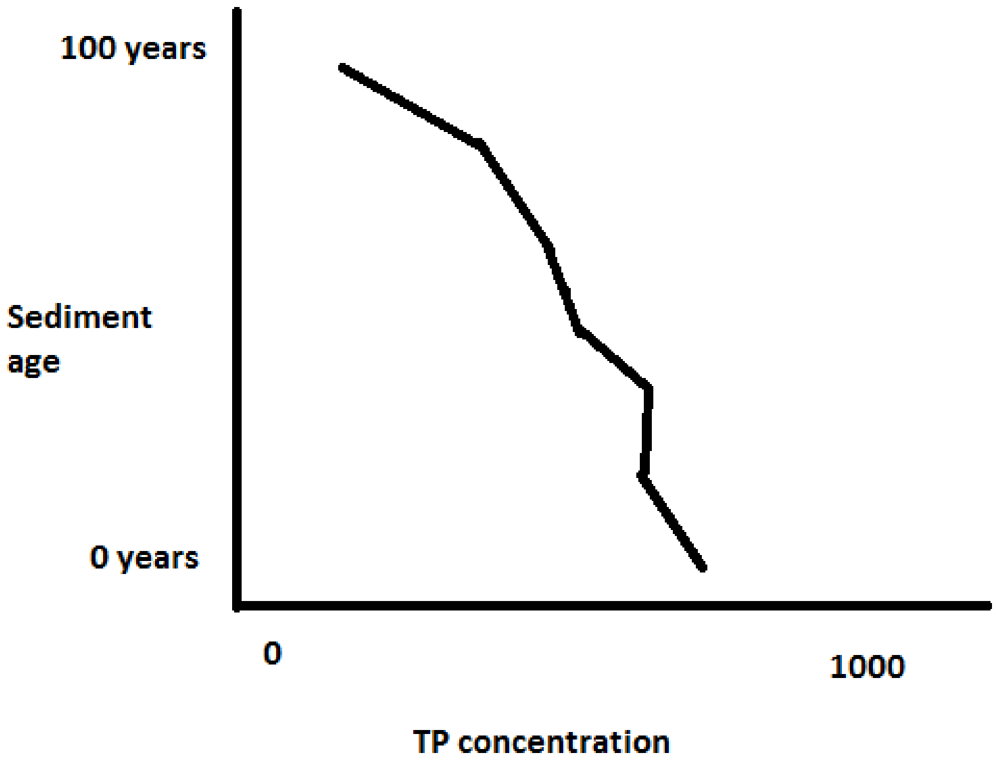

Figure 25. A hypothetical example of the typical results from a sediment core when measuring TP concentration with sediment age.

5.3 Shoreline Erosion

Another issue gaining community attention is that of foreshore erosion, particularly in the south eastern corner where it is suggested that high pedestrian activity, gaps in vegetation, and impervious surfaces contribute to the perceived erosion and steeper incline of the shore. This is largely anecdotal evidence, including personal communications of long term residents and various photographs (e.g. Fig. 2; Fig. 3 and Fig. 26). A comparison of the grassed areas in Figure 2 and Figure 3 suggests there may be a degree of erosion that has occurred which may be attributed to pedestrian traffic, stormwater runoff and/or wind/wave forces combined with fluctuating water levels. In surrounding areas (particularly near the south eastern corner) there has also been documented erosion with one source suggesting 15 metres of grass has been eroded over the past two years (pers. comm.). Various actions have been undertaken by Council to reduce foreshore erosion including the placement of logs, restoration of vegetation to stabilise banks, sand dumping in eroding areas, the use of exclusion zones programs. Excessive erosion has the potential to increase sedimentation loads and turbidity, which in some cases have the potential to shorten the lifespan of a lake system. High turbidity levels have the potential to become a nuisance to recreational users and can also increase water temperatures through enhanced solar absorption. Furthermore, areas which are prone to erosion have often shown to exhibit higher than normal nutrient loads in adjacent waters due to an increase in fertile material entering a waterbody. The effect of erosion on the water quality of Lake Ainsworth is at this point undetermined.

There is also local concern regarding the erosion of the sand-dunes at Seven Mile Beach immediately to the east of Lake Ainsworth. With increased storm activity (including the movement of tropical cyclones to the south) and sea level rise there is an identified threat that the sand dunes protecting Lake Ainsworth may be eroded to the point that the Lake becomes open to the ocean. Severe sand dune erosion caused by storm activity has been widely documented (e.g. in Narrabeen, Sydney) and continues to be a major threat to urban development and natural resources along the east coast.

Figure 26. Erosion occurring along the eastern foreshore at Lake Ainsworth. Blue-green algae also present.

6. Conclusions and Recommendations

6.1 Conclusions

A 12 month snapshot analysis of the water quality at Lake Ainsworth has now been conducted. The results suggest that physico-chemical parameters such as dissolved oxygen, pH, turbidity and electrical conductivity are within the expected range of values and will not affect the integrity of the Lake and that it will remain suitable for primary recreational contact. There are degrees of seasonal variation with the parameters mentioned above and also with the parameters mentioned in **4. Water Quality Results and Discussion** and as a result it is necessary to calculate average (and/or median) values relative to each season. This gives environmental managers a better understanding of the specific processes that are occurring in Lake Ainsworth and how best to manage current and impeding issues.

The results of *Enterococci* abundance suggest there may be a slight risk of faecal contamination occurring in Lake Ainsworth, however, this is generally typical of ecosystems with no or limited ocean flushing. An investigation into the source of microbial activity occurring at sample site LA4 may significantly change the perception of water quality in Lake Ainsworth. If the contamination is a result of avian activity, the public health risks are significantly lower and the water quality may be significantly better than previously thought. Furthermore, if the contamination is a result of stormwater flows, then necessary adjustments could be made to reduce or treat stormwater runoff entering the Lake, with the use of water sensitive urban designs.

The results from the nutrient sampling suggest that Lake Ainsworth has significantly high amounts of nutrients with mean total phosphorous (TP) levels peaking in the summer months. These are important findings and suggest blue-green algae blooms will continue to thrive in Lake Ainsworth. Increased mean values of TP in the summer may indicate the importance of stratification in releasing nutrients from the Lake sediment bed. The relationship between the eastern road and an apparent deterioration of water quality in Lake Ainsworth is undetermined in this report. To determine a time period and potential source of high nutrient levels in Lake Ainsworth it would be recommended to collect a sediment core in the deepest section of the Lake (discussed in more detail in **5.2** and **7.2**). This would enable environmental managers to observe changes in nutrient levels over an extended period of time (50-100 years) and perhaps draw linkages between historic events and nutrient influx. Finding a similar type of lake to Lake Ainsworth would be useful as a reference guide and would allow better interpretation of the results obtained at Lake Ainsworth. However, this would be challenging and may not even be possible.

Compared with previous years, the data are becoming more organised and readily available and will provide useful information regarding the state of particular systems. It is recommended to keep the current sampling regime with continued organisation of obtained data. It was noted that data are stored in different databases, particularly in 2014 and prior, for algal abundance, bacteriological and physico-chemical data. Organising historic data is extremely time consuming, however, necessary and the continued monitoring of data entry will ensure there are limited complications in interpreting and using comparative data in the future. Analysing data using the program 'Hydstra' is effective and versatile and should be continued to be utilised. There are numerous recommendations for data collection and storage previously mentioned in **4.1 Water Quality Results and Discussion** and these will be outlined in **7.2 Key Recommendations.** There is now considerably more data available and as such a Coastal Management Program (CMP) can be developed.

6.2 Key recommendations

Table 7. Key recommendations

Management Actions	Issues	Reason for selection	Priority	Agency
Action 1: Develop Coastal Management Program	Continued management and maintenance of Lake Ainsworth	Ensure the integrity of Lake Ainsworth is maintained and remains suitable for public recreation	High	BSC, DPI, NSW Crown Lands
Action 2: Describe algal data with number of bloom events/year (see **Appendix 4**)	Algal abundance data	Determine effectiveness of management strategies (e.g. installation of aerator) in reducing the occurrence of algal blooms	High	BSC
Action 3: Further investigate the organisation of *Enterococci* data	*Enterococci* data not available in Hydstra	Describe data efficiently and effectively. Allow quick analyses of *Enterococci* data over monthly/seasonal basis	Medium	BSC
Action 4: Discuss with Council software engineers feasibility of adding sample sites to iPad configuration	Lake Ainsworth sample sites not available through iPad	Complete sampling of Lake Ainsworth more efficiently and effectively	Medium	BSC
Action 5: Discuss with Council software engineers feasibility of adding water temperature data to Hydstra	Water temperature data not currently accessible in Hydstra	Long term monitoring of water temperature and optimising the period in which the aerator is running. Also determine high risk algal bloom periods	Medium	BSC
Action 6: Continue to monitor depth profiles of Lake Ainsworth (1-2 samples/season)	Lack of current data describing the effectiveness of aerator achieving destratification	Determine the effectiveness of the current aeration regime on the destratification of the water column	Medium	BSC
Action 7: Determine the history of nutrient loading in Lake Ainsworth (from the 1930s onwards) using paleolimnological methods (see **4.2**)	High nutrient levels	Determine the significance of current nutrient levels and whether the situation is improving or deteriorating	Medium	SCU and BSC
Action 8: Microbial source tracking (see **1.4** and **6.2**)	High microbial count	Determine the origin of microbes in Lake Ainsworth and address the issue	Medium	BSC and TSC (Tweed Lab)
Action 9: Determine the feasibility of using	High nutrient levels	Lower nutrient levels in Lake Ainsworth at minimum cost	Medium	Lennox Head

Management Actions	Issues	Reason for selection	Priority	Agency
water hyacinth to lower nutrient levels in Lake Ainsworth	and persistence of water hyacinth			Landcare and BSC
Action 10: Develop control and removal plan of water hyacinth in liaison with Lennox Head Landcare	Water hyacinth invasion	Prevent invasive aquatic plant from smothering Lake Ainsworth.	Medium	Lennox Head Landcare and BSC
Action 11: Investigate and measure development plan in conjunction with engineers	Ongoing erosion	To reduce the impact of associated sedimentation issues and improve grassed areas	Medium	BSC
Action 12: Instalment of additional native riparian vegetation	Limited buffer zone, high nutrient levels, visual amenity, low bank stability	Improve water quality, improve visual amenity, reduce abundance of water hyacinth and blue green algae, improve bank stability and reduce **erosion**	Medium	BSC
Action 13: Spatial survey of *Enterococci* abundance (includes taking large number of samples during one day)	High microbial abundance	Pinpoint location(s)/source(s) of faecal contamination so it can be properly addressed	Medium	BSC
Action 14: Consider feasibility of flow meters or chemical tracers/dyes (or automatic data loggers) Sample storm water drains (as per LAPS, 1996) and determine the extent of influence	Investigate the effect of stormwater flow on the Lake	Determine the contribution of stormwater drains to increased levels of microbes Observe relationship between stormwater and Lake water microbial counts see if relationship exists and whether there is a certain lag-time	Low	BSC
Action 15: After investigation has been completed consider following options: litter booms, sediment traps and gross pollutant traps and the construction of mini wetlands	Potential stormwater flows	Improve water quality by treating stormwater flows	Low	BSC
Action 16: Sediment cores around edge of Lake	High nutrient levels	Determine ratio of nutrients in water column/sediments – understand the dynamics of nutrient influx and storage	Low	BSC
Action 17: Detailed investigation into the presence of hydrocarbons and heavy metals by undertaking sediment sampling	Road traffic and potential decreased quality of water	The presence of hydrocarbons and heavy metals at sample sites near and away from road may determine the effect of road on water quality	Low	BSC
Action 18: Collect chlorophyll – a data once every 6 – 8 weeks (increase frequency of sampling in algal bloom periods)	Observe relationship between blue-green algae and presence of chlorophyll-a data	Determine whether relationship exists between these two variables and observe patterns of algal abundance throughout non-sampling period to gain better understanding	Low	BSC

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Appendix

1. Calculations for Lake Ainsworth Trophic Category

According to the table produced by Brown and Simpson (2001) (see; **Table. 2**), eutrophic Lakes have mean chlorophyll-a (chl-a) levels of around 14 ug/L with a range from 2.7-78 ug/L, a total phosphorous (TP) value of around 84 ug/L with a range from 16 – 390 ug/L and for total nitrogen (TN), the mean value is 1900 ug/L with a range from 390 – 6100 ug/L. TP and TN data have been calculated from 270 and 210 samples respectively, collected once a week over a period of 12 months. Chl-a data have been calculated from eight samples collected over a period of 10 months (August 2015 – May 2016). After the values for Lake Ainsworth are converted from mg/L to ug/L the mean chl-a is 34.375 ug/L with a range from 18 – 59 ug/L, TP mean is 123.4 ug/L with a range from 27 – 350 ug/L and the TN mean is 795 ug/L with a range from 124 – 2797 ug/L (**Table 3**).

A Trophic State Index (TSI) equation developed by Carson (1977) can be used to define the state of the system. The equation: $\mathrm{TSI}(\mathrm{TP}) = 14.42 \ln(\mathrm{TP}) + 4.15$ was used to determine the trophic state of Lake Ainsworth. Mean TP = 123.4 ug/L.

$$14.42 \ln(123.4) + 4.15 = 73.6$$

Another equation using mean chl-a as a variable can also be used in conjunction to determine the trophic state of Lake Ainsworth: $\mathrm{TSI}(\mathrm{CHL}) = 9.81 \ln(\mathrm{CHL}) + 30.6$. Mean chl-a = 34.375.

$$9.81 \ln(\mathrm{CHL}) + 30.6 = 65.3$$

TSI values greater than 50 are generally considered to be eutrophic. TSI values less than 40 are generally considered to oligotrophic and TSI values between 40 and 50 are considered to be mesotrophic. Optimally, three parameters are used to measure the trophic state of a system (chlorophyll *a*, total phosphorous (TP) and Secchi depth) with priority given to chlorophyll *a* as it is often the most accurate in predicting algal biomass and therefore, the trophic state of a system. Because Council don’t analyse Secchi depth data (Due to misleading water clarity data associated with the dissolved tannins and the water colour) and instead use Nephelometric Turbidity Units (NTU), Council describes the trophic state (TSI value) of Lake Ainsworth using chl-a and TP. Although TP can be used to some extent to determine the trophic state of a system it is also important to recognise that TP does not take into account reversibly bound phosphorous and thus may underestimate bioavailable phosphorous. This becomes potentially problematic as reversibly bound phosphorous can be up to 80% of the total phosphorous load and therefore, it may be necessary to measure TP and desorpable phosphorous (DP). The results of this equation are subject to interpretation and due to the generalisation of this equation only provide a rough estimate. Furthermore, this equation was developed to categorise Lakes in the northern hemisphere (North America) and may only have limited application for Lakes in the southern hemisphere, especially considering the generally low nutrient conditions of Australia. Despite this, the equation still provides useful insights into the nutrient requirements for cyanobacterial blooms to persist and therefore a rough determination of the trophic state of an ecosystem.

2. Groundwater Characteristics

Recent work performed by Perkins *et al*. (2015) has highlighted the influence of groundwater seepage on the function of Lake Ainsworth. They estimated that over the course of a year, 55 ± 50% of the total Lake volume originates from groundwater seepages. Senden *et al*. (1996) estimated that in 1995 Lake Ainsworth received an average of 196 m^{-3} day^{-1} of groundwater input with 357 m^{-3} day^{-1} escaping the Lake and entering the ocean through the permeable sand barrier (Perkins *et al*. 2015). Using a different groundwater identification scheme (radon mass balance), Perkins *et al*. (2015) estimated daily groundwater input to be 840 ± 763 m^{-3} day^{-1}, which is more than four times the estimate calculated by Senden *et al*. (1996). It is important to recognise that there were different climatic conditions in 1996 and 2013-2014; with Senden *et al*. (1996) experiencing 14% below-average rainfall and Perkins *et al*. (2015) experiencing 50% below-average rainfall. Furthermore, Senden *et al*. (1996) used stratigraphic and lithological relationships to identify groundwater input, whereas, Perkins *et al*. (2015) used a radon (^{222}Rn) mass balance. Lake sediment heterogeneity is a likely cause for the apparent patchiness of groundwater input into Lake Ainsworth. Groundwater input may be more significant in areas where the Lake's sediments are predominantly sandy (Perkins *et al*. 2015). In contrast, the presence of organic rich muds ('gyttja') in the Lake's bed may reduce or alter groundwater inputs (Senden *et al*. 1996; Perkins *et al*. 2015). The general movement of groundwater was highlighted by Senden *et al*. (1996) and appears to travel from the Newrybar swamp and through a permeable sand barrier and is released into the ocean.

3. Statistical Analyses

A one-way ANOVA was performed to determine whether there was a significance difference between Lake Ainsworth Sites; LA2 (Lake Ainsworth East), LA3 (Lake Ainsworth South) and LA4 (Lake Ainsworth West). There was a significance difference in the abundance of *Enterococci* across the three sample sites (one-way ANOVA, df $^{2,\ 264}$, F = 3.030, P = 0.001). To determine exactly which sites significantly differed, a variety of Post-hoc tests were performed. These included; a Tukey HSD test; a Scheffé multiple comparison; and a Bonferroni and Holm multiple comparison. The results from all post-hoc tests Indicated that site LA4 harboured significantly more *Enterococci* than site LA2 and site LA3 There was no significant difference found between site LA2 and LA3. For the purpose of analysis, data with a score of '<1 CFU/100mL' have been transformed to '1 CFU/100mL'.

4. Quantifying the Abundance of Cyanobacteria (Blue-Green Algae)

It may be possible to use raw data points to represent the data and calculate total yearly values, or alternatively a mean may be calculated for a certain time-period (i.e. weekly/monthly/yearly). Further, depending on the question it may be appropriate to gather means or raw data points at each composite sample site (LA1 and LA2 vs LA3 and LA4) and then comparisons between the north and south end can be made. Frequency of bloom events (indicating a certain score as the threshold for a bloom) could be another method to calculate the abundance of cyanobacteria over an extended period of time. In addition, the frequency of ‘Red Alerts’, ‘Amber Alerts’, ‘Green Alerts’ and ‘No Alerts’ could potentially be used as a factor that measures the abundance of cyanobacteria. To determine the relative abundance of potentially toxic algae species over an extended period of years, data are currently being analysed. Furthermore, due to the vulnerability of algal species to wind dispersion there could be a relationship between algal abundance, season and location. For example, it could be hypothesised that due to prevailing N/NE winds in the warmer months there will be increased abundance of algal species in the southern end and in the cooler months increased abundance in the northern end caused by prevailing S/SE winds. These hypothetical findings would help management predict the occurrence of blooms based on temperature and season.

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