Lake Illawarra Estuary Health and Water Quality Report 2021

August 2021

Prepared by Wollongong City Council

Summary

Wollongong City Council and Shellharbour City Council have been monitoring water quality and estuary health in Lake Illawarra since October 2013. This is a report for period November 2019 to April 2021, focussing on those measurements that are especially important for assessing the lake condition for its ecosystem health and recreational use. For estuary ecosystem health, the measurements considered in this report are nitrogen and phosphorus, turbidity and chlorophyll *a* concentration, and for recreational use, the bacterial species enterococci.

For estuary ecosystem health, the water quality patterns observed for the 2019/20 and 2020/21 period are not different from previous years. Temporal and spatial variations continue to be observed. Nitrogen, phosphorus, chlorophyll *a* concentration, and turbidity peak over the summer months (November to April) in response to temperature and daylight changes, and the outer less flushed areas have poorer water quality than the entrance and main body of the lake. Water quality at some of the these outer less flushed sites appear to be improving over time though. Rainfall patterns have been observed to have a significant impact on water quality in previous reports, with good results usually attributed to dry periods, and hence less catchment run-off. However, the 2020/21 summer was the wettest since 2016/17 and it was also the wettest year total since 2016/17. While there were high values in nutrients and chlorophyll *a* associated with rainfall events, it appears the lake is maintaining good estuary health. The results show that for the 2020/21 period most of the sites are in good condition, with two of the in-lake sites in very good condition.

Site 6 in Griffins Bay was the only site rated as being in poor condition and is a site that has been rated as fair to very poor in past years. This was largely a result of several very high chlorophyll *a* and turbidity values over the summer period. This site has continuously been rated as fair to very poor since 2013/14, indicating the high input of nutrients and sediment from the catchment in this area and the lack of flushing that occurs in this bay. The lack of improvement at the site needs investigation as it could mean that the nutrient loads are persistent and need management.

Assessing recreational water quality (primary and secondary contact) has been utilised through sampling for enterococci at three sites in Lake Illawarra since 2018. The results show relatively good compliance, particularly at Kanahooka and Ski Way Park. These results may look encouraging but need to be treated with caution as they may not be representative of the situation in these areas all the time. Rainfall is known to have a significant effect on enterococci levels, but it is difficult to quantify as the sampling should be taken at the same day or soon after a rainfall event.

Monitoring the health of the lake should continue, as long-term datasets are essential to gain insights into how the lake is changing over time and is of greater value than focusing on specific individual sampling events. Given the large-scale developments occurring in the catchment of the lake, it is important that the health of the lake is monitored. The implementation of the suite of management actions in the Lake Illawarra Coastal Management Program to control catchment inputs is strongly supported, and long-term monitoring of the lake will inform whether investment in the lake is making a difference.

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1 Introduction

Lake Illawarra is a significant natural asset for the community, and it is highly valued for its ecological, social and economic attributes (BMT 2020a). Wollongong City and Shellharbour City Councils, in partnership with the State Government, have prepared a Coastal Management Program to address the main threats to the Lake values. Catchment development and its potential impact on water quality in the Lake is identified to be one of the most significant threats needing to be managed (BMT 2020 b). Several actions in the Coastal Management Program for the Lake relate to protecting water quality, and targeted monitoring, evaluation and reporting of water quality and other health indicators are recommended to track the outcome of implementing these actions (refer to Appendix 1 for the list of water quality improvement and management actions in the Lake Illawarra Coastal Management Program 2020-2030).

There is a long history of water quality monitoring in the Lake, with various agencies involved at various times. Wollongong City and Shellharbour City Councils took on this responsibility in October 2013, often with funding and technical assistance from the DPIE coast and estuary program, and since then regular reports on the results have been issued. These reports have considerable detailed analysis and show that there can be considerable spatial and temporal variation in water quality, with season and weather (particularly rainfall) patterns having a major influence. This report covers the monitoring period from November 2019 to April 2021 and focusses on those measurements that are especially important for assessing the lake condition for its ecosystem health and recreational use.

2 Monitoring program

2.1 Water quality and estuary health monitoring

Eleven sites within Lake Illawarra are monitored monthly for water quality and estuary health (Table 1, Figure 1). The parameters sampled are:

- Temperature
- pH
- Dissolved oxygen
- Salinity
- Turbidity
- Nitrogen
- Phosphorus, and
- Chlorophyll *a*.

Nitrogen is analysed as total nitrogen in unfiltered water (TN), the total after filtration (FTN), the amount present as nitrate and nitrite (often referred to as NOx's), and as ammonia, the reactive inorganic forms which are generally considered to be more bioavailable.

Phosphorus is analysed as total phosphorus in unfiltered water (TP), in filtered water (FTP), and as filterable reactive phosphorus (FRP). The filterable reactive phosphorus generally constitutes simple inorganic phosphorus (such as orthophosphate) and is considered more bioavailable than other forms of phosphorus.

Chlorophyll *a* is an indicator of the microalgal abundance in a water body, and its measure is preferred for estuary health assessment as it is reported to be a good short-term indicator of response to a range of pressures and management, including nutrient (such as nitrogen and phosphorus) status.

From January 2019, the field sampling and analysis has been carried out by Sydney Water, who have been undertaking the laboratory analysis for this project since the 2013. Sampling was not able to be undertaken in January 2020 and in-lake sites were not able to be sampled from April – June 2020 due to Covid restrictions.

2.2 Recreational water quality

Over the 2018/19 summer, three new sites were included for recreational water quality testing, following the NSW Beachwatch Program protocols, which test for the presence of enterococci – a group of bacteria indicating water quality condition for recreational use.

A site at the entrance (called Entrance lagoon beach) has been monitored for many years by the NSW Beachwatch Program and the data is analysed and reported within the NSW Beachwatch framework (NSW DPIE 2020). Currently the three new sites added by Council cannot be reported under the NSW Beachwatch program as data is required to be captured for a number of years.

The new sites added by Council in 2018/19 were at Ski Way Park, Kanahooka, and Purry Burry Point, which are popular launch sites for many recreational pursuits in the Lake (Table 1, Figure 1). These three sites were tested for the presence of enterococci on 21 occasions between October 2020 and April 2021.

Table 1: Description of the 11 sites monitored for water quality and estuary ecosystem health (in blue) and 3 sites monitored for recreational water quality (in orange)

Water Quality and estuary health sites		
Site ID	**Site location**	**Lake Zone**
Site 2	Boat ramp at Windang Peninsula	Lake entrance
Site 3	Bridge to Picnic Island	Lake entrance
Site 3A	Jetty at Boonerah Point Reserve	Foreshore
Site 4	Jetty at Sailing Club at Burroo Bay	Foreshore
Site 5	Boat ramp and jetty at Kanahooka	Foreshore
Site 6	Jetty at Griffins Bay Wharf	Foreshore
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
Recreational water quality sites		
Purry Burry Point	Primbee	Foreshore
Ski Way Park	Oak Flats	Foreshore
Kanahooka	Kanahooka/Koonawarra	Foreshore

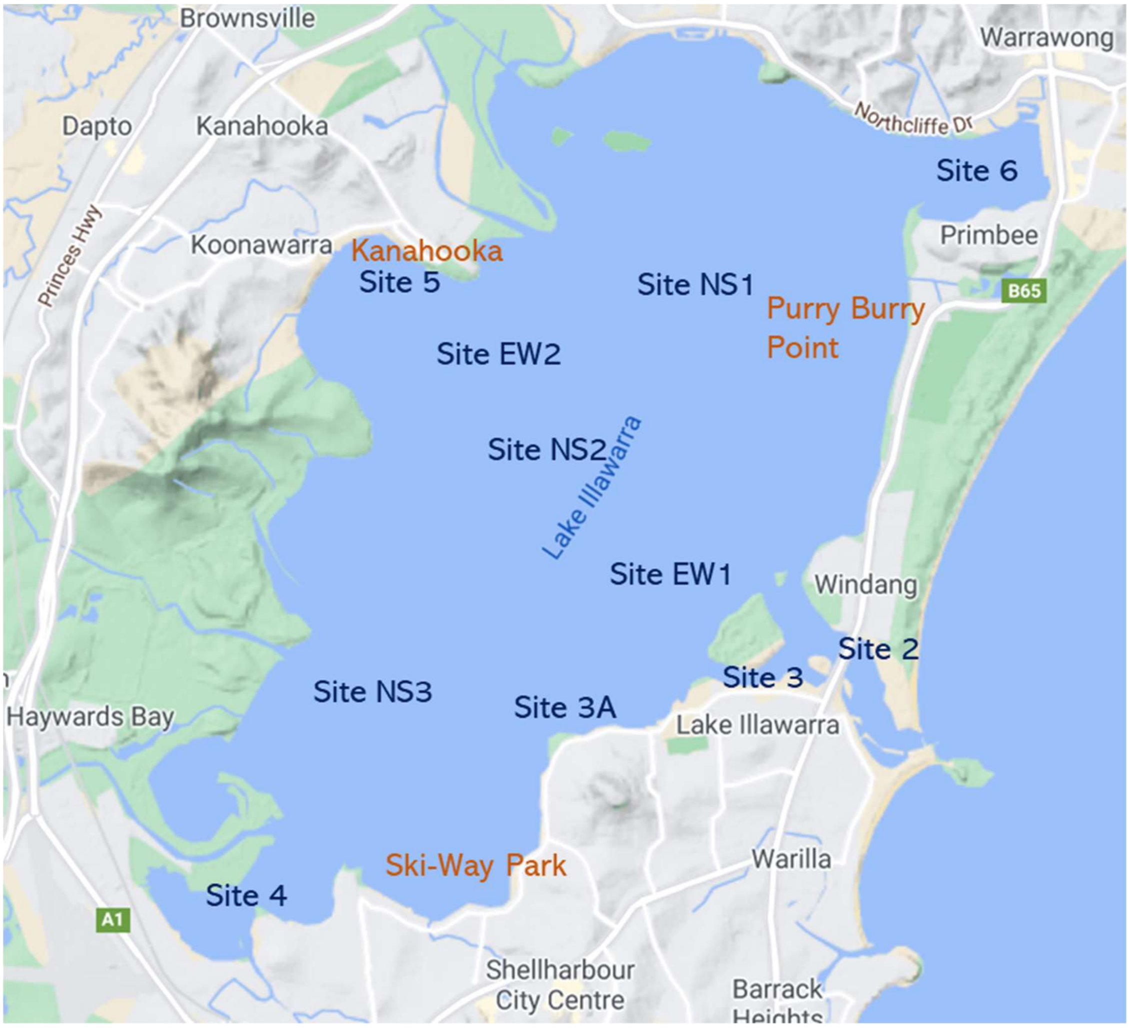


Figure 1: Map showing location of the 11 sites monitored by Council for water quality and estuary ecosystem health (in blue) and the 3 sites for recreational use (in orange)

3 Data Analysis

3.1 Water quality analysis for estuary ecosystem health

As in previous years, all indicators including those not covered in this report have been plotted against sampling date, rainfall, and the corresponding guideline trigger value for an assessment of the spatial and temporal patterns evident from October 2013 to April 2021 for the 11 sites monitored for estuary ecosystem health. The indicators discussed in depth in this this report are nitrogen, phosphorus, chlorophyll *a* and turbidity, which are some of the more important indicators of estuary ecosystem health and the catchment influence on the Lake. The guideline trigger values utilised are given in Table 2.

Table 2: Guideline trigger values

Parameter	Guideline	Source
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)	0.015mg/L	ANZECC (2000)
Ammonia	0.015 mg/L	ANZECC (2000)
Total Phosphorous (TP)	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[a]	State of NSW and DPIE
Turbidity	5.7 NTU[b]	State of NSW and DPIE

[a] This value has been updated to 5 µg/L in State of NSW and Office of Environment and Heritage (2016)
[b] This value has been updated to 6 NTU in State of NSW and Office of Environment and Heritage (2016)

The guideline trigger values 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. These are also the values utilised 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, retaining these values as the desired target condition for the rest of the lake is reasonable at this time.

The data for TN, TP, chlorophyll *a* and turbidity have also been subjected to a trend analysis using the water quality software program eWater to determine whether statistically significant trends are apparent for these indicators at any of the sites over the eight 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 influence on water quality. Rainfall effects can detract from the seasonality pattern, and to account for this, data points that were greater than two standard deviations from the mean were excluded from the analysis. The trend analysis was performed with the filtered data.

3.2 Estuary ecosystem health condition

The estuary ecosystem health condition of each site has been determined based on its chlorophyll *a* and turbidity status over the summer months. The summer period is taken to be from 1 November to 30 April, while the winter is from 1 May to 31 October. The methodology 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 3 (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 3: Descriptors for estuary ecosystem health condition grades

Grade	Definition
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.

3.3 Water quality for recreational use

The results of the monitoring for recreational water quality at the three new sites included by Council will feed into the Beachwatch Program, to be reported according to its protocols once data over a longer term has been collected and can be reliably used with other site characteristics to grade the sites for swimming purposes.

The analysis carried out for this report is only preliminary and calculates the percentage of the testing occasions when the sites complied with the guidelines for primary and secondary recreational use contact criteria (Table 4).

Table 4: Guideline trigger values for recreational use

Recreational Use	Guideline trigger value (enterococci)
Primary contact	35 cfu/100ml
Secondary contact	230 cfu/100ml

(source: ANZECC (2000))

4 Results

Several factors can influence water quality in a lake such as Lake Illawarra. These include weather, catchment runoff, assimilation and/or release of dissolved substances in the water by lake sediments, aquatic plants and animals, and the extent of flushing of the waterbody by tidal and catchment flows. These factors may not be uniform through the lake, suggesting variations in water quality can be expected in space and time. Rainfall has a significant influence on water quality and was considered an important factor for some of the water quality patterns observed in the 2019/21 period. Table 5 presents the seasonal and yearly total rainfall records for the last twelve years and it shows that the 2020/21 summer was the wettest since 2016/17 and also the wettest year total since 2016/17.

Table 5: Seasonal rainfall (mm) at Darkes Road since 2009

Year	Winter	Summer	Year total
2009/10	333.5	523	856.5
2010/11	520	800	1320
2011/12	476.5	616	1092.5
2012/13	215	515	730
2013/14	498.5	813	1311.5
2014/15	365	771.5	1136.5
2015/16	461	460	921
2016/17	602.5	748	1350.5
2017/18	108	458	566
2018/19	253	407	660
2019/20	286.5	598	884.5
2020/21	474.5	720	1194.5

4.1 Temporal analysis of parameters

4.1.1. Temperature, salinity and pH

Long term graphs of temperature, salinity and pH since 2014 have been presented in Appendix A for the 11 sites monitored for water quality and estuary health. In the recent 18 months sites continue to show a seasonal pattern in temperature as evident in previous years. The temperature variation between summer and winter can be as much as approximately 10-15^{0}C, and this can be expected to cause seasonal change in other water quality processes which are temperature dependent.

A pH range of 7 to 8.5 is considered to be satisfactory for estuarine ecosystems (ANZECC 2000). Values did not go below 7 for the November 2019- April 2021 period, with only several exceedances slightly above 8.5 suggesting there are no concerns relating to pH at Lake Illawarra.

Salinity since 2014 has been graphed against the daily rainfall records (Appendix A). The results show that a salinity of around 35ppt continues to be maintained, except close to rainfall events where it decreases temporarily. In this regard, there was a significant decrease in March 2021 coinciding with a rainfall event over six days. Some of the value were unusually low, suggesting there may have been sampling instrument calibration problems at the lower levels of salinity for some sites related to this event, or freshwater was sitting on top of the water column.

4.1.2 Nitrogen

When assessing the condition of an estuarine water body, chlorophyll *a* and turbidity are considered better indicators of estuary ecosystem health than the nitrogen and phosphorus concentrations. High nutrient concentrations do not always correlate with poor estuary health (Scanes et al. 2007), and there can often be a weak correlation between nitrogen loads and chlorophyll *a* concentrations (Roper et al. 2011). High nutrient inputs can, however, ultimately lead to poor water quality, and monitoring their concentrations in different parts of the lake can help identify inputs where nutrient may be significant and thus require management.

Over the November 2019 to April 2021 period the concentrations of nitrate, nitrite and ammonia were generally below or close to their respective detection limits (0.01mg/L), indicating these more bio-available forms of nitrogen continue to be rapidly utilised by phytoplankton and other plant life in the Lake. The exception to this, as in other preceding years is Griffins Bay (Site 6), where sporadic higher nitrate and ammonia concentrations were detected. This indicates that the catchment around Griffins Bay is a significant contributor to the nitrogen load of the lake. Another observation for this period is that all sites had very high nitrite, nitrate and ammonia concentrations during the March 2021 sampling event.

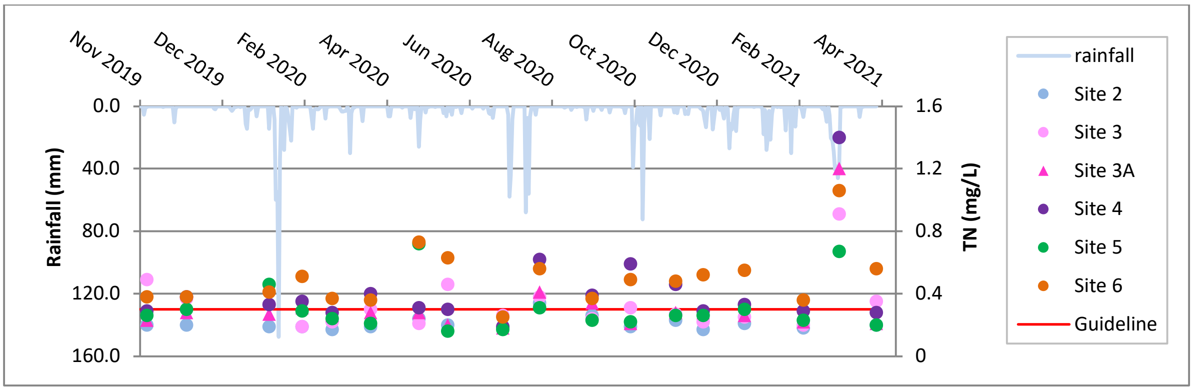
Figure 2 shows total nitrogen (TN) values and rainfall for the period November 2019 to April 2021 for the foreshore and in-lake sites. In Appendix A graphs of the results from the last twelve years are presented for all 11 sites. As with nitrate, nitrate and ammonia concentrations, Griffins Bay had consistently high TN values (Figure 2a). Site 4 also had high TN values, and this pattern of these two sites having high TN values is reflective of patterns in other years. For all foreshore sites though, there were very high total nitrogen values during the March 2021 sampling event, with sites exhibiting values 2 to 4 times greater than the ANZECC guideline (0.3mg/L) (Figure 2).

For the in-lake sites (Figure 2b) overall there were lower TN values compared to the foreshore sites. However, site NS1 had six high TN values throughout November 2019-April 2021, which is a different result compared to other years. As with the foreshore sites, all in-lake sites had very high TN values during the March 2021 sampling period, with values three to four times greater than the ANZECC guideline. Higher TN values could be a result of 2020/21 being the wettest since 2016/17, and thus an increase in runoff that is carried into the lake from the catchment.

During the March 2021 sampling event there was a rainfall event of 46 mm the day before sampling and approximately 200mm in the 6 days preceding, thus explaining the consistently high nitrogen values across all sites at this time. There were other larger rainfall events between November 2019 and April 2021, for example, in February, August and November 2020 (Figure 2). However, none of the sampling events coincided with them, with most of the sampling occurring approximately 10 days later and thus the possibly high nutrient levels that may have occurred with those rainfall events were not captured by this sampling program. Some sites, particularly Sites 4 and 6 still showed some high total nitrogen values 10 days later, indicating nitrogen inputs from catchment sources or lake bed sediments are greater around Griffins (Site 6) and Burroo (Site 4) Bays, and the enclosed nature of these parts of the lake may be preventing their full circulation with the rest of the lake. For other sites, the relatively low nitrogen values showed approximately 10 days after rainfall events indicate the nutrients were flushed quite quickly out of the lake and/or rapidly utilised by the phytoplankton and other plant life in the lake.

The filtered total nitrogen (FTN) for the recent 12 months (Figure 3) continues to show better compliance with its guideline trigger value than TN, with the exception being Site 4 and Site 6. Similar to the pattern for TN, all foreshore and in-lake sites had FTN values two to four times greater than the ANZECC guideline in March 2021 (Figure 3). 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, and so FTN can only be less than or equal to TN. The FTN (dissolved) fraction generally made up about 70 to 80% of the TN (total nitrogen) regardless of the time of the year.

A: Foreshore sites



B: In-lake sites

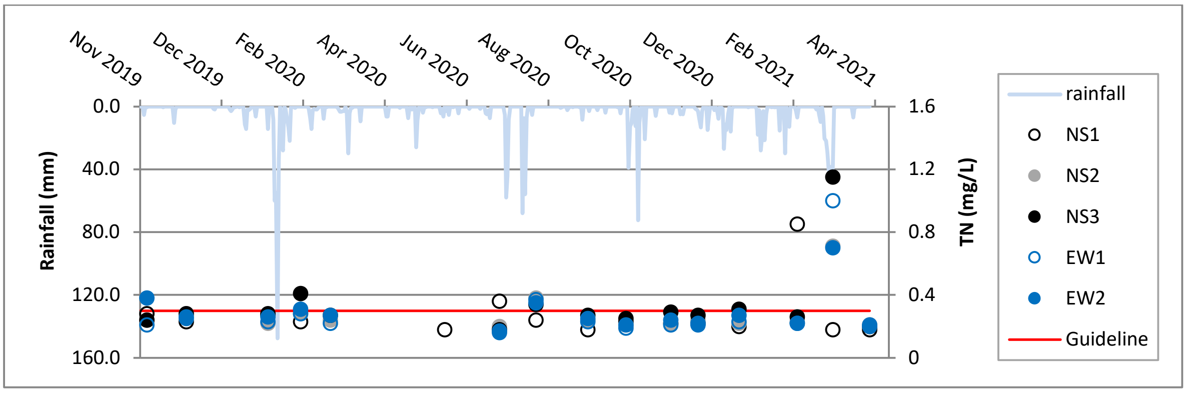
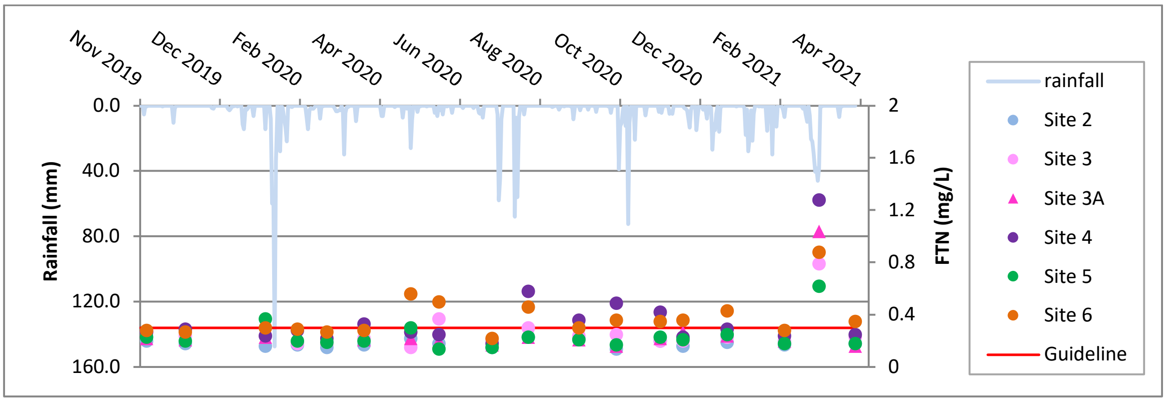


Figure 2: Plots of total nitrogen (TN) and rainfall for November 2019 to April 2021 for the (A) Foreshore (lake edge) sites and (B) In-lake sites

A: Foreshore sites



B: In-lake sites

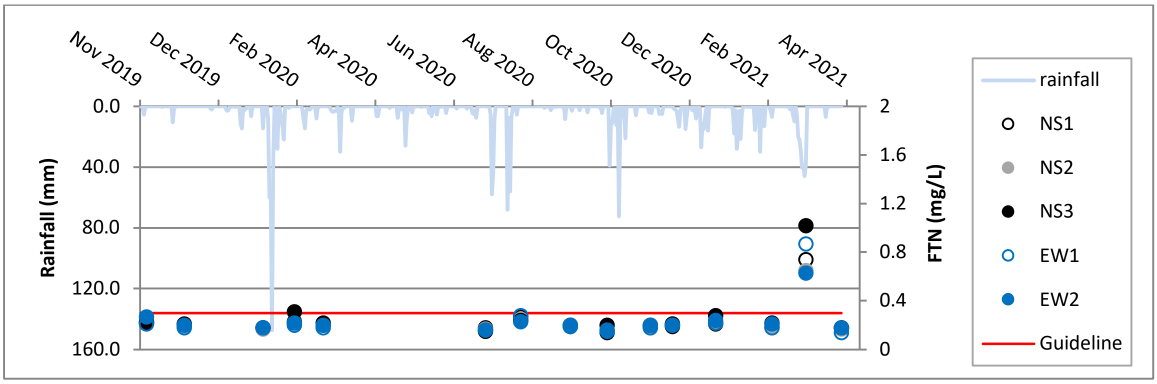


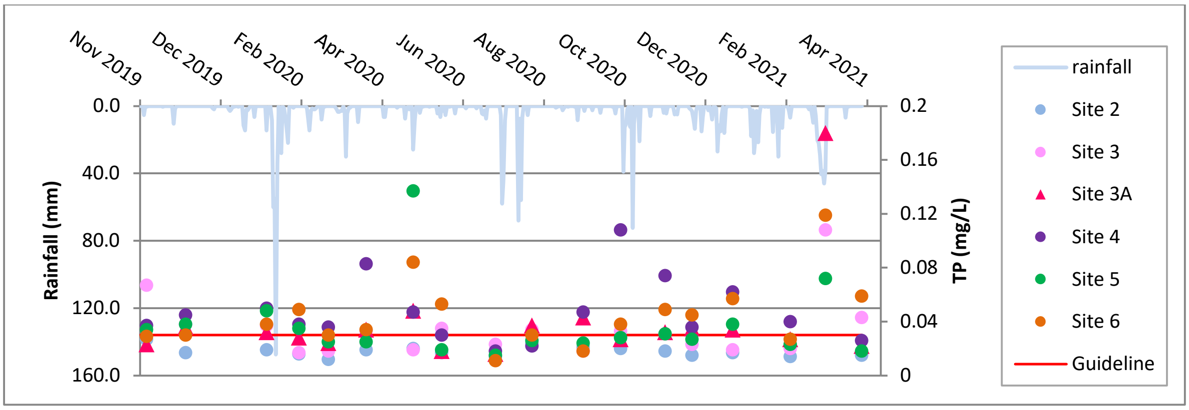
Figure 3: Plots of filtered total nitrogen (FTN) and rainfall for November 2019 to April 2021 for the (A) Foreshore (lake edge) sites and (B) In-lake sites

4.1.3 Phosphorus

Figure 4 shows total phosphorous (TP) values and rainfall for the period November 2019 to April 2021 for the foreshore and in-lake sites. In Appendix A graphs of the results from the last twelve years are presented. For the foreshore sites (Figure 4a) the recent observations are very similar to previous observations, with several sites routinely exceeding the guideline value, and with greater variation of total phosphorus values at the lake edge sites compared to in-lake sites. Along the lake edges, Burroo Bay (Site 4) and Griffins Bay (Site 6) continued as in past years to have the highest concentrations, with Site 3 also showing high values. As with total nitrogen, all foreshore sites had very high TP values for March 2021, with values two to six times greater than the ANZECC guideline. (Figure 4a).

The in-lake sites (Figure 4b) show better compliance with the ANZECC guideline, with the only exception to this during the March 2021 sampling period. All sites had values two to five times greater than the ANZECC guideline at this time (Figure 4b). These high values can be attributed to the rainfall event that occurred the day before sampling.

A: Foreshore sites



B: In-lake sites

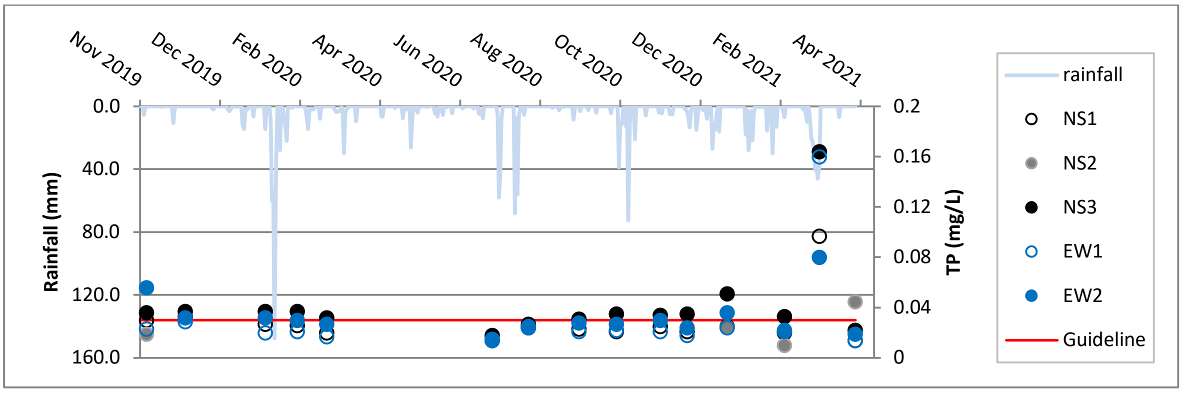
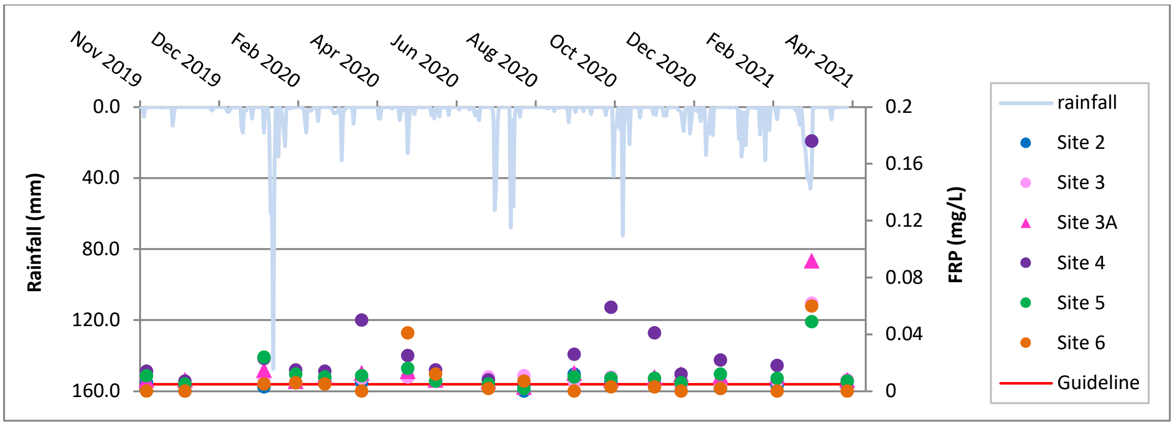


Figure 4: Plots of total phosphorous (TP) and rainfall for November 2019 to April 2021 for the (A) Foreshore (lake edge) sites and (B) In-lake sites

The filterable reactive phosphorus (FRP) results are presented in Figure 5. 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.

A: Foreshore sites



B: In-lake sites

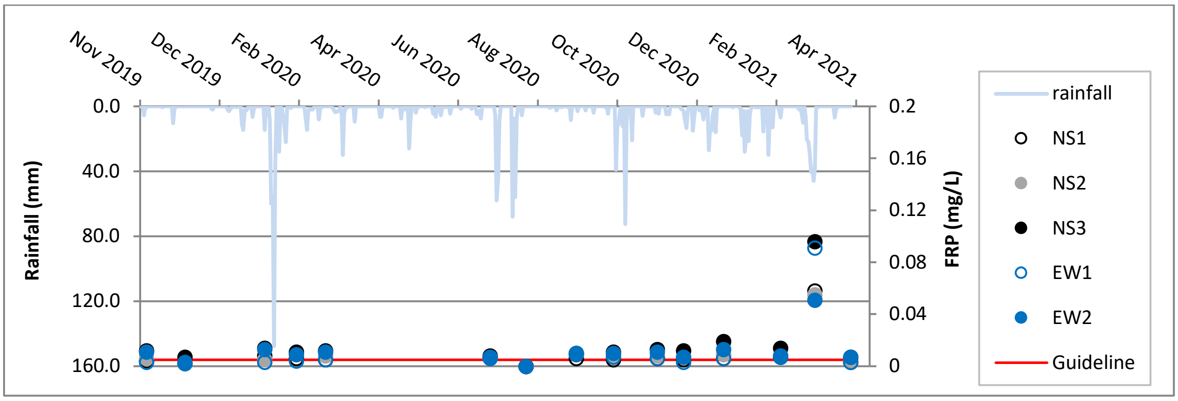


Figure 5: Plots of filterable reactive phosphorus (FRP) and rainfall for November 2019 to April 2021 for the (A) Foreshore (lake edge) sites and (B) In-lake sites

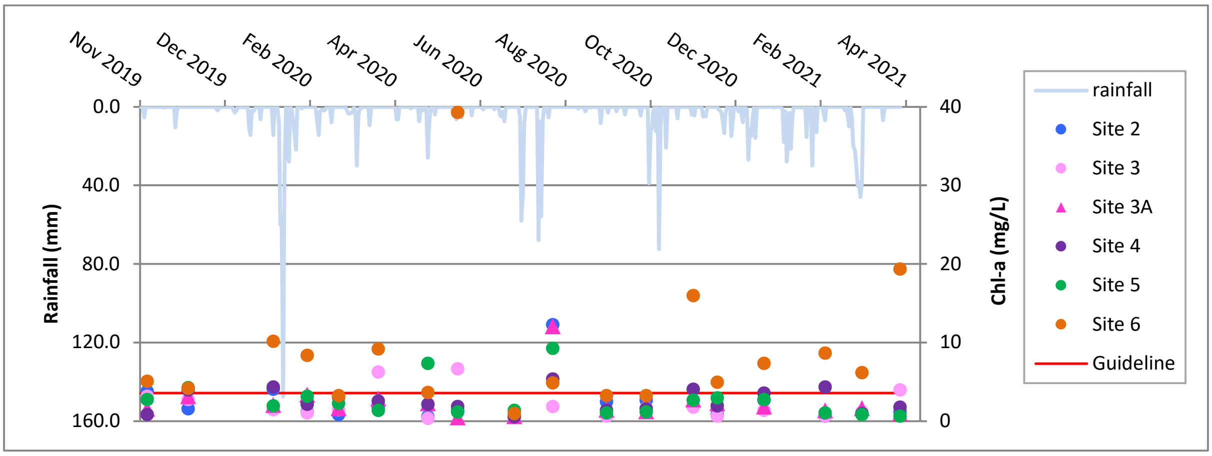
4.1.4 Chlorophyll *a*

The results for chlorophyll *a* are presented in Figure 6. Most foreshore and in-lake sites show compliance with the trigger value, and there was increases in chlorophyll *a* over the summer period, but these were often only small increases. The expected seasonal pattern of increases in chlorophyll *a* over summer was not exceedingly apparent, compared to other years (refer to Appendix A). The exception to this is Site 6 which exceeded the trigger value twelve times over the sampling period, especially over the warmer months.

During August 2020 all sites except Site 3, exceeded the trigger value, with very high values being exhibited. Foreshore sites had values up to three times greater than the trigger value, while four of the in-lake sites had values approximately four times greater than the trigger value. There was a rainfall event 10 days earlier which could explain these high values during a winter period (Figure 6).

Interestingly, a very large rainfall event occurred on the 10th February (146.5mm), which would have caused major catchment run-off. Sampling occurred 17 days later, and most of the foreshore sites were below the trigger value (except Site 6 Griffins Bay), and the in-lake sites were just above or near the trigger value. This indicates either nutrients were quickly flushed out of the lake and/or rapidly utilised by the phytoplankton and other plant life in the lake.

A: Foreshore sites



B: In-lake sites

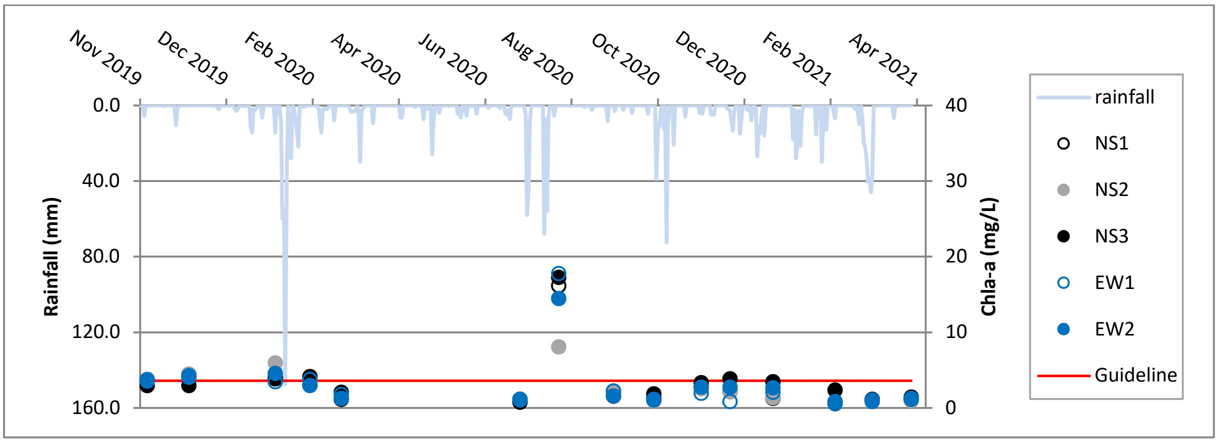


Figure 6: Plots of chlorophyll *a* and rainfall for November 2019 to April 2021 for the (A) Foreshore (lake edge) sites and (B) In-lake sites

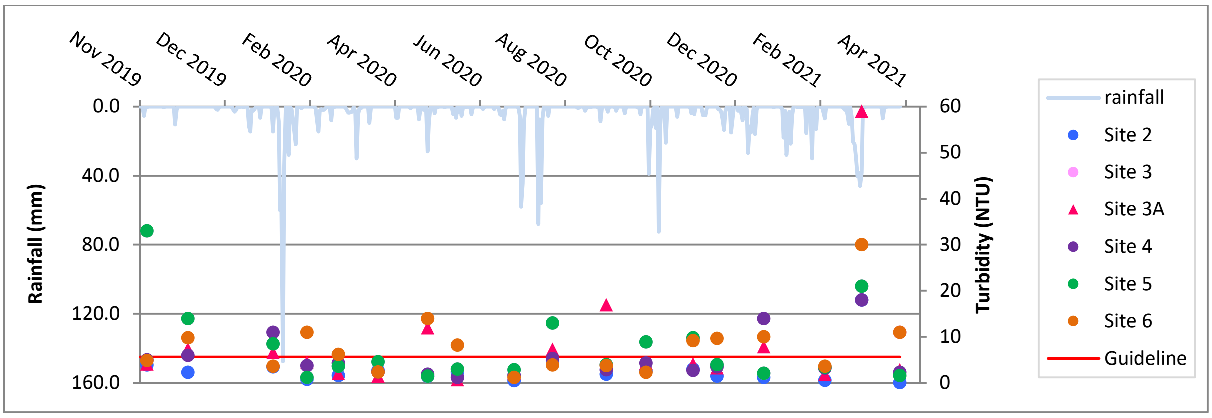
4.1.5 Turbidity

Turbidity gives an indication of light availability in the water and is influenced by the amount of suspended material present. In a relatively shallow lagoon such as Lake Illawarra, together with the amount of suspended microscopic algae and other organisms, the nature of the bottom sediments (whether muddy or sandy), the weather conditions (especially wind and rain), and boating or other traffic that can cause local turbulence in the water are all important factors that can affect the turbidity levels, as well as catchment run-off.

The results for the last 18 months again show greater exceedance of the trigger value for turbidity at the foreshore sites than within the main body of the lake (Figure 7). 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, 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) increases over summer, and this is another factor influencing the turbidity of the water. However, this pattern as not as evident as in past years.

The foreshore sites are generally shallower than the in-lake zones, and are dominated by muddy bottom sediments, except around the eastern margin where sediments are sandier. These mud-dominated edge sites can generally be expected to be more turbid than the sites around the entrance and in the deeper in-lake zones, as any turbulence in the water caused by wind or boating activities can quickly mobilise the bottom sediments. The results obtained agree with this expectation, where the in-lake sites remain largely stable. All foreshore and in-lake sites showed high turbidity values in association with the rainfall event in March 2021.

A: Foreshore sites



B: In-lake sites

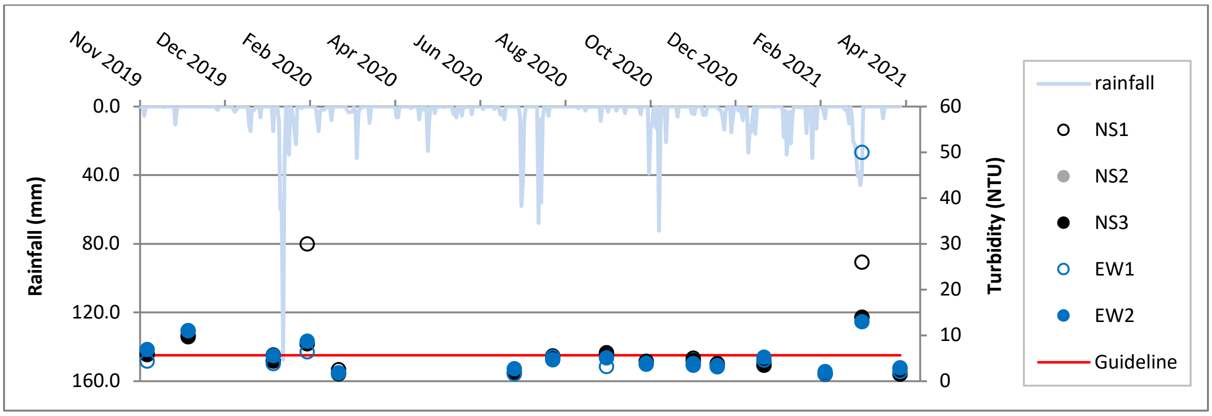


Figure 7: Plots of turbidity and rainfall for November 2019 to April 2021 for the (A) Foreshore (lake edge) sites and (B) In-lake sites

4.2 Water quality and estuary health trends

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. 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, and these can detract from the background trend. Whether these factors are significant must be considered in any trend analysis.

The Seasonal Kendall method has been selected for the trend analysis as it allows for seasonal differences in the data. Rainfall effects can detract from the seasonality pattern, and to account for this, data points that were greater than two standard deviations from the mean were excluded from the analysis. The trend analysis was performed with the filtered data for total nitrogen, total phosphorous, turbidity and chlorophyll *a*. A decreasing trend means that the values are decreasing over time (and hence an improvement in the condition of that site).

A statistically significant decreasing trend could be detected for three of the foreshore sites – Sites 4, 5 and 6 for all parameters– sites that are especially vulnerable to catchment run-off. Site 3A showed a statistically decreasing trend for all parameters, except total phosphorous (Table 6). Interestingly Site 4 and Site 6 showed decreasing trends for all parameters. These sites continuously show high nitrogen and phosphorous values, but it appears these values, while still high, are decreasing over time. This is a significant result as well considering the 2020/21 was the wettest year total since 2016/17. Previous decreasing trends in recent years have been explained by those years being unusually dry, and hence a lack of catchment run-off, but it appears those decreasing trends are continuing despite increased rainfall events. Site 3 was the only site to have an increasing trend for total nitrogen and total phosphorous. The reason for this could be that increased sand deposition across the seaward end of this channel observed over time is restricting flushing of this area.

No significant trends were selected for the in-lake sites, except Site NS1 showed a statistically decreasing trend for total nitrogen.

Table 6: Results of trend analysis for chlorophyll *a*, turbidity, total nitrogen and total phosphorous at all sites

Site	Chlorophyll *a*	Turbidity	Total nitrogen	Total phosphorous
2	none	none	none	none
3	none	none	Increasing trend	Increasing trend
3A	Decreasing trend	Decreasing trend	Decreasing trend	none
4	Decreasing trend	Decreasing trend	Decreasing trend	Decreasing trend
5	Decreasing trend	Decreasing trend	Decreasing trend	Decreasing trend
6	Decreasing trend	Decreasing trend	Decreasing trend	Decreasing trend
NS1	none	none	Decreasing trend	none
NS2	none	none	none	none
NS3	none	none	none	none
EW1	none	none	none	none
EW2	none	none	none	none

4.3 Estuary ecosystem health condition

The estuary ecosystem health condition is based on the chlorophyll *a* and turbidity data for the summer period (November to March), as recommended under the NSW MER program (State of NSW and Office of Environment and Heritage 2016), using the guideline trigger values of 3.6 µg/L for chlorophyll *a* and 5.7 NTU for turbidity. The results for the recent summer (2020/21) are presented in Figure 8, together with results from each summer period from 2013 for all sites monitored so changes over the years can be seen. There have been changes in the number and location of some sites over the years.

The results show that for the 2020/21 period most of the sites are in good condition, with two of the in-lake sites in very good condition (Figure 8). This is a significant result considering the 2020/21 summer was been the wettest since 2016/17. Previous results of sites being in good condition (e.g. 2018/19) were often related to dry weather and hence a lack of catchment run-off. It would appear though that despite the wet weather and hence an increase in catchment inputs from several rainfall events over the last year, the lake is maintaining good estuary health.

Site 6 in Griffins Bay was the only site rated as being in poor condition. This was largely a result of several very high chlorophyll *a* and turbidity values over the summer period. This site has continuously been rated as fair to very poor since 2013/14, indicating the high input of nutrients and sediment from the catchment in this area and the lack of flushing that occurs in this bay.

Ongoing water quality issues in Griffins Bay were also noted in September 2020 with extensive macroalgal blooms occurring from Primbee foreshore at Griffins Bay to Purry Burry in the south (see photos below). The lack of improvement in this area needs investigation as it could mean that the nutrient loads are persistent and needs management intervention.

Photos of macroalgae blooms along Primbee foreshore September 2020 (Photo credit: D Wiecek DPIE)

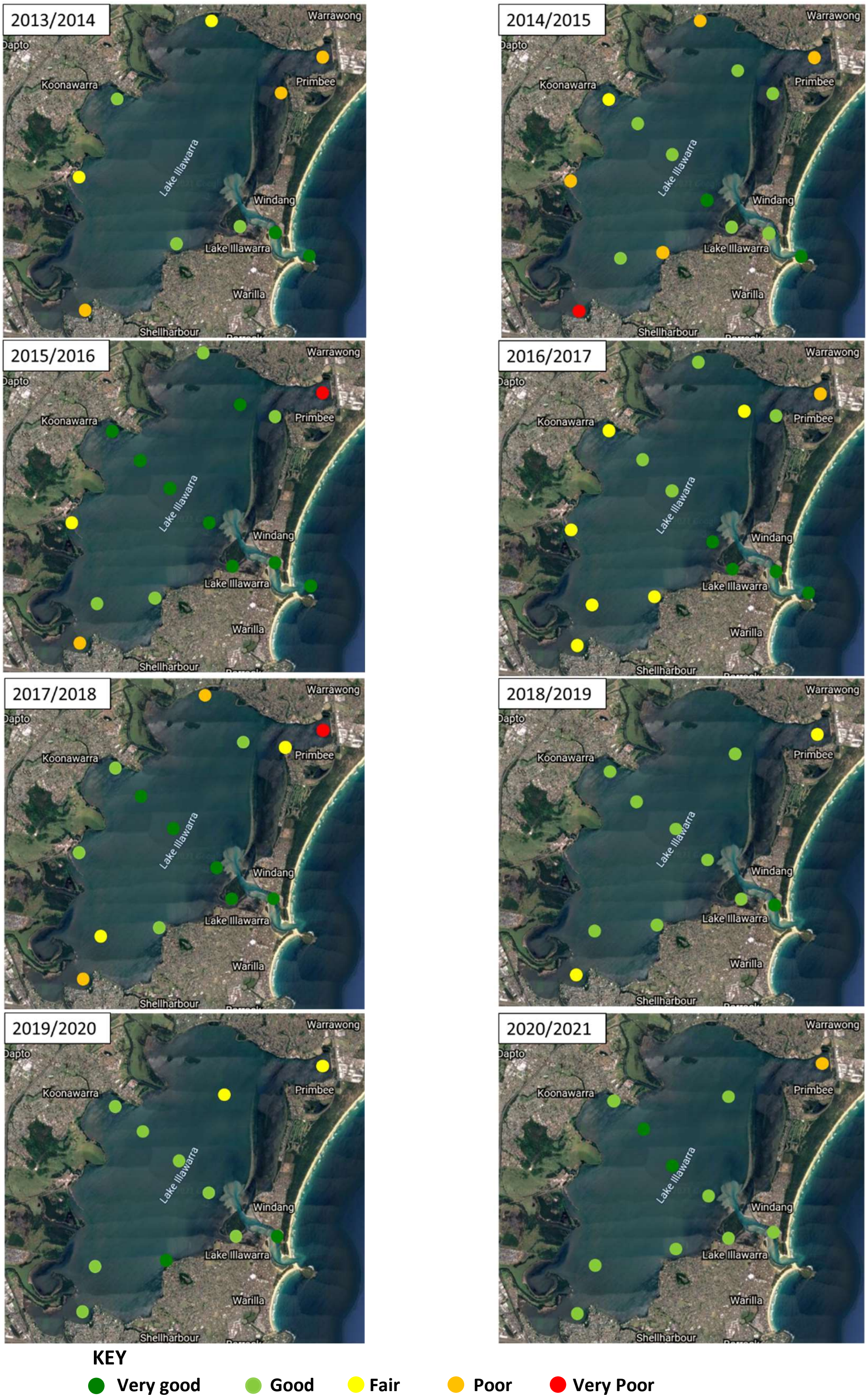


Figure 8: Estuary health condition ratings (based on chlorophyll *a* and turbidity) over the summer period (November to April) for each year since 2013 for 11 sites monitored across Lake Illawarra.

In past years other foreshore sites have had poorer estuary health condition ratings compared to the in-lake sites and was related to these lake edge sites being more susceptible to catchment inputs. Turbidity at edge sites can also be easily influenced by prevailing wind conditions at the time of sampling, particularly as the lake is very shallow, and by other disturbances such as boating. However, in the last few years there has been an improvement in the health of foreshore sites, with all (except Site 6 at Griffins Bay) being rated as being in good condition.

The current estuary health condition of the lake might seem like a good result, but it is important to note it is based on chlorophyll *a* and turbidity, and doesn't include other indicators of estuary health, such as macrophyte distribution, seagrass depth limits or fish assemblages. The inclusion of these estuary health indicators would assist in a greater understanding and assessment of the lake condition and should be considered for inclusion in coming years.

4.4 Recreational water quality

Figure 9 shows the percentage compliance of the 21 test occasions meeting the recreational water guideline for primary (35 cfu/100 ml) and secondary (230 cfu/100 ml) contact for three sites sampled for the presence of enterococci. Kanahooka and Ski Way Park had relatively good compliance for primary recreation and Kanahooka had 100% of samples meeting secondary recreation compliance, with Ski Way Park having 95%. Purry Burry had the lowest compliance levels out of the three sites but this is to be expected given its proximity to Griffins Bay. These results may look encouraging but need to be treated with caution as they may not be representative of the situation in these areas all the time. Rainfall is known to have a significant effect on water quality and enterococci levels and it is recommended that swimming should be avoided during and for up to one day following heavy rain at ocean beaches and up to three days at estuarine sites (NSW DPIE 2020). The effect of rainfall was difficult to quantify for the 2020-20201 summer period as most of the Beachwatch sampling days did not correspond to rainfall events (Figure 10).

The entrance site (called Entrance Lagoon Beach) that is sampled, analysed and reported under the NSW Beachwatch program was rated as good for the 2019-2020 period (NSW DPIE 2020). The beach suitability grade of good means that the location has generally good microbial water quality and water is considered suitable for swimming most of the time (NSW DPIE 2020).

No NSW Beachwatch summary report was available for the 2020-2021 period at the time of publication of this report.

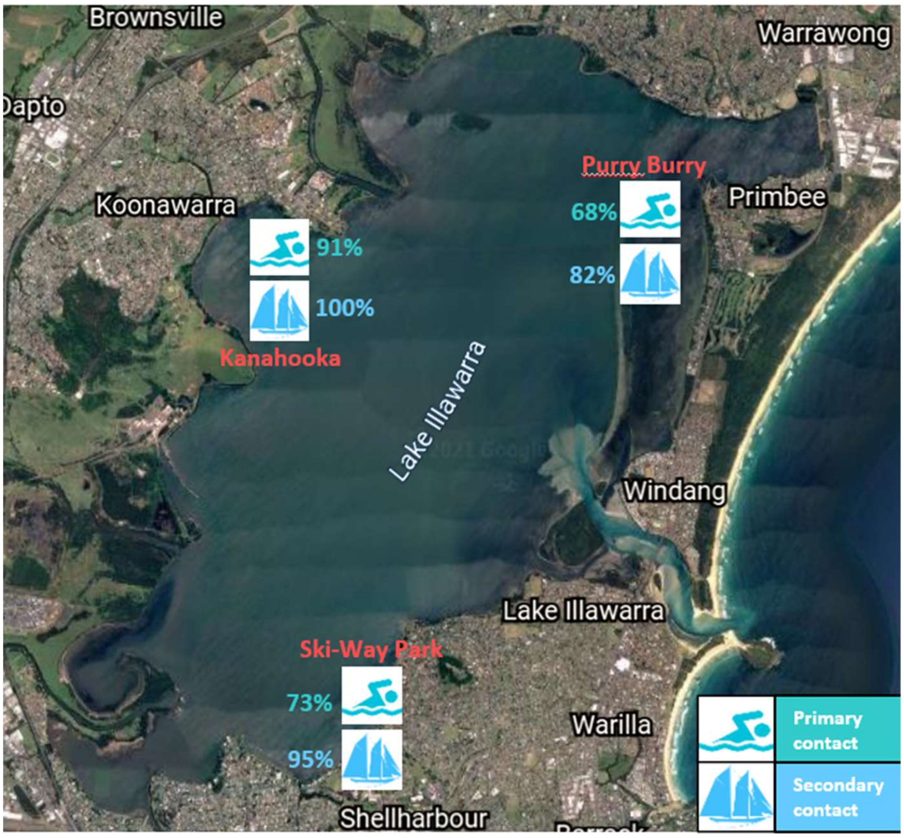


Figure 9: Percentage of the test occasions meeting primary (35 cfu/100 ml) and secondary (230 cfu/100ml) contact recreational water quality guidelines, at three locations within Lake Illawarra.

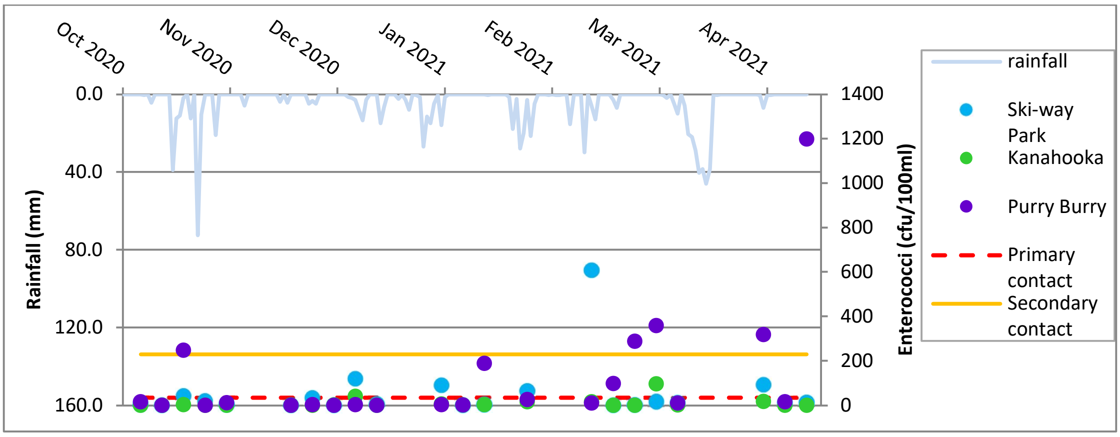


Figure 10: Plot of enterococci concentrations against rainfall from October 2020-April 2021

5 Conclusion

This report has reviewed selected indicators to describe the water quality and estuary health condition evident in Lake Illawarra in the 18 months from November 2019 to April 2021, and for estuary health trends since 2013. The indicators are nitrogen and phosphorus concentrations, turbidity and chlorophyll *a* for estuary health, and the bacterial species enterococci for recreational use.

Evidence for strong spatial variation in nutrient values and turbidity around the lake, as noted in previous reports, has been reinforced with recent data. Water quality at the foreshore edge sites show greater variation and more exceedances of the ANZECC guidelines or trigger values than the in-lake sites. This is to be expected given the lake edge sites are closer to catchment inputs and are not as greatly flushed as the in-lake sites. Also, the foreshore sites are generally shallower than the in-lake zones, and are dominated by muddy bottom sediments, except around the eastern margin where sediments are sandier. These mud-dominated edge sites can generally be expected to be more turbid than the sites around the entrance and in the deeper in-lake zones, as any turbulence in the water caused by wind or boating activities can quickly mobilise the bottom sediments.

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, albeit not as evident as past years (refer to Appendix A for long-term data series). 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 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 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.

During the March 2021 sampling event there was a rainfall event of 46 mm the day before sampling and approximately 200m in the six days preceding, and consistently high values for all parameters across all sites were recorded. There were other larger rainfall events between November 2019 and April 2021, for example, in February, August and November 2020 (Figure 2). However, none of the sampling events coincided with them, with most of the sampling occurring approximately 10-17 days later and thus the possibly high nutrient levels that may have occurred with those rainfall events were not captured by this sampling program. Some sites, particularly Sites 4 and 6 still showed some high total nitrogen values 10 days later, indicating nitrogen inputs from catchment sources or lake bed sediments are greater and persistent around Griffins (Site 6) and Burroo (Site 4) Bays, and the enclosed nature of these parts of the lake may be preventing their full circulation with the rest of the lake. For other sites, the relatively low nitrogen values showed approximately 10 days after rainfall events indicate the nutrients were flushed quite quickly out of the lake and/or rapidly utilised by the phytoplankton and other plant life in the lake. This suggests that following a rainfall event, the lake may return to near seasonal water quality conditions fairly rapidly. However, this will be dependent on the residence time of the materials introduced into the lake, but also spatial differences within different areas of the Lake.

Calculations indicate a potential residence time of 3 to 20 days for Lake Illawarra (WCC 2018), noting this was based on coarse methodologies with several limitations. 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. Spatial variations in water quality across the different sites in Lake Illawarra discussed in this report and previous reports have shown that this is certainly not the case. The spatial differences suggest that the residence time for the more central portion of Lake Illawarra is shorter than that for the more enclosed areas of the lake in the north (e.g. Griffins Bay) and the south. Longer residence times in the more enclosed north and south of the lake, where water quality can be 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. This could be one of the reasons water quality in Site 6 Griffins Bay remains consistently poor.

Based on current analysis the condition of the estuary seems to be improving over the period 2013-2021, with all sites except for Griffins Bay, rated good to very good for 2020/221. This is a significant result given that 2020/21 was the wettest year since 2016/17. Interestingly three of the foreshore sites also showed decreasing trends for nutrients, chlorophyll *a* and turbidity. Site 4 at Burroo Bay, while still showing intermittently high nutrient values seems to be improving over the long term, with an improvement in its grading over the last two years. Continuation of the monitoring program will help establish how the lake responds following extended wet weather periods. Also, the current condition of the lake might seem like a good result, but it is important to note it is based only on chlorophyll *a* and turbidity, and doesn't include other indicators of estuary health, such as macrophyte distribution, seagrass depth limits or fish assemblages. The inclusion of these estuary health indicators would assist in a greater understanding and assessment of the lake condition.

Water quality for primary and secondary contact recreational use of the lake was generally good over the testing period, particularly at Kanahooka and Ski-way Park. These results may look encouraging but need to be treated with caution as they may not be representative of the situation in these areas all the time. Rainfall is known to have a significant effect on water quality and enterococci levels, but it is difficult to quantify as the sampling should be taken at the same day or soon after the rainfall event.

Monitoring of the health of the lake should continue, as long-term datasets are essential to gain insights into how the lake is changing over time. Given the large-scale developments occurring in the catchment of the lake, it is important that the health of the lake is monitored. The implementation of the suite of management actions in the Lake Illawarra Coastal Management Program to control catchment inputs is strongly supported, and long-term monitoring of the lake will inform whether investment and management action in the lake is making a difference.

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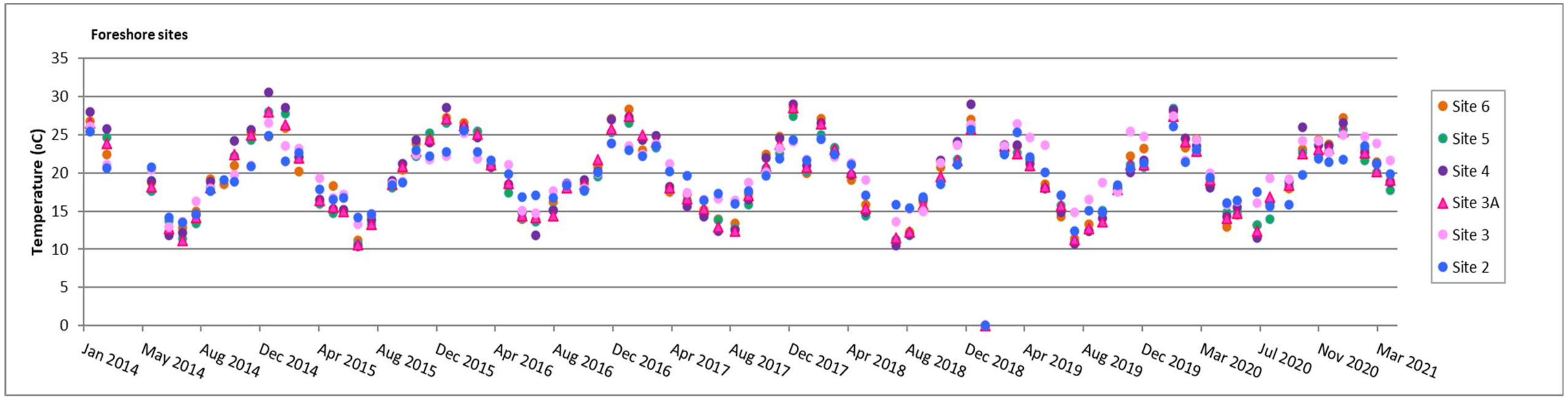
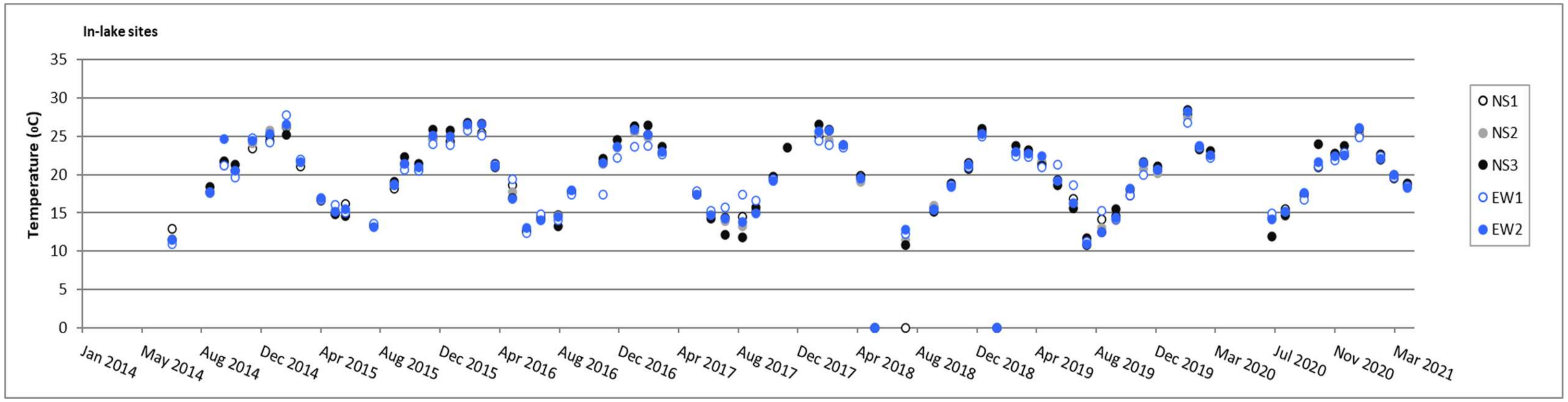
Appendix 1: List of management actions in the Lake Illawarra Coastal Management Program relating to improving water quality

Strategy 1: Improve Water Quality (WQ)	
WQ1	Implement a Risk Based Stormwater Management Framework for the Lake Illawarra catchment
WQ2	Upgrade existing stormwater quality management measures, or install new devices, which may include water sensitive urban design or other design that will improve water quality as well as entrance habitat and natural values
WQ3	Review and prioritise maintenance and cleaning regime for existing stormwater quality devices
WQ4	Design and implement targeted catchment input monitoring as required for developments resulting in a large-scale change or intensification of land use
WQ5	Reduce sediment load to the Lake by improving compliance with erosion & sediment controls for development sites
WQ6	Reduce the impact of sewer overflows
WQ7	Implement water quality monitoring programs for estuary health, recreational use and physico-chemical and bacteriological indicators in the Lake and its catchment
WQ8	Improve litter management
WQ9	Investigate and manage potential pollution sources including contaminated sites that contribute to poor water quality in the Lake.

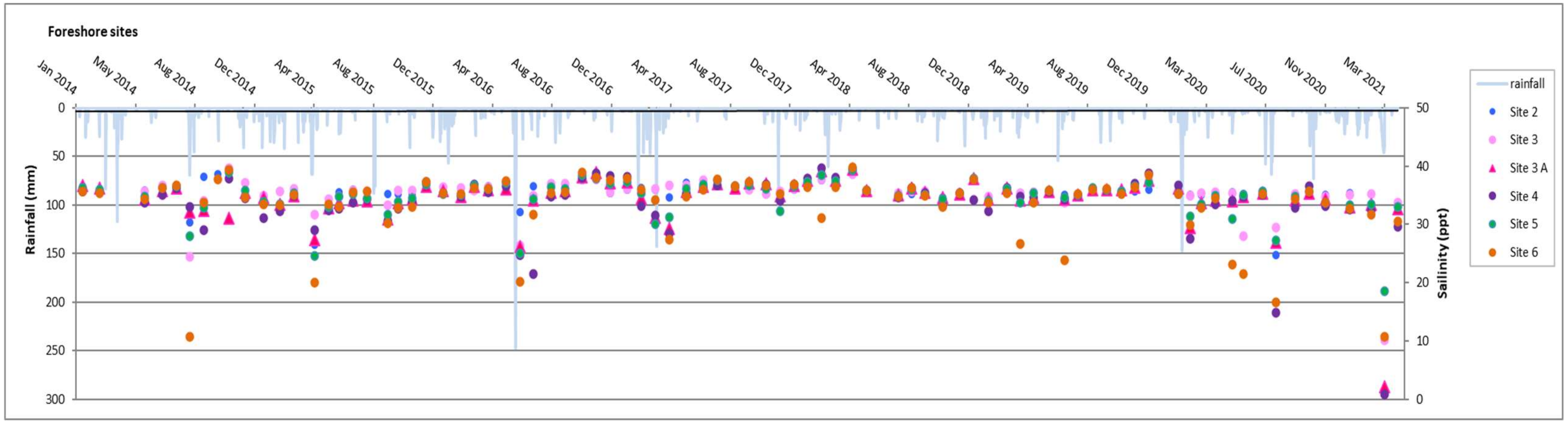
Appendix 2: Long-term plots of parameters at all sites from 2013/14 to 2021

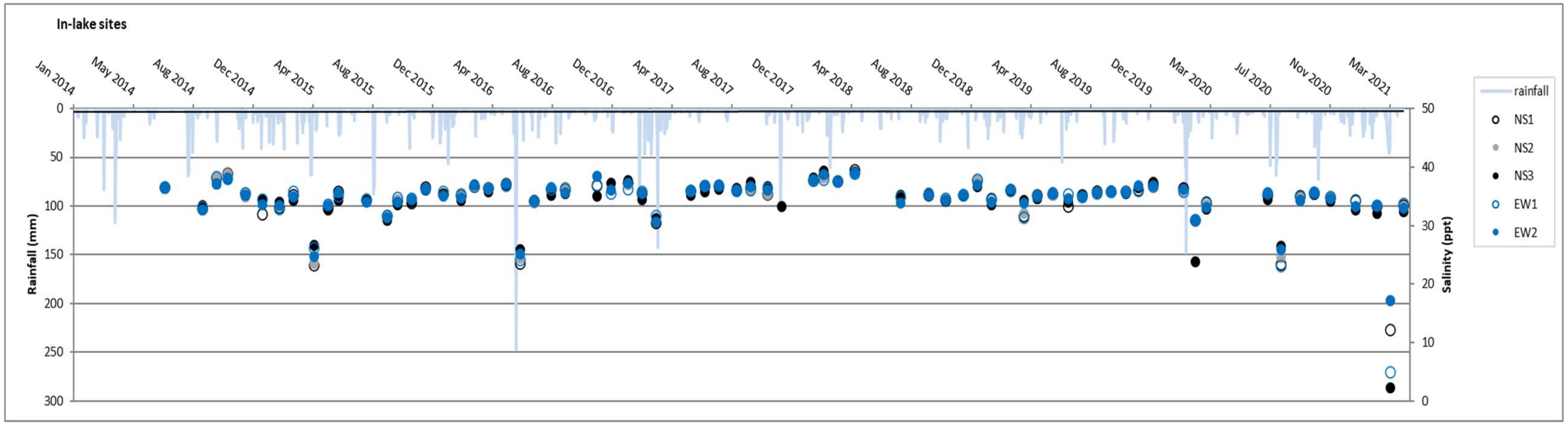
Plots of Temperature (^{0}C) from 2014 to April 2021



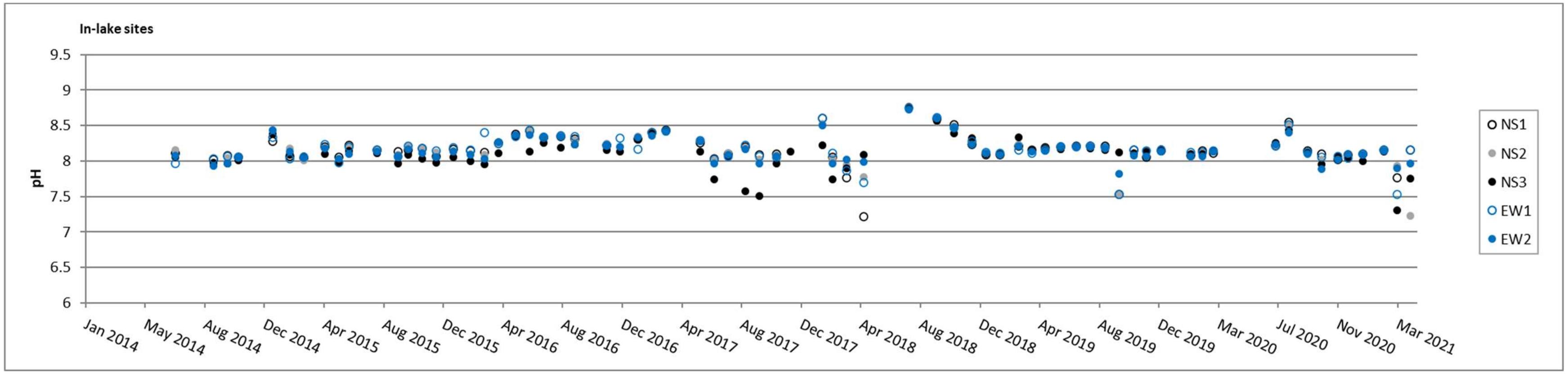


Plots of Salinity (ppt) from 2014 to April 2021

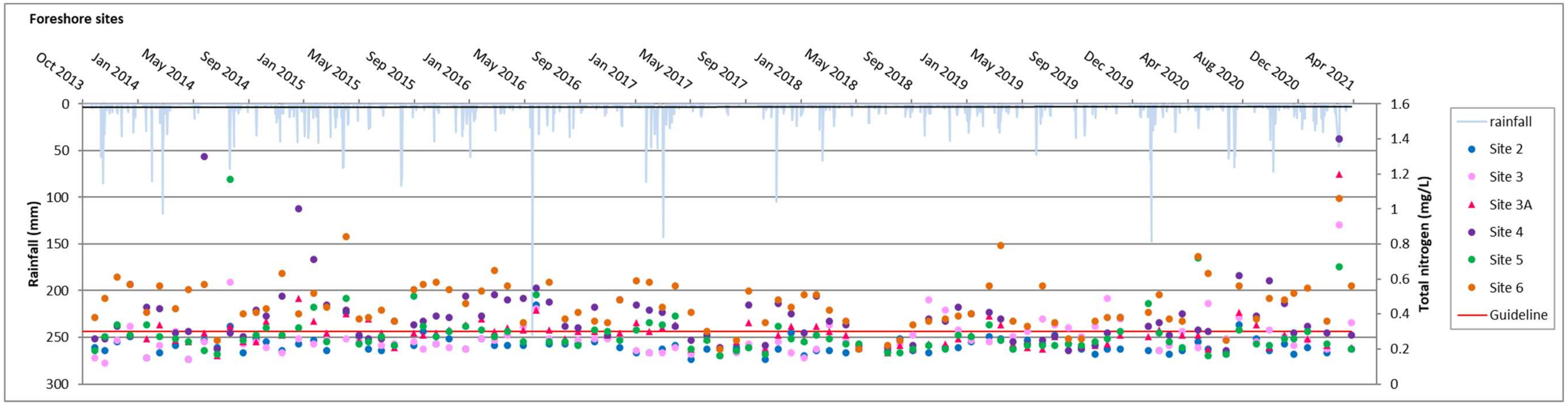


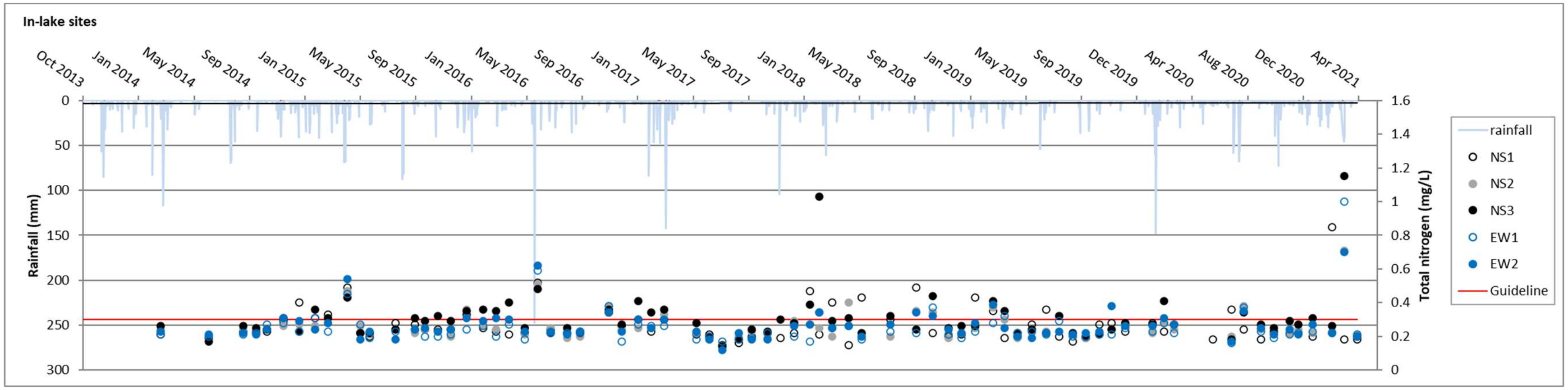


Plots of pH from 2014 to April 2021

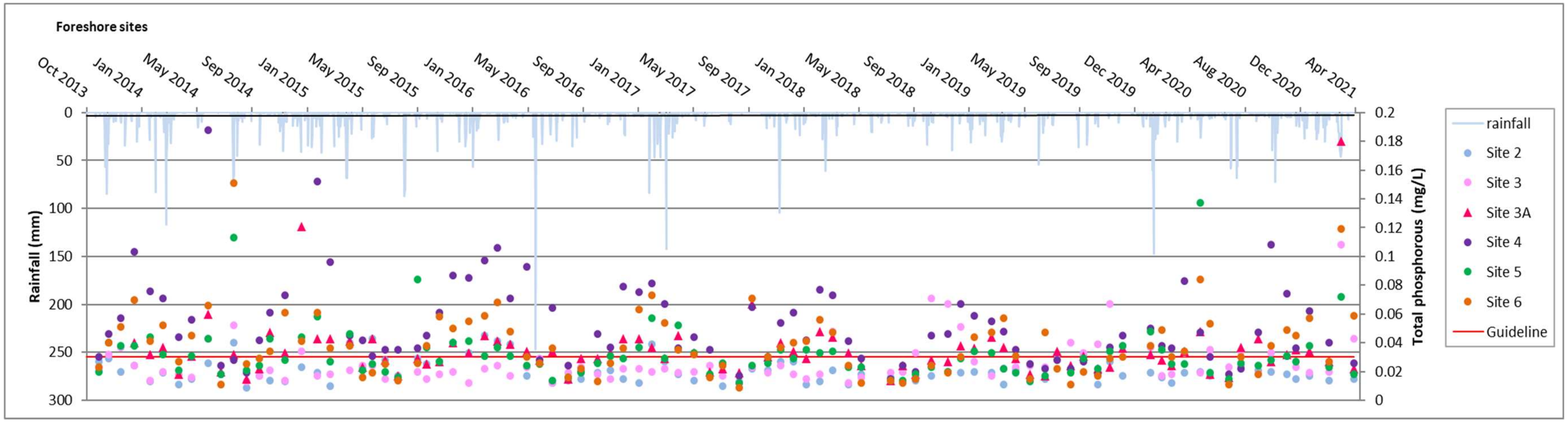


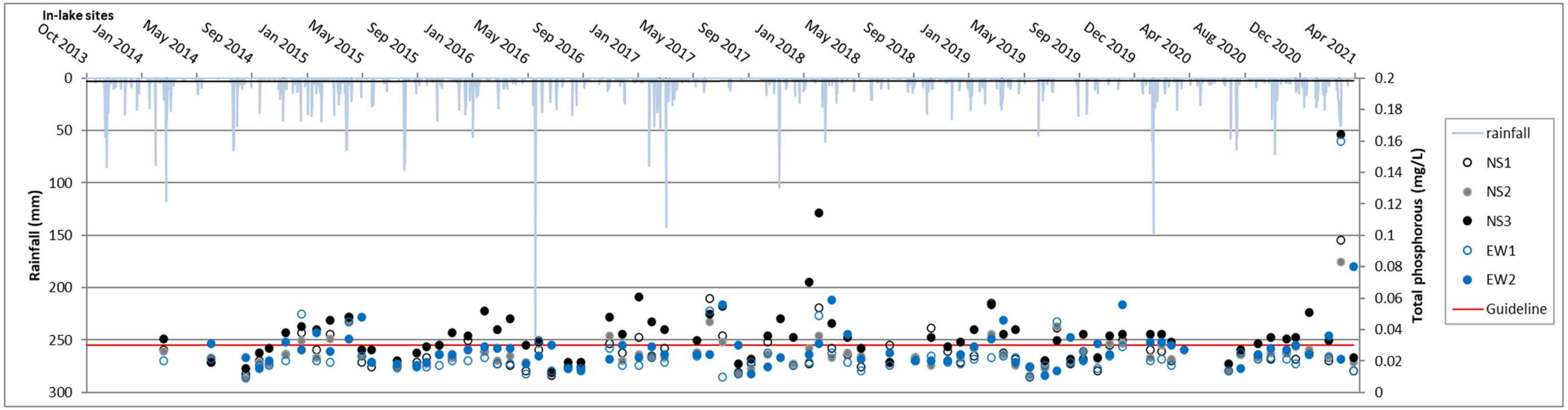
Plots of Total nitrogen (mg/L) from 2013 to April 2021



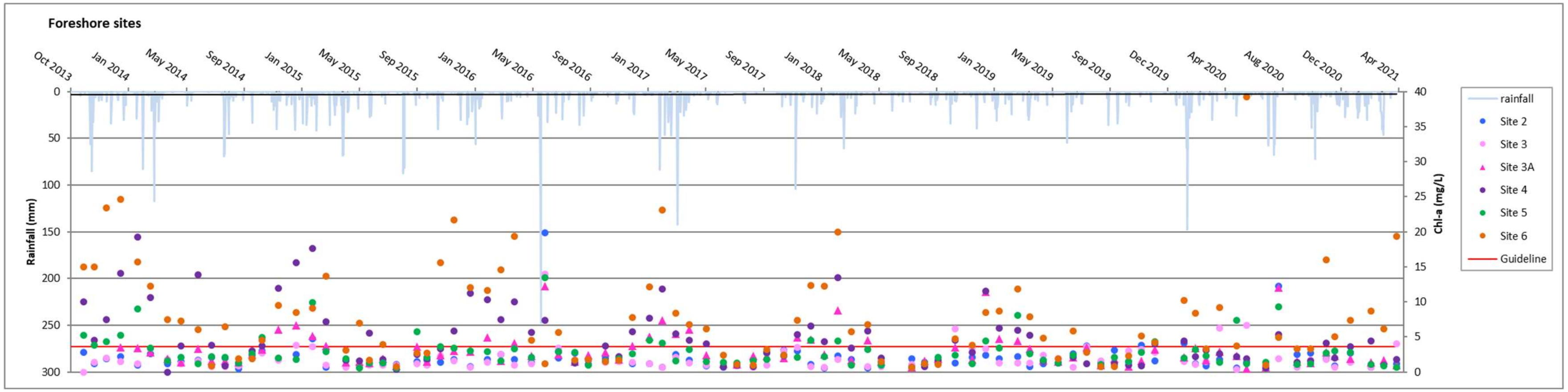


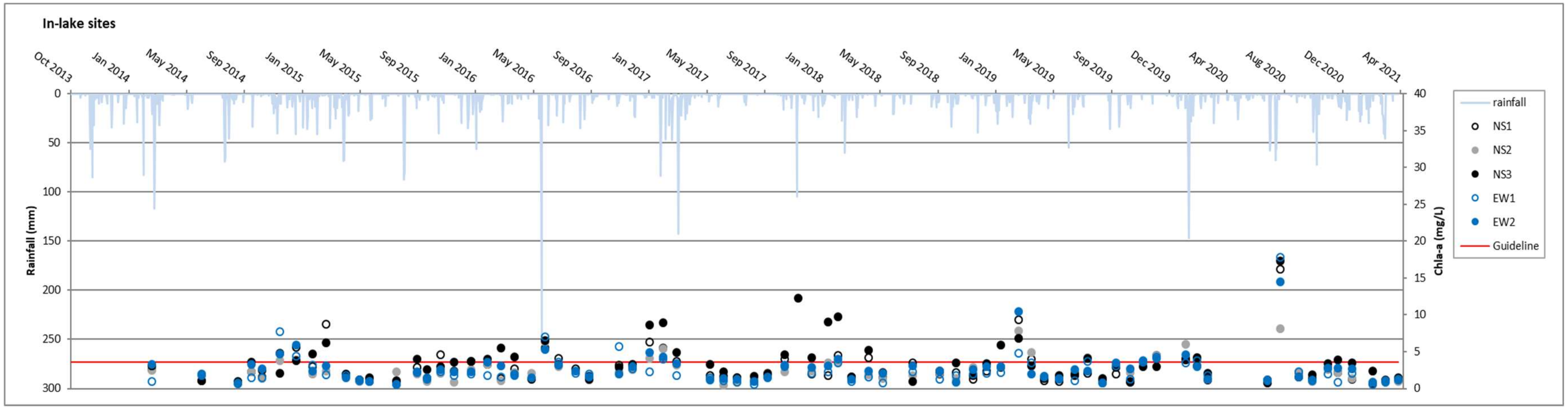
Plots of Total Phosphorous (mg/L) from 2013 to April 2021





Plots of Chlorophyll *a* (µg/L) from 2013 to April 2021





Turbidity (NTU) from 2013 to April 2021