Lake Illawarra Estuary Health Monitoring and Reporting

Report - June 2018

Prepared by Wollongong City Council

Summary

Wollongong City Council has been monitoring water quality in Lake Illawarra since October 2013, in partnership with Shellharbour City Council, the Office of Environment and Heritage, and the University of Wollongong, with funding support from the NSW Government under the Estuary Grants Program. The first report on the outcomes of this program was issued in August 2015, and this was followed up by further reports in July 2016 and June 2017. This is the next report in the series and includes the observations of the past 12 months in reporting the outcomes of the monitoring.

Over the five years of this monitoring program, 15 sites around the lake have been tested monthly for a range for water quality indicators. Two additional sites have been monitored in near real-time for a more limited number of physical parameters. The parameters monitored overall are temperature, dissolved oxygen, pH, salinity, turbidity, and nitrogen, phosphorus, and chlorophyll *a*. The results show that seasonal and weather patterns continue to have an important influence on water quality. Over the summer months (November to April), nutrients and chlorophyll *a* concentrations increase with increasing temperature and daylight hours.

There is strong spatial variability in water quality and the estuary ecosystem health condition of the lake. The entrance channel and the areas of the lake close to it are generally in good to very good condition while areas further away from the entrance and in the more enclosed sections in the north and south of the lake are in much poorer condition. This can be a reflection of the extent of flushing of the lake and suggests that the extreme north and south sections have very limited flushing of the high nutrient loads in these areas. Catchment inputs are especially significant as the year to year variability in water quality and the estuary ecosystem health condition, particularly in the central part of the lake, is related to rainfall.

Four locations within the lake show a statistically significant trend in water quality over the five years of monitoring. At three of these locations, a decrease in the concentration of nitrogen, phosphorus or chlorophyll *a* is apparent while at the fourth location, there is an increase in chlorophyll *a*. The trend analysis was not able to fully account for variations resulting from rainfall changes from year to year, and therefore the decreasing trends at the three locations may be related to the current year being unusually dry. Given this situation, the increase in chlorophyll *a* at the fourth location is noteworthy, as this occurs in the south of the lake which drains a catchment which has undergone a significant increase in the development footprint in recent years. This highlights the importance of putting in effective mechanisms to control catchment inputs to protect the lake into the future.

Continued monitoring of the lake is recommended to confirm any emerging trends in water quality, and to assess the effectiveness of management measures to protect the health of the lake going into the future.

Contents

1 Introduction

Lake Illawarra is a significant natural asset for Wollongong City and Shellharbour City Councils, and the lake is highly valued by the local communities for its ecological, social and economic attributes (BMT WBM 2018). A state-wide assessment of NSW estuaries found Lake Illawarra to be in very good condition but subject to high pressure (NSW Government 2010). The pressure on the lake is expected to intensify, as the development footprint in its catchment continues to increase. An assessment of the lake's response to this pressure, and whether better management strategies are necessary to protect its health, requires a targeted monitoring, evaluation and reporting framework.

The former Lake Illawarra Authority (LIA) had a water quality monitoring program for the lake. With its disbandment from 2013, the responsibility for managing the lake was handed back primarily to Wollongong City and Shellharbour City Councils. This included the responsibility for monitoring water quality in the lake. From October 2013, the lake has been monitored by Wollongong City Council, in partnership with Shellharbour City Council, the Office of Environment and Heritage, and the University of Wollongong, with funding support from the NSW Government under the Estuary Management Grants Program.

In August 2015, Wollongong City Council prepared a report reviewing the data collected over the first 18 months of the program as well as the earlier LIA data, and recommended that the monitoring continue (Wollongong City Council 2015). The next two reports were issued in July 2016 and in June 2017, which included new data obtained over the corresponding periods. These reports further confirmed the findings of the first report that considerable spatial and temporal variability can exist in the lake (Wollongong City Council 2016, 2017). These three reports are available for viewing on the Wollongong City Council webpage. This report includes the data collected in the 12 months since April 2017, and provides a holistic analysis of water quality and estuary ecosystem health condition of the lake across the five years.

2 Background

Lake Illawarra and its catchment straddle the local government areas of Wollongong City and Shellharbour City Councils. The lake has a surface area of 35 km^2, and a catchment of 235 km^2, which lies mostly to the west and is currently mostly undeveloped. However, there are plans to convert a significant part of this area to residential land, and the Calderwood development in the Shellharbour LGA has already significantly advanced in the five years since October 2013. Another major development is in West Dapto, which proposes to add about 19,000 households to the catchment over the next 50 years. Several creeks drain the catchment and discharge into the lake from the west, and in the east there is a trained entrance which connects the lake to the Pacific Ocean (Figure 2-1). The average depth of the lake is about 1.8 m. The increase in the development footprint of the catchment presents a risk to the health of Lake Illawarra, and this issue needs to be forefront of how these developments are planned and managed into the future.

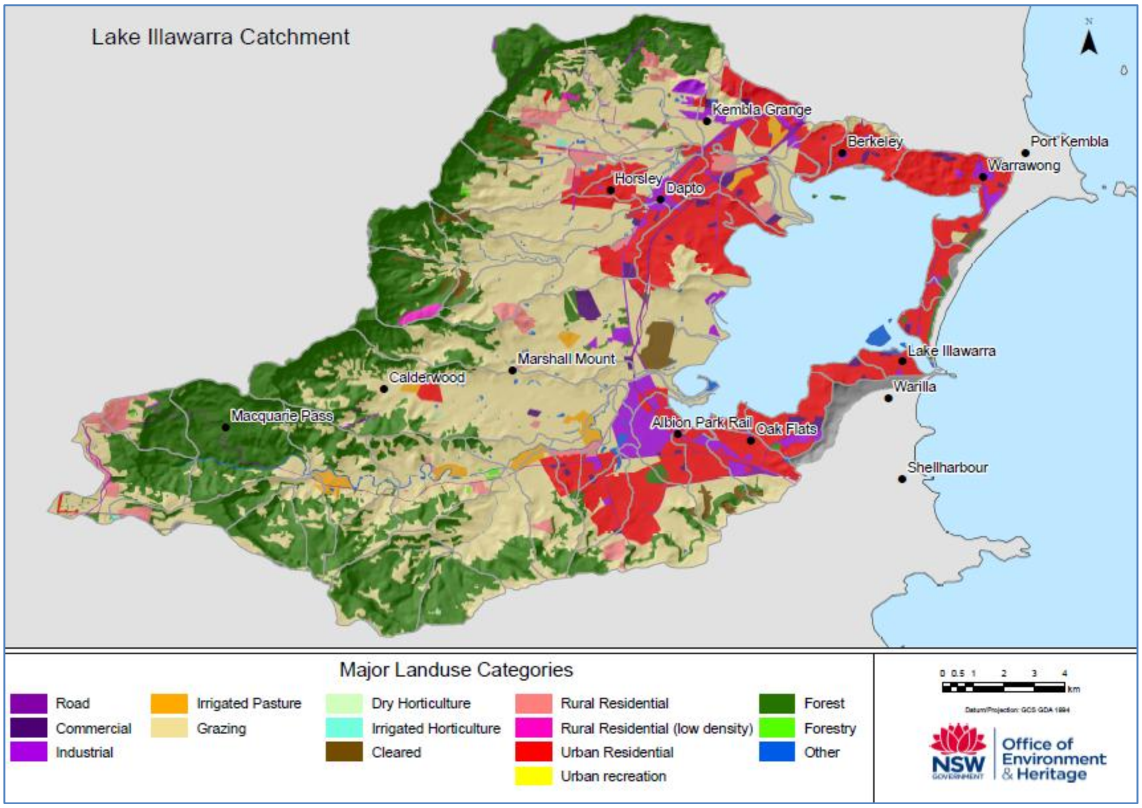


Figure 2-1 Lake Illawarra and its catchment

While the greater part of the catchment is currently not developed, the areas in the immediate surroundings of the lake have significant development; and stormwater from these areas flow into the lake, often with not much treatment. The number of such stormwater outlets is believed to be around 200 (Lake Illawarra Authority 2013). The condition of the lake was very poor in the past, and widespread massive algal blooms were frequently experienced (Lake Illawarra Authority 2010). Over time, measures have been taken to address this situation, which have included training the lake's entrance to maintain an open condition and improve flushing, and installing several stormwater quality improvement devices and wetlands along the lake's margins. As there are no longer significant issues with algal blooms, water quality is perceived to have improved since the permanent opening, but this has been difficult to quantify due to limited comparable data and studies.

WBM Oceanics (2003) discussed the results obtained by Pacific Power, one of the predecessors of Energy Australia, which currently operates the power station at Tallawarra on the western margins of the lake. Pacific Power monitored several locations within the main body of the lake from 1987 to 1991, and again from 1996 to 2000. Their results show that, for most of those periods, the measured parameters, particularly nitrogen, phosphorus, and chlorophyll *a* concentrations, did not comply with the respective ANZECC guideline trigger values (ANZECC 2000). The lake also appeared to be well mixed with little difference in water quality between the various locations, including the entrance, which was reported to be more similar to the rest of the lake than to the ocean water.

This study provides useful data on lake conditions prevailing before the entrance intervention works were initiated, and eventually completed in 2007.

The Lake Illawarra Authority commenced its monitoring in 2005, two years before the entrance works were completed, but they sampled the edges rather than on the main body of the lake. The data collected to 2009 has been reviewed in a lake condition assessment report (Lake Illawarra Authority 2010). The value of this dataset in addressing questions about the impact of the trained entrance on lake water quality is limited, as no locations within the main body of the lake were monitored. Whether the lake edge sites monitored could be considered representative of the main body was also not addressed. Nevertheless, for the sites monitored, the report concluded that no impact of the entrance works on water quality was obvious; highlighting how other factors besides entrance flushing could play an important role in water quality.

The monitoring conducted by Wollongong City Council covers a much wider area of the lake than any of the previous studies. The new information means that the lake changes across space and time can be better understood. The report issued in August 2015 examined the data collected in the first 18 months of this program, and compared this to past datasets from other programs. It showed considerable variations in water quality across the lake. The more enclosed south west and north east sections had very poor water quality, but this was not reflected in the rest of the lake. Further variation appeared between the entrance areas and the more central body of the lake. A strong seasonal and weather influence was also evident, with water quality deteriorating over summer months and over wet weather periods. In addition, comparison of mainly nutrient data from a period before the entrance was trained (1996 to 2000) with the data collected by the councils over the 18 months suggested that the condition of the lake had improved since the entrance was trained. The report recommended that monitoring continue to build a longer term dataset that can further verify these findings, and help track the lake response to ongoing catchment changes. The next two reports issued in July 2016 and June 2017 confirmed the existence of these spatial and temporal variations in water quality.

Another recent report assesses change since 2005, using data collected by the LIA, Wollongong City Council and OEH, as part of its state-wide monitoring, evaluation and reporting program for estuaries (Wiecek, et al. 2016). The results from this study suggest that while there may be some improvement in nutrient concentrations after the 2007 entrance works, this trend is not consistent for all parameters and across all sites. No improvement is evident for chlorophyll *a* and turbidity across all sites, which are considered better indicators of estuary ecosystem health. While it is clear from this study that there has not been a lot of measured improvement since 2007, it remains more difficult to determine whether water quality in the lake prior to completion of entrance training was poorer because of limited data that exists for the period immediately prior to 2005.

3 Monitoring Program

3.1 Location of sampling sites

Figure 3-1 shows the location of the sampling sites monitored by Wollongong City Council and Figure 3-2 shows the two sites monitored by the Manly Hydraulics Laboratory. The Manly Hydraulics Laboratory program is described in Section 3.4; and the sections preceding describe the council program. Sites 1, 2, 3, 4, 5 and 6 in Figure 3-1 were previously monitored by the LIA, and these sites were retained in the council program. Four additional sites (Sites 3A, 4A, 5A, and 6A) were added in January 2014 to get more representative coverage of the lake margins. Five locations were added in March 2014 within the main body of the lake: NS1, NS2, NS3 along a north-south transect and EW1 and EW2 along an east-west transect. The 15 sites can be grouped into three categories, the entrance area, along the lake edges, or in-lake, depending on their location within the lake (Table 3-1)

Figure 3-1 Map showing location of the monitoring sites

Table 3-1 Description of monitoring sites

ID	Site Location	Lake Zone
Site 1	Entrance Channel at the south training wall	Lake Entrance
Site 2	Boat ramp at Windang Peninsula	Lake Entrance
Site 3	Bridge to Picnic Island	Lake Entrance
Site 3A	Jetty at Boonerah Point Reserve	Lake Edge
Site 4	Jetty at Sailing Club at Burroo Bay	Lake Edge
Site 4A	Jetty at Tallawarra Power Station	Lake Edge
Site 5	Boat ramp and jetty at Kanahooka	Lake Edge
Site 5A	Jetty at Holborn Park Reserve	Lake Edge
Site 6	Jetty at Griffins Bay Wharf	Lake Edge
Site 6A	Jetty at Purry Burry Reserve	Lake Edge
NS1	North along a north-south transect	In-lake
NS2	Middle along a north-south transect	In-lake
NS3	South along a north-south transect	In-lake
EW1	East along an east-west transect	In-lake
EW2	West along an east-west transect	In-lake

3.2 Frequency of monitoring

All entrance and lake edge sites (except Sites 1 and 2) have been monitored monthly; monitoring for most sites commenced in October 2013, whilst those labelled "A" in January 2014. The in-lake sites were monitored in March 2014, July 2014, Sep 2014, and monthly since then. Monitoring at Site 1 was discontinued after December 2017 because of safety considerations, as access to this site requires climbing down over training wall rocks which have become unstable. However, this is not a major drawback for the program, as Site 2 which is also in the entrance area, has similar water quality as Site 1. Site 2 was monitored twice on the scheduled monitoring day, once on the incoming tide and then on the outgoing tide, for nine months from August 2017 to April 2018, to determine the extent of any change in water quality as a result of mixing and flushing of the lake over a tidal cycle.

3.3 Sample collection and Water Quality measurements

The focus of the council monitoring program is on assessing estuary ecosystem health, and the water quality measurements being made reflect this goal. At each site, the prevailing rainfall, wind and wave conditions are noted. Then, a sampling pole and bottle are used to collect 8 to 10 batches of water, which are combined into a bucket previously rinsed with site water. The test samples are obtained from the composite, to ensure that the samples analysed are representative of the site, especially for constituents such as chlorophyll *a*, which can be patchy over small areas. The test samples include a litre of unfiltered water for chlorophyll *a*, and approximately 200 ml of filtered (0.45 µm filter) and unfiltered water for various forms of the nutrients, nitrogen and phosphorus.

All samples are kept in cold storage (<4 ^{o}C) while in the field. The chlorophyll *a* samples are sent away for analysis on the day of sampling, and the nutrient samples the next day after being allowed to freeze for a day. The samples are analysed by the Sydney Water Analytical Laboratory based in West Ryde in Sydney. Other measurements are made in-situ after test samples have been collected, with a pre-calibrated YEO-KAL water quality multimeter, calibrated by staff at the University of Wollongong. These on-site measurements include temperature, pH, dissolved oxygen, salinity, and turbidity. A HACH model turbidity meter is available as a backup.

Nitrogen is analysed as total nitrogen in unfiltered water (TN), the total after filtration (FTN), and the amount present as nitrate and nitrite (often referred to as NOx's), and as ammonia. These latter inorganic forms of nitrogen are considered to be generally more bioavailable than TN and FTN. Phosphorus is analysed as total phosphorus in unfiltered water (TP), in filtered water (FTP), and as filterable reactive phosphorus (FRP). The filterable reactive phosphorus constitutes generally simple inorganic phosphorus (such as orthophosphate), and is considered to be more bioavailable than other forms of phosphorus. Chlorophyll *a* is an indicator of the microalgal abundance in a water body, and is preferred as a measure for estuary ecosystem health assessment, as it is reported to be a good short-term indicator of response to a range of pressures and management, including nutrient inputs.

3.4 Manly Hydraulics Laboratory Monitoring

The Manly Hydraulics Laboratory was contracted by the Lake Illawarra Authority to install and operate instrumentation at two locations within the lake, at Koonawarra and Cudgeree Bays, to provide near real-time measurements of a number of physical water quality indicators. This arrangement has been retained under the current program. Temperature, pH, and salinity are monitored at both stations, whilst dissolved oxygen is measured at Koonawarra only. Figure 3-2 shows the location of these monitoring stations.

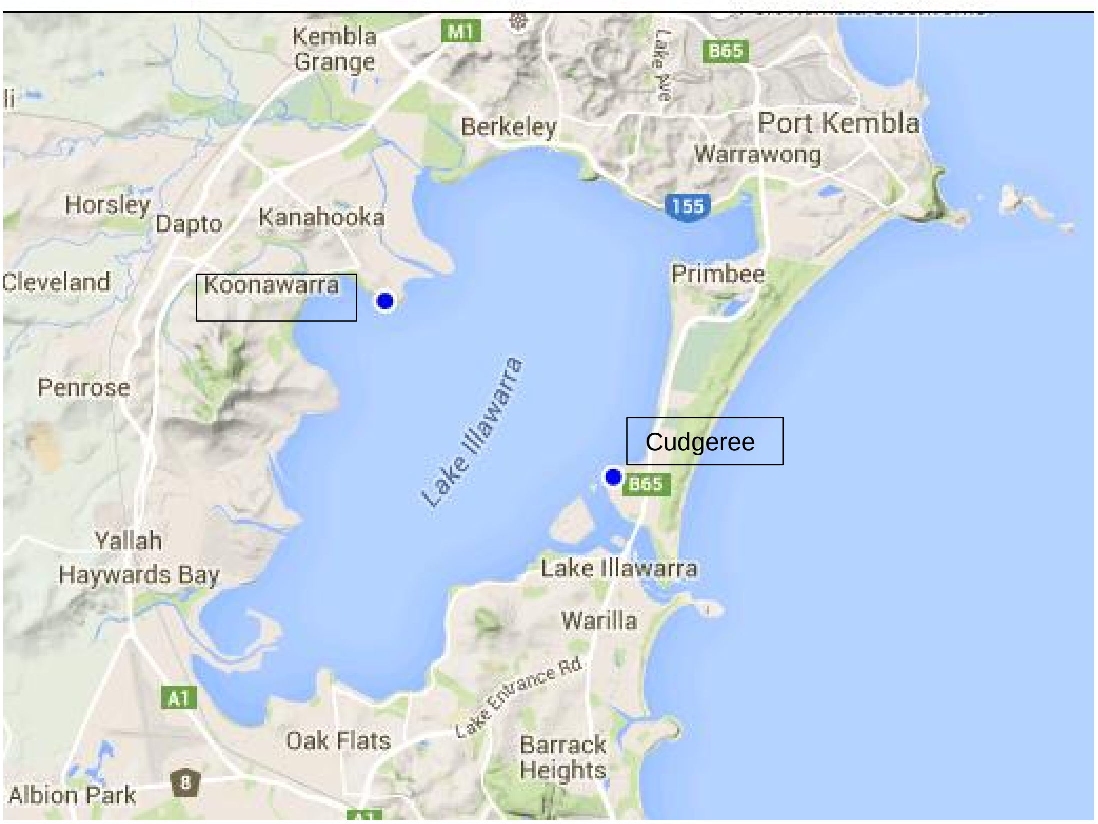


Figure 3-2 Map showing location of the two Manly Hydraulics monitoring stations

4 Data Analysis

4.1 Water Quality

The indicators monitored are plotted against sampling date, rainfall, and the corresponding guideline trigger values where available (Table 4-1), for a qualitative assessment of the spatial and temporal patterns evident over the five years of monitoring. Rainfall records used are for the Darkes Road station, a location close to Lake Illawarra. The guideline trigger values utlilised for chlorophyll *a* and turbidity continue to be the values previously adopted for the NSW Monitoring, Evaluation and Reporting Program (State of NSW and Office of Environment and Heritage 2013) rather than the updated values (State of NSW and Office of Environment and Heritage 2016), in order to maintain consistency with the values ulitised in earlier reports in this series. In any event, the central body of Lake Illawarra (the in-lake sites) and the entrance sites often have chlorophyll *a* and turbidity values close to or less than the 2013 guidelines trigger values, and these are the values that have been utilised by OEH in developing a risk-based framework for protecting the health of Lake Illawarra (Office of Environment and Heritage and the Environment Protection Authority 2017). Therefore, there is reasonable grounds for retaining these values as the desired target condition for the rest of the lake.

Table 4-1 Guideline trigger values utilised

Parameter	Guideline	Source
Dissolved oxygen*	80 to 100% saturation	ANZECC (2000)
pH	7 to 8.5	ANZECC (2000)
Turbidity	5.7 NTU[a]	State of NSW and Office of Environment and Heritage (2013)
Total Nitrogen (TN)	0.3 mg/L	ANZECC (2000)
Filtered Total Nitrogen (FTN)	0.3 mg/L	Based on TN from ANZECC (2000)
Nitrate and Nitrite (NOx's)	0.015 mg/L	ANZECC (2000)
Ammonia	0.015 mg/L	ANZECC (2000)
Total Phosphorus	0.03 mg/L	ANZECC (2000)
Filtered Total Phosphorus	0.03 mg/L	Based on TP from ANZECC (2000)
Filtered Reactive Phosphorus	0.005 mg/L	ANZECC (2000)
Chlorophyll *a*	3.6 µg/L[b]	State of NSW and Office of Environment and Heritage (2013)

* Dissolved oxygen was measured as mg/L, therefore the percent saturation guideline could not be utilised
[a] This value has been updated to 6 NTU in State of NSW and Office of Environment and Heritage (2016)
[b] This value has been updated to 5 µg/L in State of NSW and Office of Environment and Heritage (2016)

The extent of spatial variability in the lake has been determined using multidimensional scaling. The extent to which the lake is flushed has an important bearing on the impact of catchment and other inputs on spatial variability. Three empirical methods are used to determine the potential residence time of materials introduced into the lake, and consider the implications of this for water quality. In addition, for Site 2, where the incoming and outgoing water have been analysed, a paired t-test is used for insight into any change in water quality as a result of mixing and flushing of the lake over a a normal tidal cycle.

The data for TN, TP, chlorophyll *a* and turbidity have also been subjected to a trend analysis to determine whether statistically significant trends are apparent for these indicators at any of the sites over the five years. The non-parametric Seasonal Kendall test has been used for this, a method that is widely used to detect trends where there is a significant seasonal infuence on water quality.

4.2 Estuary Ecosystem Health Condition

The estuary ecosystem health condition of each site has been determined on the basis of its chlorophyll *a* and turbidity status over the summer months (November to April). The methodolgy used is consistent with that recommended by the NSW Monitoring, Evaluation and Reporting (MER) Framework, which assesses the degree of compliance of these parameters with their water quality trigger values, and allocates a condition grade ranging from very poor to very good, as described in Table 4-2 (State of NSW and Office of Environment and Heritage 2013). As noted above, the trigger values utilised for chlorophyll *a* and turbidity are 3.6 µg/L and 5.7 NTU respectively, rather than the updated values as reported in 2016 (State of NSW and Office of Environment and Heritage 2016).

Table 4-2 Descriptors for estuary ecosystem health condition grades

Grade	Defintion
Very Good	The indicator meets the benchmark values for almost all of the time period.
Good	The indicator meets the benchmark values for most of the time period.
Fair	The indicator meets the benchmark value for some of the time period.
Poor	The indicator does not meet the benchmark value for most of the time period.
Very Poor	The indicator does not meet the benchmark value for almost all of the time period.

5 Results and Discussion

In a waterbody such as Lake Illawarra, a number of factors can influence the water quality observed at any point in time. These include weather conditions, catchment inputs, uptake and release of materials by sediments and aquatic plants and other organisms, and extent of flushing by tidal waters and catchment runoff. These factors may not necessarily be uniform throughout the lake in space and time, and this can be reflected in the results obtained. One of the more significant factors changing over time is weather conditions, and the relevance of this is for Lake Illawarra is discussed below.

5.1 Weather Conditions

The weather conditions recorded for Lake Illawarra are the daily rainfall totals and wind and wave conditions prevailing on the day of sampling. Wind and wave conditions are important because they determine the level of turbulence in the water and in a lake such as Lake Illawarra, dominated by silty bottom sediments, this can have an effect on water clarity (turbidity) and other indicators which are related to the amount of suspended material in the water (such as nitrogen and phosphorus concentrations). The shallower edge and entrance sites are likely to be affected more than the in-lake sites, but this depends on their level of exposure and the wind direction. The wind and wave conditions usually varied from site to site and from one monitoring occasion to another.

Rainfall conditions are important because they determine the level of catchment influence on water quality in the lake. Table 5-1 presents the winter, summer and total annual rainfall data for the past nine years for a site in the lake's catchment, and it shows that that the recent 12 months have been unusually dry when compared to earlier periods. This means that runoff from the catchment would have been very limited in the recent 12 months in comparison to previous years, and raises the question whether this variation is reflected in the water quality conditions observed.

Table 5-1 Seasonal rainfall (mm) at Darkes Road for the past nine years

Season	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18
Winter	333.5	520	476.5	215	498.5	365	461	602.5	108
Summer	523	800	616	515	813	771.5	460	748	458
Total	856.5	1320	1092.5	730	1311.5	1136.5	921	1350.5	566

Winter – May to October; Summer – November to April

5.2 Physical Measurements

5.2.1 Temperature

Temperature has an important influence on the biogeochemical reactions occurring in a waterbody. Its real-time measurement at the Cudgeree and Koonawarra stations (Figure 5-1) and the monthly measurement at the other 15 sites (Figure 5-2) in the recent 12 months continue to show a seasonal pattern as evident in previous years. The variation between summer and winter can be as much as 20 ^{o}C. This is a significant difference and can be expected to cause seasonal change in other water quality processes which are temperature dependent.

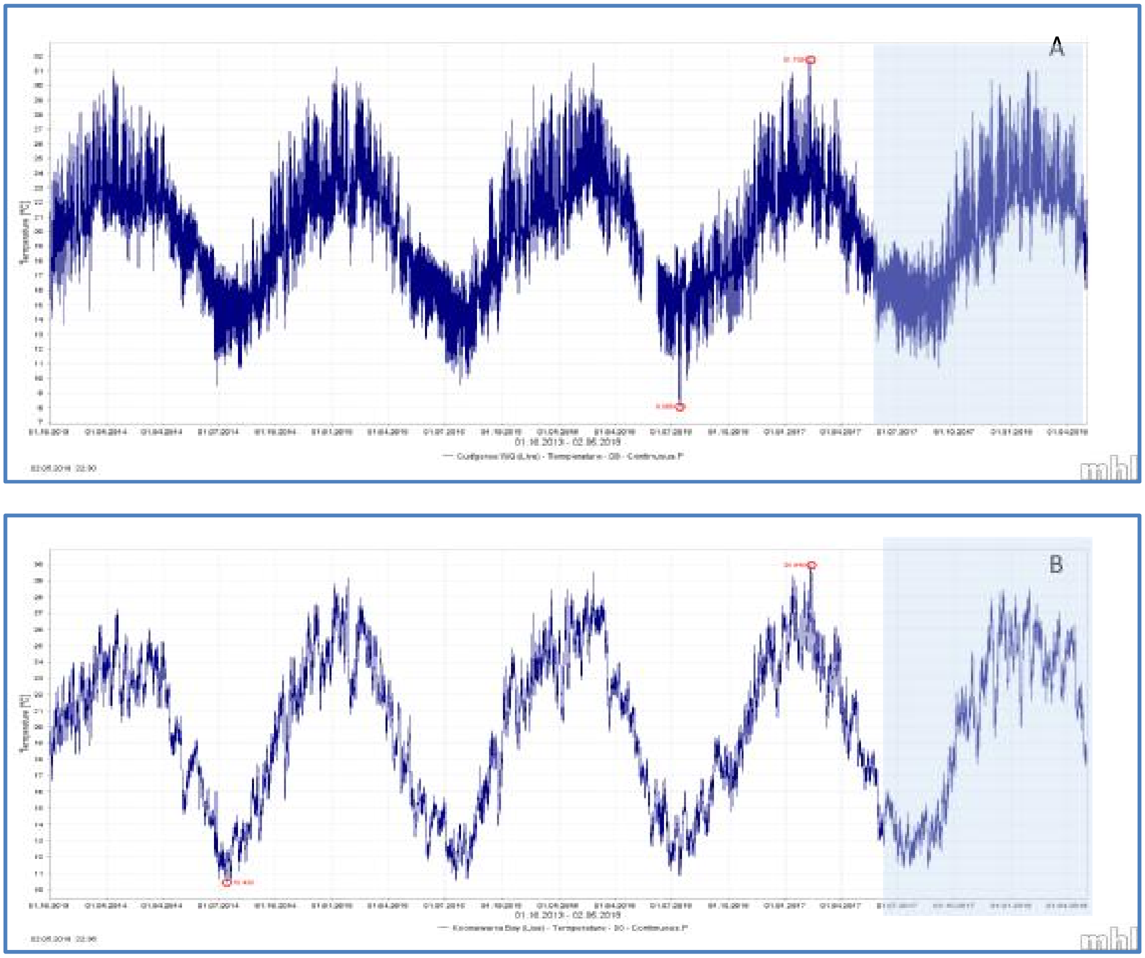
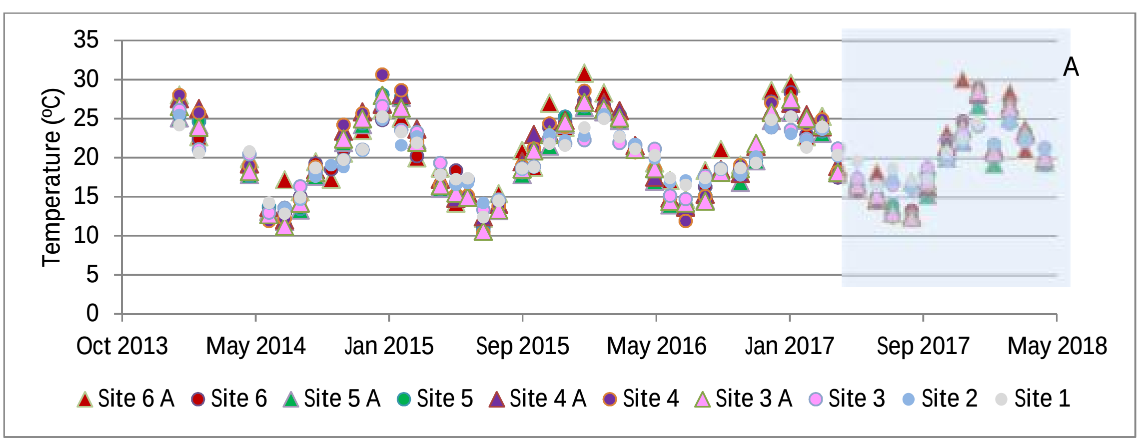


Figure 5-1 Plots of temperature against time for the Cudgeree (A) and Koonawarra (B) monitoring stations – shaded area shows the recent 12 months



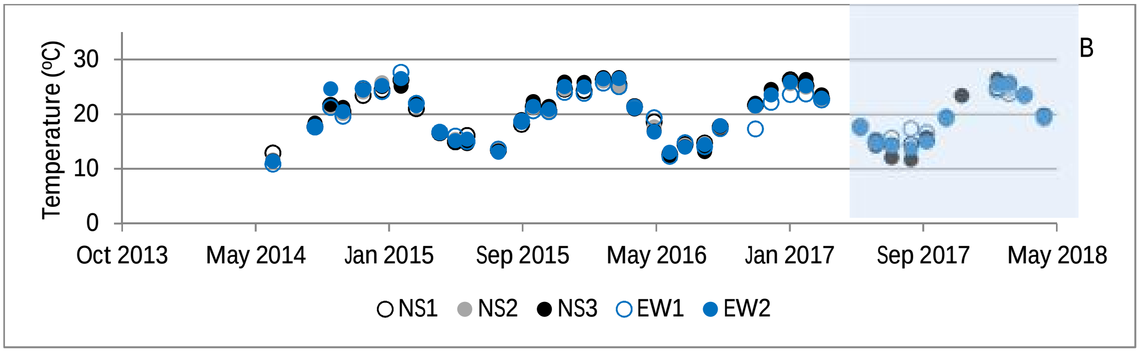


Figure 5-2 Plots of temperature against time for the lake edge and entrance sites (A) and in-lake locations (B) – shaded area shows the recent 12 months

5.2.2 Dissolved Oxygen

The amount of dissolved oxygen present in a waterbody is a balance between supply (aeration, diffusion, photosynthesis) and demand (respiration, decomposition) processes, and it is influenced by the temperature, pressure and salinity of the water. Where no salinity gradient is present, there is usually a decrease in dissolved oxygen with increasing temperature. Therefore, daily and seasonal variations in water temperature can be expected to show related variations in the dissolved oxygen concentrations.

Continuous measurement of dissolved oxygen is only done at the Koonawarra station, and the observations to April 2018 are presented in Figure 5-3, whilst the monthly observations at the edge, entrance and in-lake locations are presented in Figure 5-4. As noted in previous reports, daily and seasonal variations continue to be evident, with generally higher concentrations occurring over the winter than the summer months because of the temperature effect on dissolved oxygen. In the recent 12 months, the concentrations ranged from 5 to 10 mg/L again, and these values are not unsatisfactory for the protection of aquatic ecosystems. The exception around May and June 2017 when concentrations approached 15 mg/L is probably related to instrument malfunction rather than real values. Also, as noted before, there is not as much variation between in-lake locations as between the lake edge locations on any sampling occasion. As before, this can be explained in terms of the temperature effect. All in-lake sites are able to be monitored within an hour or so, when the ambient temperature is unlikely to vary much from start to finish. This is not the case for the edge sites, which are monitored from early morning to late afternoon, when there can be considerable change in the ambient temperature.

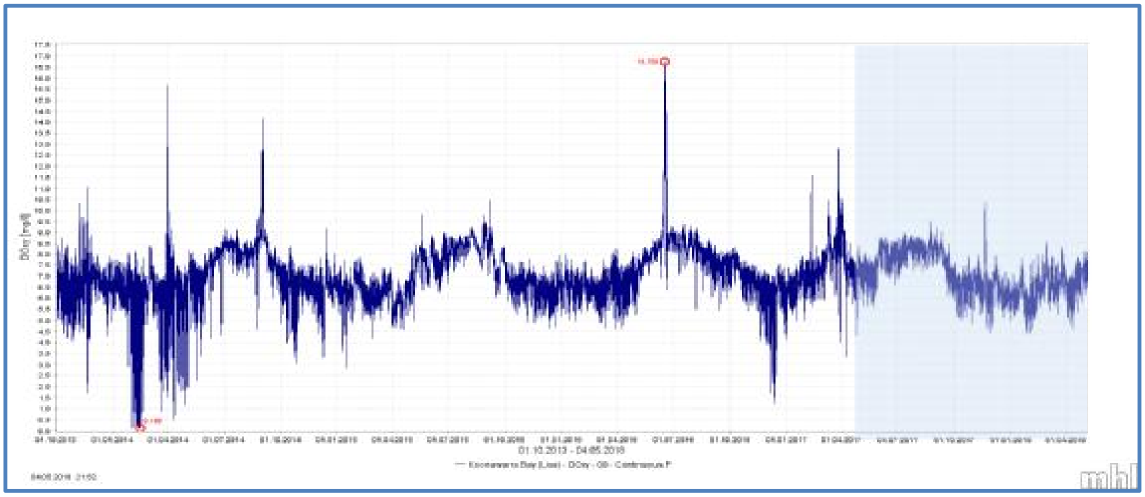


Figure 5-3 Plot of dissolved oxygen against time for the Koonawarra monitoring station – shaded area shows the recent 12 months

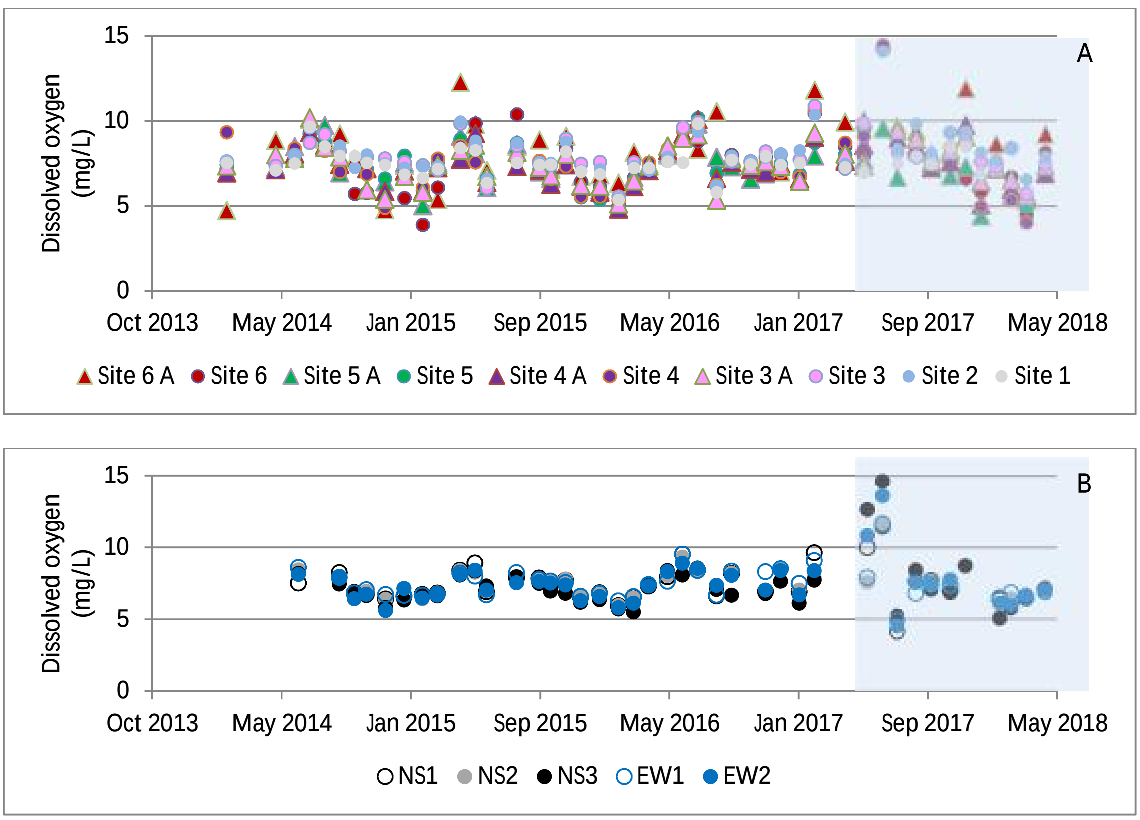


Figure 5-4 Plots of dissolved oxygen against time for the lake edge and entrance sites (A) and in-lake locations (B) – shaded area shows the recent 12 months

5.2.3 pH

The pH at the Cudgeree and Koonawarra monitoring stations (Figure 5-5), and at the edge, entrance sites in-lake locations (Figure 5-6) shows that the pH is rarely below 7, and more likely to be around 8 at all locations, which is close to the pH of seawater (8.2). A range of 7 to 8.5 is considered to be satisfactory for estuarine ecosystems (ANZECC 2000), which would suggest that there are no concerns relating to pH at Lake Illawarra.

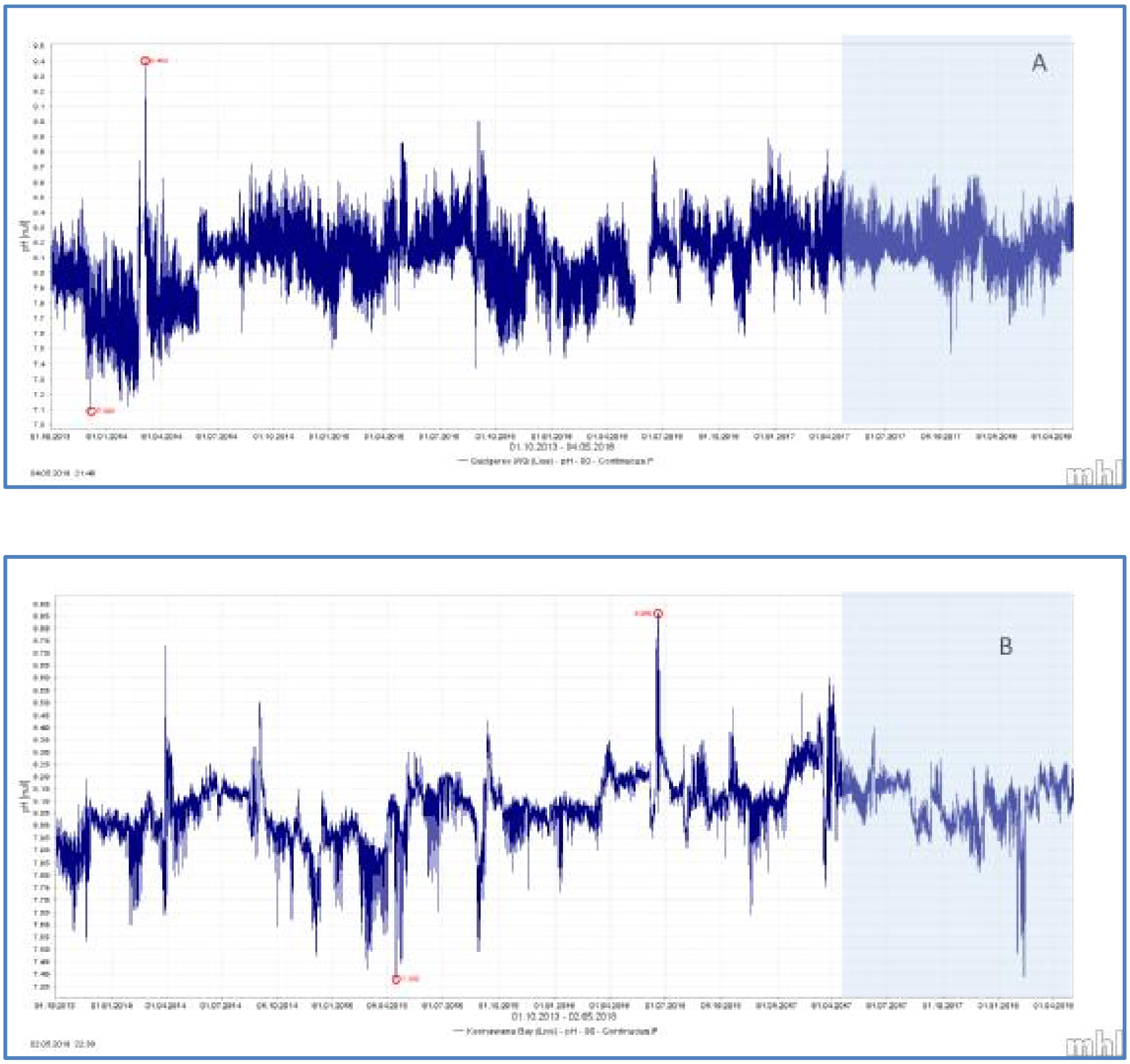


Figure 5-5 Plots of pH against time for the Cudgeree (A) and Koonawarra (B) monitoring stations – shaded area shows the recent 12 months

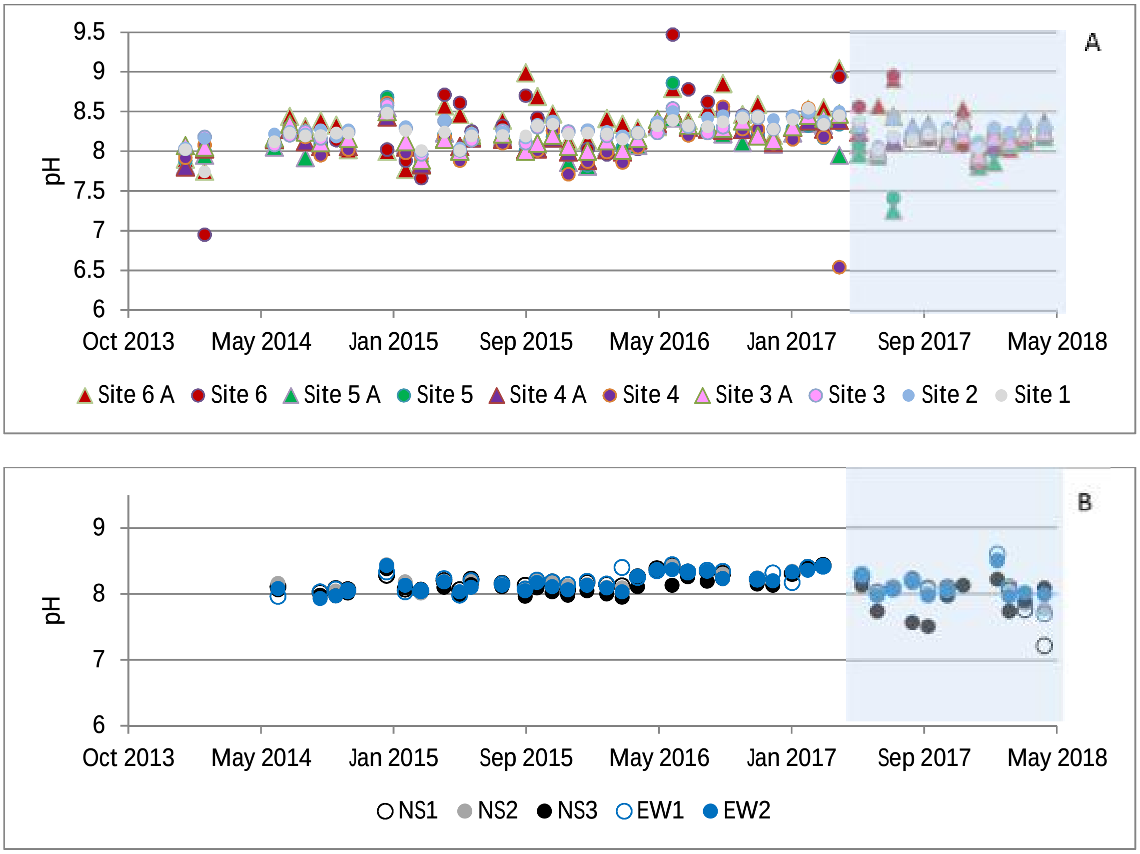
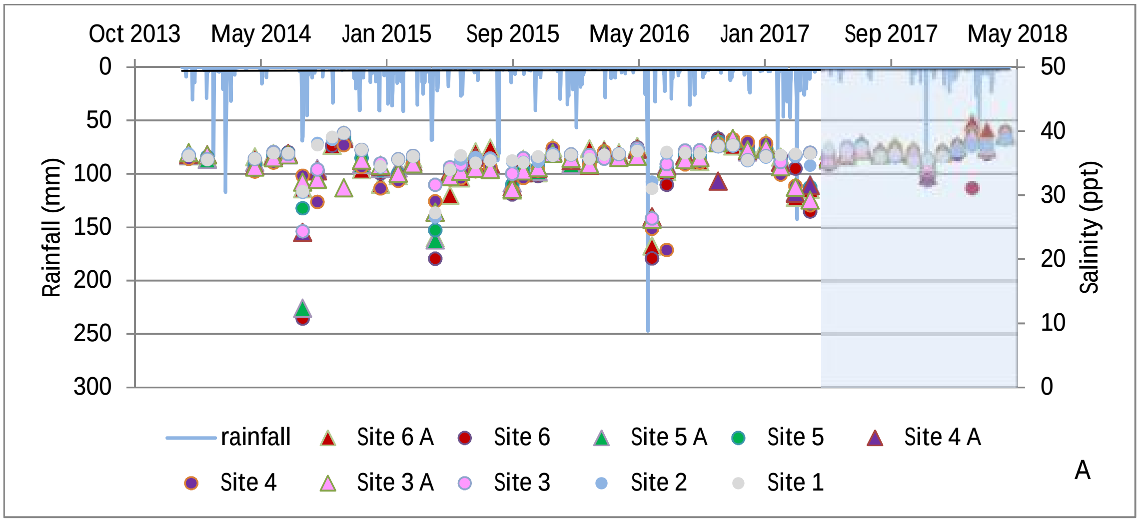


Figure 5-6 Plot of pH against time for the lake edge and entrance sites (A) and in-lake locations (B) – shaded area shows the recent 12 months

5.2.4 Salinity

Figure 5-7 presents the salinity recorded at the edge, entrance and in-lake locations over the monitoring period, against the daily rainfall records for the period. The results show that a salinity value of around 35 ppt continues to be maintained, except close to rainfall events when it decreases temporarily. The recent 12 months have been unusually dry and as a result there have not been too many occasions when this has happened. If anything, the drier period has resulted in salinity values higher than 35 ppt being frequently recorded in recent months. Estuarine biota are generally tolerant of fluctuations in salinity, so the changes recorded are not expected to be a cause for concern.



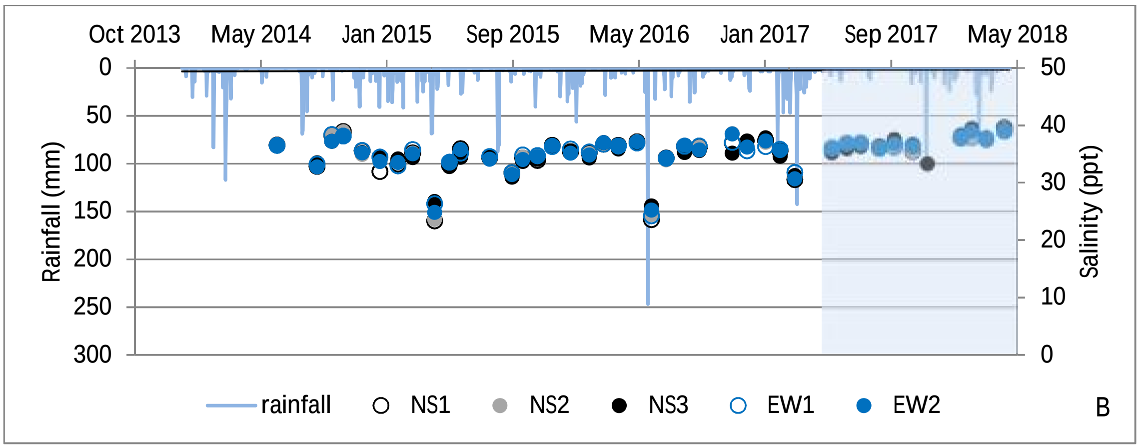
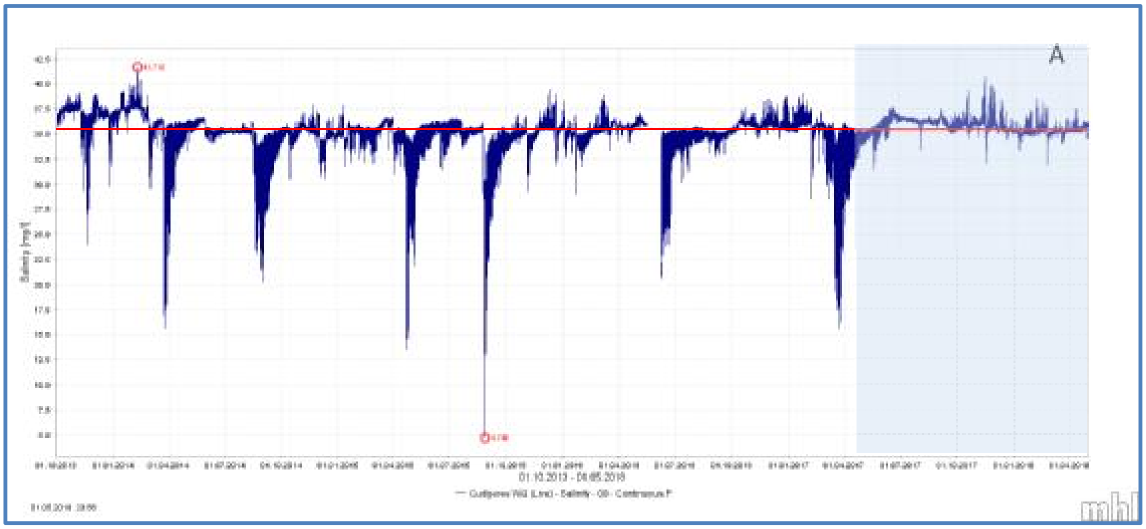


Figure 5-7 Plots of salinity and rainfall against time for the lake edge and entrance sites (A) and in-lake locations (B) – shaded area shows the recent 12 months

The continuous measurements of salinity at Cudgeree and Koonawarra stations (Figure 5-8) show similar results to the monthly monitored sites, with dips in salinity around rainfall events when more runoff from the catchment flows into the lake. This is more noticeable for Koonawarra than the Cudgeree monitoring station. This is because the Koonawarra station is on the western side of the lake and closer to where the tributaries to the lake discharge, and it is therefore more susceptible to freshwater inflows than Cudgeree, which is on the eastern side and closer to the tidal inlet.



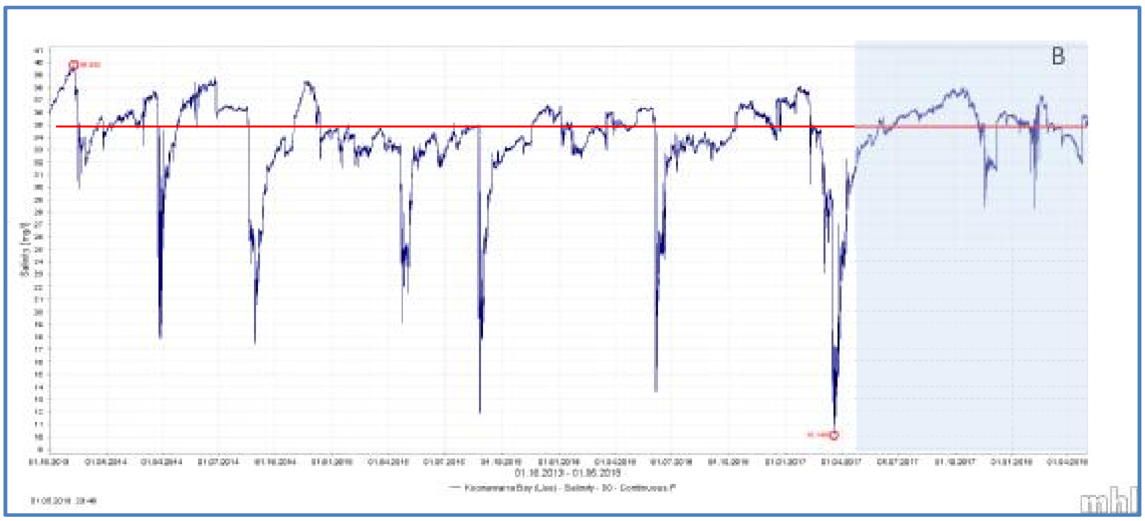
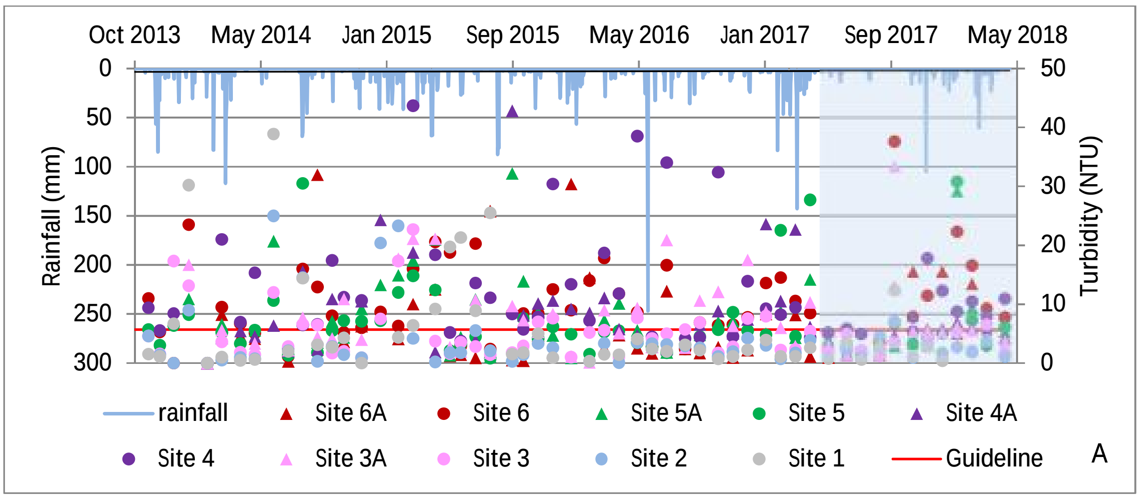


Figure 5-8 Plots of salinity against time for the Cudgeree (A) and Koonawarra (B) monitoring stations (red line marks a salinity level of 35 ppt and shaded area shows the recent 12 months)

5.2.5 Turbidity

Turbidity is not monitored as part of the continuous monitoring program at Cudgeree and Koonawarra. The data for the monthly monitored locations are presented in Figure 5-9. A turbidity of 5.7 NTU was previously recommended as the trigger value for assessing the health of estuarine ecosystems that are classified as a "Lake" (State of NSW and Office of Environment and Heritage 2013), and this value was utilised in previous Council reports on lake water quality. This trigger has now been increased to 6 NTU (State of NSW and Office of Environment and Heritage 2016), but a trigger of 5.7 NTU will continue to be used for Lake Illawarra to maintain continuity with previous reports.

The results for the last 12 months again show greater exceedance of the trigger value at the edge sites than within the main body of the lake. In addition, although there is much deviation at the edge sites, associated with many different factors that can influence the turbidity of the water in these locations (as discussed in previous reports), a background seasonal pattern is emerging suggesting a summer maximum (around January) and a winter minimum (around June). This is because the microscopic algal content of the water (reflected by the chlorophyll *a* content which is discussed Section 5.2.3) increases over summer, and this is another factor influencing the turbidity of the water.



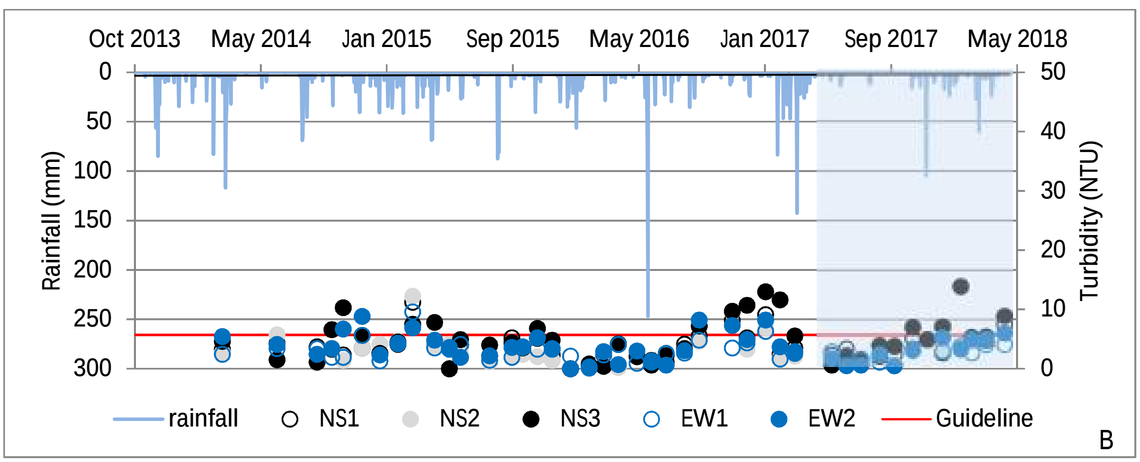


Figure 5-9 Plots of turbidity and rainfall against time for the lake edge and entrance sites (A) and in-lake locations (B) – shaded area shows the recent 12 months

5.3 Nutrients and Chlorophyll *a*

When assessing the condition of a water body, chlorophyll *a* and turbidity are considered to be better indicators of estuary ecosystem health than the nitrogen and phosphorus concentrations, as high nutrient concentrations do not always correlate with poor water quality (Scanes, et al. 2007). High nutrient inputs can, however, lead to poor water quality, and monitoring their concentrations in different parts of the lake can help identify where nutrient inputs may be significant and may require management.

5.3.1 Nitrogen

The concentrations of nitrate, nitrite, and ammonia were again almost always below or close to their respective detection limits (0.01 mg/L for all) in the recent 12 months, indicating that these more bio-available forms of nitrogen continue to be rapidly utilised by phytoplankton and other plant life in the lake. Nitrogen is considered to be the limiting nutrient for primary production in Lake Illawarra and the results for nitrate, nitrite and ammonia for the recent 12 months lead further support to this hypothesis (WBM Oceanics Australia 2003). A limiting nutrient is a relatively scarce element which controls the amount of plant growth in the lake.

The exception to this general trend has been noted again around the Griffins Bay area (Sites 6 and 6A) where ammonia concentrations in the range of 0.03 to 0.06 mg/L were measured at up to six occasions over the recent 12 months. While these are not significantly higher than the background values, a very high value has been reported at Griffins Bay previously when the ammonia concentration exceeded the background value by about 100 times around the high rainfall event associated with the East Coast Low of June 2016. This suggested that the catchment around this part of the lake is a significant contributor to the nitrogen load on the lake. The current results lead further support to this suggestion.

Figure 5-10 presents the total nitrogen (TN) concentrations recorded in the recent 12 months together with the previously recorded results. The recent results are generally consistent with previous observations, showing much higher concentrations at some of the lake edge sites than at the entrance sites or the in-lake zones, except in February 2018, when a very high concentration (about 1 mg/L) was recorded at NS3, an in-lake site in the lake's south. There was not much rainfall around this sampling occasion, and such a high value has not been recorded at any of the in-lake sites since the beginning of this monitoring program, even when there was significant rainfall in the catchment, which suggests that this may be an anomaly due probably to contamination of the test sample.

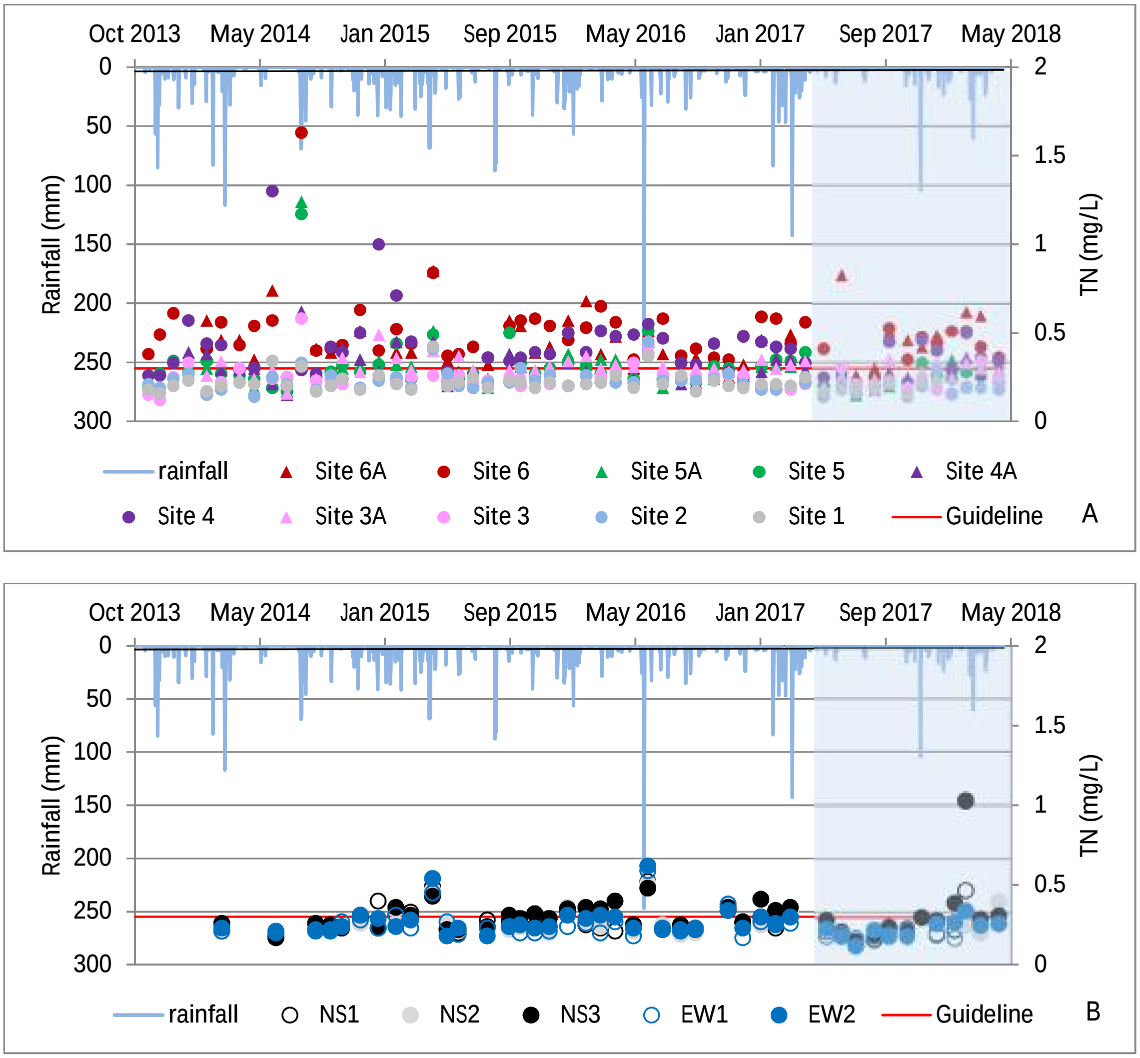
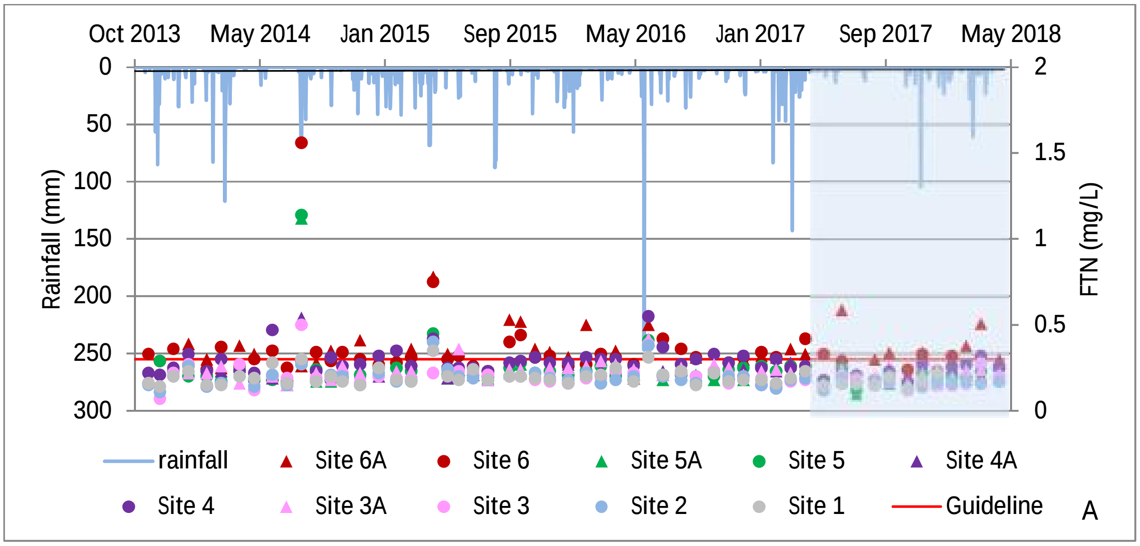


Figure 5-10 Plots of total nitrogen (TN) and rainfall against time for the lake edge and entrance sites (A) and in-lake locations (B) – shaded area shows the recent 12 months

The filtered total nitrogen (FTN) for the recent 12 months (Figure 5-11) shows better compliance with the guideline trigger value than the total nitrogen, as was evident in previous reports. For Site NS3, the anomaly noted for TN is evident for FTN as well, but this can be expected as the test sample for each is obtained from the same composite. The TN value represents nitrogen that is present in water in both the dissolved and suspended forms, including microscopic algae and sediments, while the FTN excludes the suspended component. In most areas of the lake, the dissolved fraction makes up about 80% of the total nitrogen regardless of the time of the year. The exceptions are at Burroo Bay (Site 4) and Griffins Bay (Site 6) over the summer months when the dissolved and suspended forms are about equal, because of the significant increase in the amount of microscopic algae at these sites over the summer months (as evident by the chlorophyll *a* results).



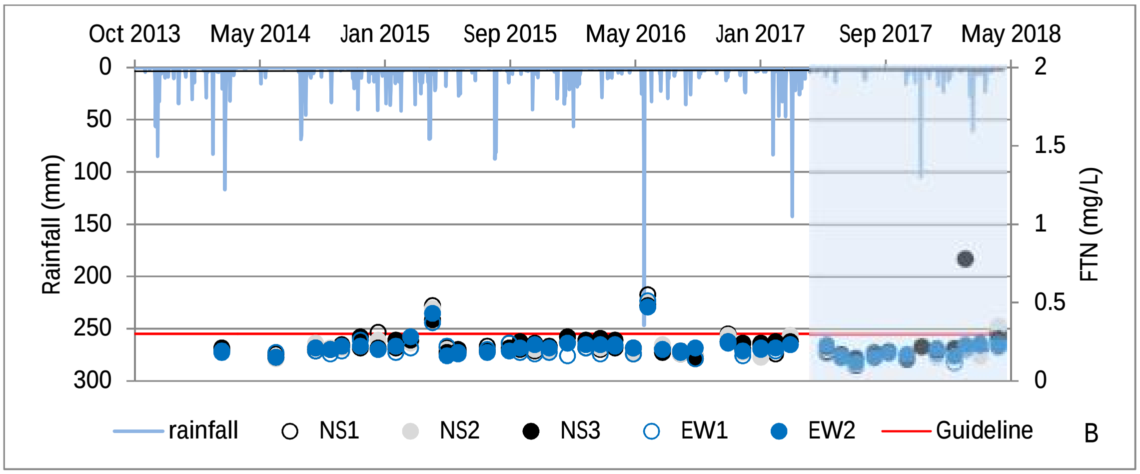


Figure 5-11 Plots of filtered total nitrogen (FTN) and rainfall against time for the lake edge and entrance sites (A) and in-lake locations (B) – shaded area shows the recent 12 months

5.3.2 Phosphorus

Figure 5-12 presents the total phosphorus (TP) concentrations measured in the lake over the recent 12 months alongside previously recorded measurements. The recent observations are very similar to previous observations, with a number of sites routinely exceeding the guideline value. Along the lake edges, Burroo Bay (Site 4) continued to exhibit the highest concentrations, followed closely by Griffins Bay (Site 6), and within the lake itself, the south (NS3) continued to have the highest concentrations. However, the very high concentration recorded at NS3 in February 2018 coincides with the nitrogen observations for this site and may be an anomaly due to sample contamination as well, as was suggested for the nitrogen results.

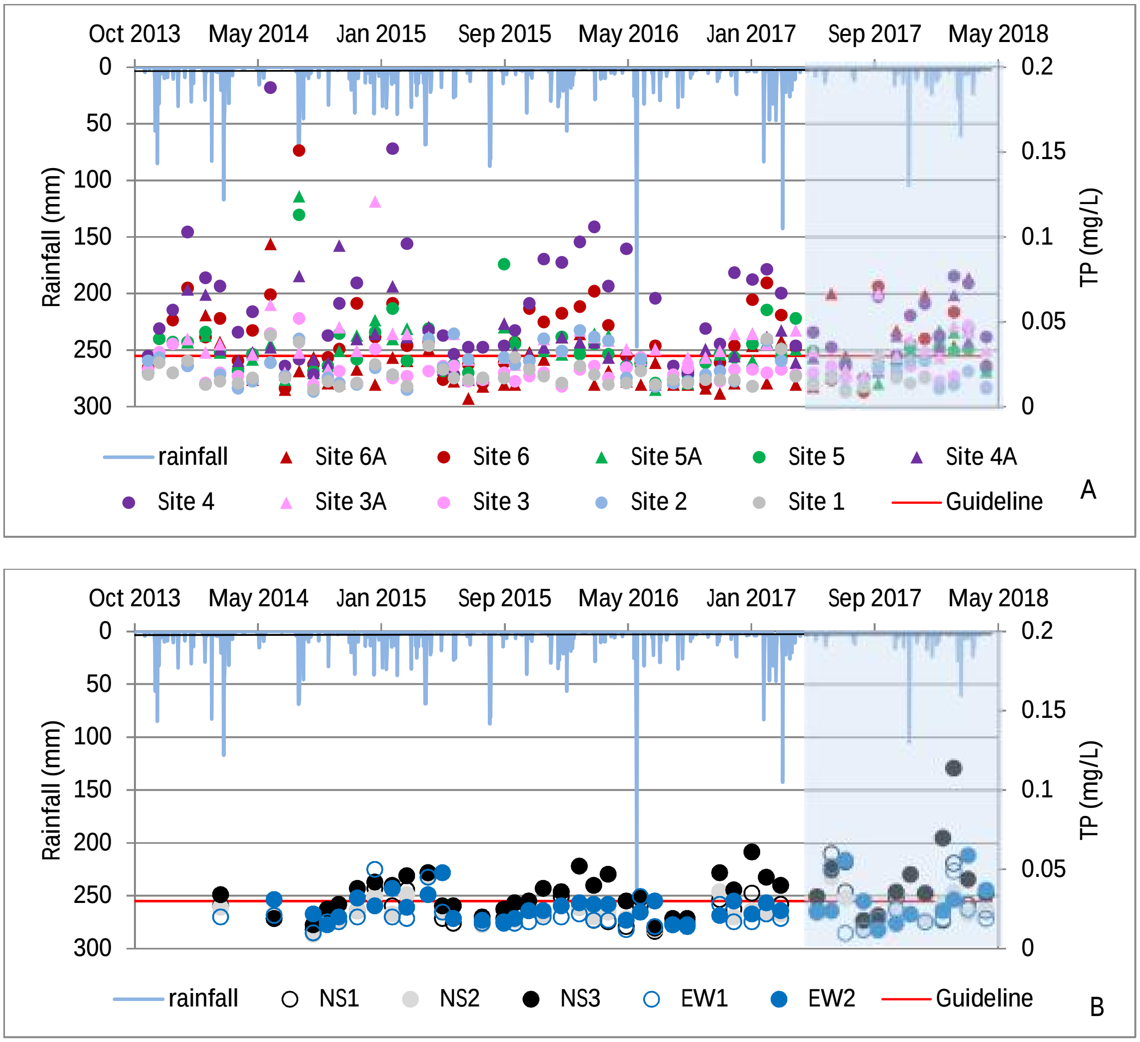


Figure 5-12 Plots of total phosphorus (TP) and rainfall against time for the lake edge and entrance sites (A) and in-lake locations (B) – shaded area shows the recent 12 months

The filtered total phosphorus (FTP) results are presented in Figure 5-13, and the data for the recent 12 months continue to show better compliance with the guideline value at most sites, except at Burroo Bay (Site 4) along the lake's edges, and in the south (NS3), the west (EW2) and the north (NS1) in the main body of the lake.

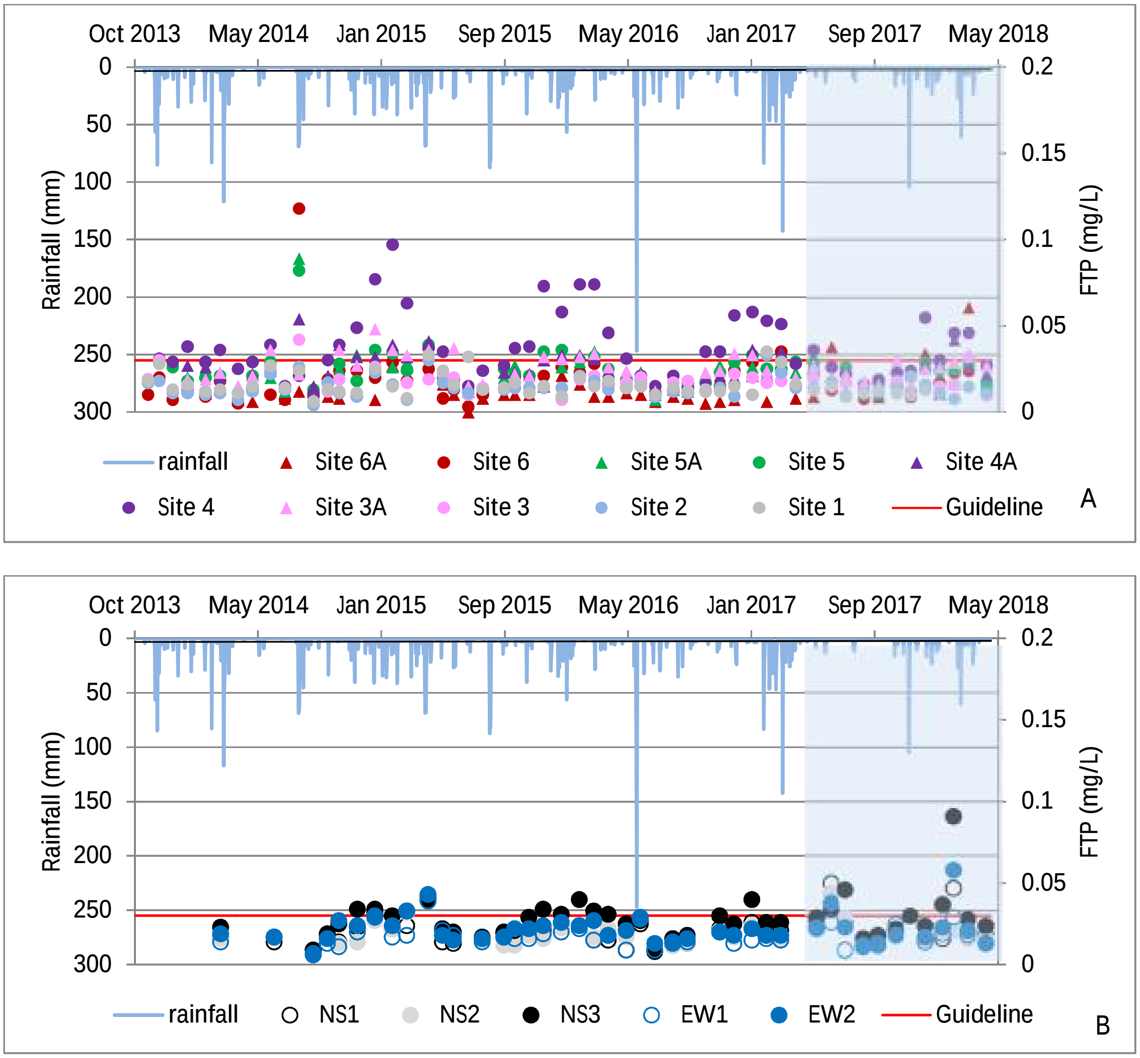
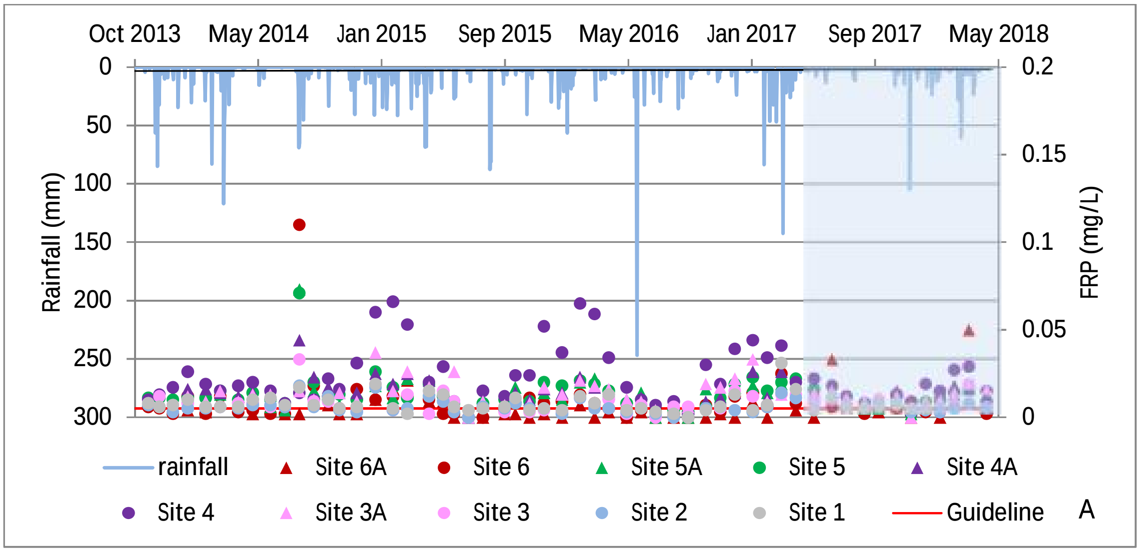


Figure 5-13 Plots of filtered total phosphorus (FTP) and rainfall against time for the lake edge and entrance sites (A) and in-lake locations (B) – shaded area shows the recent 12 months

The filterable reactive phosphorus (FRP) results are presented in Figure 5-14. The guideline value for this form of phosphorus is very low at 0.005 mg/L, and in a phosphorus-rich environment such as Lake Illawarra (catchment soils are not phosphorus deficient), most sites continue to exceed this guideline value. At most sites, about 70 to 80% of the total phosphorus (TP) in the water is present in the dissolved form (FTP), and about half of this dissolved fraction is in the reactive form (FRP). The detection of this reactive form of phosphorus in the water suggests that phosphorus is not a limiting nutrient for primary production in the lake.



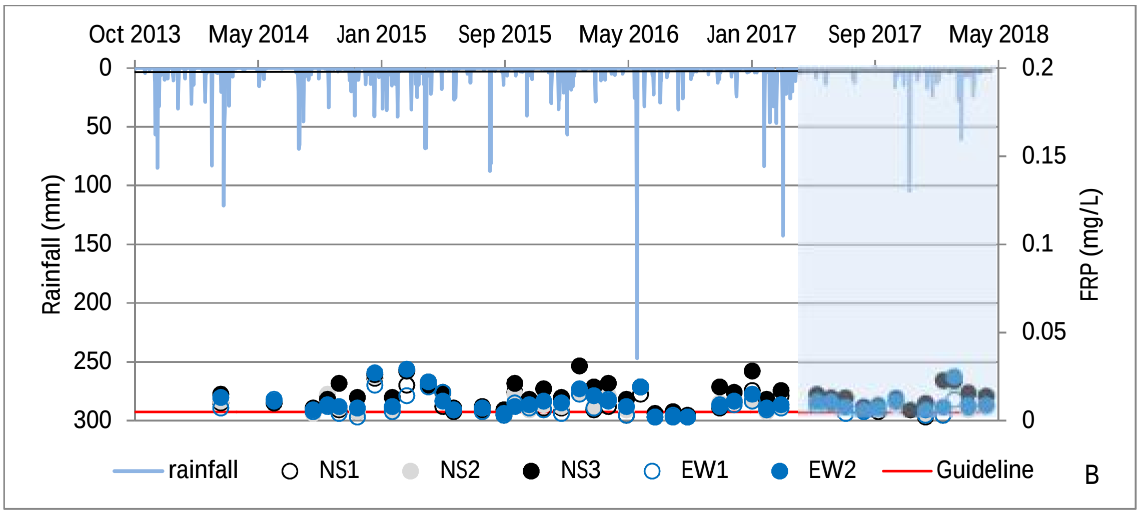


Figure 5-14 Plots of filtered reactive phosphorus (FRP) and rainfall against time for the lake edge and entrance sites (A) and in-lake locations (B) – shaded area shows the recent 12 months

5.3.3 Chlorophyll *a*

The results for chlorophyll *a* are presented in Figure 5-15, which show generally similar patterns in the recent 12 months when compared to previous data, with concentrations peaking in the summer months and reducing to around the guideline trigger value around the winter months. The site patterns are similar to those for nitrogen and phosphorus. Along the edges of the lake, chlorophyll *a* is most abundant at Griffins Bay (Site 6) and this is followed closely by Burroo Bay (Site 4). Within the main body of the lake, the south (NS3) has the highest concentration, and well above the guideline trigger value over the summer months.

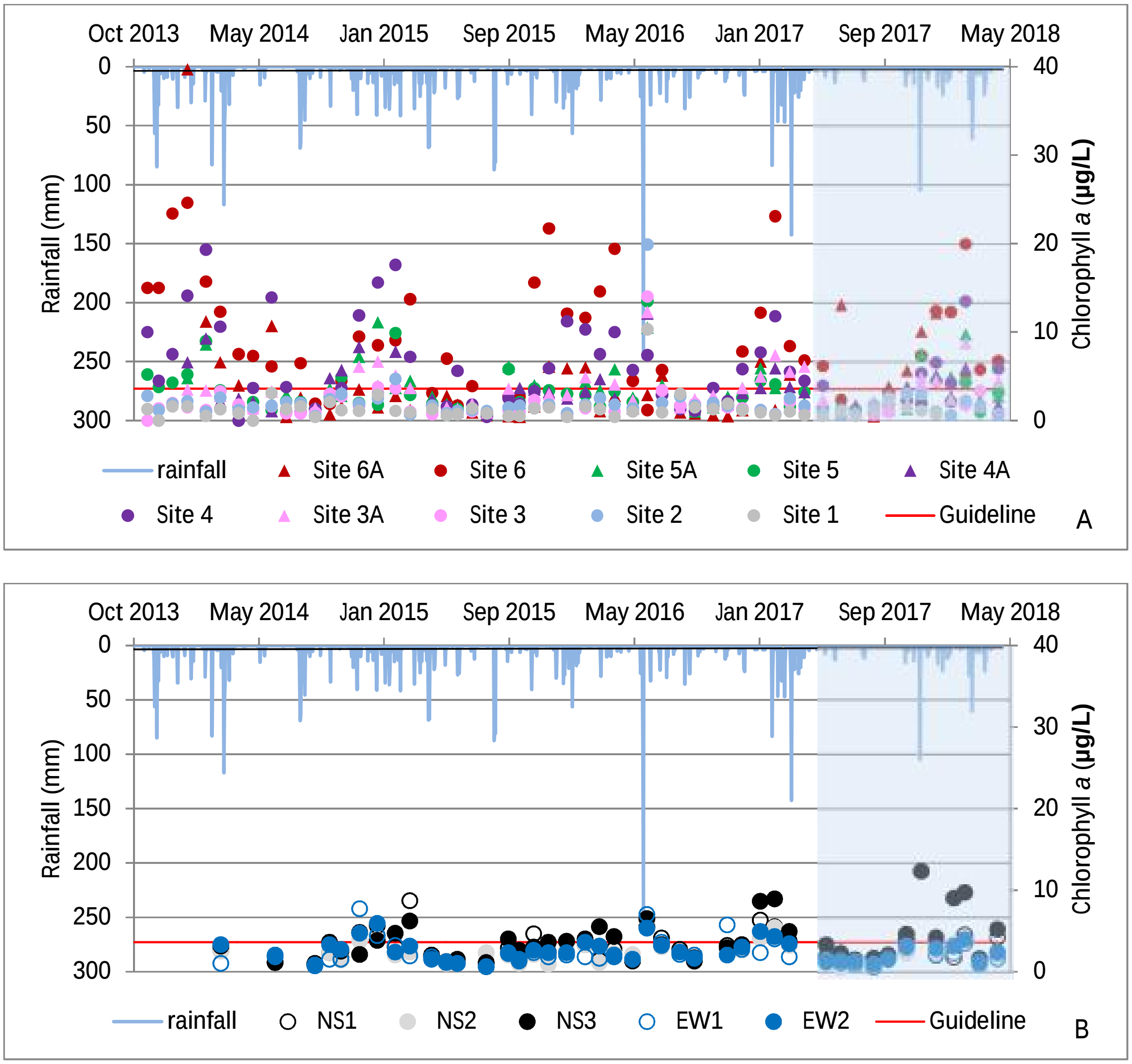


Figure 5-15 Plots of chlorophyll *a* and rainfall against time for the lake edge and entrance sites (A) and in-lake locations (B) – shaded area shows the recent 12 months

5.4 Spatial Variations in Water Quality

Multi-dimensional scaling of the results was used in the report issued in July 2016 to demonstrate the level of spatial similarity between sites. The results suggested water quality varied across the lake from east to west and from north to south. For this report, the analysis was rerun adding more recent data and the results are similar (Figure 5-16).

The 15 sites have been separated into five groups. The entrance sites (Sites 1, 2 and 3) and the in-lake sites EW1 and NS2, areas of the lake which are directly aligned with the entrance channel, are in one group, within which the water quality is considered to be similar. Within the lake itself, Site 6 (Griffins Bay), Site 4 (Burroo Bay) and Site 6A (Purry Burry Bay) are in different groups by themselves, and therefore considered to be different from the rest and from each other. The remaining sites are in another group which has water quality not too different from the first group containing the entrance sites and the two nearby in-lake sites

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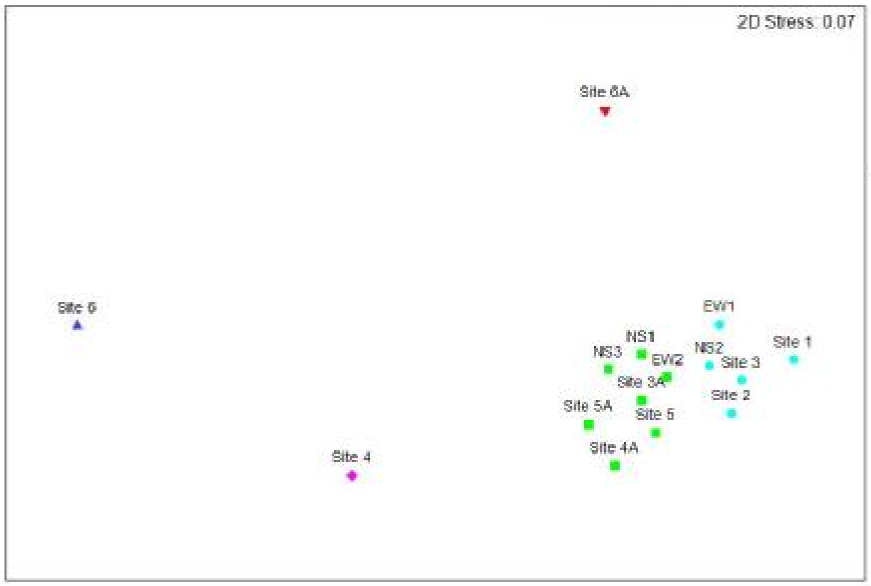


Figure 5-16 Results from multi-dimensional scaling of chlorophyll *a* at the sites

The five groups of sites are outlined on a map of the lake which shows that they are related to their proximity to the entrance channel and the extent of their enclosure (Figure 5-17). These results could be indicative of the extent of flushing and/or mixing of the lake water. The section of the lake closest to the entrance channel (EW1 and NS2) is very similar to the sites in the entrance channel itself because this area of the lake must be flushed very well. The area immediately surrounding this section is placed close to the entrance sites because this area is probably also flushed but not as well as the entrance sites. Further away from the entrance, the more enclosed areas in the north and south of the lake are in different groups by themselves because flushing there must be very limited, and the inputs controlling water quality must vary from one site to another.

There are other factors such as catchment and benthic sediment inputs which probably also vary depending on location within the lake, and these can be additional reasons for the patterns observed. Sites close to the entrance could be dominated by sandy bottom sediments which do not add a high nutrient load to those areas. Sites further away from this area are closer to the creeks discharging into the lake and these areas can be expected to have siltier bottom sediments with a greater nutrient load. In the more enclosed bays in the north and south, very silty beds are actually visibly evident, and the surrounding catchments are intensively developed and inputs from these areas are probably also significant in rendering these sites different from each other and the rest.

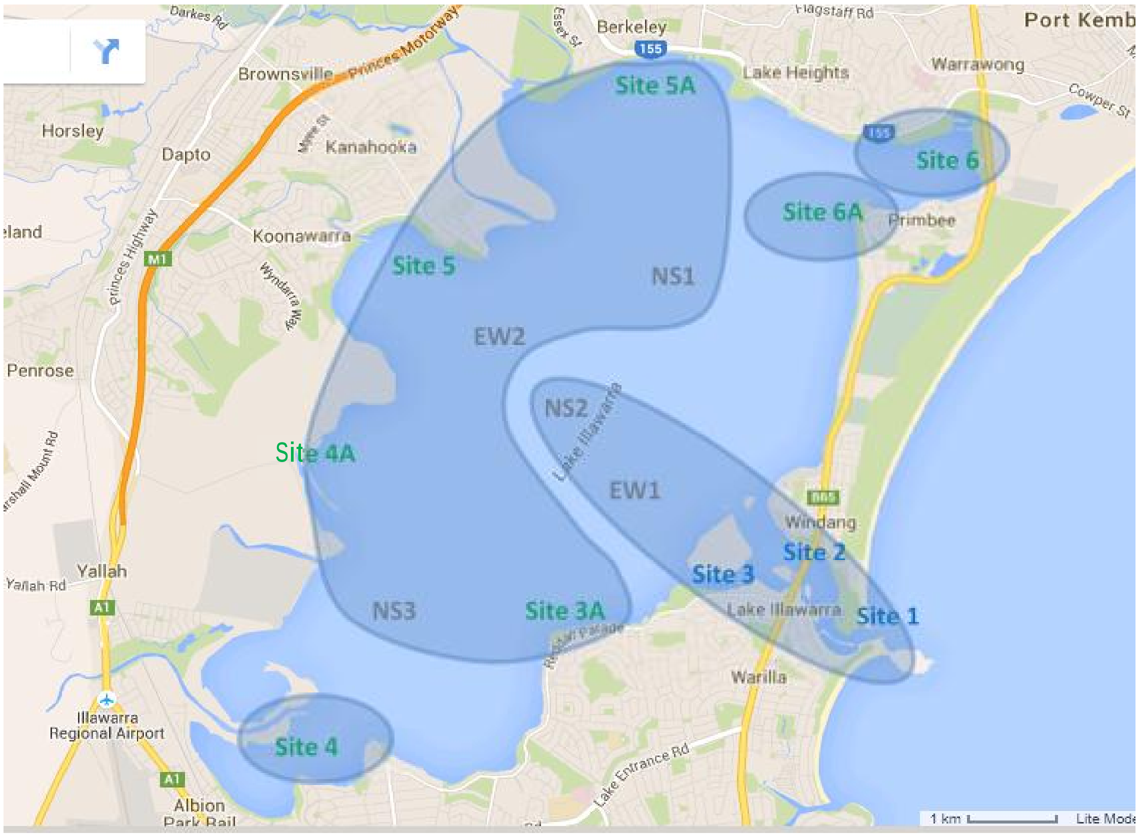
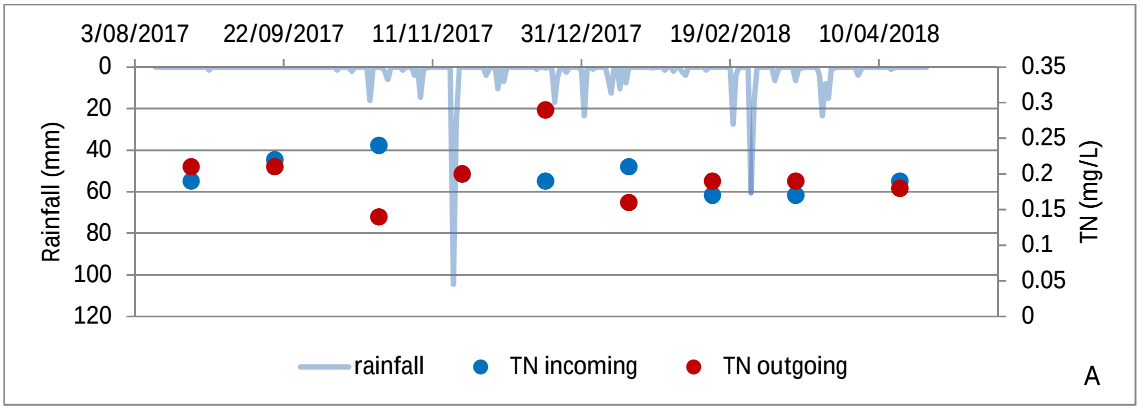


Figure 5-17 Location of the five groups of sites within the where water quality is different

The degree to which the incoming tidal water is exchanged with lake water in the outgoing tide was further investigated by comparing the incoming and outgoing water at Site 2 in the entrance channel at high and low tides respectively. The indicators nitrogen and phosphorus were selected for this rather than chlorophyll *a* because chlorophyll *a* concentrations change through the day with temperature and light variations. Changes in the concentration of chlorophyll *a* in incoming and outgoing water therefore cannot be related exclusively to the extent of flushing, as they could be due to changing temperature and light conditions over the tidal cycle. The results for nitrogen and phosphorus are given in Figure 5-18. While TP in outgoing water does appear generally higher than in incoming water, there is no statistically significant difference between the two for either of the indicators. This result could be further support that there is no significant exchange of the incoming water with the more nutrient rich waters in the areas in the south and north of the lake over a normal tidal cycle, when there is not much hydraulic pressure from catchment runoff.



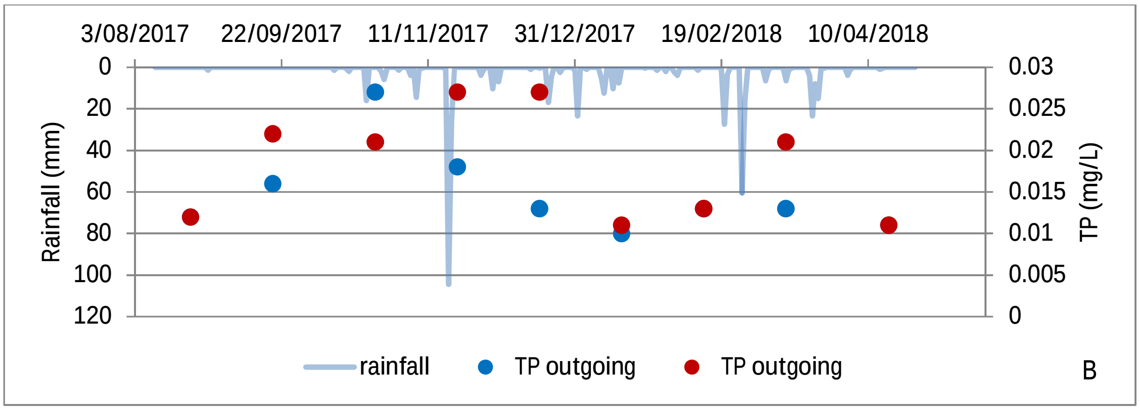


Figure 5-18 Total nitrogen (A) and total phosphorus (B) concentrations in incoming and outgoing water at Site 2

5.5 Temporal Variations in Water Quality

Temporal variations in water quality can be evident over different timescales. The results show that as in previous years seasonal differences continue to be apparent. Over the summer months (November to April) when temperatures and daylight hours are greater than in the winter months (May to November), higher nutrient and chlorophyll *a* concentrations are present in the water. This seasonal pattern is not uncommon and as has been observed in other waterbodies, regardless of rainfall conditions. This suggests that there must be internal sources within the lake, such as nutrient rich bottom sediments which release of nutrients into the water column over the summer months, and cause favourable conditions for phytoplankton growth.

Superimposed on the seasonal pattern is the effect of rainfall, which can cause a change in water quality (usually increasing the concentration of nutrients and chlorophyll *a*) at any time. Whether the rainfall effect is obvious in the monitoring results depends on the amount of rainfall and the monitoring date in relation to the rainfall event. The amount of rainfall would need to be firstly sufficient to flush the catchment and discharge nutrients and other materials into the lake. Secondly, monitoring would have to be conducted before the materials discharged can be flushed out of the lake.

While the recent 12 months have been very dry overall (Table 5-1), there were two occasions when rainfall in excess of 50 mm was received. There was 131 mm over 18 and 19 November 2017 when the lake was monitored within two days of this event, and 60 mm on 26 February 2018, two weeks after the lake had been monitored for this month, and about three weeks before the next monitoring for March 2018 was undertaken. No obvious impact of these rainfall events above the seasonal trends is obvious, except for chlorophyll *a* at NS3 in the south of the lake, where a spike was recorded for the November event. This suggests that following a rainfall event, the lake may return to near seasonal water quality conditions fairly rapidly. This will however be dependent on the residence time of the materials introduced into the lake.

5.5.1 Estimation of Residence Time

Ellis et al (1977) estimated residence time in the lake to be about 60 days, forty years ago when its entrance was highly shoaled. With the entrance now permanently open and evidence of tidal penetration occurring through all areas of the lake, this time can be expected to have become much shorter. Three very empirical methods are used below to estimate what the residence time might be at present and what this means for water quality in the lake.

There are significant limitations with the three methods utilised, as they are subject to several assumptions. These are that the lake is well mixed, that the water that enters on the incoming tide does not simply leave on the following outgoing tide, and the water leaving the lake does not return on the next incoming tide. More reliable methods of determining the residence time include field-based tracer methods involving the release of drogues, drifters or dyes and/or numerical modelling. The limitations of the methods utilised in this report are important and these methods should not be relied upon for any significant management decision for the lake.

The first method is the simplest and is based on how much the lake level changes between high and low tides, and how this compares with the depth of the lake. The lake level is monitored by the Manly Hydraulics Laboratory and examination of their data shows that this water level difference is about 0.3 m. Assuming the average depth of the lake to be 1.8 m, and that each tidal cycle displaces a layer 0.3 m deep, complete displacement of the lake water would occur in 6 tidal cycles, which would happen over 3 days.

The second method is based on the tidal prism in comparison to the volume of the lake. The tidal prisms on the flood and ebb tides are reported as 4.85×10^6 m^3 and 4.09×10^6 m^3 respectively (Young, et al. 2014). Based on the lake surface area of 35 km^2 and an average depth of 1.8 m, the volume of the lake is approximately 63×10^6 m^3. Using the lower ebb tide tidal prism value for the calculation, about 16 tidal cycles would be required to displace the total volume of the lake, and this would occur over 8 days.

The third method is based on the rate of change in salinity over a period of low rainfall when catchment discharges are not expected to be significant. The continuous monitoring undertaken by the Manly Hydraulics Laboratory shows the salinity at Koonawarra was 19 ppt on 29 March 2014. In the following six days there was no rainfall, and the salinity increased to 30 ppt over this time. Given that seawater has a salinity of 35 ppt, the fraction of freshwater at any other salinity lower than this value can be calculated. This fraction turns out to be 0.45 on 29 March 2014 [(35-19)/35] and 0.14

six days later [(35-30)/35]. This means that the fraction of freshwater displaced per day is 0.05 [(0.45-0.14)/6], and 20 days would be required to displace the total volume of the lake [1/0.05].

These calculations indicate a potential residence time of 3 to 20 days. This may explain why the water quality changes resulting from catchment runoff are not obvious if monitoring is not conducted soon after the rainfall event. These residence times are based however on the assumption that the lake is spatially uniform, and there is complete mixing of all areas of the lake. The discussion on spatial variations in water quality has shown that this is certainly not the case. The spatial differences suggest that the residence time for the more central portion the lake (where the Koonawarra station for method 3 is located) is shorter than that for the more enclosed areas of the lake in the north and the south.

Longer residence times in the more enclosed north and south of the lake, where water quality is already poor, could mean that catchment inputs have more time to be incorporated into bottom sediments. These sediments are part of the internal nutrient reserves that feed the water column, resulting in the poor water quality observed in these areas over summer. In these areas, therefore, water quality can get worse over time.

5.5.2 Water Quality trends from 2013 to 2018

The water quality trends over time are important because they can inform whether management strategies put in place to protect the health of the lake are effective. However, data over a reasonably long period is required for these trends to become apparent, as there can be significant short term variation arising from seasonal and meteorological effects, which can detract from the overall trend. The council monitoring program has now been in operation for five years and whether any trends are apparent over this timeframe was investigated.

To account for seasonal differences in the dataset, the Seasonal Kendall method was selected as it allows for seasonality in data patterns. To account for rainfall effects which detract from the seasonality pattern, a decision was made to exclude data points that were greater than two standard deviations from the mean. This resulted in some (no more than five) data points being excluded from a dataset of more than 40 to 50 observations, and this means that rainfall effects may not have been totally removed, as moderate changes related to this factor could still be present. The trend analysis was then performed on the filtered data to test whether statistically significant trends could be detected for the indicators, total nitrogen, total phosphorus chlorophyll *a* and turbidity. The results are given in Appendix 1, which show no significant trend appearing anywhere except for the few locations and indicators listed in

Table 5-2.

Table 5-2 Sites showing a significant trend in water quality

Region	Site	Indicator	Trend	Probability
Lake Edge	LI4A - Tallawarra	TP	decreasing	<0.1
Lake Edge	LI4 – Burroo Bay	Chlorophyll *a*	decreasing	<0.1
In-lake	NS1 – lake north	TN	decreasing	<0.01
In-lake	NS3 – lake south	Chlorophyll *a*	increasing	<0.1

Table 5-2 suggests water quality has improved in three locations, at least with respect to one indicator, but degraded at another location. This contrasting result is surprising but can be possible in a lake which is spatially not fully mixed, where the factors controlling water quality may vary from site to site. The improving trend may also be an artefact, as rainfall effects have not been totally removed from the analysis, and the decreasing trends noted could be the result of the 2017/18 year being unusually dry. The result for Site NS3 in the south of the lake, however, is interesting, where in spite of the current year being very dry, chlorophyll *a* appears to be increasing. This trend if persisting is of concern and questions need to be asked now as to the possible reasons for this. This southern part of the lake drains a catchment which has undergone a significant increase in the development footprint since the start of this monitoring program, and whether this is the reason for the results needs attention

The lack of any statistically significant trends in most locations indicates the difficulty of detecting trends when various factors influence water quality and these factors play out in different ways over space and time. Given this situation, five years may not be long enough for any trends to show up and monitoring over a longer period may be required.

5.6 Estuary Ecosystem Health Condition

The estuary ecosystem health condition is based on the chlorophyll *a* and turbidity data, as recommended under the NSW MER program (State of NSW and Office of Environment and Heritage 2016), but continuing to use the guideline trigger values of 3.6 µg/L for chlorophyll *a* and 5.7 NTU for turbidity. The results for the recent summer are presented in Figure 5-19, together with results from earlier summers for all sites monitored.

The estuary ecosystem health condition of the lake as a whole is better represented by the results of the in-lake locations rather than the edge or entrance sites, as discussed in previous reports. Turbidity at the edges sites can be easily influenced by wind conditions prevailing at the time of sampling or by other disturbances such as boating activities. Entrance sites, on the other hand, may be more representative of the incoming ocean water than the main body of the lake. The results for the in-lake zones generally show good to very good conditions through the years, except in 2016/17. Over this summer the condition of the lake had deteriorated when compared to the previous two summers, and this was thought to be related to the summer of 2016/17 being very wet.

The results for the current summer show that all in-lake sites have improved except for NS3 in the south. The improvement in most areas may be related to the current year being unusually dry in comparison to previous years. However, the lack of any improvement in the south of the lake needs to be tracked closely, as it could mean that the nutrient load for this part of the lake is increasing and needs management.

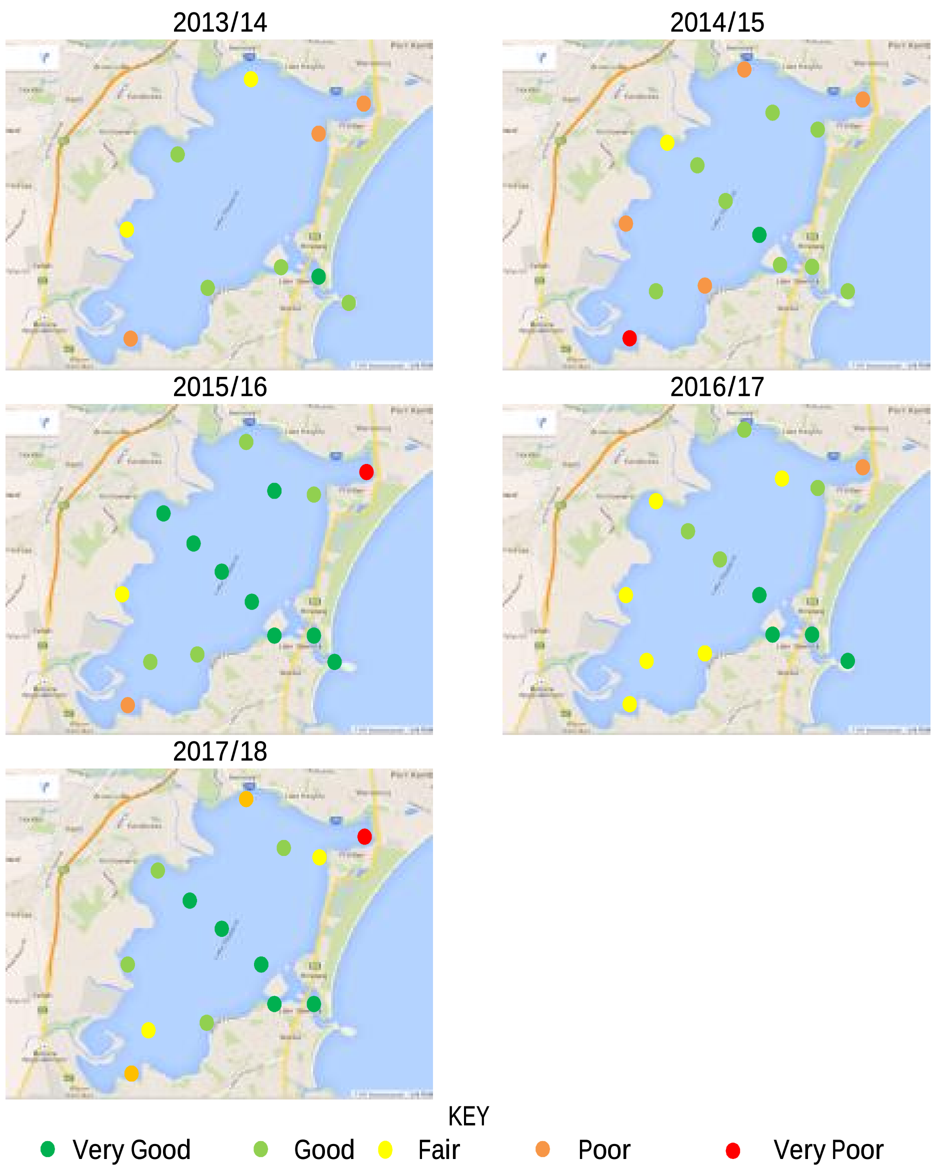


Figure 5-19 Estuary health condition over summer based on chlorophyll *a* and turbidity measurements in the lake

5.7 Recreational Water Quality

Currently, the lake is not monitored for recreational water quality as part of this monitoring program. However, the statewide Beachwatch program monitors a site within the entrance area, the Entrance Lagoon Beach, for swimming conditions and issues daily pollution forecasts. Figure 5-20 displays the enterococci concentrations measured by this program over the last five years. It shows several occasions when the water was not suitable for recreational use. In the recent 12 months, the guideline for primary contact (35 cfu/100 ml) was exceeded on at least seven occasions and secondary contact (230 cfu/100 ml) on one occasion. These occasions appear generally around rainfall events which would suggest the main source of the pollution is stormwater runoff. This site is in the entrance channel and probably gets reasonably well flushed, but the results show that it is still susceptible to bacterial pollution on occasions. Therefore, areas further away in the lake, which are used for recreational activities and where flushing may be less effective, may need to be monitored, as proposed in the Coastal Management Program being prepared for Lake Illawarra.

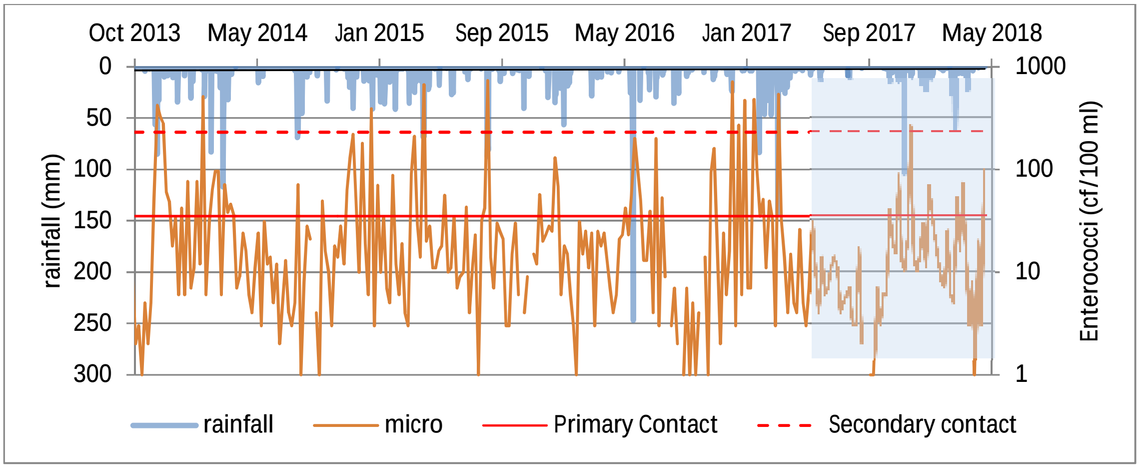


Figure 5-20 Plot of enterococci concentrations against rainfall at the Entrance Lagoon Beach (shaded area shows the recent 12 months)

6 Conclusions

This report has reviewed the water quality data collected for Lake Illawarra in the 12 months to April 2018 and compared this with earlier results. The strong seasonal influence on water quality noted in previous reports is apparent again, as is the influence of weather conditions. Nutrient and chlorophyll *a* concentrations peak over the summer months, in association with the higher temperatures and greater light availability prevailing over this period. Weather conditions, in particular rainfall, can disrupt or enhance this pattern, but the recurring underlying seasonal pattern suggests there is a significant internal source, such as benthic sediments, which supply considerable amounts of nutrients to the overlying water.

Evidence for strong spatial variation in the lake, noted in previous reports, has been reinforced with recent data, with water quality getting poorer with increasing isolation from the entrance channel. This pattern of spatial variation has been attributed primarily to the extent of flushing by tidal waters. This factor is considered significant in water quality being relatively good in the more central part of the lake and poor to very poor in the more enclosed areas further out in the north and south of the lake.

The recent 12 months have been unusually dry when compared to the previous 12 months, and while some improvement in the estuary ecosystem health condition is evident in the more central part of the lake, the more enclosed areas in the north and south have got worse. This shows that catchment runoff is only one of the many factors that may affect water quality in the lake.

The extent to which catchment runoff will impact on water quality over time is dependent on the residence time of materials introduced into the lake. Using very empirical methods, the residence time has been determined to be between 3 to 20 days, but this applies to the more central part of the lake which is flushed more efficiently. In areas further out, such as in the more enclosed areas in the north and south, the residence time is likely to be much longer. This means that while impacting water quality around rainfall events, catchment inputs can also be incorporated into internal reserves that feed the water column.

Trends in water quality over time can indicate the potential long term contribution of catchment inputs. Over the five years that the lake has been monitored by the councils, no statistically significant decreases in water quality is evident at any of the monitoring sites, except at NS3 in the south of the lake. The lack of any significant trend in most areas may be related to the difficulty of isolating short term meteorological changes from the underlying trend, and datasets longer than five years may be necessary for these trends to become apparent. The result for NS3 should be cause for caution, as it could be linked to major developments in the catchment area on this side of the lake.

7 Recommendations

Wollongong City and Shellharbour City Councils are currently preparing a Coastal Management Program for Lake Illawarra, which is expected to set the future management strategies for the lake. The water quality and estuary ecosystem health monitoring requirements for the future are being reviewed as part of this process. Monitoring of the health of the lake should certainly continue, as longer term datasets are required to get good insights into how the lake is changing. This report has shown that there are similarities in water quality between the 15 sites that are currently monitored. Therefore, the number of sites that need to be monitored in the future can be reduced if there are budget constraints. In addition, savings are also possible through discontinuing the monitoring being undertaken by the Manly Hydraulics Laboratory, as this program has already generated a long term dataset and is duplicating some of the measurements made by the council program.

Catchment discharges can have a significant influence on water quality in the lake in the short as well as the long term. There is already some preliminary evidence for water quality and estuary ecosystem health in the south of the lake deteriorating as the catchment for this part of the lake is developed. Therefore, any management arrangements made to protect the health of the lake going into the future must address catchment impacts. The suite of actions being proposed in the draft Coastal Management Program for Lake Illawarra to control catchment inputs is strongly supported.

8 Acknowledgements

Wollongong City Council would like to acknowledge the collaboration of the University of Wollongong School of Earth and Environmental Sciences in this project, coordinated through Emeritus Professor John Morrison, and the funding and technical support through the NSW Office of Environment and Heritage.

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Appendix 1 – Results of the Seasonal Kendall analysis for trends in water quality

Region	Site	Start Date	Indicator	Data count	Mean	S.D.[+]	Mean + 2SD	Results excluded[*]	Trend	Probability
In-lake	NS1	Mar-14	TN (mg/L)	42	0.26	0.08	0.42	3	decreasing	<0.01
In-lake	NS2	Mar-14	TN (mg/L)	42	0.26	0.07	0.4	2	no trend	0.1
In-lake	NS3	Mar-14	TN (mg/L)	43	0.31	0.13	0.57	1	no trend	0.1
In-lake	EW1	Mar-14	TN (mg/L)	42	0.24	0.08	0.4	2	no trend	0.1
In-lake	EW2	Mar-14	TN (mg/L)	42	0.26	0.09	0.44	2	no trend	0.1
Lake Entrance	LI1	Oct-13	TN (mg/L)	51	0.25	0.05	0.35	2	no trend	0.1
Lake Entrance	LI2	Oct-13	TN (mg/L)	55	0.24	0.06	0.36	2	no trend	0.1
Lake Entrance	LI3	Oct-13	TN (mg/L)	55	0.25	0.07	0.39	2	no trend	0.1
Lake Edge	LI3A	Jan-14	TN (mg/L)	52	0.26	0.06	0.38	3	no trend	0.1
Lake Edge	LI4	Oct-13	TN (mg/L)	55	0.28	0.18	0.64	3	no trend	0.1
Lake Edge	LI4A	Jan-14	TN (mg/L)	52	0.26	0.08	0.42	3	no trend	0.1
Lake Edge	LI5	Oct-13	TN (mg/L)	55	0.28	0.14	0.56	1	no trend	0.1
Lake Edge	LI5A	Jan-14	TN (mg/L)	52	0.28	0.15	0.58	1	no trend	0.1
Lake Edge	LI6	Oct-13	TN (mg/L)	55	0.32	0.3	0.92	2	no trend	0.1
Lake Edge	LI6A	Jan-14	TN (mg/L)	51	0.3	0.15	0.6	5	no trend	0.1
In-lake	NS1	Mar-14	TP (mg/L)	42	0.025	0.011	0.047	3	no trend	0.1
In-lake	NS2	Mar-14	TP (mg/L)	42	0.024	0.008	0.04	2	no trend	0.1
In-lake	NS3	Mar-14	TP (mg/L)	43	0.037	0.017	0.071	1	no trend	0.1
In-lake	EW1	Mar-14	TP (mg/L)	42	0.022	0.01	0.042	4	no trend	0.1
In-lake	EW2	Mar-14	TP (mg/L)	42	0.026	0.01	0.046	3	no trend	0.1
Lake Entrance	LI1	Oct-13	TP (mg/L)	51	0.019	0.008	0.035	4	no trend	0.1
Lake Entrance	LI2	Oct-13	TP (mg/L)	55	0.022	0.01	0.042	2	no trend	0.1
Lake Entrance	LI3	Oct-13	TP (mg/L)	55	0.021	0.008	0.037	3	no trend	0.1
Lake Edge	LI3A	Jan-14	TP (mg/L)	52	0.035	0.016	0.067	1	no trend	0.1

Lake Edge	LI4	Oct-13	TP (mg/L)	55	0.062	0.043	0.148	3	no trend	0.1
Lake Edge	LI4A	Jan-14	TP (mg/L)	52	0.035	0.017	0.069	3	decreasing	<0.1
Lake Edge	LI5	Oct-13	TP (mg/L)	55	0.033	0.017	0.067	2	no trend	0.1
Lake Edge	LI5A	Jan-14	TP (mg/L)	52	0.032	0.017	0.066	1	no trend	0.1
Lake Edge	LI6	Oct-13	TP (mg/L)	55	0.041	0.023	0.087	1	no trend	0.1
Lake Edge	LI6A	Jan-14	TP (mg/L)	51	0.027	0.019	0.065	4	no trend	0.1
In-lake	NS1	Mar-14	Chl *a* (µg/L)	42	2.9	1.7	6.3	1	no trend	0.1
In-lake	NS2	Mar-14	Chl *a* (µg/L)	41	2.3	1.2	4.7	2	no trend	0.1
In-lake	NS3	Mar-14	Chl *a* (µg/L)	41	3.9	2.6	9.1	2	increasing	<0.1
In-lake	EW1	Mar-14	Chl *a* (µg/L)	41	2.3	1.6	5.5	3	no trend	0.1
In-lake	EW2	Mar-14	Chl *a* (µg/L)	42	2.5	1.3	5.1	2	no trend	0.1
Lake Entrance	LI1	Oct-13	Chl *a* (µg/L)	51	1.4	1.4	4.2	1	no trend	0.1
Lake Entrance	LI2	Oct-13	Chl *a* (µg/L)	55	2.1	2.6	7.3	1	no trend	0.1
Lake Entrance	LI3	Oct-13	Chl *a* (µg/L)	55	1.8	1.9	5.6	1	no trend	0.1
Lake Edge	LI3A	Jan-14	Chl *a* (µg/L)	52	3.3	2.2	7.7	2	no trend	0.1
Lake Edge	LI4	Oct-13	Chl *a* (µg/L)	55	6	4.7	15.4	3	decreasing	<0.1
Lake Edge	LI4A	Jan-14	Chl *a* (µg/L)	52	3.3	2.3	7.9	3	no trend	0.1
Lake Edge	LI5	Oct-13	Chl *a* (µg/L)	55	3	2.3	7.6	3	no trend	0.1
Lake Edge	LI5A	Jan-14	Chl *a* (µg/L)	52	3.5	2.5	8.5	4	no trend	0.1
Lake Edge	LI6	Oct-13	Chl *a* (µg/L)	55	8.3	6.6	21.5	4	no trend	0.1
Lake Edge	LI6A	Jan-14	Chl *a* (µg/L)	52	4	6	16	1	no trend	0.1
In-lake	NS1	Mar-14	Turbidity (NTU)	40	3.8	2.2	8.2	0	no trend	0.1
In-lake	NS2	Mar-14	Turbidity (NTU)	41	3.3	2.5	8.3	3	no trend	0.1
In-lake	NS3	Mar-14	Turbidity (NTU)	41	5.3	2.4	10.1	0	no trend	0.1
In-lake	EW1	Mar-14	Turbidity (NTU)	42	3	1.7	6.4	1	no trend	0.1
In-lake	EW2	Mar-14	Turbidity (NTU)	41	3.7	2.2	8.1	3	no trend	0.1
Lake Entrance	LI1	Oct-13	Turbidity (NTU)	50	5.4	8.3	22	1	no trend	0.1
Lake Entrance	LI2	Oct-13	Turbidity (NTU)	53	3.7	5.3	14.3	4	no trend	0.1

Lake Entrance	LI3	Oct-13	Turbidity (NTU)	54	4.9	4.5	13.9	3	no trend	0.1
Lake Edge	LI3A	Jan-14	Turbidity (NTU)	51	10.4	16.4	43.2	2	no trend	0.1
Lake Edge	LI4	Oct-13	Turbidity (NTU)	54	24.7	60.9	146.5	1	no trend	0.1
Lake Edge	LI4A	Jan-14	Turbidity (NTU)	52	11.9	17.4	46.7	3	no trend	0.1
Lake Edge	LI5	Oct-13	Turbidity (NTU)	54	9	16.5	42	1	no trend	0.1
Lake Edge	LI5A	Jan-14	Turbidity (NTU)	51	8.9	10.4	29.7	2	no trend	0.1
Lake Edge	LI6	Oct-13	Turbidity (NTU)	53	11.5	10.5	32.5	2	no trend	0.1
Lake Edge	LI6A	Jan-14	Turbidity (NTU)	51	9.5	17.7	44.9	2	no trend	0.1

$^{+}$ S.D. – standard deviation

* Results excluded indicate number of data points excluded from analysis because they are significantly greater 2 standard deviations from the mean