Lake Illawarra Estuary Health and Water Quality Report 2022

Prepared by Wollongong City Council

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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 the monitoring period from May 2021 to April 2022, 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 water quality patterns observed for 2021/22 period were largely driven by the large and continuous rains over summer and early autumn. 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 2021/22 summer was the wettest since the program began, making the sampling period (May 2021 to April 2022) the wettest yearly total as well. 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 2021/22 period most of the sites are in good condition, with one of the in-lake sites in very good condition.

Site 6 in Griffins Bay and Site 5 in Koonwarra Bay were the only sites rated as being in fair condition. This was largely a result of several very high chlorophyll *a* and turbidity values due to catchment run-off from the high rainfall events experienced in summer and early autumn.

Assessing recreational water quality (primary and secondary contact) has been utilised through sampling for enterococci at three sites in Lake Illawarra since 2018. Estuarine sites are particularity impacted by potential sources of faecal contamination, including stormwater and urban and rural run-off. All sites had lower percentage compliance than the previous year and reflects the wet weather conditions and associated flooding over summer.

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 and the potential impacts of a changing climate, 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.

Contents

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 NSW Government Department of Planning and Environment (DPE) coast and estuary management program, and since then regular reports on the results have been issued. These reports have considerable detailed analysis and show that there can be 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 May 2021 to April 2022 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.

2.2 Recreational water quality

Since 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 are not reported under the NSW Beachwatch program.

The new sites added by Council in 2018/19 to measure recreational water quality are located 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 2021 and April 2022.

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

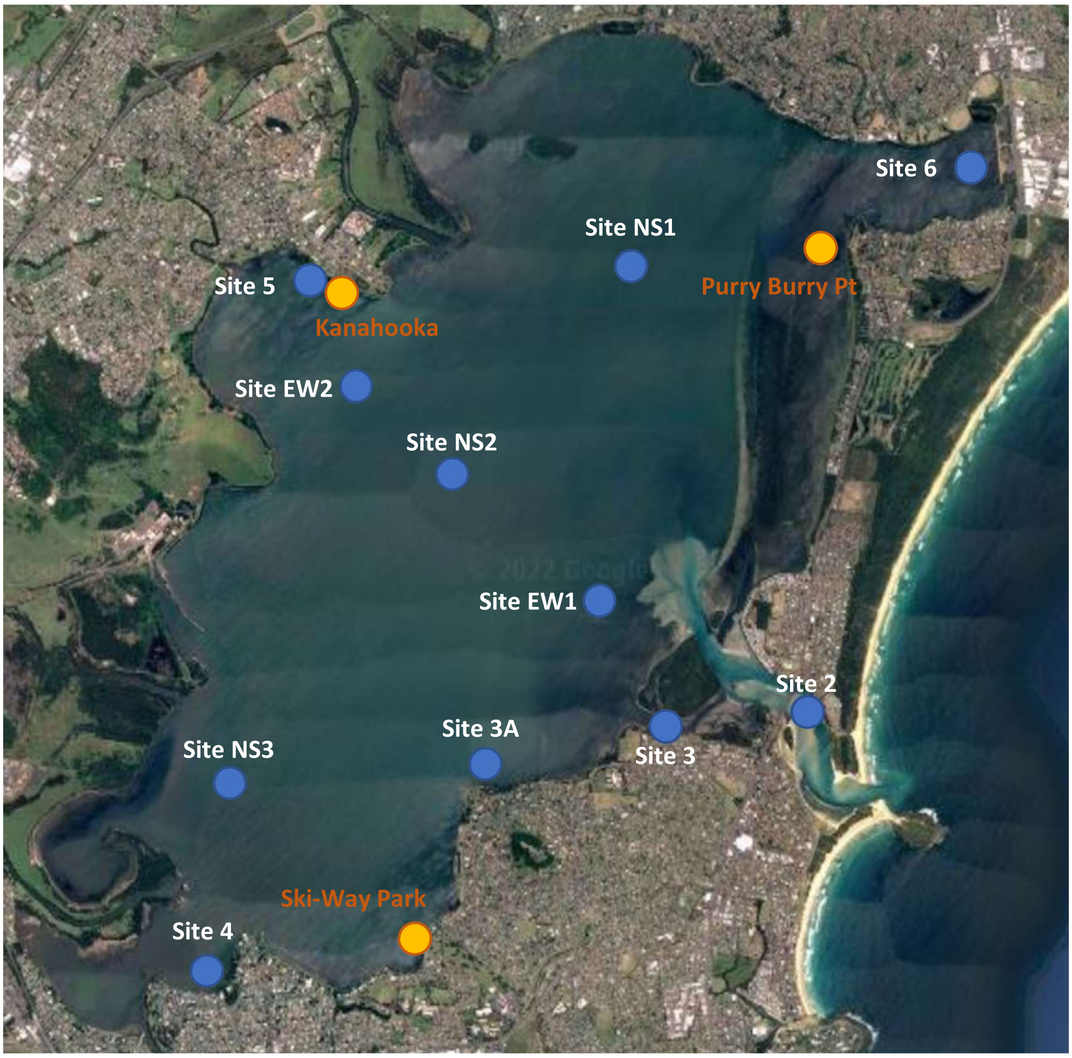


Figure 1: Map showing location of the 11 sites monitored by Council for water quality and estuary ecosystem health (in blue) and the 3 sites for recreational use (in orange)

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 2022 for the 11 sites monitored for estuary ecosystem health. The indicators discussed in depth in this this report are various forms of nitrogen and phosphorous, 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 DPE
Turbidity	5.7 NTU[b]	State of NSW and DPE

[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 for estuaries and coastal lakes, 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 analysis on the three sites within Lake Illawarra tested for the presence of enterococci 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 the water quality patterns observed in the 2021/22 period. Table 5 presents the seasonal and yearly total rainfall records for the last twelve years and it shows that the 2021/22 summer was the wettest since the program began and also the wettest year total.

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

Year	Winter (1 May to 31 Oct)	Summer (1 Nov-30 April)	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
2021/22	384.5	1425.5	1810

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 2 for the 11 sites monitored for water quality and estuary health. In the past 12 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 May 2021- April 2022 period, with only two exceedances above 8.5 at Site 6 suggesting there are no concerns relating to pH at Lake Illawarra.

Salinity since 2014 has been graphed against the daily rainfall records (Appendix 2). 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 dramatic decrease in salinity in February and March 2022 coinciding with large and continued rainfall events and high freshwater inflows into the estuary.

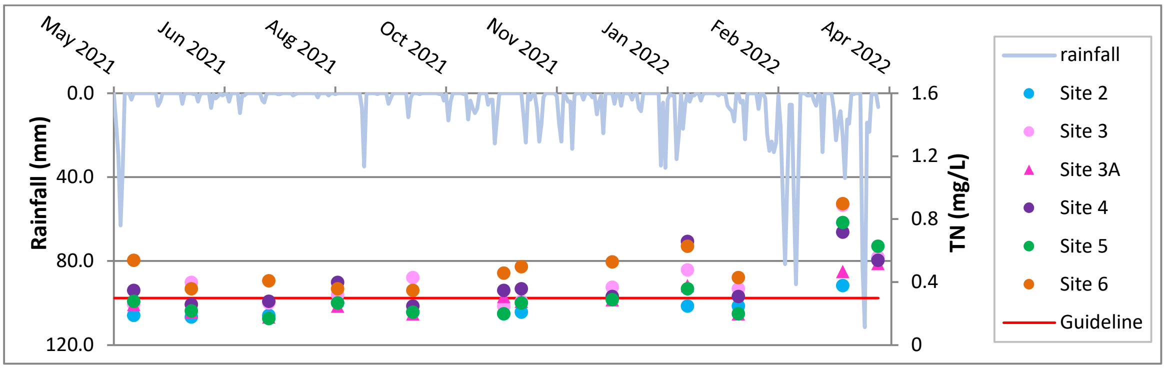
Salinity fell to between 9.4 to 13 at sites within the Lake, and between 10.9 to 21.8 at foreshore sites (Appendix 2).

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 nutrients may be significant and thus require management.

Over the May 2021 to April 2022 period the concentrations of nitrate, nitrite and ammonia were generally below or close to their respective detection limits (0.01mg/L) for the majority of the time, 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 was in March and April, where higher nitrate and ammonia concentrations were detected at most sites. High rainfall events occurred at this time resulting in a significant increase of the nitrogen load of the lake. Similar to preceding years Site 6 (Griffins Bay) displayed the highest nitrate, nitrite and ammonia concentrations.

A: Foreshore sites



B: In-lake sites

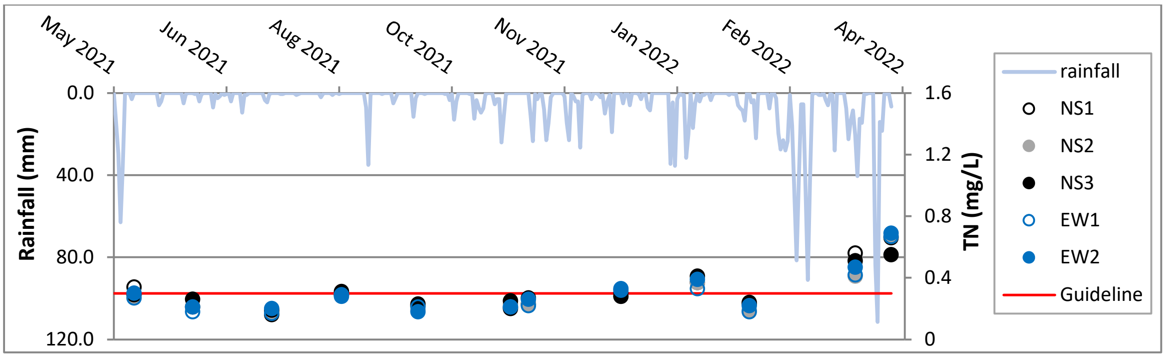


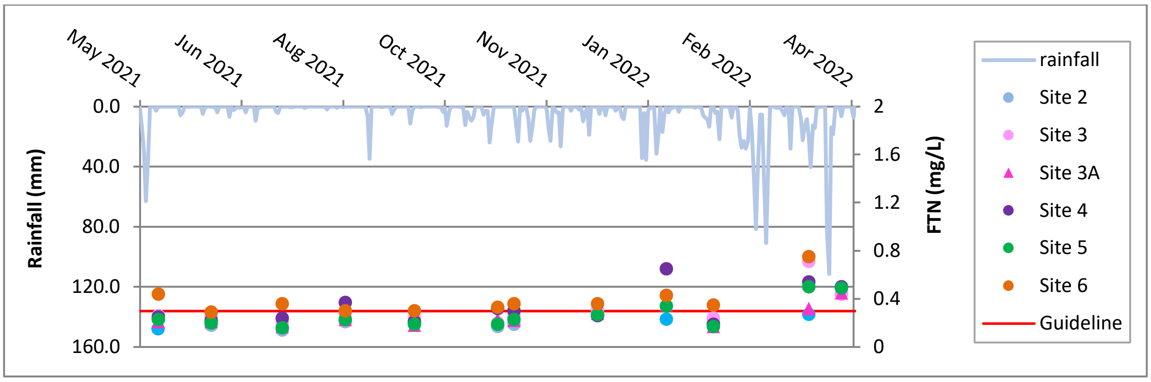
Figure 2: Plots of total nitrogen (TN) and rainfall from May 2021 to April 2022 for the (A) Foreshore (lake edge) sites and (B) In-lake sites

Figure 2 shows total nitrogen (TN) values and rainfall for May 2021-April 2022 for the foreshore and in-lake sites. In Appendix 2 graphs of the results from the last eight years are presented for all 11 sites. As with nitrate, nitrate and ammonia concentrations, Griffins Bay (Site 6) 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.

All foreshore sites, except Site 2 had high TN values during January 2022. In March and April 2022 all foreshore and in-lake sites exhibited high TN values, above the ANZECC guideline and were related to extreme rainfall events (Figure 2). For the majority of the rest of the sampling period though many of the foreshore and in-lake sites were below, or just above the recommended ANZECC guideline for TN (Figure 2a and 2b).

The TN value represents nitrogen that is present in water in both the dissolved and suspended forms, including microscopic algae and sediments, while the filtered total nitrogen (FTN) excludes the suspended component. The FTN for the May 2021-April 2022 period (Figure 3) continues to show better compliance with its guideline trigger value than TN. Similar to the pattern for TN, all foreshore and in-lake sites had FTN values two to three times greater than the ANZECC guideline in April 2022 (Figure 3).

A: Foreshore sites



B: In-lake sites

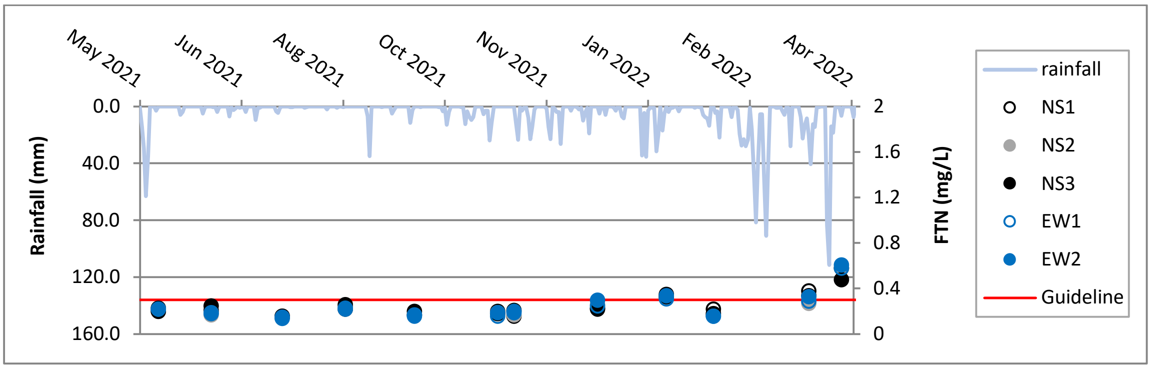


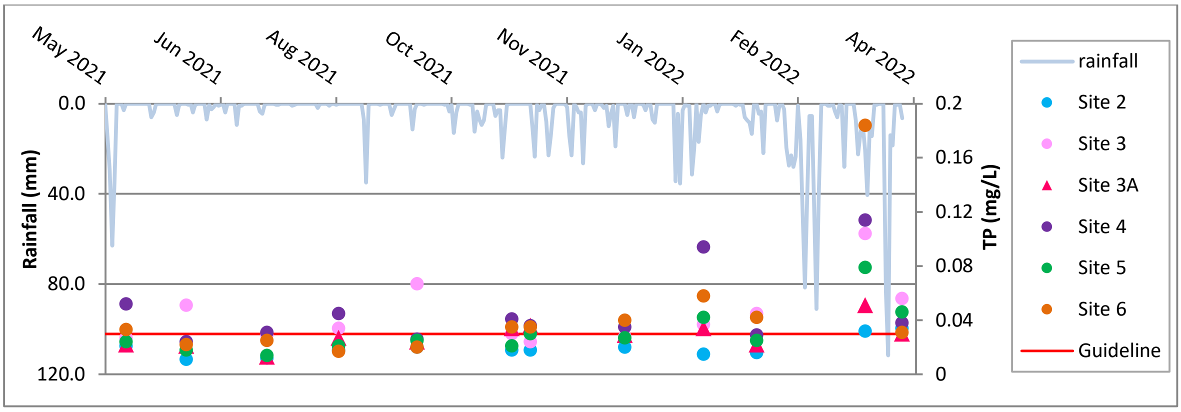
Figure 3: Plots of filtered total nitrogen (FTN) and rainfall from May 2021 to April 2022 for the (A) Foreshore (lake edge) sites and (B) In-lake sites

4.1.3 Phosphorus

Figure 4 shows total phosphorous (TP) values and rainfall for the period May 2021-April 2022 for the foreshore and in-lake sites. In Appendix 2 graphs of the results from the last eight 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 Picnic Island (Site 3), Burroo Bay (Site 4) and Griffins Bay (Site 6) showed the highest values throughout the period. As with total nitrogen, all foreshore sites had very high TP values for March 2022, with values two to six times greater than the ANZECC guideline (Figure 4a).

The in-lake sites (Figure 4b) show better compliance with most sites being below or just above the ANECCZ guideline. Interestingly, during the March 2021 event that saw high values of TN at all sites and high TP values at the foreshore sites, values of TP in-lake were just above the ANZECC guideline (Figure 4b).

A: Foreshore sites



B: In-lake sites

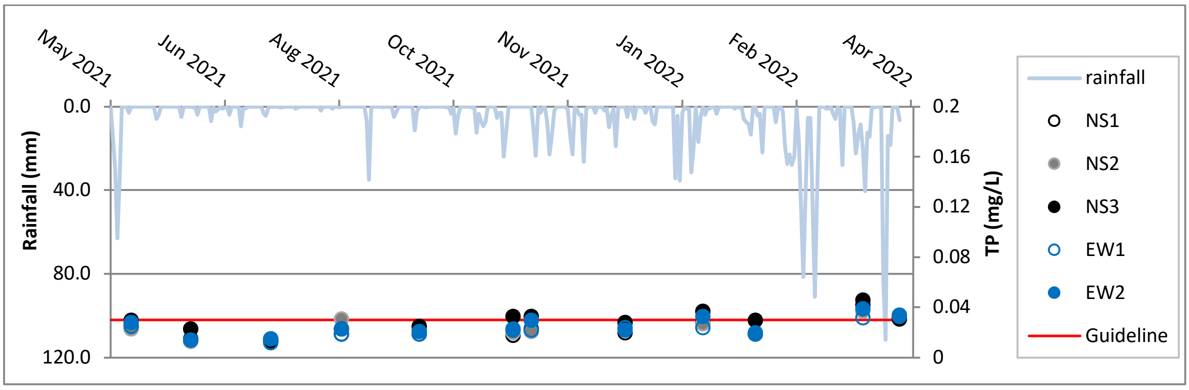
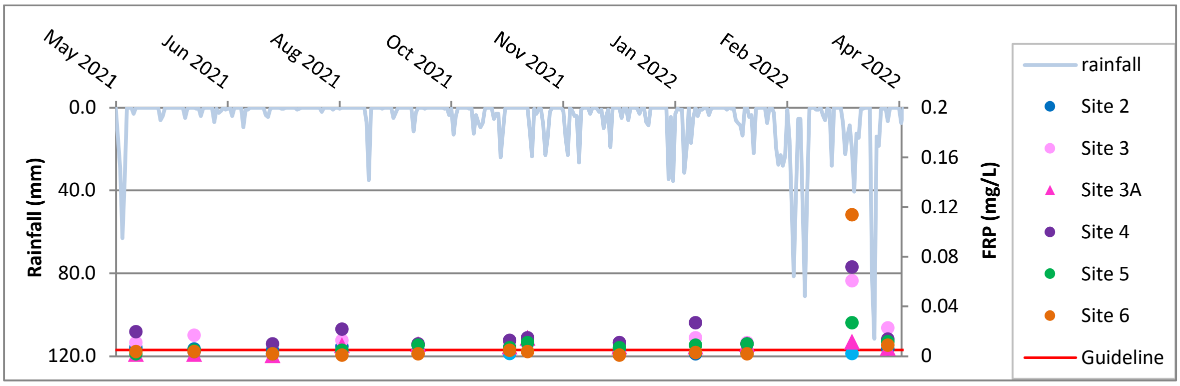


Figure 4: Plots of total phosphorous (TP) and rainfall from May 2021 to April 2022 for the (A) Foreshore (lake edge) sites and (B) In-lake sites

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 have naturally high phosphate levels), 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

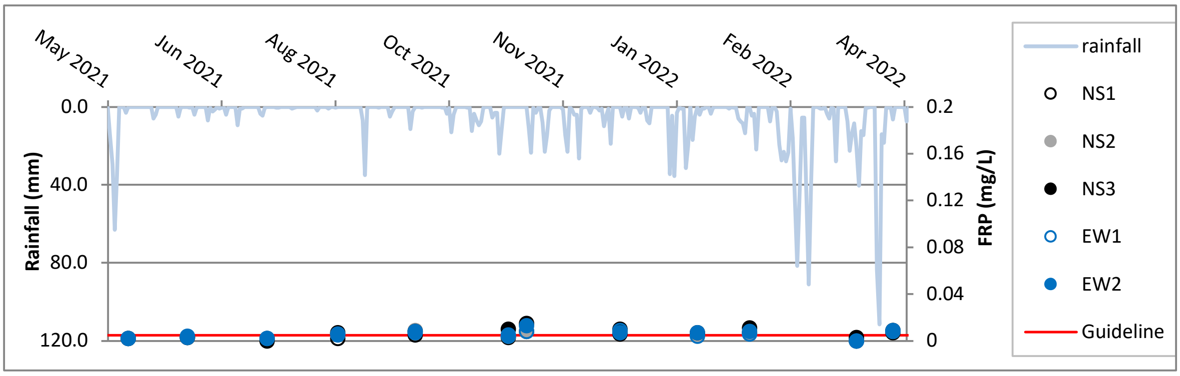


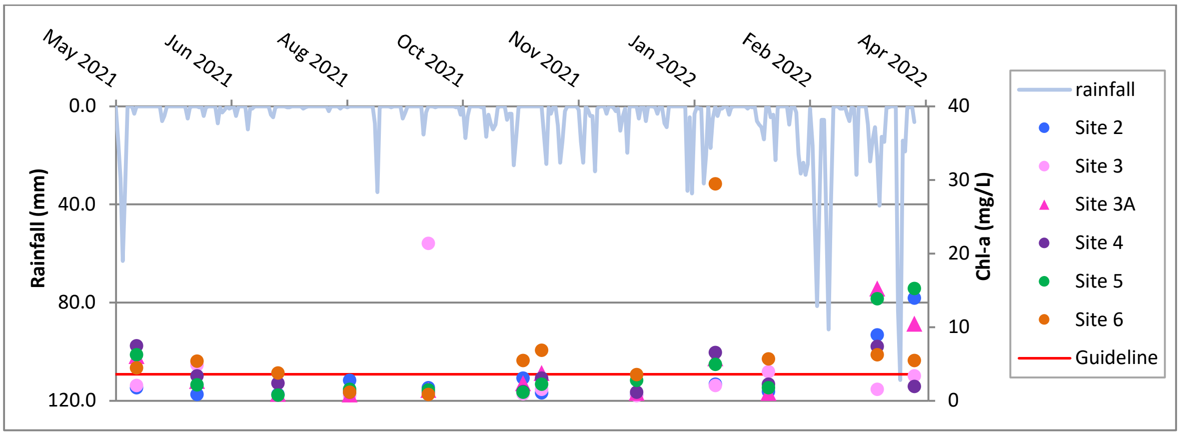
Figure 5: Plots of filterable reactive phosphorus (FRP) and rainfall for May2021 to April 2022 for the (A) Foreshore (lake edge) sites and (B) In-lake sites

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 NSW MER trigger value. The expected seasonal pattern of increases in chlorophyll *a* over summer was not exceedingly apparent, with only small increases. Rather patterns appear more related to rainfall events (Figure 6). For the majority of the year most foreshore and in-lake sites were below or just above the trigger value of 3.6 ug/L (Figure 6). 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. Site 6 at Griffins Bay which in the last reporting period showed high chlorophyll *a* values for most of the time had noticeably lower chlorophyll *a* values.

The exception to this was during a rainfall event in May 2021, and the consistently high rainfall experiences during late summer and early autumn for the March and April 2022 sampling events, where the majority of the foreshore sites and all the in-lake sites had high chlorophyll *a* values, from 2 to 4 times greater than the trigger value (Figure 6).

A: Foreshore sites



B: In-lake sites

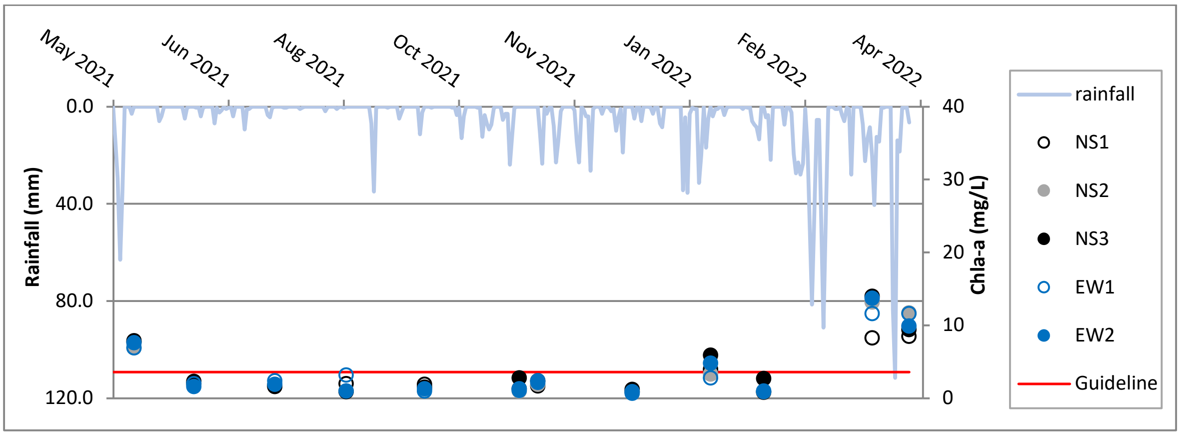


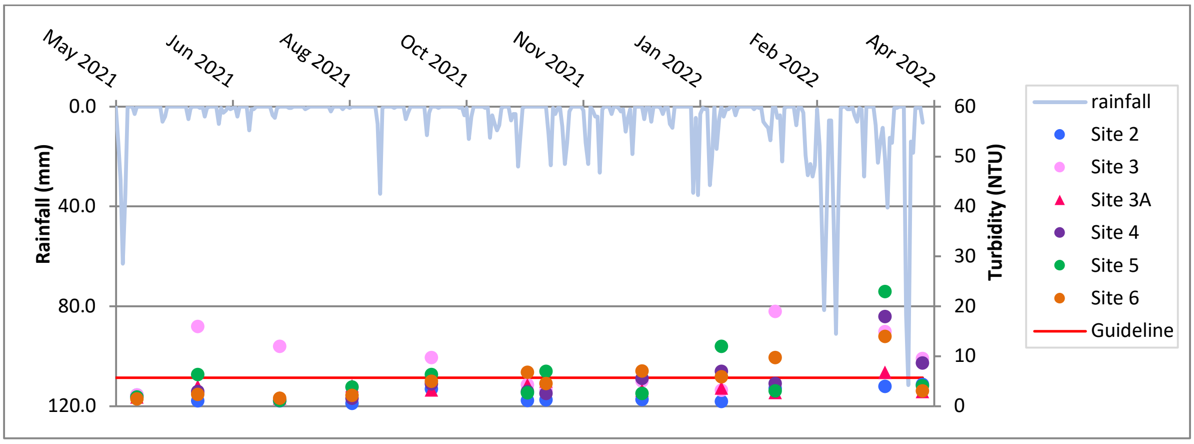
Figure 6: Plots of chlorophyll *a* and rainfall from May 2021 to April 2022 for the (A) Foreshore (lake edge) sites and (B) In-lake sites

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 12 months show for the majority of the sampling period foreshore sites and -in-lake sites were below or just above the trigger value. Interestingly turbidity exceedances were much lower than the previous year (see Appendix 2 and WCC 2021). The exception to this is the late summer/early autumn period where high rainfall impacted turbidity levels at the majority of the foreshore sites. The in-lake sites only showed a minor increase in turbidity levels (Figure 7). The foreshore sites are 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. Also the foreshore sites are more impacted by catchment run-off. The results obtained agree with this expectation, where the in-lake sites remain largely stable, even during the high rainfall events over the summer (Figure 7).

A: Foreshore sites



B: In-lake sites

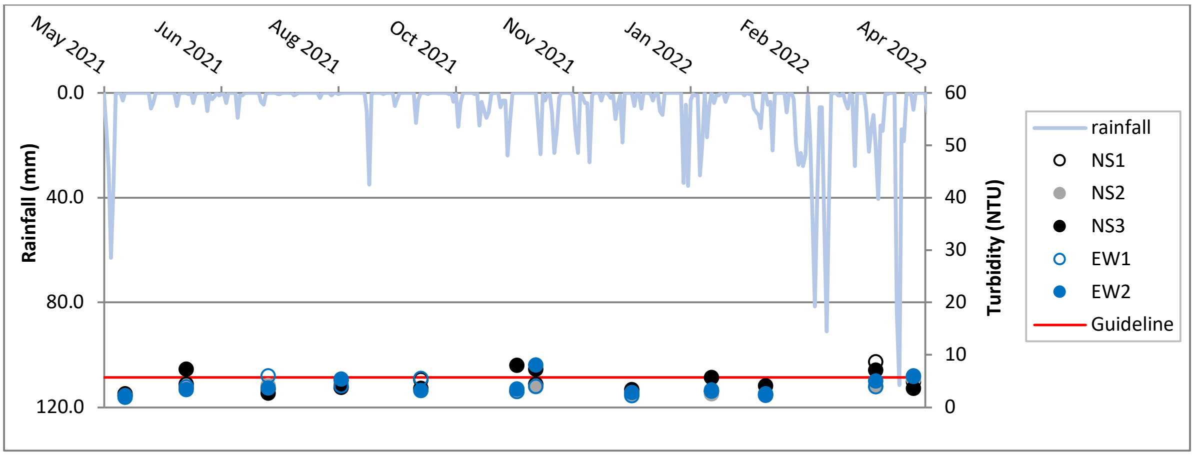


Figure 7: Plots of turbidity and rainfall from May 2021 to April 2022 for the (A) Foreshore (lake edge) sites and (B) In-lake sites

Most foreshore sites though were below or just above the NSW MER trigger level with a few notable exceptions (Figure 6a). Foreshore site – Site 3 experienced high turbidity levels six times; in June, July and September 2021 which were not related to high rainfall events of February-April 2022 where most foreshore sites have high turbidity levels (Figure 6a). This site is located between the foreshore and the southern side of Picnic Island. Increased sand deposition due to the entrance channel changes are likely causing this site to be increasingly shallow and less flushed and any winds would stir up sediment easily due to this shallowness. This area also has a large stormwater drain that flows into the lake, and maybe be causing high turbidity levels.

As mentioned, all foreshore sites had high turbidity levels in March 2021 (except Site 2 located near the entrance). This was related to high rainfall at the time. Site 5 had turbidity levels four times greater than the trigger level, and also had the highest turbidity level on two other occasions. This site is located in the bay between Koonwarra and Kanahooka and Brooks Creek flows into it. Catchment run-off from this creek likely explains the high turbidity at this site at times.

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 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.

Notably, all sites, except one, show either a decreasing trend for parameters or no significant trend. Foreshore sites are particularly vulnerable to catchment run-off, and it is significant that Sites 3A, 4 and 5 have decreasing trends for 3 of the 4 parameters despite them being close to feeder creeks and catchment inputs (Table 6).

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	no trend	no trend	no trend	no trend
3	no trend	increasing trend	increasing trend	increasing trend
3A	decreasing trend	decreasing trend	decreasing trend	no trend
4	decreasing trend	decreasing trend	no trend	decreasing trend
5	decreasing trend	no trend	decreasing trend	decreasing trend
6	decreasing trend	decreasing trend	no trend	no trend
NS1	no trend	no trend	no trend	no trend
NS2	no trend	no trend	no trend	no trend
NS3	no trend	no trend	no trend	no trend
EW1	no trend	no trend	no trend	no trend
EW2	decreasing trend	no trend	no trend	no trend

Site 6 has a decreasing trend for chlorophyll *a* and turbidity. While this site continues to experience high nitrogen values (of which there is no increasing or decreasing trend for), the long-term trend in chlorophyll *a* value at this site is decreasing. This would indicate that the nitrogen is being rapidly utilised by the phytoplankton and other plant life in this area. Previous decreasing trends at these 4 foreshore sites 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. This is a significant result as well considering the 2021/22 summer was the wettest and the highest year total since sampling began in 2009.

Similar to the last reporting period Site 3 was the only site to have an increasing trend for any parameter, showing an increasing trend for turbidity, 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, plus the presence of a stormwater drain in the vicinity.

No significant trends were selected for the in-lake sites, except Site EW2 showed a statistically decreasing trend for chlorophyll *a*.

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 (2021/22) are presented in Figure 8. Results from the previous years from each summer period from 2013 are shown the Figure 9 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 2021/22 period eight of the eleven sites are in good condition, with one of the in-lake sites in very good condition (Figure 8). This is a significant result considering the 2021/22 summer was the wettest since the program began in 2013. 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 5 at Koonawarra Bay and Site 6 in Griffins Bay were the only sites rated as being in fair condition. This was largely a result of several very high chlorophyll *a* and turbidity values over the summer period related to rainfall events. Site 6 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. However, this site did improve from a poor rating in the last reporting period to fair in 2021/22 (Figure 8 and 9). Koonwarra Bay was reported as being in good condition in the last reporting period. It's fair rating in this reporting period was related to higher chlorophyll *a* values. This is likely to be related to the high nitrogen inputs from the Brooks Creek catchment during the very high rainfall events over the summer period.

KEY
Very good Good Fair Poor Very Poor

Figure 8: Estuary health condition ratings (based on chlorophyll *a* and turbidity) over the summer period (November to April) for 2021/22 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 (Figure 8). 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 the majority of the foreshore sites now being rated as being in good condition.

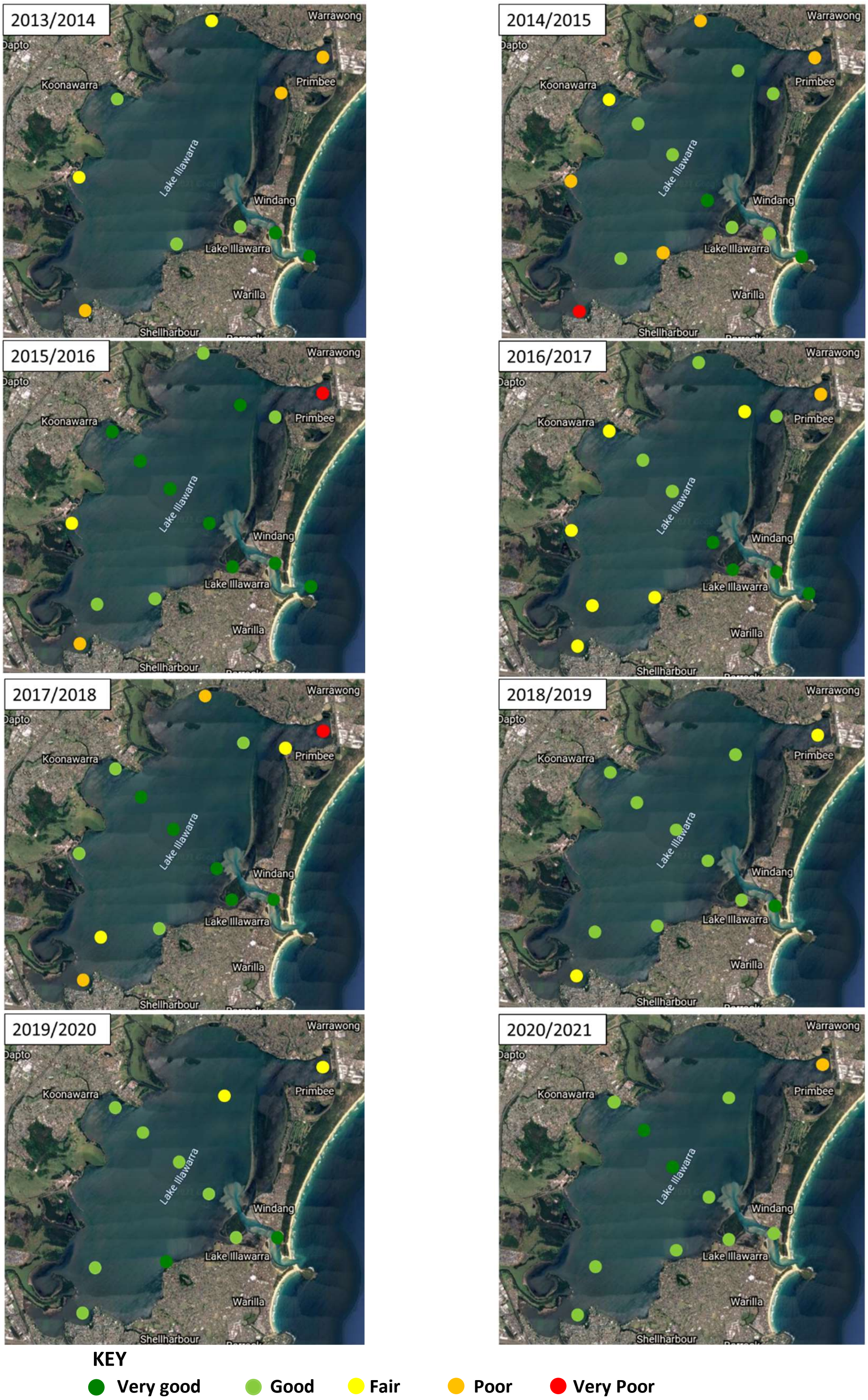


Figure 9: Estuary health condition ratings (based on chlorophyll *a* and turbidity) over the summer period (November to April) for each year from 2013-2021 for 11 sites monitored across Lake Illawarra.

4.4 Recreational water quality

Figure 10 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 estuarine sites sampled for the presence of enterococci. Estuarine sites are particularity impacted by potential sources of faecal contamination, including stormwater and urban and rural run-off. All sites had lower percentage compliance than the previous year and reflects the wet weather conditions and associated flooding over summer and early autumn (Figure 10 and 11). This was particularly noticeable at Kanahooka, which had 91% of compliance with primary recreational guidelines and 100% with secondary over the 2020/21 summer (WCC 2021), whereas this year it was 70% and 80% respectively. This bay has a tributary directly running into it and highlights the impact that stormwater and wastewater inputs can have on recreational water quality. Purry Burry and Ski-Way Park had similar percentage compliance for primary and secondary recreation, with these sites being safe for swimming 55-60% of the time over summer period.

Several extremely high enterococci levels were recorded at Ski-Way Park and Kanahooka in particular. Rainfall is the major driver of pollution and enterococci levels to recreational water quality, 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 noticeably apparent for the 2021/22 summer period as most of the sampling days corresponded with rainfall events (Figure 11).

The entrance site (called Entrance Lagoon Beach) that is sampled, analysed and reported under the NSW Beachwatch program was rated as good for the 2020-2021 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 2021-2022 summer period at the time of publication of this report.

Figure 10: 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.

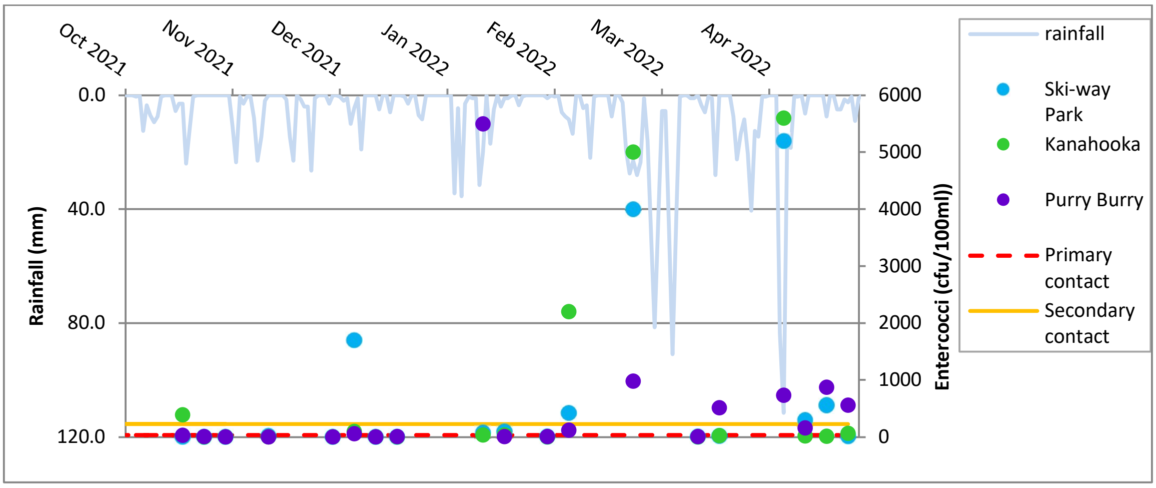


Figure 11: Plot of enterococci concentrations against rainfall from October 2021-April 2022

5 Conclusion

This report has reviewed selected parameters and indicators to describe the water quality and estuary health condition in Lake Illawarra for the period May 2021 to April 2022, and for trends in estuary health 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 2 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.

However, the overriding influence on water quality and estuary health of Lake Illawarra for this reporting period was the impact of the large and sustained rainfall events during summer and early autumn. Large freshwater inflows into estuaries can change salinity regimes (including stratification and circulation patterns), water balances and water quality (i.e., changes to the transformations of nitrogen and phosphorus, which occur within areas of high turbidity from catchment-derived sediments), alter sedimentation, erosion rates and nutrient loads, and change flushing and residence times (Glamore et al. 2016). Such changes were apparent in Lake Illawarra over late summer and early autumn. Increases in nitrogen, phosphorous, chlorophyll *a* and turbidity were evident across all sites. A dramatic decrease in salinity was also seen at the foreshore and in-lake sites, showing clearly how large the freshwater flows were.

Water quality changes resulting from catchment runoff have not been as obvious in other years as monitoring needs to be conducted soon after the rainfall event. The sustained and high rainfall resulted in clear changes to water quality at both foreshore and in-lake sites. For some parameters though the impact of rainfall and increased catchment run-off was not as evident. For example, turbidity levels at the in-lake sites remained stable and close to the trigger level despite the significant wet weather, most likely due to differing residence times within the Lake. The spatial differences reinforce that the residence time for the more central portion of Lake Illawarra is shorter than that for the more enclosed areas of the lake (e.g., Griffins Bay). Longer residence times in the more enclosed north 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. This could be one of the reasons Site 5 at Kanahooka saw a decrease in its estuary health condition in this reporting period. Conversely Site 6 Griffins Bay saw a slight improvement in its estuary health rating from poor to fair. While chlorophyll *a* and turbidity levels were lower at this site than the previous year, the area could also have experience greater flushing due to high freshwater loads coming into the bay. Griffins Bay over the years has had consistently fair to very poor estuary health condition and is likely related to the several stormwater drains that enter this bay and the poor flushing that usually occurs due to its enclosed nature.

Previous reports have shown that approximately 10 days after rainfall events nutrients were flushed quite quickly out of the lake and/or rapidly utilised by the phytoplankton and other plant life in the lake (WCC 2021). This suggests that following a rainfall event, the lake may return to near seasonal water quality conditions fairly rapidly. Sampling results for May and June 2022 show that this appears the case for the majority of the sites.

Based on current analysis the condition of the estuary seems to be improving over the period 2013-2021, with nine of the eleven sites rated good to very good for 2021/22. This is a significant result given that this was the wettest year total and wettest summer since the program began in 2013/14. 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 significant wet weather and hence an increase in catchment inputs over the last year, the lake is maintaining good estuary health. Interestingly three of the foreshore sites also showed decreasing trends for nutrients, chlorophyll *a* and turbidity. Site 6 had decreasing trends for chlorophyll-a and turbidity and no trends for the other parameters. Only Site 3 showed increasing trends for any parameter, with an increasing trend for chlorophyll *a*, 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, plus the presence of a stormwater drain at this vicinity.

The in-lake sites and Site 2 all showed no trend for chlorophyll *a*, turbidity, nitrogen and phosphorus levels, with the exception of site EW2 that had a decreasing trend for chlorophyll *a*. However, all these sites have had either a good condition or very good condition from the start of the program. This program has shown that water quality and estuary health of the Lake is overall considered of good condition. While this reporting period has clearly shown the impact of wet weather events and the associated impacts of catchment run-off, Lake Illawarra appears resilient and maintaining good estuary health. It is important to note that this is based on only two indicators of estuary health and other ecological impacts may be occurring.

The impact of catchment run-off though was particularly evident on recreational water quality that was monitored over the summer period. Estuarine sites are particularity impacted by potential sources of faecal contamination from dog/pet faeces and sewerage overflows, including urban and rural stormwater run-off. All of the three sites had lower percentage compliance than the previous year (WCC 2021). Rainfall is the major driver of pollution and high enterococci levels to recreational water quality, and it is recommended that swimming should be avoided up to three days at estuarine sites following heavy rain (NSW DPIE 2020).

Continuation of the monitoring program will help establish how the lake responds following extended wet weather periods and the impact of catchment run-off, as well as gaining insights to how the estuary is varying over time and responding to changing climate regimes. Climate change is expected to cause heavy rainfall events to become more extreme with an increase in east coast lows over the warmer months. This will lead to increased catchment run-off, periods of decreased salinity in estuarine waters, and increased sediment and nutrient loads in coastal and estuarine waters (Adapt NSW 2022).

As part of the implementation of the Lake Illawarra Coastal Management Program, Wollongong and Shellharbour City Councils have also begun a catchment water quality program. This program for the next two and a half years will capture baseline water quality monitoring data, including from wet weather events for a number of environmentally and aesthetically important urban and rural creeks within the Lake Illawarra catchment to assist in current and future environmental management and monitoring programs.

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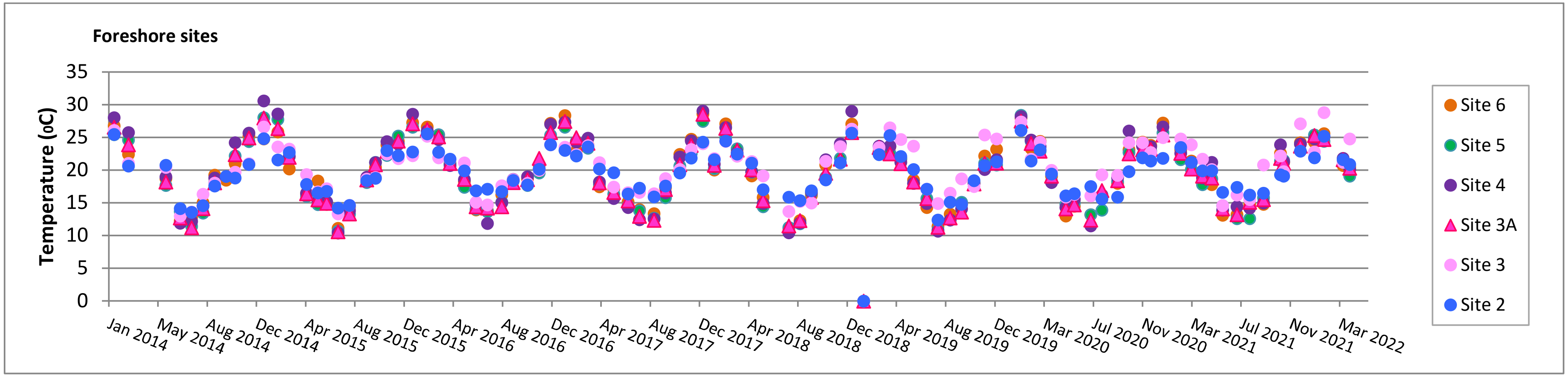
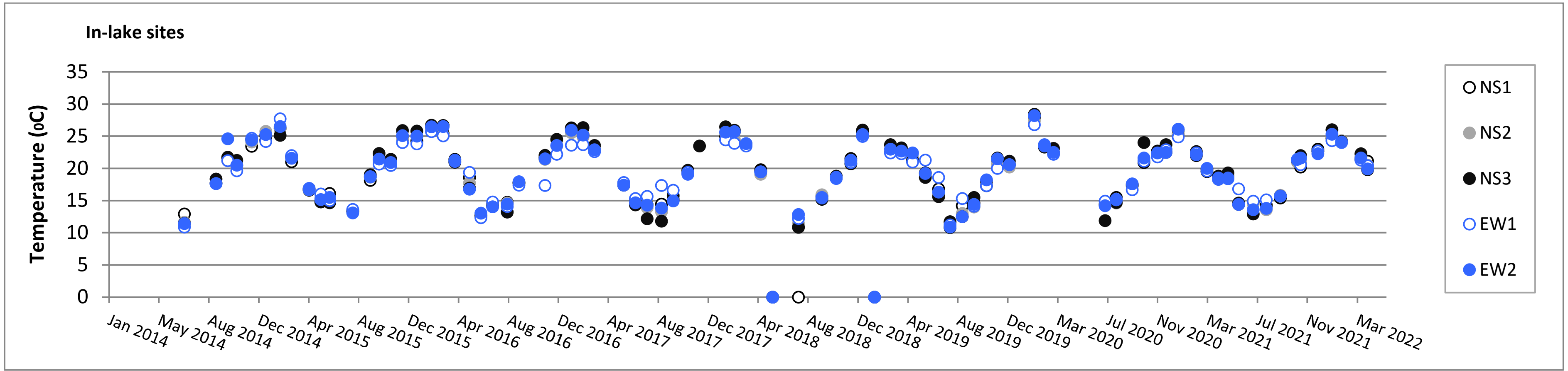
Appendix 1: List of management actions in the Lake Illawarra Coastal Management Program relating to improving water quality

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 April 2022

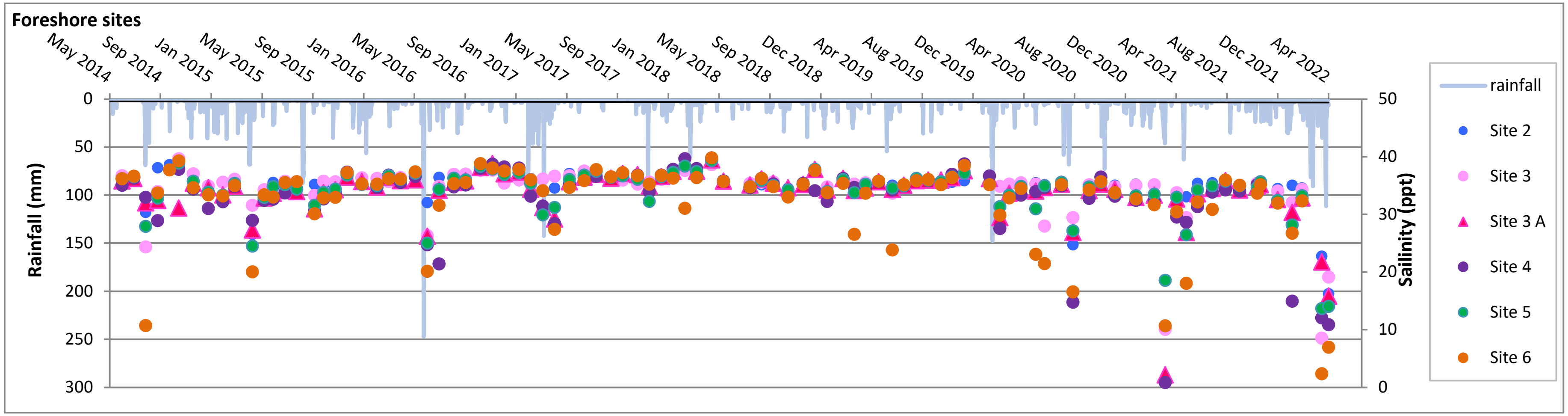
Plots of Temperature (^{0}C) from 2014 to April 2022

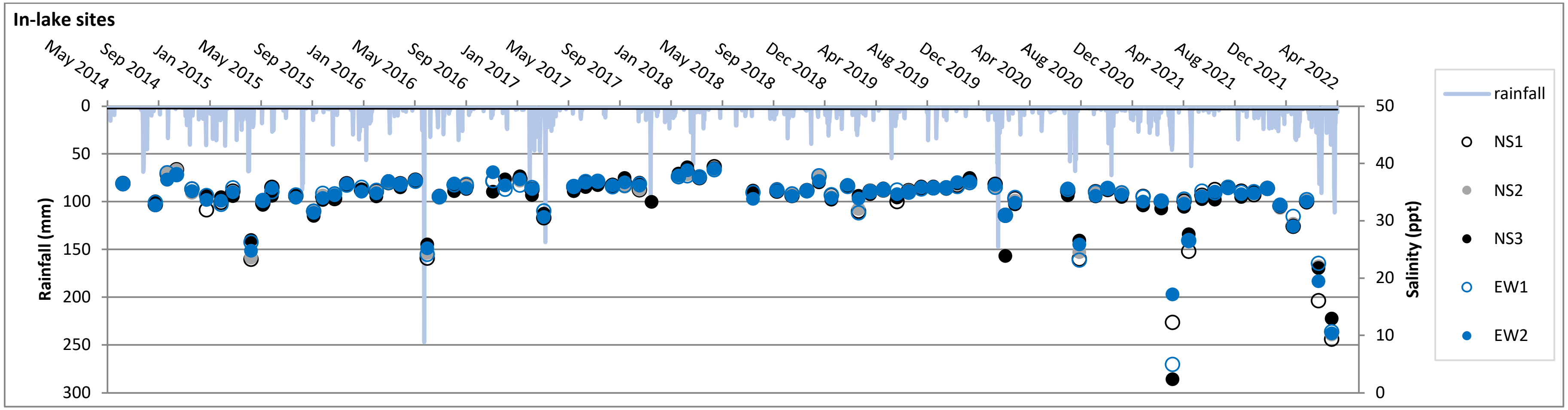




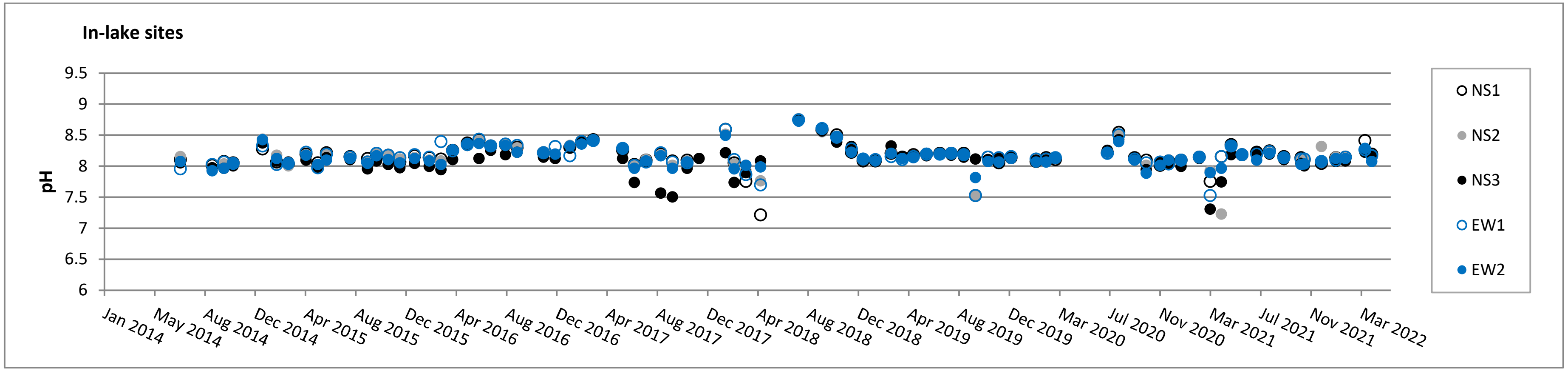
Note: zero readings due to equipment issues

Plots of Salinity (ppt) from 2014 to April 2022

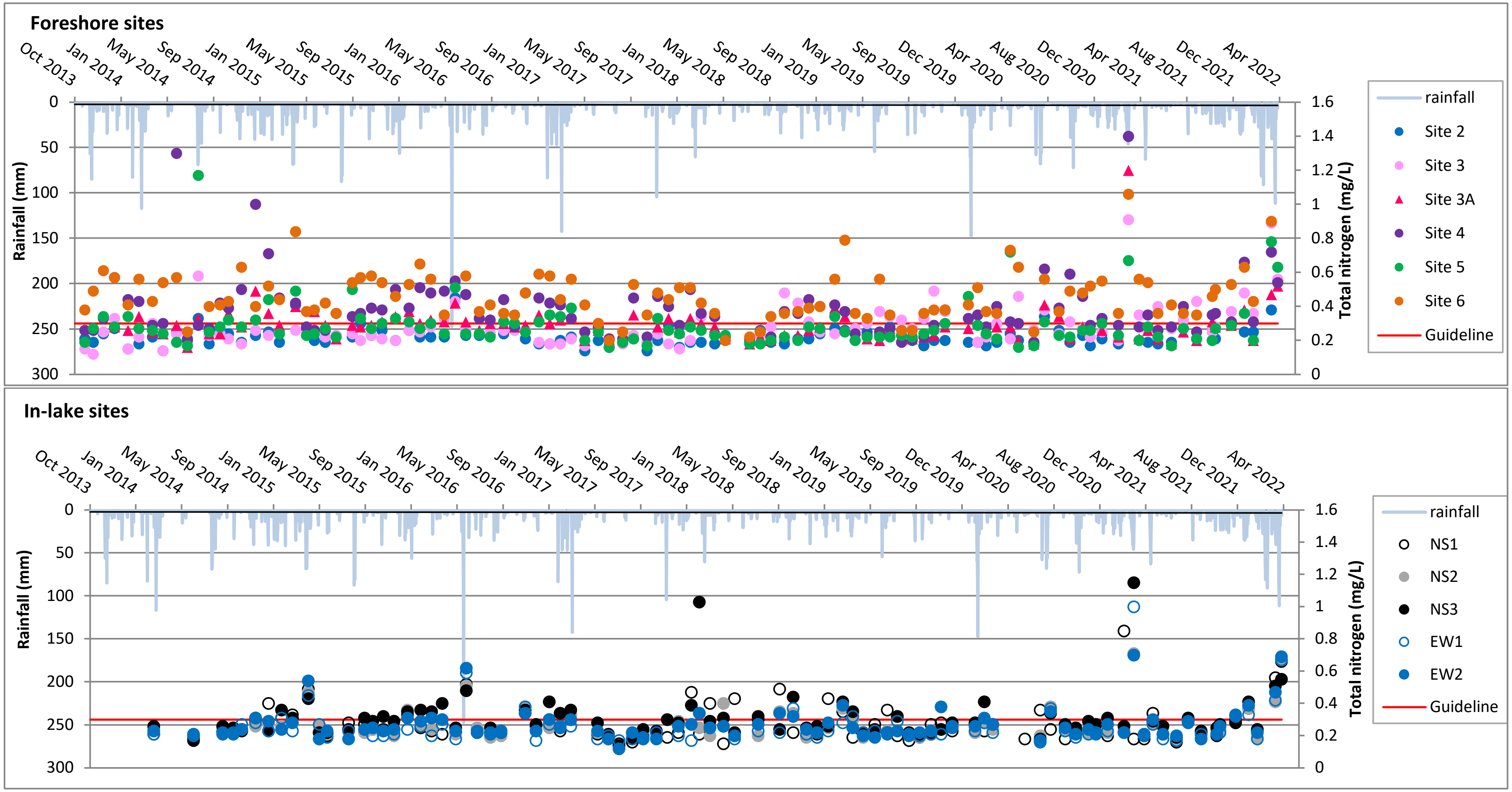




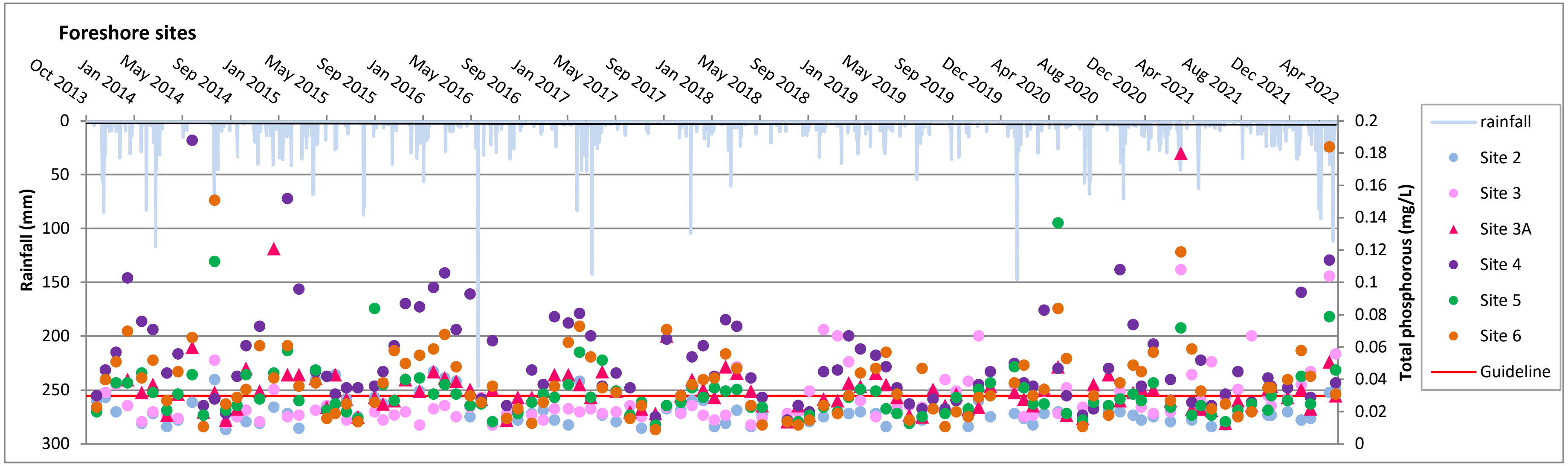
Plots of pH from 2014 to April 2022

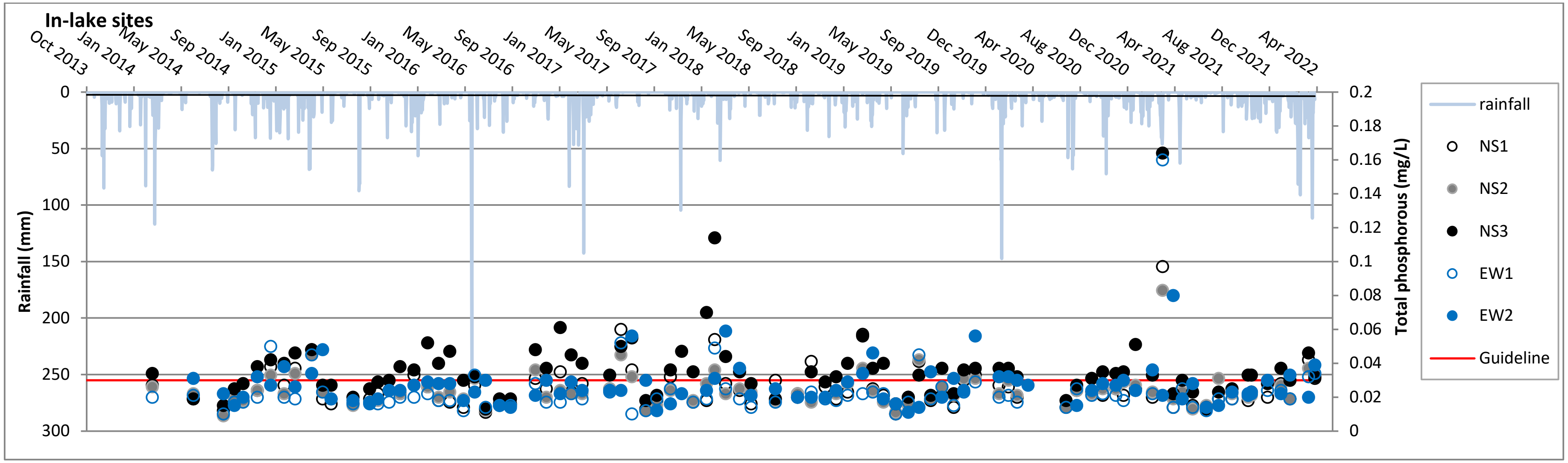


Plots of Total Nitrogen (mg/L) from 2013 to April 2022

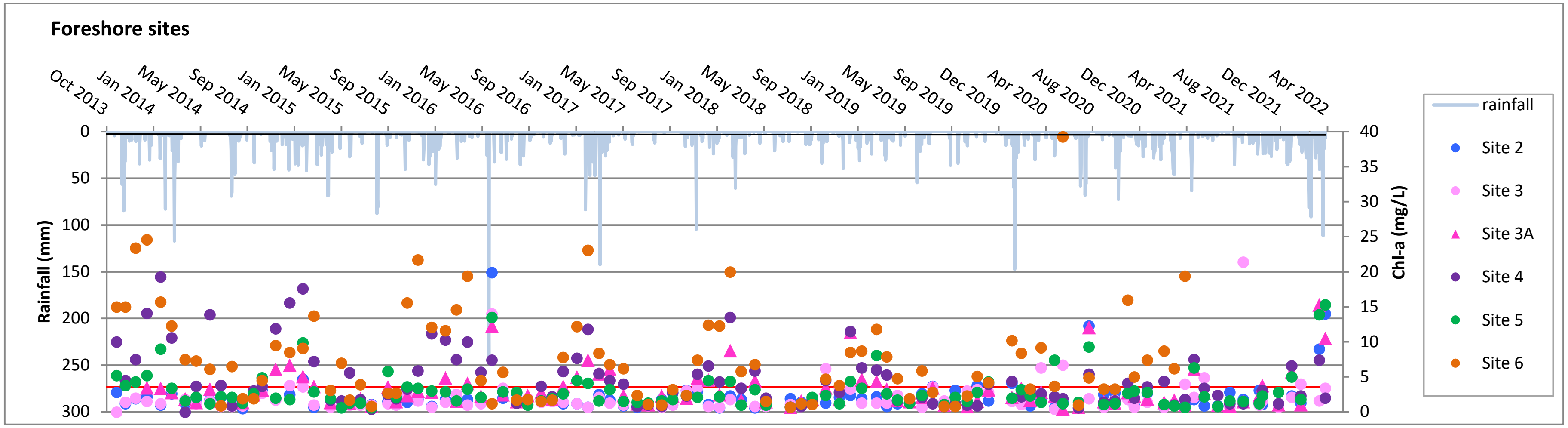


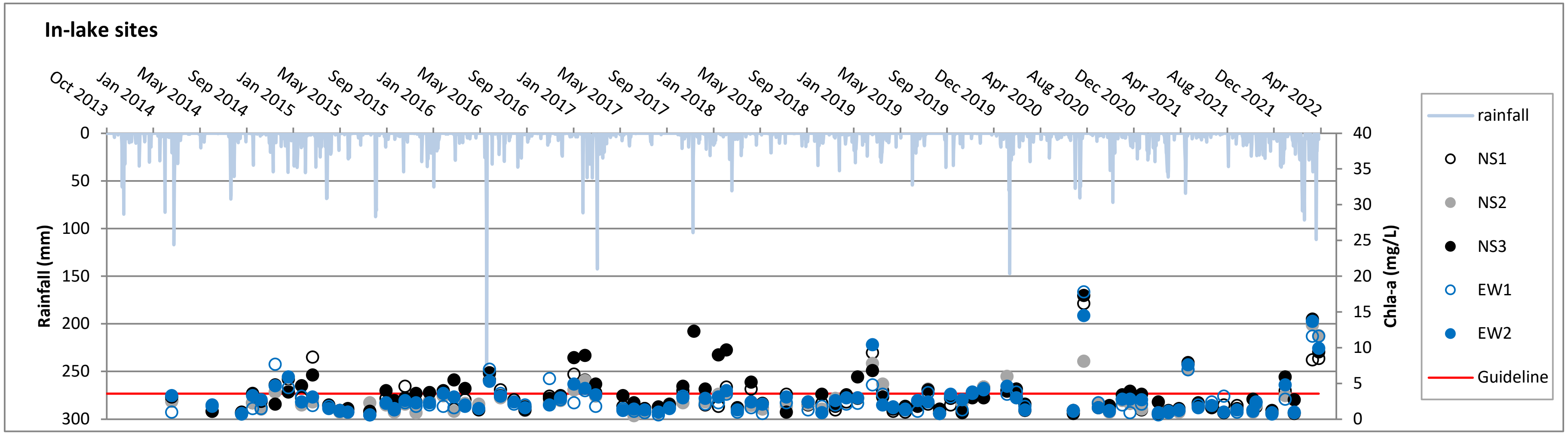
Plots of Total Phosphorous (mg/L) from 2013 to April 2022





Plots of Chlorophyll *a* (μg/L) from 2013 to April 2022





Plots of Turbidity (NTU) from 2013 to April 2022