Lake Illawarra Water Quality and Estuary Health Monitoring Program

Report - August 2015

Prepared by Wollongong City Council
Summary

Wollongong City Council, in partnership with Shellharbour City Council, started a water quality and estuary health monitoring program for Lake Illawarra, with financial and technical support from the NSW Estuary Management Program, in October 2013. Fifteen locations across the lake are monitored monthly for a range of water quality indicators, and Manly Hydraulics Laboratory has been contracted to undertake continuous monitoring of some physical indicators at a location in the eastern and the western part of the lake. This report reviews the data collected in the first 18 months of the program, and compares the current condition with the condition evident from previous records of water quality for the lake.

The water quality indicators monitored are temperature, dissolved oxygen, pH, salinity, turbidity, and nitrogen, phosphorus, and chlorophyll a concentrations. For most of these parameters, a strong seasonal influence is apparent, associated with the higher temperatures, daylight hours, and productivity over the summer months. Imposed on this is the influence of weather conditions, with wind and rain generally resulting in an increase in the concentrations measured.

Water quality and the estuary health condition are variable across the lake. There is significant nutrient enrichment in the more enclosed north-east and south-west sections of the lake. The rest of the lake including the edges in the middle reaches, the main body of the lake and the entrance area are similar and have better water quality. The estuary health condition generally reflects this same pattern. However, the condition assessment is based on only one indicator of estuary health, chlorophyll a, and other indicators would need to be examined to confirm this status.

The current condition of the lake appears to have been the same for at least the last 5 to 6 years, and to have improved when compared with water quality from 1996 to 2000. The lake also appears to have become more saline since the entrance has been trained. The review recommends that the monitoring be continued to further verify the results of this report.
1 Introduction

Lake Illawarra is important to the local community for its ecological, social and economic values. A previous state-wide assessment of NSW estuaries found the lake to be in very good condition but subject to high pressure (NSW Government, 2010). The pressure on the lake is intensifying, as its catchment continues to be developed. How the lake is responding to this increasing pressure, and whether better control measures are necessary to protect its health, requires a targeted monitoring, evaluation and reporting framework that can address these issues.

The former Lake Illawarra Authority (LIA) ran a water quality monitoring program for the lake. With its disbandment, a number of lake responsibilities were handed back to Wollongong and Shellharbour City Councils. The two councils decided to continue with the water quality monitoring, and were successful in securing funding support from the NSW Estuary Management Program to review the program and implement a more targeted framework to assess the estuary health condition of the lake. Nearly two years of data have been collected since the councils took over the monitoring in October 2013. This report reviews the results obtained in the first 18 months and makes recommendations on how the program should proceed into the future.

2 Background

Lake Illawarra is a 35 km$^2$ coastal water body lying in the local government areas of Wollongong and Shellharbour City Councils. Its catchment of 235 km$^2$ lies mostly to the west and is largely undeveloped. Several creeks drain the catchment and discharge into the lake, which itself has a trained entrance in the east discharging into the Pacific Ocean (Figure 2-1). With an average depth of about 2 m, it is considered to be a shallow lake.

The immediate surrounding areas of the lake are urbanised and nearly 200 stormwater outlets or drains discharge into the lake from these areas (Lake Illawarra Authority, 2013). The lake was considered to be in very poor condition in the past, and massive algal blooms were frequently experienced (Lake Illawarra Authority, 2010). Measures put in place to improve water quality are the trained entrance, and several stormwater improvement devices including a number of wetlands along parts of the lake margin. Anecdotal evidence points to an improvement in water quality in recent years.

Many organisations have monitored water quality in Lake Illawarra, but they have differed in the locations monitored, the indicators measured, and the period of monitoring. This does not make it easy to determine how the condition of the lake has changed with time, as many factors can have an influence on water quality, and these factors have not always been recorded or recognised.
Pacific Power was one of the organisations monitoring the lake. Several locations within the main body of the lake were monitored from 1987 to 1991 and from 1996 to 2000, and the data has been reviewed by WBM Oceanics (2003). The main findings of this review were that many of the measured parameters, particularly nitrogen, phosphorus, and chlorophyll a concentrations, did not comply with their ANZECC guideline trigger values (ANZECC, 2000) for most of the time. The lake also appeared to be well mixed with little difference in water quality between the various locations monitored, including the entrance. The entrance area was reported to be more similar to the rest of the lake than to the ocean water. The monitoring was undertaken when the lake did not have a trained entrance.

Monitoring by the LIA commenced two years before the completion of the entrance training works in 2007, but their focus was more on the edges of the lake rather than on the main body. The data collected to 2009 has been reviewed in a lake condition assessment report (Lake Illawarra Authority, 2010). The value of this dataset in addressing questions about the impact of the trained entrance on lake water quality is limited, as no locations within the main body of the lake were monitored. Whether the lake edge sites monitored could be considered representative of the main body was also not addressed. Nevertheless, for the sites monitored, the report concluded that no impact of the entrance works on water quality was obvious.

The recent monitoring conducted by the two councils has covered a much wider area of the lake than any of the previous studies. It therefore brings in considerable new information towards understanding the current condition of the lake and how it has changed over time.
3 Monitoring Program

3.1 Location of sampling sites

Figure 3-1 shows the location of the sampling sites. Sites 1, 2, 3, 4, 5 and 6 were previously monitored by the Lake Illawarra Authority, and these sites were retained when the two councils took over the program in October 2013. However, questions over whether these sites could be treated as representative of the rest of the lake led to an extension of the program to other sites. Four additional sites along the margins of the lake (Sites 3A, 4A, 5A, and 6A) were added in January 2014. From March 2014, five locations within the main body of the lake along a north-south (NS1, NS2, NS3) and east-west (EW1 and EW2) transects were added. The 15 sites can be allocated to different categories: as located in the entrance area, along the lake edges, or in-lake zones (Table 3-1).

![Figure 3-1 Map showing location of the monitoring sites](image)

Table 3-1 Description of monitoring sites

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

### 3.2 Frequency of monitoring
All entrance and lake edge sites have been monitored monthly; the sites not labelled with an “A” since October 2013, and the “A” labelled ones since January 2014. The in-lake sites were monitored in March 2014, July 2014, Sep 2014, and monthly thereafter.

### 3.3 Sample collection and Water Quality measurements
The focus of the monitoring program is on assessing estuary health, and the water quality measurements being made reflect this goal. At each site, a sampling pole and bottle are used to collect 8 to 10 batches of water, which are composited into a bucket previously rinsed with site water. The test samples are obtained from the composite, to ensure that the samples analysed are representative of the site, especially for constituents such as chlorophyll a, which can be patchy over small areas. Both filtered (through a 0.45 µm filter) and unfiltered subsamples from the composite are obtained and sent to Sydney Water Analytical Laboratory for nitrogen, phosphorus, and chlorophyll a analysis.

On-site measurements are performed after samples have been collected for laboratory analysis, using a YEO-KAL water quality multimeter, provided and calibrated by the University of Wollongong. The on-site measurements include temperature, pH, dissolved oxygen, salinity, and turbidity. A WCC turbidity meter (TPS Model WP-88) is used as a backup on occasions.

Nitrogen is analysed as total nitrogen in unfiltered water (TN), the total after filtration (FTN), and the amount present as nitrate and nitrite (often referred to as NOx's), and as ammonia, 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 to be 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.
3.4 Manly Hydraulics Laboratory Monitoring
The Manly Hydraulics Laboratory was contracted by the Lake Illawarra Authority to install and operate instrumentation at two locations within the lake, at Koonawarra and Cudgeree Bays, to provide continuous measurements of a number of water quality indicators. This arrangement has been retained under the current program. Temperature, pH, and salinity are monitored at both stations, whilst dissolved oxygen is also measured at Koonawarra. Since November 2014, chlorophyll a has been added to both stations, so that continuous measurements of a condition indicator can also be provided. Figure 3-2 shows the location of the monitoring stations.

![Figure 3-2 Map showing location of the two Manly Hydraulics monitoring stations](image)

4 Data Analysis

4.1 Water Quality
The indicators monitored are plotted against time, their corresponding guideline trigger values where available (Table 4-1), and the prevailing weather conditions (wind and rainfall patterns) where relevant, for a qualitative assessment of the spatial and temporal distribution patterns and the factors that might be responsible for these observations. Rainfall data for Darkes Road, which is the closest monitoring station to Lake Illawarra, was provided by the Manly Hydraulics Laboratory.
Comparisons are also made with previous datasets where available to determine how water quality has changed with time.

**Table 4-1 Guideline trigger values utilised**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Guideline</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dissolved oxygen</td>
<td>80 to 100% saturation</td>
<td>ANZECC (2000)</td>
</tr>
<tr>
<td>pH</td>
<td>7 to 8.5</td>
<td>ANZECC (2000)</td>
</tr>
<tr>
<td>Turbidity</td>
<td>5.7 NTU</td>
<td>State of NSW and Office of Environment and Heritage (2003)</td>
</tr>
<tr>
<td>Total Nitrogen (TN)</td>
<td>0.3 mg/L</td>
<td>ANZECC (2000)</td>
</tr>
<tr>
<td>Filtered Total Nitrogen (FTN)</td>
<td>0.3 mg/L</td>
<td>Based on TN from ANZECC (2000)</td>
</tr>
<tr>
<td>Nitrate and Nitrite (NOx's)</td>
<td>0.015 mg/L</td>
<td>ANZECC (2000)</td>
</tr>
<tr>
<td>Ammonia</td>
<td>0.015 mg/L</td>
<td>ANZECC (2000)</td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>0.03 mg/L</td>
<td>ANZECC (2000)</td>
</tr>
<tr>
<td>Filtered Total Phosphorus</td>
<td>0.03 mg/L</td>
<td>Based on TP from ANZECC (2000)</td>
</tr>
<tr>
<td>Filtered Reactive Phosphorus</td>
<td>0.005 mg/L</td>
<td>ANZECC (2000)</td>
</tr>
<tr>
<td>Chlorophyll a</td>
<td>3.6 µg/L</td>
<td>State of NSW and Office of Environment and Heritage (2003)</td>
</tr>
</tbody>
</table>

Dissolved oxygen was measured as mg/L, therefore the percent saturation guideline could not be utilised

**4.2 Estuary Health Condition**

The estuary health condition of each site has been determined using the chlorophyll a data only. The methodology used to grade chlorophyll a is consistent with that recommended by the NSW Monitoring, Evaluation and Reporting (MER) Framework, which assesses the degree of compliance with a water quality trigger value, and allocates a condition grade ranging from very poor to very good, as described in Table 4-2 (State of NSW and Office of Environment and Heritage, 2013).

**Table 4-2 Descriptors for estuary health condition grades**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Good</td>
<td>The indicator meets the benchmark value for almost all of the time period.</td>
</tr>
<tr>
<td>Good</td>
<td>The indicator meets the benchmark value for most all of the time period.</td>
</tr>
<tr>
<td>Fair</td>
<td>The indicator meets the benchmark value for some of the time period.</td>
</tr>
<tr>
<td>Poor</td>
<td>The indicator does not meet the benchmark value for most all of the time period.</td>
</tr>
<tr>
<td>Very Poor</td>
<td>The indicator does not meet the benchmark value for almost all of the time period.</td>
</tr>
</tbody>
</table>

The NSW MER Framework includes turbidity, in addition to chlorophyll a, in assessing ecological condition from the water quality data. However, their recommendation is for monitoring in the central basin areas of water bodies where turbidity measurements are less influenced by wind factors than in the shallower edge areas. For this report, turbidity data have not been included in the assessment anywhere, as wind patterns greatly affected the turbidity at the edge locations, and turbidity data are not available in some of the previous datasets utilised for comparison purposes. Therefore, in order to have a common basis for comparison between different regions of the lake, and over time, the condition determination was based on chlorophyll a data alone. As more in-lake turbidity data is collected over time, turbidity grading consistent with the MER framework will be considered.
5 Results and Discussion

5.1 Physical Characteristics

5.1.1 Temperature
Water temperature has an important bearing on aquatic processes. The continuous measurement of temperature at the Cudgeree and Koonawarra monitoring stations shows that variations occur over both daily and seasonal cycles, but the seasonal variation is greater than the daily variation (Figure 5-1). The winter to summer range is about 20 °C, whereas the daily range is about 5 °C. The daily range at the Cudgeree station also appears to be slightly greater than at the Koonawarra station, and this could be due to the difference in the water depths at these two locations. The average water depth at the Cudgeree station is about 0.5 m, as against 1 m at Koonawarra, and this must result in the water being more responsive to changes in the air temperature at the Cudgeree site.

![Figure 5-1 Plots of temperature against time for the Cudgeree (A) and Koonawarra (B) monitoring stations](image)

Monthly recordings of water temperature since the monitoring was taken over by the councils in October 2013 are shown in Figure 5-2. Again, the seasonal influence at all of the locations monitored is apparent. For any particular month, however, the range for the lake edge and entrance sites appears to be greater than for the in-lake zones. This is not unusual, given that the
edge and entrance sites are shallower than the in-lake zones, and six hours or more were required to complete their monitoring, over which time the ambient temperature changed markedly. This variation is not observed for the in-lake zones, as they were all monitored within an hour or two.

Figure 5-2 Plots of temperature against time for the lake edge and entrance sites (A) and in-lake locations (B)

5.1.2 Dissolved Oxygen

Dissolved oxygen (DO) is important for the health of a water body, as the organisms that live in the water require this gas for their respiration. The concentration of DO depends on its supply (aeration, diffusion, photosynthesis) and demand (respiration, decomposition) processes, and on the temperature, pressure and salinity of the water. In clean surface waters with no salinity gradient, dissolved oxygen concentrations will decrease with an increase in temperature. Therefore, daily and seasonal variations in water temperature can be expected to show a related influence on the dissolved oxygen concentrations.

Continuous measurements of dissolved oxygen were only performed at the Koonawarra station, and the results are presented in Figure 5-3, whilst the monthly measurements at the edge, entrance and in-lake locations are presented in Figure 5-4. As expected, daily and seasonal variations are evident, with generally higher concentrations occurring over the winter than the summer months. There is also greater variation across the edge and entrance sites than across the in-lake zones, as observed for temperature. This could be the result of the influence of temperature on dissolved oxygen concentrations, but may also be due to varying amounts of catchment-derived organic and other materials at the edge locations that consume oxygen when undergoing decomposition. The values
across all locations, however, ranged from 5 to 10 mg/L, which are not unsatisfactory from an estuary health perspective.

![Figure 5-3 Plot of dissolved oxygen against time for the Koonawarra monitoring station](image)

**Figure 5-3** Plot of dissolved oxygen against time for the Koonawarra monitoring station

![Figure 5-4 Plots of dissolved oxygen against time for the lake edge and entrance sites (A) and in-lake locations (B)](image)

**Figure 5-4** Plots of dissolved oxygen against time for the lake edge and entrance sites (A) and in-lake locations (B)

5.1.3 pH

The pH range has an influence on aquatic processes and organisms. The measurements at the Cudgeree and Koonawarra monitoring stations (Figure 5-5), and at the edge, entrance sites (Figure
5-6) and in-lake locations (Figure 5-7) show that the pH was rarely below 7, and more likely to be around 8 at all locations, which is close the pH of seawater (8.2). A range of 7 to 8.5 is considered satisfactory for estuarine ecosystems (ANZECC, 2000), so pH is not an issue for Lake Illawarra.

Figure 5-5 Plots of pH against time for the Cudgeree (A) and Koonawarra (B) monitoring stations

Figure 5-6 Plot of pH against time for the lake edge and entrance sites
5.1.4 Salinity

The monthly measurements of salinity at the edge, entrance and in-lake locations are overlaid with rainfall (Figure 5-8), which shows that salinity was generally around 35 ppt, except around rainfall events when it went down to about 20 ppt at the in-lake zones, and to about 10 ppt at some of the edge sites. However, in the following month, the salinity had climbed back to over 30 ppt at all locations, suggesting rapid flushing with seawater, and efficient mixing within the lake.
The monthly data also show that while there is little variation between the in-lake zones on any particular occasion, this is not true for the 10 edge and entrance locations. During major wet weather events, some edge sites, particularly Site 6 at Griffins Bay, and Site 5A at Berkeley had much lower salinity than others, suggesting greater stormwater inputs at these sites on these occasions.

The continuous salinity measurements at Cudgeree and Koonawarra stations are presented in Figure 5-9, which shows that salinity at these sites in dry weather is also around 35 ppt, decreases to about half this value around wet weather events, but rapidly rises back to over 30 ppt within a month of these events.

The rapid rise and maintenance of salinity at over 30 ppt around most of the lake can be attributed to the trained entrance, which has kept the entrance effectively open, enabling free exchange with ocean water. The situation prior to the entrance works is of interest, and Figure 5-10 presents the data for the Koonawarra station for the period 2000 to 2006 (equivalent data for Cudgeree is not available). Salinity then was less than 30 ppt for significantly longer periods of time, presumably when the entrance was closed and freshwater inflows were retained longer. This result suggests that the lake has become more saline in recent years.

Figure 5-9 Plots of salinity against time for the Cudgeree (A) and Koonawarra (B) monitoring stations
5.1.5 Turbidity

The MHL monitoring stations at Cudgeree and Koonawarra Bays do not measure turbidity, and only monthly data collected by the councils is available for this parameter (Figure 5-11). A turbidity of 5.7 NTU has been recommended as the trigger value for assessing the health of estuarine ecosystems that are classified as a “Lake” (State of NSW and Office of Environment and Heritage, 2013). The results for Lake Illawarra show that this value is often significantly exceeded at many of the edge sites. Within the lake itself, the southern and western zones sometimes exceed the trigger, but not by much. The overall average for the in-lakes zones is 4.5 NTU, which compares favourably with the trigger of 5.7 NTU. However, the in-lake zones were never monitored during strong wind conditions, whereas the edge and entrance sites were, and this difference can have a significant influence on their relative values.

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 (wind and rain), and boating or other traffic that can cause local turbulence in the water are also important. The lake edge 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 can quickly mobilise the bottom sediments. The results obtained are in agreement with this expectation.

Figure 5-11 also shows that, for the lake edge and entrance sites, the highest turbidity measurements were recorded when moderate to strong winds were blowing, rather than around big rainfall events. On these windy occasions, even the sandy bottom sites along the eastern margin had elevated turbidity readings, highlighting the significance of wind in the factors that influence turbidity. The impact of wind for a particular site was often noted to be greater when it was blowing onshore rather than offshore. For this reason, the same sites did not always have the highest values. For example, the sandier eastern edge or entrance sites sometimes were more turbid than other
mud-dominated sites, such as at Griffins (Site 6) and Burroo (Site 4) Bays, which at other times were much more turbid.

Comparative turbidity data for the lake from the recent past could not be located, so it is unclear how turbidity has been affected by lake changes, such as the entrance works. In the early 80's, however, the average turbidity within the lake under light wind conditions, was reported to be 3.5 NTU (WBM Oceonics Australia, 2003). The average now under moderate to light wind conditions is only slightly higher at 4.5 NTU.

![Figure 5-11 Plots of turbidity and rainfall against time for the lake edge and entrance sites (A; dotted lines indicate moderate to strong wind conditions) and in-lake locations (B)](image)

5.2 Nutrients and Chlorophyll a
The nutrients monitored, nitrogen and phosphorus, are both essential for primary productivity in an aquatic ecosystem, but, excessive amounts can lead to algal blooms and poor water quality. Chlorophyll a is a measure of the amount of planktonic algae in water, and its value is influenced largely by light availability and the nitrogen and phosphorus concentrations.

When assessing the condition of a water body, chlorophyll a and turbidity are considered to be better indicators of estuary health, than the nitrogen and phosphorus concentrations, as high nutrient concentrations do not always correlate with poor water quality (Scanes, Coade, Doherty, & Hill, 2007). High nutrient inputs can, however, be responsible for poor water quality, and monitoring their concentrations in water can help identify areas where nutrient inputs need to be controlled.
5.2.1 Nitrogen

The concentrations of nitrate, nitrite, and ammonia were almost always below their respective detection limits, indicating that these more bio-available forms of nitrogen are rapidly utilised by phytoplankton and other plant life in the lake. Nitrogen is considered to be the limiting nutrient for primary production in this lake and the results for nitrate, nitrite and ammonia support this hypothesis (WBM Oceanics Australia, 2003). These nitrogen forms are not discussed further in this report.

The total nitrogen (TN) concentrations are presented in Figure 5-12, against the guideline trigger value of 0.3 mg/L, the daily rainfall totals, and wind conditions. The results suggest that both weather conditions and the season have an influence on the values obtained. In general, higher concentrations occur with very windy or rainy weather, and during summer more than over winter.

A marked spatial variation in the concentrations across the lake is also evident, with much higher values at the edge sites in the north-east at Griffins Bay (Site 6) and south-west at Burroo Bay (Site 4) than at other edge or entrance sites or the in-lake zones. At these two sites, the total nitrogen routinely exceeded the guideline trigger value of 0.3 mg/L, and the summer peak could be as high as twice this amount. All other edge and entrance sites and the in-lake zones had concentrations close
to or less than the guideline value, except around large rainfall events, when there was some
elevation at other sites, such as at Kanahooka (Site 5).

The results for filtered total nitrogen (FTN) show better compliance with the guideline trigger value
at all sites across the lake than the total nitrogen concentrations (Figure 5-13). This means that
significant amounts of particulate nitrogen occur at some sites, causing the guideline value to be
exceeded when total nitrogen (TN) concentrations are measured. The variation between the edge
sites that was apparent for TN, and the seasonal effect, is also less prominent. In summer,
microscopic algal blooms occur, which vary from site to site (confirmed by the results for chlorophyll
a later) and the nitrogen present in these blooms is responsible for the variations observed for TN in
unfiltered water. In the middle of summer, the TN at some sites (Sites 6, 6A, 5, 5A, 4, 4A) can double
as a result of this process. For both total and filtered total nitrogen, the site at Griffins Bay (Site 6)
generally had the highest concentrations.

![Figure 5-13](image1.png)

**Figure 5-13** Plots of filtered total nitrogen (FTN) and rainfall against time for the lake edge and entrance sites (A; dotted
lines indicate moderate to strong wind conditions) and in-lake locations (B)

5.2.2 Phosphorus

The total phosphorus (TP) concentrations are presented in Figure 5-14, against the guideline value of
0.03 mg/L, the daily rainfall totals, and the wind conditions. As for total nitrogen, weather
conditions and season have an influence on the concentrations recorded, and higher concentrations
were generally obtained when windy or rainy weather was prevalent, and during the summer than over the winter months. However, unlike for total nitrogen, more edge sites besides those at Griffins (Site 6) and Burroo (Site 4) Bays, exceeded the guideline value through the monitoring period. Only sites in the entrance channel at the Windang Boat Ramp (Site 2) and in the trained part of the entrance (Site 1) generally complied. Within the in-lake zones, zones in the south (NS3) and west (EW2) also showed slight exceedances on some occasions. Burroo Bay (Site 4) had the highest concentrations generally, and in summer could be about two and a half times the guideline value.

The filtered total phosphorus (FTP) results are presented in Figure 5-15, which show better compliance with the guideline value for all sites, except for Burroo Bay (Site 4), which still exceeded the guideline value by as much as 2 ½ times in the 2014/15 summer. This summer was generally wetter than the previous one, which could be the reason for this difference. Unlike for filtered total nitrogen, a seasonal trend appears to be present for filtered total phosphorus, with higher concentrations occurring around the summer months. This could suggest that an increase in the release of phosphorus into the water over the summer months, as also noted by WBM Oceanics (2003). The total phosphorus (TP) over the summer months can more than double at some edge
sites, as a result of the extra phosphorus bound in suspended planktonic and other material in the water.

The filterable reactive phosphorus data are presented in Figure 5-16. The guideline value for phosphorus in this form is very low at 0.005 mg/L, and the results show that most of the edge and entrance sites and the zones within the lake exceeded this value most of the time. Amongst the edge sites, Burroo Bay (Site 4) again had the highest concentrations, and within in-lake zones, it was generally the western side (EW2). A seasonal trend as for filtered total phosphorus is apparent, suggesting greater release of this form also into the water over the summer months. Filtered reactive phosphorus is a component of the filtered total phosphorus, and the percentage present in this form varies from 30 to 100%, with no obvious pattern between sites or seasons. Burroo Bay (Site 4) has the highest concentrations of all forms of phosphorus measured.
5.2.3 Chlorophyll a

The data for chlorophyll a are presented in Figure 5-17, against the guideline value of 3.6 µg/L, the daily rainfall totals, and the wind conditions. Along the edges of the lake, Griffins Bay (Site 6) and Burroo By (Site 4), which routinely had the highest nitrogen and phosphorus concentrations, recorded chlorophyll a concentrations significantly greater than the guideline value. Sites towards the east and towards the entrance channel generally showed good compliance, as did the zones within the lake itself. More than wind or rainfall conditions, the season appears to have the greatest impact on the concentrations recorded. Over summer, the values at locations such as Griffins and Burroo Bays increased almost four-fold.

Continuous measurements of chlorophyll a at the Koonawarra and Cudgeree Bay monitoring stations are shown in Figure 5-18. The results are only preliminary as quality control issues are still being sorted out for this measurement, but they show higher chlorophyll a concentrations at Koonawarra than at Cudgeree. This is in general agreement with the pattern suggested by the monthly program, which shows that the lowest concentrations occur at sites around the east and the entrance channel.
Figure 5.17 Plots of chlorophyll a and rainfall against time for the lake edge and entrance sites (A; dotted lines indicate moderate to strong wind conditions) and in-lake locations (B)

5.2.4 Spatial Distribution Patterns

The data collected on nitrogen, phosphorus and chlorophyll a indicate that the edges of the lake around Griffins Bay in the north-east (Site 6) and Burroo Bay in the south-west (Site 4) have the highest concentrations, which exceeded the guideline values by a significant amount. This is apparent mostly around the summer months when conditions are more conducive for an increase in phytoplankton activity. Other edge and entrance sites and the zones within the lake had much better compliance with the guideline values.
Figure 5-18 Plots of chlorophyll a against time for the Cudgeree (A) and Koonawarra (B) monitoring stations.

Figure 5-19 presents the average total nitrogen (TN) concentrations for the locations over the summer months, and shows the extent of its enrichment across the lake. Significant enrichment appears to be currently happening only in the north-east and south-west edge areas of the lake, with all other regions showing reasonable compliance with the guideline trigger value of 0.3 mg/L. The fact that adjacent edge sites and the in-lake zones show much better compliance could mean that 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 total phosphorus, significant enrichment is evident along most of the edge sites, as well as within the southern zone of the lake (Figure 5-20). The average concentration at Burroo Bay far exceeded all other results, and the region around it shows greater enrichment than other areas of the lake, suggesting a significant source of phosphorus in this part of the lake or adjacent catchment.
Figure 5-19 Average total nitrogen (TN) concentrations in Lake Illawarra over the summer period (guideline trigger value is 0.30 mg/L)

Figure 5-20 Average total phosphorus (TP) concentrations in Lake Illawarra over the summer period (guideline trigger value is 0.030 mg/L)
The results for chlorophyll a show the average concentrations at Griffins and Burroo Bays were highest and about 2 1/2 times the guideline trigger value of 3.6 µg/L (Figure 5-21). Edge sites to the north at Berkeley (Site 5A) and to the west around Tallawarra (Site 4A) also had reasonable enrichment, but the averages are only about 1 1/2 times the guideline trigger value. All other areas show reasonable compliance.

Figure 5-21 Average chlorophyll a concentrations in Lake Illawarra over the summer period (guideline trigger value is 3.6 µg/L)

5.2.5 Comparison with Past Water Quality

5.2.5.1 Lake Edge and Entrance Sites since 2009
Data collected by the Lake Illawarra Authority for the 3 entrance and 3 edge sites from 2009 has been combined with the current data from WCC for the same sites, and the results show that the current nutrient and chlorophyll a patterns have been present at least since 2009 (Figure 5-22). The same seasonal pattern is evident for all the constituents, with sites at Griffins and Burroo Bays routinely exceeding the guideline trigger values, and greater phosphorus enrichment at Burroo Bay than at Griffins Bay. Data for the period earlier than 2009 has not been included because of issues around quality control of the data for that period. There was no monitoring of any in-lake zones by the LIA.
Figure 5-22 Plots of rainfall and total nitrogen (A), filtered total nitrogen (B), total phosphorus (C), filtered total phosphorus (D), filtered reactive phosphorus (E), and chlorophyll a (F) against time for the lake edge and entrance sites since May 2009.
5.2.5.2  In-lake Sites since 2010

Energy Australia-Yallah has been monitoring sites within the lake monthly for a number of years, and the data collected since 2010 was provided to WCC for this report. Figure 5-23 shows the location of their monitoring sites. Except for Sites TA4 and TA5, the rest are within the western side of the lake. There are sites that are equivalent to the sites being monitored by the councils: TA3 is equivalent to EW2, TA4 to NS2, TA5 to EW1, and TA8 to NS3. The water quality indicators monitored by Energy Australia-Yallah are a number of physical characteristics, nitrogen in the form of ammonia, nitrate, and nitrite, phosphorus as reactive phosphorus, and chlorophyll a. The nitrogen forms measured are almost always below detection limits, but reactive phosphorus and chlorophyll a are present in measureable quantities.

![Figure 5-23 Map showing location of the sites being monitored by Energy Australia-Yallah](image)

The results for reactive phosphorus and chlorophyll a are presented in Figure 5-24, together with the results obtained by WCC, to see if there is agreement between the two datasets over the period where they overlap, and whether the earlier Energy Australia-Yallah results can be utilised for detecting changes in the lake over time. Energy Australia-Yallah normally conducts its monitoring earlier in the day (between 8 and 9 am) whereas the WCC sampling is done around mid-morning (around 10 to 11 am). Given that chlorophyll a concentrations change through the day, this could be expected to have some effect on the two datasets. However, the WCC results do not appear to be different from the Energy Australia data for the period where they overlap, therefore the earlier Energy Australia-Yallah data has been used to determine whether there is significant variation over time.
Figure 5-24 Plots of rainfall and filtered reactive phosphorus (A) and chlorophyll a (B) against time for the Energy Australia-Yallah and council in-lake locations.
The reactive phosphorus results suggest no significant change since 2010, and no particular seasonal or other pattern. The results for chlorophyll a suggest a seasonal variation, and possibly an increase in recent years. However, this could be due to rainfall variations, as the concentrations recorded appear to be higher when there is a sustained period of wet weather. Table 5-1 gives the rainfall totals for the winter and summer periods from 2009 to 2015 as well as the annual totals, and shows that the two recent summers, when chlorophyll a concentrations were reasonably high, have been wetter than the previous two summers. This suggests the condition of the lake can change depending on the rainfall conditions. The annual average rainfall for areas around Wollongong is reported to be around 1300 mm (BoM data for Port Kembla and Wollongong Stations) which means that there has been no period over the monitoring period of above average rainfall. Monitoring of the lake sites under much wetter conditions is important to determine what impact it has on the lake water quality.

Table 5-1 Rainfall for the summer and winter periods for the Darkes Road monitoring station (data provided by Manly Hydraulics Laboratory)

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</thead>
<tbody>
<tr>
<td>Winter</td>
<td>1 May to 31 Oct</td>
<td>333.5</td>
<td>520</td>
<td>476.5</td>
<td>215</td>
<td>498.5</td>
<td>365</td>
</tr>
<tr>
<td>Summer</td>
<td>1 Nov to 30 Apr</td>
<td>523</td>
<td>800</td>
<td>616</td>
<td>515</td>
<td>813</td>
<td>771.5</td>
</tr>
<tr>
<td>Annual</td>
<td>1 May to 30 Apr</td>
<td>856.5</td>
<td>1320</td>
<td>1092.5</td>
<td>730</td>
<td>1311.5</td>
<td>1136.5</td>
</tr>
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5.2.5.3 In-lake Sites before Entrance Works

A question that is of interest to many is how the entrance works, which were completed in 2007, have impacted on the lake water quality, particularly in relation to the main body of the lake. Data for this region of the lake for the period immediately before and after these works were undertaken could not be located, but some data for the period 1996 to 2000 is reported in WBM Oceanics (2003). This includes compliance of various water quality indicators with guideline values. The data on percentage compliances for total nitrogen, total phosphorus and chlorophyll a are presented in Figure 5-25, together with compliances for the lake zones from the current data, which shows a clear difference between the two periods. From 1996 to 2000, most of the lake areas had very low compliances for the three constituents, but the situation has improved remarkably since then. The entrance works may have helped in bringing about this change, as they are now allowing greater turnover of the lake water.

WBM Oceanics (2003) reported the lake to be well mixed, with the entrance area having water quality more representative of the main body of lake than the incoming ocean water. The current data suggest more zonation within the lake with the central and entrance areas more affected by incoming ocean water, and the margins to the west and south possibly being more affected by catchment or lake bed conditions. Further monitoring will help to clarify the exact zonation patterns now existing within the lake.
Figure 5-25 Percentage compliance of total nitrogen, total phosphorus and chlorophyll a concentrations with their corresponding guideline values for 1996 to 2000 compared with the current situation (red shows <50% compliance)

5.3 Estuary Health Condition

The estuary health condition over the summer and winter periods for the lake edge and entrance sites since 2009, and the in-lake locations since 2010 are shown in Figures 5-26 and 5-27. The summer period is taken to be from 1 Nov to 30 April, while the winter is from 1 May to 31 Oct (Scanes, pers. comm.). As the condition determination is based on chlorophyll a concentrations, the results reflect the variations in this indicator over these periods, with the summer condition being not as good as in winter.

The results also show that the entrance and the in-lake areas are generally in good to very good condition, and poor to very poor conditions occur only at the edge sites in the north-east and south-west, and this situation has generally prevailed since 2009/10. A reliable chlorophyll a dataset for
the lake for the pre-entrance works period could not be located, so an equivalent condition assessment for that period could not be undertaken.

The current condition of the main body of the lake might seem like a good result, but it is based only on chlorophyll a, and not on other indicators of estuary health, such as macrophyte distribution and fish assemblages. These indicators should be considered in any further assessment of the lake condition.

6 Conclusions

This report has reviewed the data collected for Lake Illawarra since October 2013 for an assessment of its current water quality and estuary health condition. This information is compared with previous datasets, where available, to determine how the condition of the lake has changed over time.

For most of the parameters measured, a strong seasonal influence is apparent, associated with the higher temperatures, daylight hours, and productivity over the summer months. Imposed on this is the influence of weather conditions, with wind and rain generally resulting in an increase in the concentrations measured.

Review of the physical indicators of water quality over time suggests that the lake has become more saline in recent years. This can be attributed to the trained entrance which is now enabling greater exchange with ocean water. The more saline conditions now can also be expected to have an effect on the lakes biotic community. Mangroves, for example, are now noted to invade areas where they were previously not present. The impact of the more saline conditions on the lake’s biotic community deserves another separate study.

Introduction of additional lake edge and in-lake locations into the monitoring program by the councils has demonstrated that the sites previously monitored by the LIA do not reflect the conditions across the lake. This review has shown that significant nutrient enrichment is only occurring in the more enclosed north-east and south-west areas; and the main body of the lake and other edge areas in the middle section of the lake are more compliant with guideline trigger values. The estuary health condition of the lake generally reflects this distribution pattern. This highlights the importance of including locations within the monitoring program that enable a more representative assessment of the lake condition.

The estuary health condition of the main body of the lake has been found to be generally good to very good. However, this assessment is based only on one indicator of estuary health, chlorophyll a. Consideration of other indicators, such as macrophyte distribution and fish assemblages, would be useful in confirming this state.

The current condition of the lake appears to have been the same for at least the last 5 to 6 years. However, the monitoring so far has not covered any wetter than average periods. Continuation of the monitoring to include such conditions will help establish how the lake responds following extended wet weather periods.
Figure 5-26  Estuary health condition at the edge and entrance sites over the winter and summer periods since 2009 (circled – Council data; uncircled – LIA data)

|----------------|---------|---------|---------|---------|---------|---------|

(circled – WCC data; uncircled – LIA data)

Figure 5-27  Estuary health condition at the in-lake locations over the winter and summer periods since 2010 (circled – Council data; uncircled – Energy Australia-Yallah data)

|----------------|---------|---------|---------|---------|---------|---------|

No data

KEY to Figures 5-26 and 5-27
- Very Good
- Good
- Fair
- Poor
- Very Poor
7 Recommendations

1. The 15 sites being currently being monitored (7 edge sites, 3 entrance sites, and 5 in-lake locations) are helping to establish spatial variations in water quality and the estuary health condition across the lake. All sites are to be retained for on-going monitoring.

2. The continuous monitoring of water quality at Cudgeree and Koonawarra by the Manly Hydraulics Laboratory to be retained as a finer scale complement to the monthly monitoring undertaken by the councils.

3. Water quality and estuary health assessment under wetter than average conditions be established and compared with the current results.

4. Further assessments of the condition of the lake undertaken to consider other indicators of estuary health, such as turbidity, macrophyte distribution and fish assemblages, if available.

8 Acknowledgements

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

9 Works Cited


