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Yellagonga Regional Park wetlands water quality monitoring 2013-2014

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Prepared for,

Cities of Joondalup and Wanneroo as part of the Yellagonga Integrated Catchment Management Plan

Mine Water and Environment Research Centre

Centre for Ecosystem Management

Report No. 2014-08

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2 ACKNOWLEDGEMENTS

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FRONTISPIECE

Figure 1. Picture taken of North Lake Joondalup during 24th March 2014 sampling fieldtrip.

This document should be referenced as follows.

Newport, M.L. & Lund, M.A. (2014). *Yellagonga Regional Park wetlands water quality monitoring 2013-2014.* Mine Water and Environment Research/Centre for Ecosystem Management Report No. 2014-08, Edith Cowan University, Perth, Australia. 49pp. Unpublished report to the Cities of Joondalup and Wanneroo.

3 CONTENTS

4 EXECUTIVE SUMMARY

1. Kinnear *et al.* (1997) conducted a fifteen month study on the Yellagonga Park wetlands and concluded that they were eutrophic (enriched with nutrients) as a result of natural processes within the system and anthropogenic inputs. Lund *et al.* (2011b) and more recently Newport and Lund (2013a) have confirmed acid sulphate soils present in the southern section of the park and metal contamination of wetlands in the Park. In the second, third and fourth years of monitoring Newport *et al.* (2011), Newport and Lund (2012) and Newport and Lund (2013b) reported that ANZECC/ARMCANZ (2000) water quality guidelines for the protection of aquatic systems were being exceeded for some physical parameters, nutrients and metals throughout the park's surface waters.
2. This report covers monitoring of the Yellagonga Park wetlands as per Newport and Lund (2013b) for July 2013 to June 2014.
3. All parameters recorded were compared to the ANZECC & ARMCANZ (2000) national water quality trigger values for the 95% protection of aquatic ecosystems. In 2013/14 despite higher annual rainfall than in 2012/13, there were more prolonged periods of the drought where many sites were dry. Across the year, water hardness increased, increasing slightly some ANZECC/ARMCANZ (2000) trigger values. Overall, there were very few exceedances of trigger values except for a couple of occasions for Al, As, Hg and Zn (5 times). The fewer exceedances compared to previous years suggests the system has largely recovered from the acidification event that took place in 2011/2012 at site $\text{Drain}_{\text{Goollelal}}$. The prolonged dry periods in 2013/14 might initiate a further acidification and so continued monitoring is recommended. Previously reported high levels of U and Se appear to have been associated with instrument error – we have upgraded to a more sensitive ICP-MS which has revealed that the previous data for U and Se cannot be considered reliable. On a couple of occasions, the need for high levels of sample dilution increased detection limits for U and Se above trigger values – this suggests that there is potential for an exceedance but that it is not considered likely.

4. Nutrient concentrations remain excessive throughout much of the park, however were very low in northern Lake Joondalup and Lake Goollelal (both sites). Lake Goollelal did have some very high spikes in nutrients as it dried, presumably due to a combination of evapo-concentration and algal blooms.
5. Recommendations from this report included development of a management plan for the acid sulphate soils identified around $Drain_{Goollelal}$. It is also recommended that Lake Goollelal be prevented from drying out to the levels seen in 2011 due to the risk of acidification (similar to Lake Jandabup). The authors now believe that a reduction in sampling frequency to every 2 months will continue to provide adequate information and allow for a reduction in costs. The vegetation between south and mid Lake Joondalup appears to be preventing significant nutrient enrichment of northern Lake Joondalup. This area is effectively acting as a natural constructed wetland. It is recommended that this area be investigated to fully understand the role it is playing in nutrient removal and to ensure that this positive benefit can be maintained into the future.

5 INTRODUCTION

A number of studies conducted within Yellagonga Regional Park have concluded that Lake Joondalup is a eutrophic wetland (Congdon & McComb, 1976; Gordon *et al.*, 1981; Congdon, 1985, 1986; Davis *et al.*, 1993; Kinnear *et al.*, 1997; Kinnear & Garnett, 1999; Lund *et al.*, 2000; Lund, 2003; Cumbers, 2004). Nutrient and water budgets prepared by Congdon (1985, 1986) and Cumbers (2004) identified a significant quantity of water and nutrients entered Lake Joondalup via flow through from the southern portion of the Yellagonga wetlands chain.

Lund *et al.* (2011b) found acid sulphate soils (ASS) evident in the southern section of Yellagonga and assumed it originated from north of Lake Goollelal. A more recent investigation confirmed positive ASS results on the north side of Whitfords Avenue, known as $Drain_{Goollelal}$ in this project (Newport & Lund, 2013a). Both studies highlighted the need to monitor surface waters of Yellagonga wetlands and groundwater within the park for indicators of contamination as a result of ASS mobilisation.

The Yellagonga Integrated Catchment Management (YICM) Plan identified the need for a regular monitoring program for the wetlands of the Park. Regular monitoring under the YICM plan began in 2010. This first monitoring report results confirmed metal contamination and nutrient enrichment of the Yellagonga wetlands chain with evidence of increasing concentrations over time (Lund *et al.*, 2011b). The second monitoring report concluded that ANZECC/ARMCANZ (2000) national water quality guideline trigger values were consistently exceeded for various metals, nutrients and algal concentrations. Evidence of ASS contamination was also detected with the presence of acidic to neutral pH and iron precipitation throughout the middle section of the wetland chain (Newport *et al.*, 2011). The third monitoring report concluded that there was a worsening of the water quality throughout Yellagonga Regional Park with evidence of higher metal and metalloid contamination, lowering of water hardness and an increase in nutrient concentrations (Newport & Lund, 2012). The fourth monitoring report concluded that water quality in the Yellagonga Regional Park was similar to that of the previous two monitoring periods. The report recommended that investigations be carried out into the extent of ASS at Drain$_{Goollelal}$ and identification of sources responsible for the unusually high concentrations of phosphorus present in the South Culvert and South Lake Joondalup (Newport & Lund, 2013b).

The purpose of this study is to report on the fifth year (July 2013 to June 2014) of monitoring physico-chemical parameters, nutrient levels and metal/metalloid concentrations of thirteen key sites along the Yellagonga Regional Park water flow path. This study aimed specifically to;

- Compare monitoring outcomes with corresponding ANZECC/ARMCANZ (2000) guideline trigger values for the 95% protection level of aquatic ecosystems, as prescribed by the management plan,
- Determine variation between sites along the flow path from Lake Goollelal into North Lake Joondalup,
- Identify variations in monitoring outcomes, driven by seasonality at sites along the flow path from South Lake Goollelal into North Lake Joondalup and
- Recommend management strategies/actions and identify gaps in knowledge associated with current issues.

6 METHODS

6.1 STUDY SITE

Yellagonga Regional Park lies on the coastal limestone belt of the Swan Coastal Plain (Kinnear *et al.*, 1997). The park is located in the north-west corridor of Perth and is approximately 20 km north of Perth's central business district. Yellagonga Regional Park covers an area of approximately 1,400 ha and contains Lake Goollelal, Wallubuenup[1] Swamp (divided into a northern[2] and southern section by Woodvale Drive), Beenyup Swamp, and Lake Joondalup (divided into a northern and southern section by Ocean Reef Rd). The park is managed by the Cities of Wanneroo and Joondalup, and Department of Parks and Wildlife under the Yellagonga Regional Park Management Plan (Dooley *et al.*, 2003).

Yellagonga wetlands are nestled in an interdunal depression with a high plateau sloping to the west and generally flat to slightly undulating slopes to the east. Due to their location within the landscape, these wetlands form a chain of water bodies that are largely surface expressions of the Gnangara Mound, an unconfined groundwater aquifer which flows in a westerly direction (Kinnear *et al.*, 1997). The wetlands and swamps are interconnected throughout the park by a natural drainage line[3] (Figure 2) and surface water flows northwards following a landscape height gradient. The Park's highest water body Lake Goollelal at the south end is situated at 27 m AHD (Australian Height Datum). The gradient then slopes down to Wallubuenup Swamp (19 m AHD), into Beenyup Swamp (18 m AHD) and finally into Lake Joondalup at 18 m AHD.

[1] Often referred to as Walluburnup Swamp

[2] Whitfords Avenue also cuts off a very small section of the southern end of Wallubuenup Swamp. Between Whitfords Avenue and Hocking Rd is a small section of drain joining Lake Goollelal and Wallubuenup Swamp.

[3] Although water would have naturally flown over land between these wetlands, in some sections a more clearly defined drain has been constructed to facilitate flow.

Urbanisation has increased surface flow by increasing impermeable surface areas within the catchment and enhanced drainage into the wetlands (Kinnear *et al.*, 1997). The changes in land use and greater draw down of the Gnangara Mound have altered wetland hydrology by reducing groundwater but increasing surface inflows. Perth's Mediterranean climate of cool wet winters and hot dry summers ensures that most wetlands are normally dry toward the end of summer. Although occasionally dry in the past (Hamann, 1992), since 1999 Lake Joondalup has dried annually to small pools. Lake Goollelal has permanent water (although it almost dried in 2011). Wallubuenup Swamp dries annually while Beenyup Swamp dries on occasion.

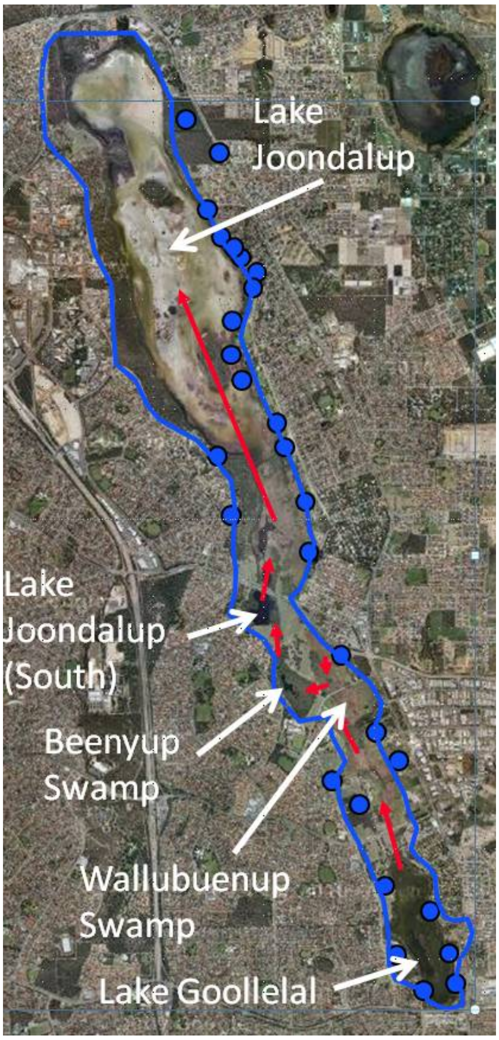


Figure 2. Direction of surface water flow through Yellagonga Regional Park wetlands, blue dots indicate drains entering the system; taken from Ove Arup & Partners (1994) and GoogleMaps (2011).

Three different underlying soil types have been identified within the Yellagonga Regional Park. These include Karakatta Sand, Spearwood Sand and Beonaddy Sand (McArthur & Bartle, 1980). Lake Goollelal, Lake Joondalup and Beenyup Swamp contain floc overlying peat sediments (Bryant, 2000; Sommer, 2006; Goldsmith *et al.*, 2008) previously incorrectly described as metaphyton by Rose (1979) and Boardman (2000).

Although sections of Yellagonga Regional Park have been previously used for agriculture, Beenyup Swamp remains highly vegetated. Stands of paperbark (*M. rhaphiophylla*) dominate the landscape, whilst a large portion of the fringing vegetation of Lake Joondalup has been replaced by lawn areas (Upton, 1996). Wallubuenup Swamp has been subject to frequent fires and has little open water with most of the swamp covered in *Typha orientalis*. February 2011 saw developers of the Chianti residential estate located on the eastern side of Wallubuenup Swamp begin clearing *Typha orientalis* and *Populus* sp trees. The developers continued to spray the *T. orientalis* and *Kikuyu* grass until February 2012 in an unsuccessful bid to eradicate the plants from the area. Lake Goollelal has residential properties and public open space bounding to the water's edge but fringing vegetation generally remains in good condition.

The following sites, listed from south to north within Yellagonga Regional Park waters, were sampled on a monthly basis (Figure3.):

South Lake Goollelal – Southern-most section of Lake Goollelal.

Lake Goollelal – Middle section of lake.

$\mathbf{Drain_{Goollelal}}$ (Site 5) – Drain outflow from Lake Goollelal under Whitfords Ave.

$\mathbf{Drain_{south}}$ (Site 6) – Drain near Della Rd.

$\mathbf{Drain_{mid}}$ (Site 7) – Drain north of Della Rd.

$\mathbf{Drain_{north}}$ (Site 4) – Outflow of southern Wallubuenup Swamp into northern Wallubuenup Swamp as it flows under Woodvale Drive.

$\mathbf{Been_{in}}$ (Site 3) – Drain between Wallubuenup Swamp and Beenyup Swamp.

$\mathbf{Been_{out}}$ (Site 1) – Outflow channel from Beenyup Swamp.

South Culvert Inlet – Outflow from Beenyup Swamp into the South Culvert.

South Culvert – South end of Lake Joondalup separated from main body of lake by Ocean Reef Road. Tunnel runs under Ocean Reef Rd allowing water to flow from south end into main body of Lake Joondalup.

South Lake Joondalup – Outflow from drain under Ocean Reef Rd into main lake water body.

Mid Lake Joondalup – Neil Hawkins Park.

North Lake Joondalup – The northernmost site of the study area.

Figure 3. Locations of the thirteen study sites in Yellagonga Regional Park (adapted from Google Earth).

Sites used in this study were chosen based on accessibility and representativeness of the flow path through Yellagonga Regional Park. Six sites, identified with a site number, were used in previous studies, namely Lund et al. (2011b) and the Lund (2007). An additional seven sites have been added to improve understanding of changes in water quality along the flow path from south to north. Figure 4 shows seasonal changes in water regimes at each of the thirteen sites.

a) South Lake Goollelal

October 2013 (wet)

April 2014 (dry)

b) Lake Goollelal

October 2013 (wet)

March 2014 (dry)

c) Drain$_{\mathbf{Goollelal}}$ (Site 5)

September 2013 (wet)

April 2014 (dry)

d) Drain$_{south}$ (Site 6)

September 2013 (wet)

April 2014 (dry)

e) Drain$_{mid}$ (Site 7)

October 2013 (wet)

April 2014 (dry)

f) Drain$_{north}$ (Site 4)

October 2013 (wet)

April 2014 (dry)

g) Been$_{in}$ (Site 3)

September 2013 (wet)

January 2014 (dry)

h) Been$_{out}$ (Site 1)

September 2013 (wet)

March 2014 (dry)

i) South Culvert Inlet

September 2013 (wet)

April 2014 (dry)

j) South Culvert

September 2013 (wet)

April 2014 (dry)

k) South Lake Joondalup

October 2013 (wet)

April 2014 (dry)

l) Mid Lake Joondalup

December 2013 (wet)

April 2014 (dry)

m) North Lake Joondalup

October 2013 (wet)

May 2014 (dry)

Figure 4. Photographs of the thirteen sites used in this study, showing seasonal changes in water regimes.

6.2 SAMPLING

This report covers monthly sampling between the July 2013 and June 2014, at the thirteen sites. A site was considered 'dry' if the water was not deep enough to sample (<50 mm). On each monthly monitoring occasion, at each site, pH, oxidation reduction potential (ORP), conductivity, temperature, dissolved oxygen (% saturation and mg L^{-1}) and turbidity were measured using a Datasonde 5a instrument. At each site, a water sample was also collected.

In the laboratory, an unfiltered aliquot (subsample) of each water sample was frozen for later determination of total nitrogen (TN) and phosphorus (TP). A filtered (0.5 µm Pall Metrigard filter paper) aliquot was then frozen for later determination of sulphate (SO_4), chloride (Cl), nitrate/nitrite (NO_x-N), filterable reactive phosphorus (FRP-P), ammonia (NH_4-N) and dissolved organic carbon (DOC; measured as non-purgeable organic carbon). Another filtered aliquot was acidified with nitric acid (to a pH <2 approximately 1% v/v) and then kept at 4°C for later determination by ICP-AES/MS of a range of metals (Al, As, Ca, Cd, Co, Cr, Fe, Hg, K, Mg, Mn, Na, Ni, Se, U & Zn).

All analyses were performed at the Natural Sciences Analytical Laboratory (Edith Cowan University) as per APHA (1999). Water hardness was estimated by calculation using factors from APHA (1999) for Ca, Mg, Fe, Al, Zn, Se and Mn.

7 RESULTS AND DISCUSSION

Rainfall during the period of this study (2013-14) totalled 755.7 mm (excluding June) which was similar to that of the 2011-12 monitoring period with 761.9 mm (Bureau of Meteorology, Wanneroo). The 2012-13 monitoring period had a lower rainfall, with a total of 566.9 mm, a difference of 188.8 mm between the last monitoring period and the current one (Figure 5).

Even though the total rainfall in 2013-14 was higher than 2012-13 and similar to 2011-12, this monitoring period was the first year with more than four months with less than 10 mm of rainfall (Figure 5). In fact November and December 2013 had 6.2 mm and 2 mm of rainfall respectively with January and February 2014 experiencing no rainfall at all. As a result, only two sites between March and April contained enough water for sampling which were sites Beenyup$_{in}$ and Drain$_{north}$. Drain$_{mid}$ was the driest site, for the first time since the monitoring program began, being sampled only between July and September 2013 when the highest monthly rainfalls were recorded. This was also similar for sites Drain$_{Goollelal}$ and Drain$_{south}$ which were only sampled between July and October 2013.

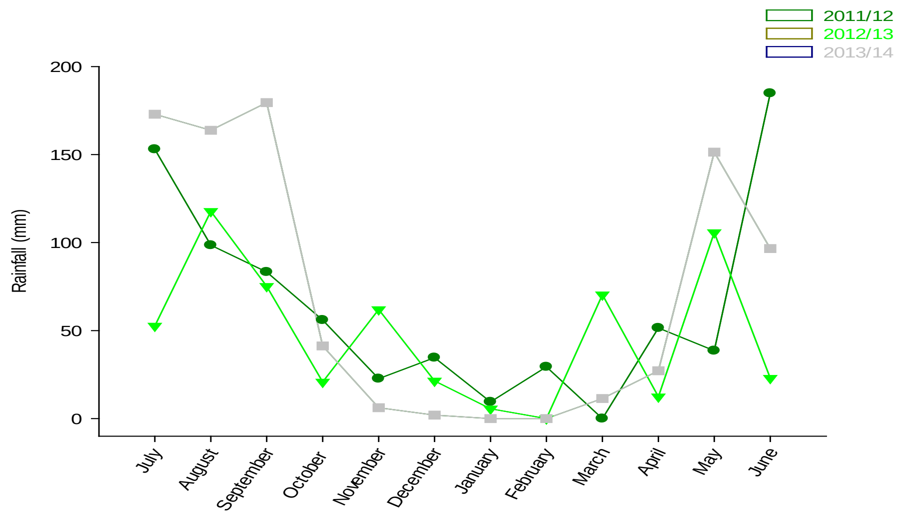
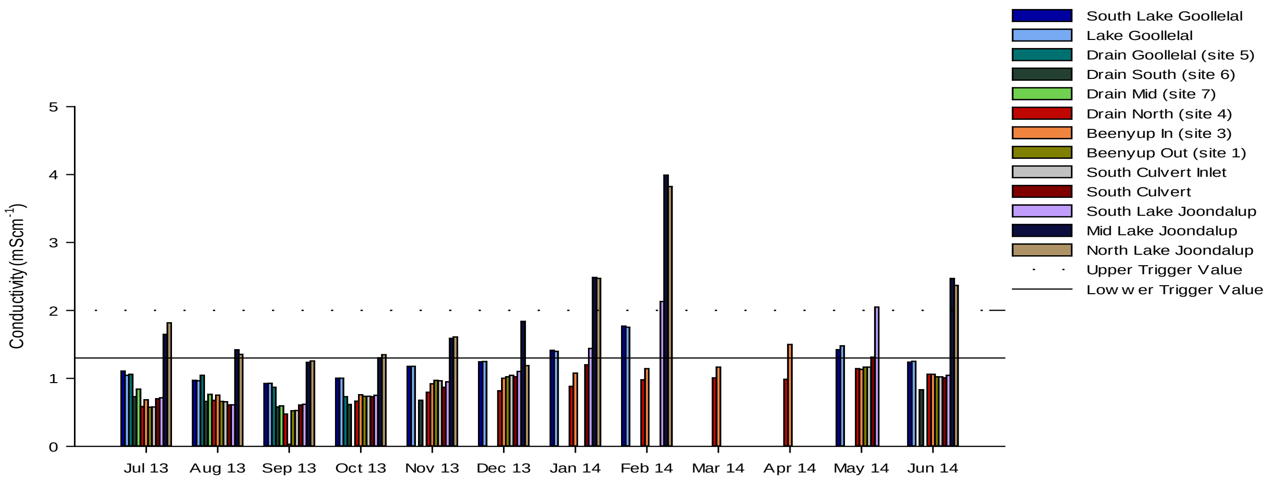


Figure 5. Graph illustrating monthly rainfall totals for 2011/12, 2012/13 and 2013/14 monitoring periods from data obtained from the Bureau of Meteorology, climate data from Wanneroo.

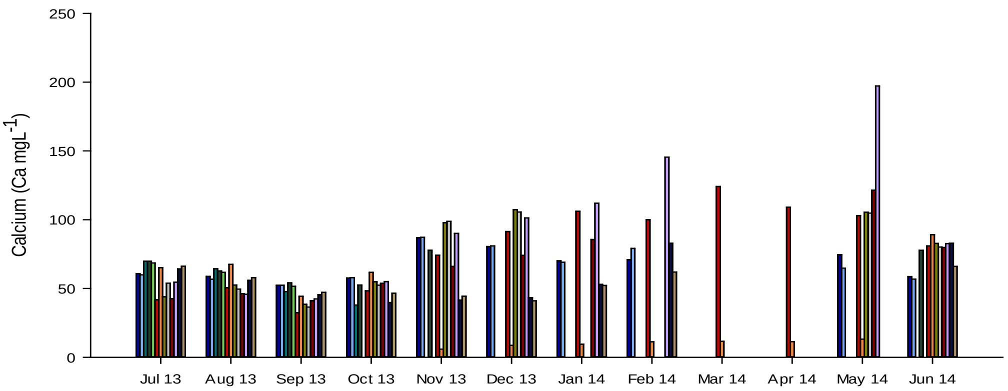
7.1 PHYSICO-CHEMISTRY

Electrical conductivity (EC) was generally slightly lower compared to the same time 2012-13, but the extended dry period ensured that at some sites conductivity was higher than previous years for a short period of time (Figure 5a). Evapoconcentration of solutes in the water is evident at the time of lowest water levels (summer) and is reflected in EC, and major solutes Ca, K, Mg, Na and Cl. The greatest concentrations of these solutes in previous years have been found in Mid and North Lake Joondalup, although this trend cannot be confirmed this year as these sites were frequently too dry to sample. In general, at all sites mean concentrations and ranges were higher for solutes in this year compared to 2012-2013, suggesting that despite greater rainfall, there was not greater dilution.

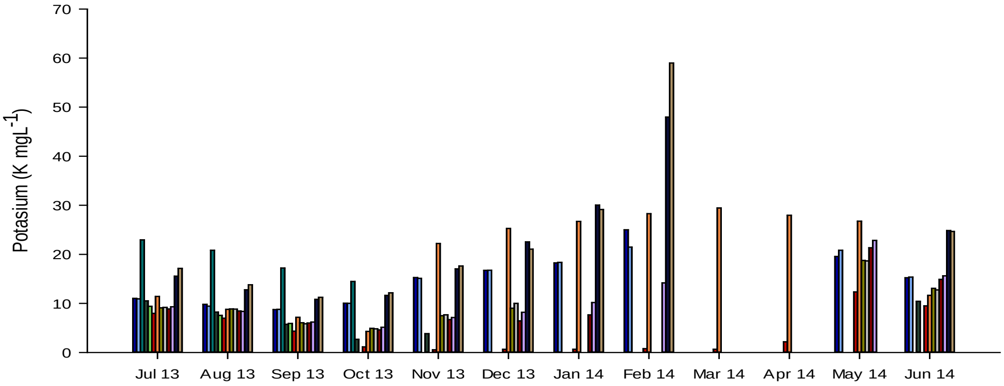
a) Electrical conductivity



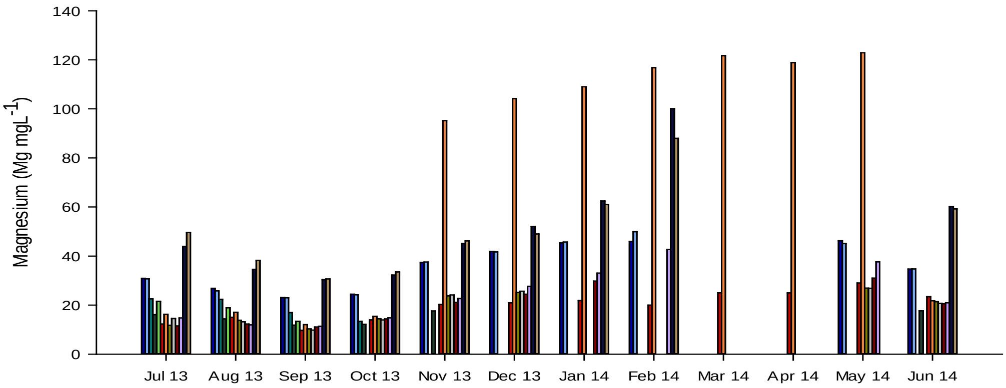
b) Calcium (Ca)



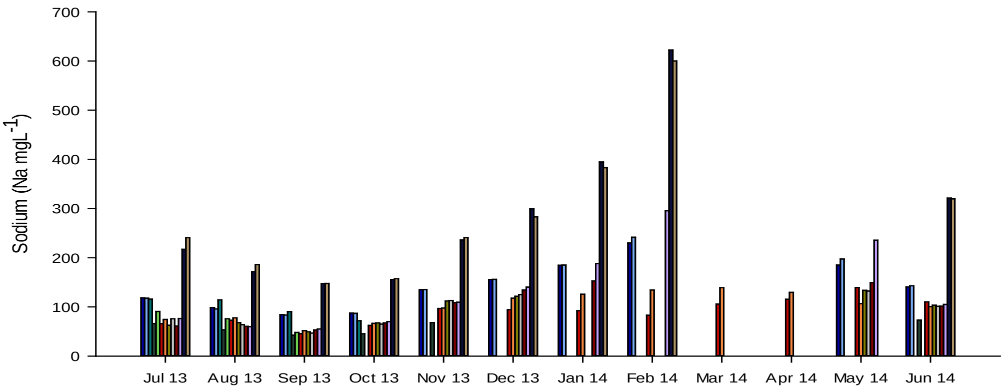
c) Potassium (K)



d) Magnesium (Mg)



e) Sodium (Na)



f) Chloride (Cl)

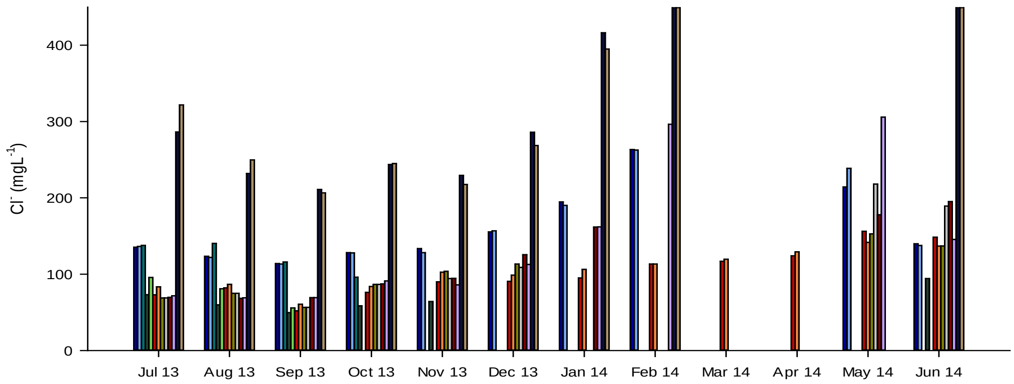


Figure 5. Changes in a) electrical conductivity, b) calcium, c) potassium, d) magnesium, e) sodium, and f) chloride over the period of monitoring at each site (July 2013 – 2014).

Table 1 Mean ±SE (range) for selected solutes (in mg L^{-1}) during the study period July 2013 to June 2014

	Ca	**K**	**Mg**	**Na**	**Cl^-**	**SO_4^{2-}**
Detection Limit	**<0.05**	**<0.5**	**<0.1**	**<0.5**	**<0.5**	**<0.5**
South Lake Goollelal	67 ± 4 (52-87)	15 ± 2 (9-25)	36 ± 3 (23-46)	142 ± 15 (84-230)	163 ± 15 (114-263)	129 ± 7 (101-180)
Lake Goollelal	66 ± 4 (52-87)	15 ± 1 (9-21)	36 ± 3 (23-50)	144 ± 16 (84-242)	165 ± 16 (113-263)	128 ± 8 (101-180)
Beenyup Out (Site 1)	73 ± 10 (38-107)	10 ± 2 (5-19)	18 ± 2 (10-27)	90 ± 11 (49-134)	97 ± 11 (57-153)	39 ± 7 (22-84)
Beenyup In (Site 3)	33 ± 9 (6-89)	19 ± 3 (4-29)	73 ± 14 (12-123)	102 ± 8 (52-139)	103 ± 6 (61-142)	81 ± 8 (32-115)
Drain North (Site 4)	80 ± 9 (32-124)	4 ± 1 (1-12)	20 ± 2 (10-29)	90 ± 8 (46-139)	99 ± 8 (52-156)	34 ± 6 (13-72)
Drain Goollelal (Site 5)	55 ± 7 (38-70)	19 ± 2 (14-23)	19 ± 2 (13-23)	98 ± 10 (72-116)	123 ± 10 (96-140)	99 ± 24 (44-150)
Drain South (Site 6)	66 ± 5 (53-78)	7 ± 1 (3-11)	15 ± 1 (12-18)	58 ± 5 (42-73)	66 ± 6 (50-90)	31 ± 3 (21-39)
Drain Mid (Site 7)	61 ± 5 (52-69)	8 ± 1 (6-9)	18 ± 2 (13-22)	72 ± 13 (48-91)	77 ± 12 (56-96)	45 ± 8 (30-58)
South Culvert Inlet	73 ± 10 (37-106)	10 ± 2 (5-19)	19 ± 2 (10-27)	90 ± 11 (47-132)	105 ± 17 (56-218)	36 ± 6 (22-70)
South Culvert	68 ± 3 (41-122)	9 ± 1 (5-21)	20 ± 1 (11-31)	99 ± 4 (53-153)	109 ± 5 (68-178)	35 ± 3 (13-113)
South Lake Joondalup	93 ± 16 (42-197)	11 ± 2 (5-23)	24 ± 4 (11-43)	134 ± 26 (55-295)	139 ± 29 (69-306)	45 ± 24 (5-258)
Mid Lake Joondalup	57 ± 2 (40-83)	21 ± 1 (11-48)	51 ± 2 (30-100)	285 ± 17 (147-622)	329 ± 22 (211-730)	105 ± 6 (13-183)
North Lake Joondalup	54 ± 1 (41-66)	23 ± 2 (11-59)	51 ± 2 (31-88)	284 ± 16 (148-600)	325 ± 20 (207-693)	111 ± 4 (67-161)

Mean water hardness was calculated for each site across the year, see Figure 7. In the 2010-2011 monitoring period all sites were categorised "extremely hard" as defined by the ANZECC & ARMCANZ (2000) water quality guidelines (Newport, Lund & McCullough, 2011). Over the next two years, hardness dropped across all sites across each successive year. In 2013-14, hardness has risen back to 2011-12 levels ensuring most sites were extremely hard. The highest hardness was 627 mg $CaCO_3L^{-1}$ in 2010-11 monitoring period at Mid Lake Joondalup (Newport *et al.*, 2011). In contrast the highest alkalinity for 2013-14 was 382 mg $CaCO_3^{L-1}$ at $Been_{in}$. Comparison of Cl (a conservative ion) between the years suggest that the 2013-14 values for hardness are possibly due to higher evapoconcentration, but may also be a reflection of additional runoff from the catchment due to the higher rains coupled with evapoconcentration due to the long dry spell. Hardness of water is important for the influence it has on the toxicity of some metals, with higher hardness reducing toxicity.

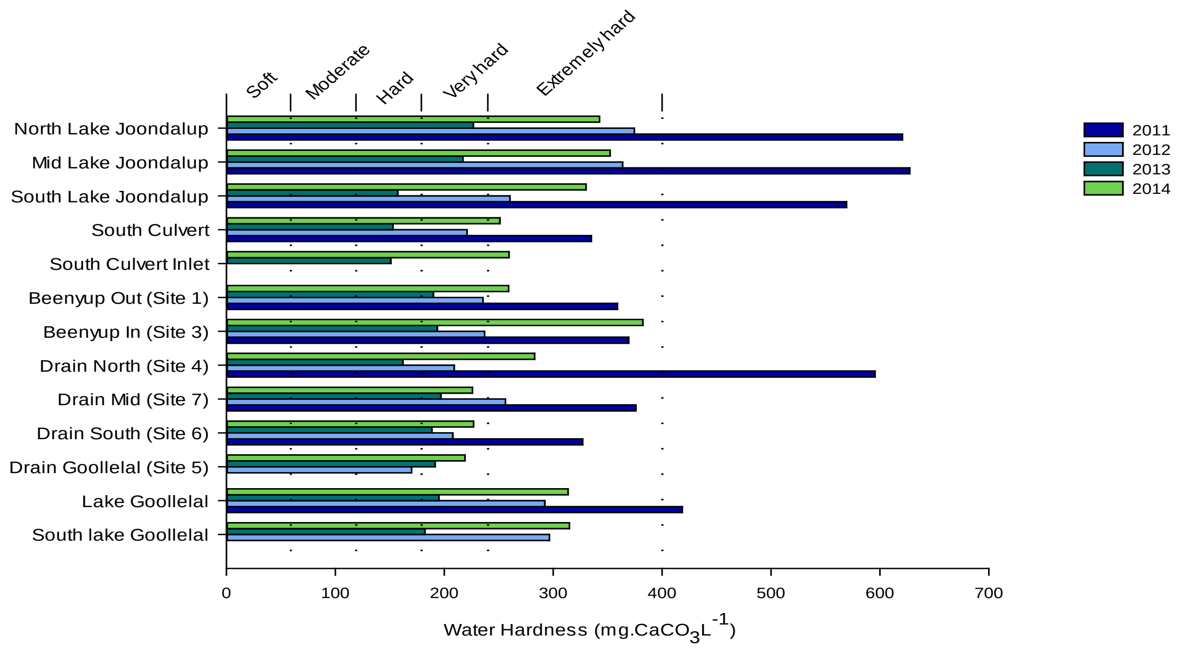
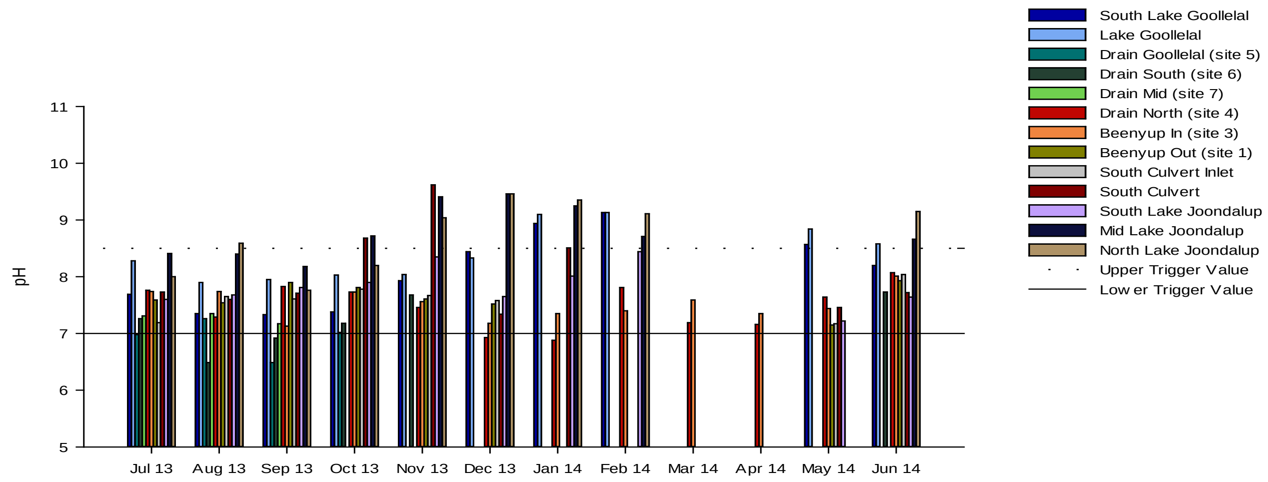


Figure 7. Calculated mean water hardness of each site for the consecutive years of monitoring, with ANZECC/ARMCANZ (2000) categories indicated.

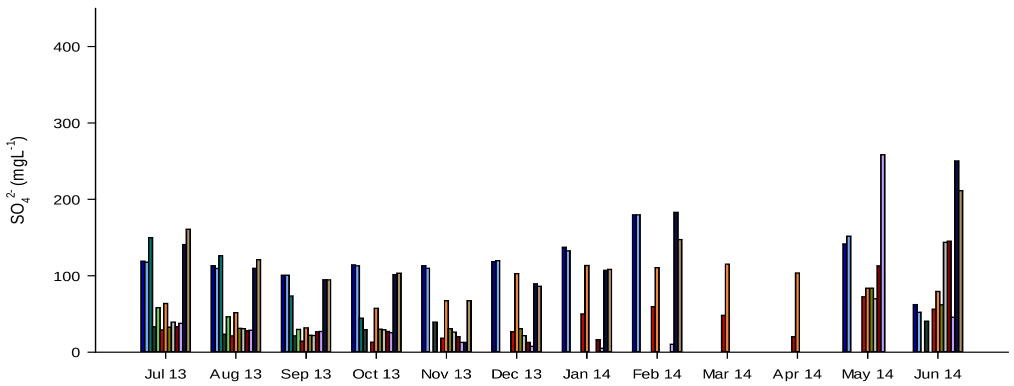
ANZECC/ARMCANZ (2000) water quality guidelines for the 95% protection of aquatic ecosystems recommend wetland pH levels between 7.0 and 8.5 (Figure 8). Beenyup inlet and outlet, $Drain_{mid}$, South Culvert Inlet and South Lake Joondalup all remained within the recommended levels for pH. $Drain_{north}$, $Drain_{Goollelal}$, and $Drain_{south}$ all had pH which dropped slightly below pH 7 reaching a minimum of 6.5. Lake Goollelal and Lake Goollelal south, South Culvert and Lake Joondalup (Mid and North) all had pH that on occasion exceed 8.5 peaking at 9.6 (South Culvert) (Figure 8 & Table 2). The alkaline pH seen in these latter sites is most likely due to the growth of algae or submerged aquatic plants, although slightly alkaline pH would be expected due to the presence of limestone (particularly in the northern sites).

Chloride to sulphate molar ratios is commonly used to indicate the presence of acid sulphate soils (ASS). Oxidation of metal sulphides (typically pyrites) into sulphuric acid, increasing sulphate relative to conservative chloride ions, which results in low molar ratios. A molar ratio of four or less is considered a good indicator of ASS contamination (Department of Local Government and Planning & Department of Natural Resources and Mines, 2002). Compared to 2011-2012 and 2012-2013, there were fewer sites and occasions which had signs of ASS contamination. The lowest ratio occurred at Been_{in} at 2.54, but South Lake Joondalup, $\text{Drain}_{\text{Goollelal}}$ and Lake Goollelal (and South) also had ratios under 4. At no site was the ratio always below 4, normally exceeding 4 in May. The site around $\text{Drain}_{\text{Goollelal}}$ is known to be surrounded by ASS identified by Newport et al. (2011). Sommer (2006) identified the presence of pyrite in the sediments of Lake Goollelal and demonstrated that on drying acidity was released. In 2011, Lake Goollelal dried to its lowest level and large areas of sediment were exposed to the air and this appears to have resulted in the production of acidity in that year and this is still evident in 2013-2014, although water pH was not significantly affected possibly due to high buffering capacity in Lake Goollelal.

a) pH



b) Sulphate (SO_4)



c) Chloride to Sulphate Molar Ratios (Cl^-:SO_4^{2-})

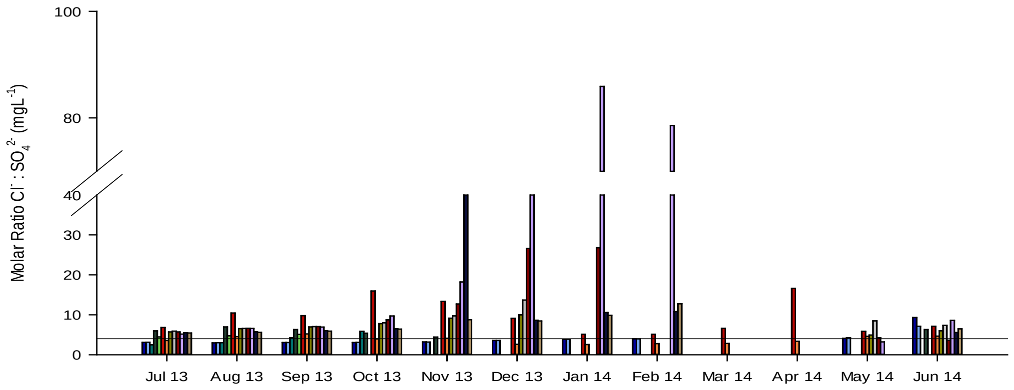


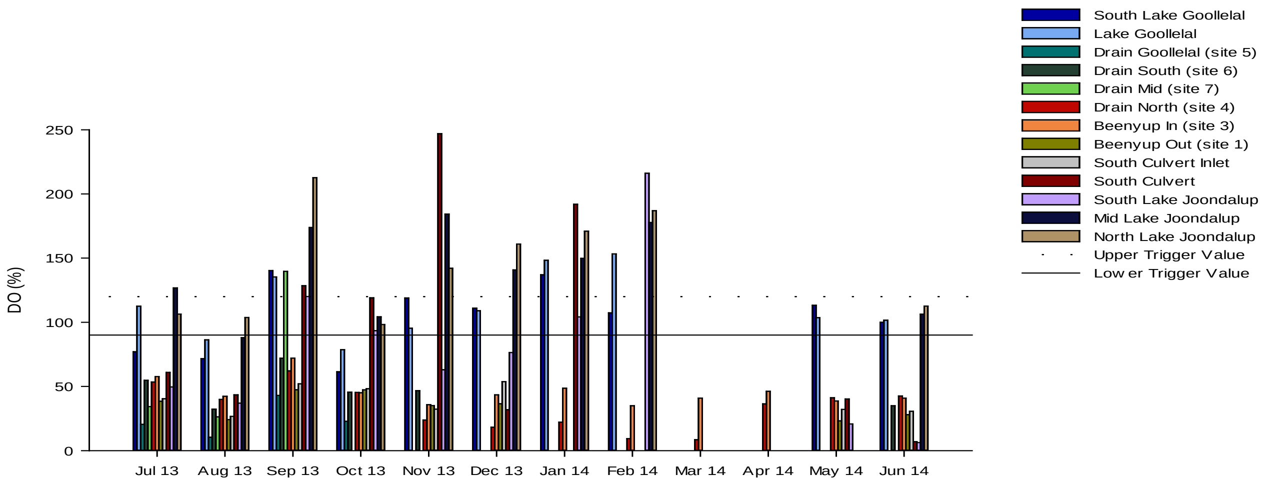
Figure 8. Changes in a) pH, b) sulphate and c) chloride to sulphate molar ratios over the period of monitoring at each site (July 2013 – June 2014) with ANZECC & ARMCANZ (2000) trigger values for the protection of aquatic ecosystems (95%).

The ANZECC and ARMCANZ (2000) trigger values for dissolved oxygen are set at above 90% and below 120%. During the period of this study all sites breached trigger values (Figure 5,

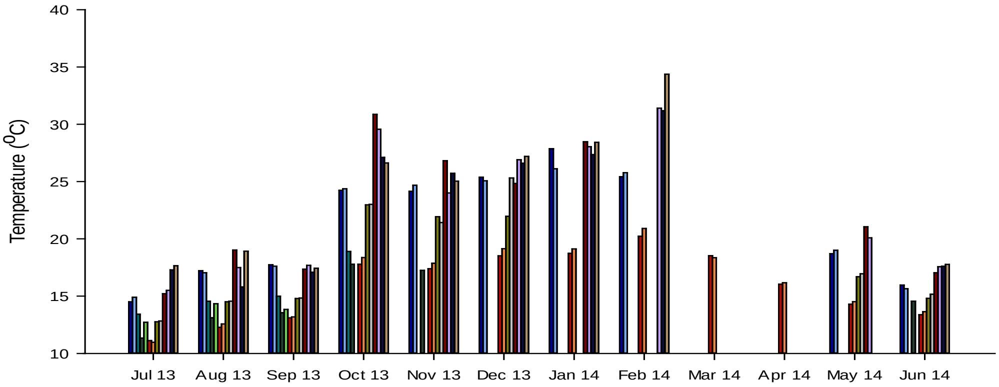
Table 2). The lakes Goollelal and Joondalup generally exceeded the upper trigger value; this is most likely due to algae or aquatic plants in the water producing oxygen through photosynthesis. The drain sites and Beenyup Swamp had dissolved oxygen concentrations that fell below the lower trigger value. This is most likely due to lack of algae or plants and the presence of oxygen demanding sediments. The lowest dissolved oxygen levels were generally too low to support most fish populations. ORP values are a measure of the oxidation and reduction potential within the water. The values were predominantly in the oxidation region reflecting dissolved oxygen levels, however particularly in the drain sites a number of records of ORP values of <100 mV were recorded which would encourage the denitrification of NOx (conversion to nitrogen gas). This is potentially beneficial but would suggest that in the sediment that ORP values would quickly decline to levels needed for sulphate reduction or even methane production. Sulphate reduction in the sediment is essentially the reverse of the acidification process and sulphate is converted back to sulphide and acidity (H^+) is reduced. Metals in the water also tend to be rendered insoluble by this process removing them from the water. This may explain why sulphate levels declined up the drain. Although this is useful in treating the ASS problems of the wetlands these conditions are not good for biota.

Water temperatures rose from June 2013 to February 2014 before declining. Temperatures in the drains (presumably due to shading) were noticeably lower than those in the Lakes.

a) Dissolved oxygen



b) Temperature



c) ORP

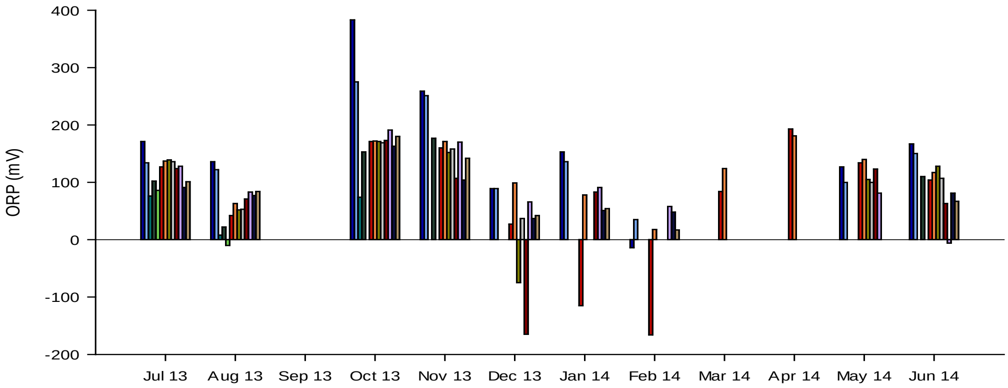


Figure 5. Changes in a) dissolved oxygen, b) temperature and c) ORP between July 2013 and June 2014 at each site with ANZECC & ARMCANZ (2000) trigger values.

Table 2. Mean ± standard error (range) for physicochemical variables over the study period (July 2013- June 2014)

	Temperature °C	Conductivity mS cm^{-1}	Dissolved Oxygen mg L^{-1}	Dissolved Oxygen %	pH	ORP mV
South Lake Goollelal	21.7 ± 1.6 (14.5-27.9)	1.23 ± 0.09 (0.92-1.77)	9.1 ± 0.8 (5-13.3)	104 ± 9 (61-140)	8.08 ± 0.23 (7.33-9.13)	153 ± 38 (-14-383)
Lake Goollelal	21.6 ± 1.5 (14.9-26.1)	1.22 ± 0.09 (0.93-1.75)	9.8 ± 0.7 (6.5-12.3)	114 ± 9 (79-153)	8.4 ± 0.16 (7.9-9.13)	137 ± 26 (35-275)
Beenyup Out (Site 1)	17.9 ± 1.6 (12.8-23)	0.81 ± 0.09 (0.53-1.17)	3.4 ± 0.3 (2.3-4.8)	36 ± 4 (23-47)	7.59 ± 0.09 (7.15-7.9)	91 ± 32 (-75-171)
Beenyup In (Site 3)	16.5 ± 1 (11-20.9)	0.88 ± 0.1 (0.03-1.17)	4.5 ± 0.4 (3.1-7.6)	45 ± 3 (35-72)	7.46 ± 0.07 (7.13-7.74)	112 ± 18 (18-193)
Drain North (Site 4)	16.2 ± 0.9 (11.1-20.2)	0.87 ± 0.09 (0.48-1.5)	3.4 ± 0.6 (0.8-6.5)	34 ± 5 (9-62)	7.45 ± 0.1 (6.88-7.84)	61 ± 35 (-166-181)
Drain Goollelal (Site 5)	15.5 ± 1.2 (13.4-18.9)	0.93 ± 0.08 (0.73-1.06)	2.4 ± 0.7 (1.1-4.3)	24 ± 7 (10-43)	6.94 ± 0.16 (6.49-7.26)	52 ± 16 (8-76)
Drain South (Site 6)	14.6 ± 1.2 (11.4-17.8)	0.65 ± 0.03 (0.58-0.73)	5.2 ± 0.8 (3.4-8)	50 ± 7 (32-72)	7.11 ± 0.2 (6.49-7.68)	100 ± 30 (22-177)
Drain Mid (Site 7)	13.6 ± 0.5 (12.7-14.3)	0.73 ± 0.07 (0.6-0.84)	6.6 ± 3.4 (2.7-13.4)	67 ± 37 (26-140)	7.28 ± 0.05 (7.17-7.35)	40 ± 28 (-10-86)
South Culvert Inlet	18.4 ± 1.8 (12.8-25.3)	0.81 ± 0.09 (0.53-1.17)	3.8 ± 0.4 (2.7-5.3)	41 ± 4 (27-54)	7.49 ± 0.09 (7.17-7.78)	107 ± 19 (37-169)
South Culvert	23 ± 2 (15.2-30.9)	0.8 ± 0.14 (0.07-1.31)	9.2 ± 2.2 (2.5-19.5)	108 ± 28 (32-247)	8.08 ± 0.28 (7.34-9.62)	77 ± 36 (-165-173)
South Lake Joondalup	23.4 ± 2 (15.5-31.4)	1.15 ± 0.2 (0.61-2.13)	7.1 ± 1.4 (1.9-15.5)	75 ± 20 (12-216)	7.85 ± 0.13 (7.22-8.44)	108 ± 15 (58-191)
Mid Lake Joondalup	23.5 ± 2.1 (15.8-31.2)	1.94 ± 0.32 (1.24-3.99)	11.9 ± 1 (7.9-16.3)	143 ± 12 (88-184)	8.82 ± 0.18 (8.18-9.46)	75 ± 16 (31-163)
North Lake Joondalup	24.5 ± 2.1 (17.4-34.4)	1.86 ± 0.32 (1.19-3.83)	12.2 ± 1.3 (7.8-20.2)	148 ± 15 (98-213)	8.69 ± 0.23 (7.76-9.46)	89 ± 19 (17-180)

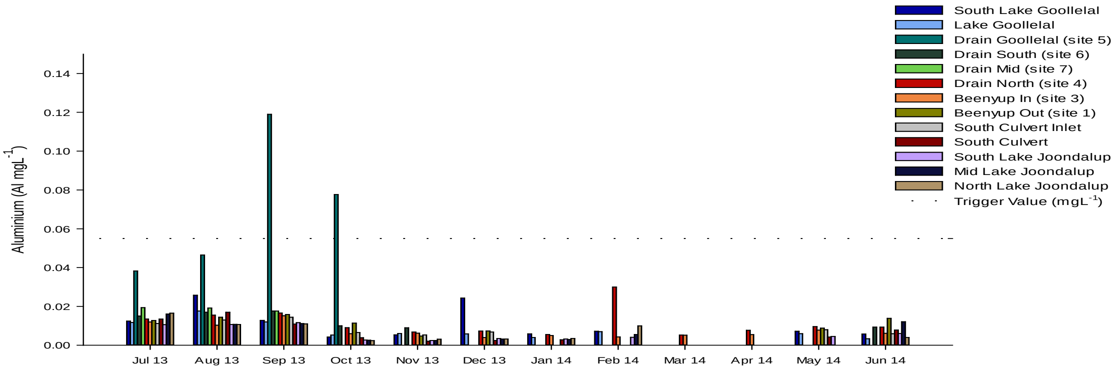
7.2 METALS AND METALLOIDS

This year we have utilised new analytical equipment (ICP-MS) which has enabled much lower detection limits for trace metals. This has highlighted that previous measurements of U and Se were not correct. Unfortunately, the previous instrument at levels close to detection of these elements would report noise as positive results. Therefore all U and Se values prior to this study can be considered suspect and should be ignored.

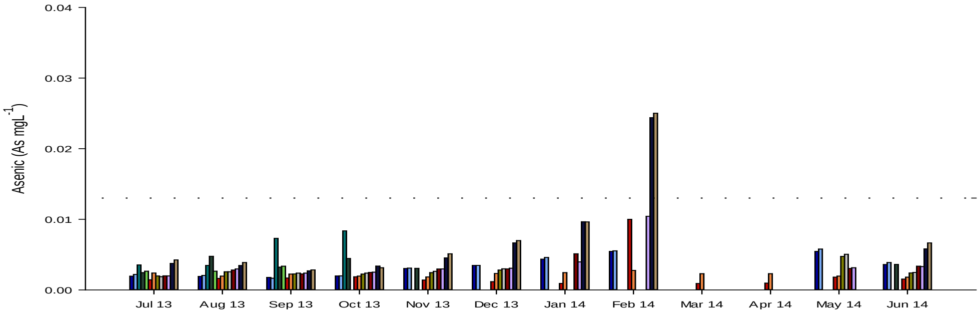
In accordance with the ANZECC and ARMCANZ (2000) guidelines, corrections to trigger values based on site specific water hardness were calculated for cadmium, nickel and zinc (see Table 3). Due to the higher average hardness this has increased the trigger levels, making it slightly harder for exceedances. During this year, Al, As, Hg, and Zn exceeded the trigger values on a couple of occasions (5 for Zn). This contrasts with previous years where more exceedances were recorded. This suggests that the harder waters and reduced metal concentrations are preventing exceedances this year. Exceedances of U and Se were noted in Table 3, however these may not have been real as analytical requirements for these particular samples resulted in detection limits above the trigger. Metal levels are all lower than in previous years indicating that water quality is improving. Iron levels were similar to slightly lower than 2012-13 suggesting that there may have been less release of Fe from pyrite upon oxidation.

Figure 6 shows the seasonal changes in select metal concentrations over the study period. Most of the metals shown have highest concentrations during the wetter months suggesting the source of the metal is from inflowing water. However, arsenic peaks in February, suggesting this may just have been an evapoconcentration effect.

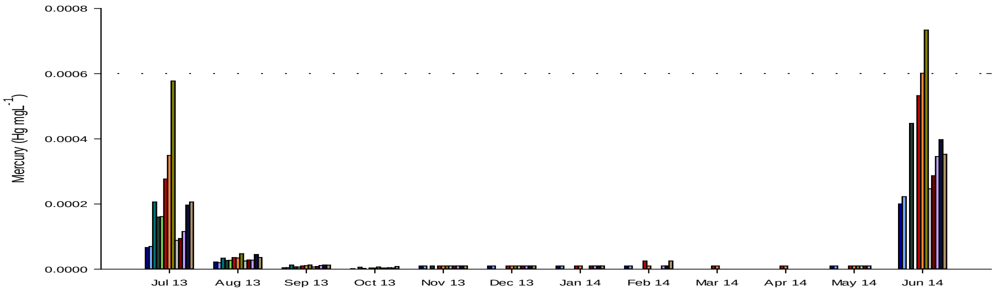
a) Aluminium



b) Arsenic



c) Mercury



d) Zinc

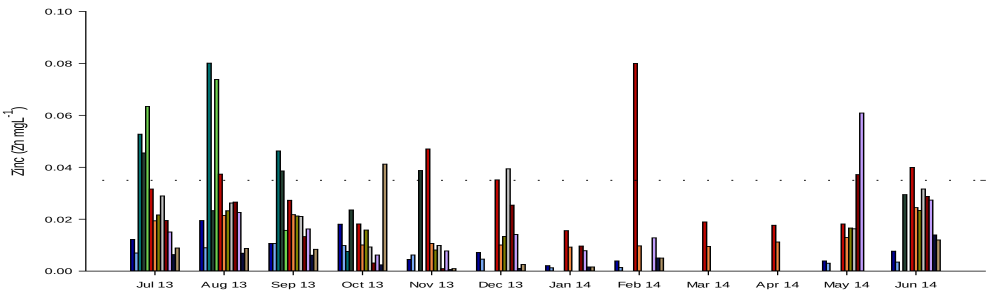


Figure 6. Occurrences of select metal and metalloid concentrations exceeding the ANZECC/ARMCANZ (2000) water quality trigger values for 95% protection of aquatic ecosystems between July 2013 and June 2014.

Interestingly the mercury spike seen in July's surface water monitoring was also observed in July's groundwater monitoring at the Goollelal North East site, where a concentration of

0.0015 mg L^{-1} was recorded. This spike in Hg appears to regularly occur each year (around June) but is common to all sites suggesting it is possibly due to inflow of winter rains rather than a localised source. Occasional spikes in other metals, even above guideline levels are extremely difficult to explain and are not of major concern unless they occur regularly or greatly exceed guideline values (to levels of acute toxicity).

Table 3 Exceedances of ANZECC/ARMCANZ (2000) water quality trigger values for 95% protection of aquatic ecosystems for metals and metalloids recorded in this study between July 2013 and June 2014

Metal/Metalloid ($mg\ L^{-1}$)	**ANZECC/ ARMCANZ (2000) Trigger Value**	**Detection Limit**	**Mean ± se (maximum value)**	**No. exceeding trigger value**
Aluminium (Al)	0.055	<0.0002	0.012 ± 0.001 (0.119)	2
Arsenic (As)	0.013 - 0.024*	<0.0001	0.0037 ± 0.0003 (0.025)	2
Calcium (Ca)	—	<0.05	65.2 ± 2.9 (197.2)	0
Cadmium (Cd)	0.0011 – 0.0016^{H}	<0.000001	0.0001 ± 0 (0.0006)	0
Cobalt (Co)	ID	<0.00001	0.0006 ± 0.0003 (0.03)	0
Chromium (Cr)	ID - 0.007^{H}	<0.0001	0.0013 ± 0 (0.0034)	0
Iron (Fe)	ID	<0.01	0.48 ± 0.05 (3.05)	0
Mercury (Hg)	0.0006 - ID*	<0.000001	0.0003 ± 0 (0.0007)	2
Potassium (K)	—	<0.5	13.23 ± 0.91 (59)	0
Magnesium (Mg)	—	<0.1	33.18 ± 2.6 (122.86)	0
Manganese (Mn)	1.9	<0.0001	0.02 ± 0 (0.09)	0
Sodium (Na)	—	<0.5	134.89 ± 9.68 (622.21)	0
Nickel (Ni)	0.0480 – 0.0779^{H}	>0.0001	0.001 ± 0.0001 (0.007)	0
Selenium (Se)	0.011	<0.00001	0.001 ± 0.0003 (0.025)	2#
Uranium (U)	0.005+	<0.000001	0.0024 ± 0.0005 (0.05)	1#
Zinc (Zn)	0.0350 – 0.06^{H}	<0.0001	0.019 ± 0.002 (0.08)	5

H Value corrected for hardness (increases trigger) as per ANZECC/ARMCANZ (2000), hardness calculated from mean values of collected data for Ca, Mg, Se, Fe, Al, Zn and Mn.
* Range for As III and V, Cr III and VI, and Hg inorganic and methyl.
** Detection limit was greater than the trigger value, therefore a conservative assessment assumes that all values potentially exceeded trigger values, however this may not have been the case.
ID Insufficient data to derive a reliable trigger value.
— No trigger provided in ANZECC/ARMCANZ (2000)
+ Low reliability, interim working level as prescribed in ANZECC/ARMCANZ (2000)
# Concentrations were BDL due to an increase in the limit of recording as a result of dilution.

Table 4 Mean ± standard error (range) for selected metals over the 12 month study period (July 2013 – June 2014). Figure marked < were below detection.

	Al	As	Cd	Co	Cr	Fe
	$\mu g\ L^{-1}$	$\mu g\ L^{-1}$	$\mu g\ L^{-1}$	$\mu g\ L^{-1}$	$\mu g\ L^{-1}$	$mg\ L^{-1}$
Detection Limit	**<0.5**	**<0.01**	**<0.01**	**<0.02**	**<0.03**	**<0.05**
Trigger Value	**55 $\mu g\ L^{-1}$**	**13-24 $\mu g\ L^{-1}$**	**0.3-1.6^{H} $\mu g\ L^{-1}$**	**ID**	**ID-6.6^{H}* $\mu g\ L^{-1}$**	**ID**
South Lake Goollelal	11.08 ± 2.49 (4.26-25.73)	3.29 ± 0.45 (1.78-5.45)	0.03 ± 0.01 (<0.01-0.06)	0.12 ± 0.01 (0.09-0.16)	1.09 ± 0.15 (0.78-1.96)	0.24 ± 0.14 (0-1.5)
Lake Goollelal	7.87 ± 1.42 (3.32-17.61)	3.42 ± 0.47 (1.65-5.78)	0.03 ± 0.01 (0.01-0.07)	0.11 ± 0.01 (0.08-0.14)	0.87 ± 0.03 (0.77-1.03)	85.3 ± 15.4 (20.9-168.4)
Beenyup Out (Site 1)	11.15 ± 1.36 (4.71-15.86)	2.68 ± 0.31 (1.98-4.74)	0.16 ± 0.08 (0.01-0.56)	0.07 ± 0.01 (0.05-0.1)	1.4 ± 0.05 (1.1-1.58)	589.0 ± 76.4 (349.6-962.4)
Beenyup In (Site 3)	7.29 ± 1 (3.97-15.21)	2.18 ± 0.08 (1.8-2.76)	0.06 ± 0.01 (0.02-0.17)	0.06 ± 0 (0.05-0.09)	1.13 ± 0.06 (0.87-1.44)	278.4 ± 44.41 (99.7-559.6)
Drain North (Site 4)	11.34 ± 2.01 (5.27-30)	2.1 ± 0.72 (0.89-10)	0.12 ± 0.04 (0.01-0.5)	0.49 ± 0.41 (0.05-5)	1.67 ± 0.1 (1.2-2.5)	789.8 ± 106.2 (241.1-1700)
Drain Goollelal (Site 5)	70.36 ± 18.29 (38.3-119.01)	5.66 ± 1.27 (3.45-8.36)	0.04 ± 0 (0.04-0.05)	0.69 ± 0.14 (0.44-0.97)	2.84 ± 0.29 (2.14-3.41)	2159.0 ± 449.3 (1293.4-3050.8)
Drain South (Site 6)	13 ± 1.64 (8.96-17.68)	3.59 ± 0.36 (2.44-4.76)	0.04 ± 0.01 (0.01-0.05)	0.06 ± 0.01 (0.04-0.08)	1.26 ± 0.03 (1.16-1.39)	452.1 ± 41.4 (351.4-573.9)
Drain Mid (Site 7)	18.71 ± 0.55 (17.61-19.34)	2.88 ± 0.24 (2.65-3.35)	0.04 ± 0 (0.04-0.05)	0.09 ± 0.01 (0.08-0.11)	1.85 ± 0.17 (1.52-2.03)	354.2 ± 58.7 (245.8-447.4)
South Culvert Inlet	8.91 ± 1.23 (5.34-14.42)	2.79 ± 0.34 (1.87-5.05)	0.04 ± 0 (0.01-0.05)	0.08 ± 0.01 (0.05-0.11)	1.44 ± 0.06 (1.09-1.62)	635.3 ± 62.4 (398.2-855.9)
South Culvert	7.18 ± 0.61 (2.06-17.01)	3 ± 0.1 (2-5.12)	0.03 ± 0 (0.01-0.04)	0.1 ± 0.01 (0.04-0.21)	1.4 ± 0.03 (0.94-1.85)	538.8 ± 30.4 (70.4-908.9)
South Lake Joondalup	5.94 ± 1.15 (2.42-11.62)	3.67 ± 0.77 (1.98-10.43)	0.08 ± 0.05 (0.01-0.49)	0.1 ± 0.02 (0.05-0.23)	1.4 ± 0.06 (1.13-1.77)	590.1 ± 53.5 (388.2-961.1)
Mid Lake Joondalup	7.43 ± 0.57 (2.46-16.12)	7.14 ± 0.76 (2.7-24.39)	0.05 ± 0.01 (<0.01-0.22)	0.09 ± 0.01 (0.03-0.29)	0.97 ± 0.03 (0.74-1.71)	74.6 ± 5.1 (17.7-125.6)
North Lake Joondalup	7.18 ± 0.56 (2.4-16.54)	7.5 ± 0.77 (2.84-25)	0.08 ± 0.02 (0.01-0.5)	3.39 ± 1.11 (0.03-30)	1.04 ± 0.06 (0.74-2.5)	58.9 ± 4.4 (15.5-112.3)

Table 5 cont.

	Hg µg L^{-1}	Mn µg L^{-1}	Ni µg L^{-1}	Se µg L^{-1}	U µg L^{-1}	Zn µg L^{-1}
Detection Limit	**<0.02**	**<0.001**	**<0.02**	**<0.05**	**<0.02**	**<0.05**
Trigger Value	**0.6 µg L^{-1}-ID***	**1.9 mg L^{-1}**	**18.1-78^{H} µg L^{-1}**	**11 µg L^{-1}**	**5^{+} µg L^{-1}**	**13.2-56.7^{H} µg L^{-1}**
South Lake Goollelal	0.03 ± 0.02 (<0.02-0.2)	6.18 ± 1.09 (1.22-10.67)	0.87 ± 0.15 (0.4-2.03)	0.3 ± 0.11 (<0.05-1.29)	0.02 ± 0.01 (<0.02-0.06)	8.95 ± 1.91 (2.09-19.45)
Lake Goollelal	0.04 ± 0.02 (<0.02-0.22)	5.87 ± 1.31 (0.71-12.06)	0.58 ± 0.05 (0.39-0.8)	0.29 ± 0.13 (0.09-1.49)	0.02 ± 0.01 (<0.02-0.07)	5.63 ± 1.09 (1.28-10.68)
Beenyup Out (Site 1)	0.18 ± 0.11 (<0.02-0.73)	19.49 ± 5.44 (5.71-45.24)	0.62 ± 0.05 (0.43-0.81)	0.35 ± 0.12 (0.17-1.16)	0.01 ± 0 (<0.02-0.02)	17.91 ± 1.92 (8.11-23.35)
Beenyup In (Site 3)	0.09 ± 0.05 (<0.02-0.6)	17.86 ± 3.3 (4.42-48.78)	0.54 ± 0.05 (0.35-0.97)	0.26 ± 0.08 (0.1-1.17)	0.01 ± 0 (<0.02-0.01)	14.19 ± 1.67 (9.22-24.45)
Drain North (Site 4)	0.08 ± 0.05 (<0.02-0.53)	36.75 ± 7.61 (6.23-87.09)	0.8 ± 0.16 (0.33-2.5)	2.32 ± 2.06 (0.09-25)	4.18 ± 4.17 (<0.02-50)	32.23 ± 5.28 (15.55-80)
Drain Goollelal (Site 5)	0.06 ± 0.05 (<0.02-0.21)	45.03 ± 15.15 (17.61-85.62)	1.22 ± 0.17 (0.94-1.71)	0.42 ± 0.04 (0.34-0.53)	0.03 ± 0.01 (<0.02-0.04)	46.68 ± 14.95 (7.58-80.11)
Drain South (Site 6)	0.11 ± 0.07 (<0.02-0.45)	8.26 ± 0.85 (4.89-10.57)	0.57 ± 0.09 (0.32-0.91)	0.37 ± 0.13 (0.13-1.03)	0.03 ± 0 (<0.02-0.04)	33.19 ± 3.73 (23.29-45.53)
Drain Mid (Site 7)	0.06 ± 0.05 (<0.02-0.16)	13.63 ± 4.38 (6.55-21.63)	0.69 ± 0.05 (0.61-0.78)	0.32 ± 0.01 (0.3-0.33)	0.05 ± 0.01 (0.04-0.06)	51 ± 17.9 (15.7-73.83)
South Culvert Inlet	0.05 ± 0.03 (<0.02-0.25)	24.4 ± 8.54 (6.61-76.24)	0.62 ± 0.06 (0.44-0.9)	0.34 ± 0.13 (0.1-1.23)	0.01 ± 0 (<0.02-0.01)	22.83 ± 3.78 (9.26-39.42)
South Culvert	0.05 ± 0.01 (<0.02-0.29)	13.66 ± 1.72 (1.48-40.48)	0.72 ± 0.04 (0.4-1.55)	0.33 ± 0.03 (0.15-1.15)	0.02 ± 0 (<0.02-0.09)	18.25 ± 1.37 (0.92-37.17)
South Lake Joondalup	0.06 ± 0.03 (<0.02-0.35)	19.38 ± 7.18 (4.94-77.46)	1.32 ± 0.64 (0.4-6.99)	0.3 ± 0.09 (0.11-1.11)	0.02 ± 0.01 (<0.02-0.09)	19.08 ± 5.1 (6.16-60.88)
Mid Lake Joondalup	0.08 ± 0.01 (<0.02-0.4)	1.72 ± 0.14 (0.48-4.06)	0.7 ± 0.06 (0.36-2.04)	0.6 ± 0.11 (0.12-3.33)	0.08 ± 0.01 (<0.02-0.25)	4.88 ± 0.46 (0.6-13.92)
North Lake Joondalup	0.07 ± 0.01 (<0.02-0.35)	2.86 ± 0.34 (0.57-10)	1.3 ± 0.24 (0.4-7)	3.3 ± 0.91 (0.13-25)	0.6 ± 0.18 (<0.02-5)	9.91 ± 1.37 (0.94-41.18)

7.3 NUTRIENTS

Dissolved organic C (DOC) concentrations were typical of Swan Coastal Plain wetlands and tended to increase slightly northwards (Figure 7), as seen in previous years. The only exception is the high concentrations seen in the Lake Goollelal sites. The lack of a surface flow (as it is closed) between the lake and the northern drain can probably explain why the lake defies the northwards trend. Concentrations of DOC peaked in the winter months.

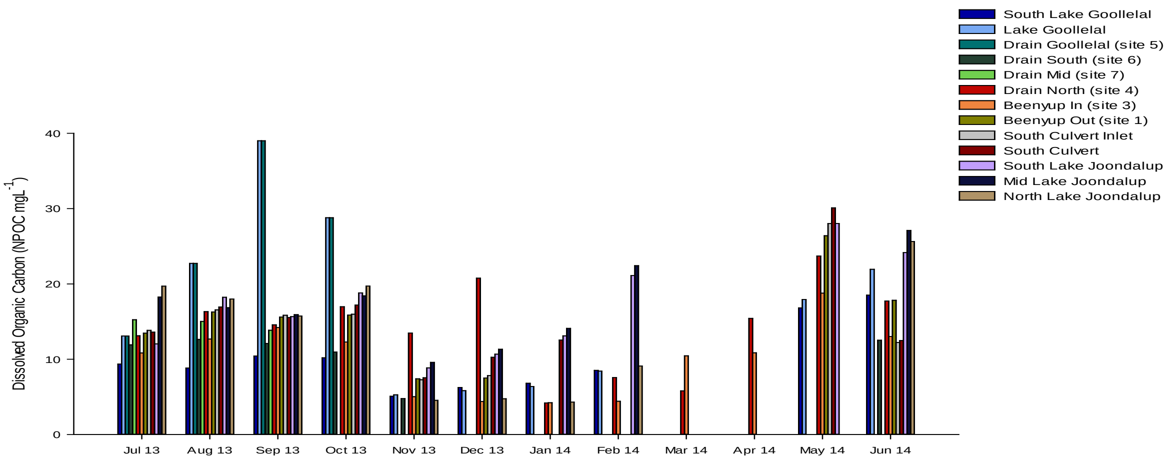


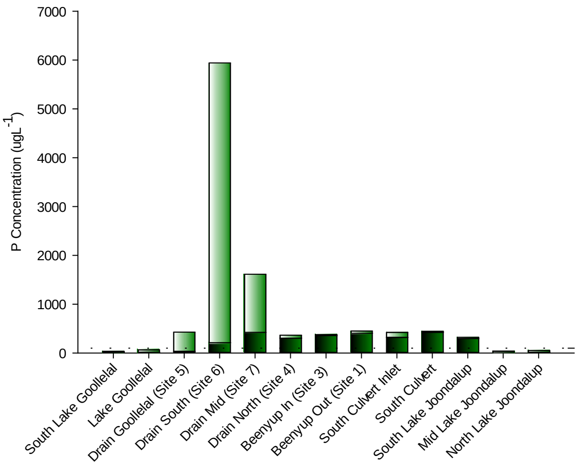
Figure 7. Dissolved organic C concentrations across the sites for the study period (July 2013 to June 2014)

Total phosphorus concentrations (Figure 8) exceeded the 60 µg L^{-1} ANZECC & ARMCANZ (2000) water quality guidelines for the 95% protection of aquatic ecosystems at all sites, except in Lake Goollelal, South Lake Goollelal (on a few occasions) and Lake Joondalup (Mid and North). Another important feature of phosphorus in the Yellagonga system was the high proportion of FRP (often exceeding 50% of the total). This is suggestive of significant groundwater inputs from catchments low in limestone (which would normally bind the FRP). The highest Total P recorded was 6,000 µg L^{-1} recorded in November 2013 at $Drain_{North}$ as it was in previous years. This extreme value was dominated by organic P which is suggestive of algal blooms; this is supported by a similarly high value for Total N.

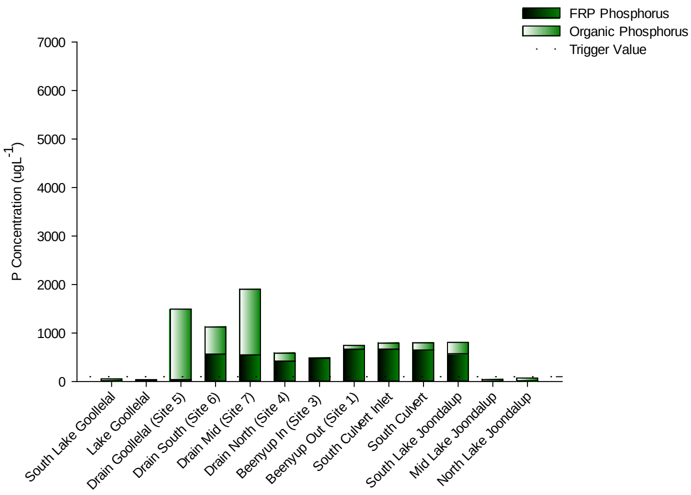
The results show that Beenyup Swamp continues to export P as recorded by Lund et al. (2011a). Particularly interesting are the slightly higher concentrations of P recorded in the

South Culvert inlet and South Culvert compared to Beenyup$_{out}$ suggesting a source of probably groundwater derived P along this short section of drain. Phosphorus then declines from South Joondalup to Mid Lake Joondalup, suggesting that the vegetation between the two is taking up the nutrients.

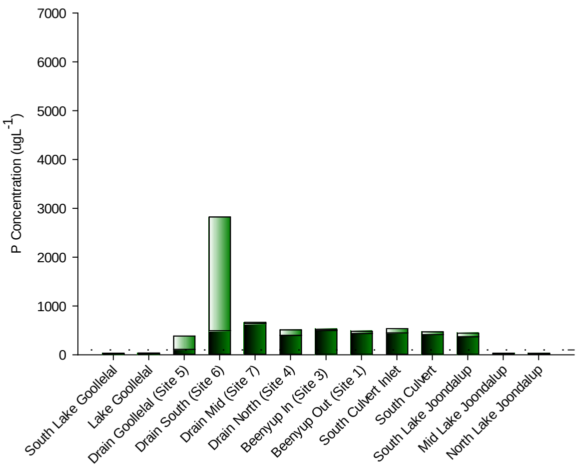
July 2013



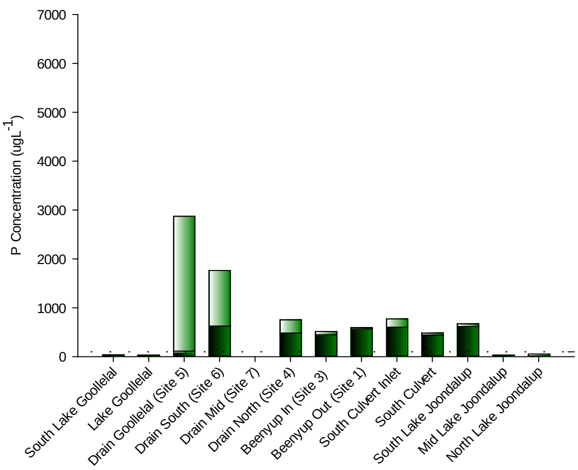
August 2013



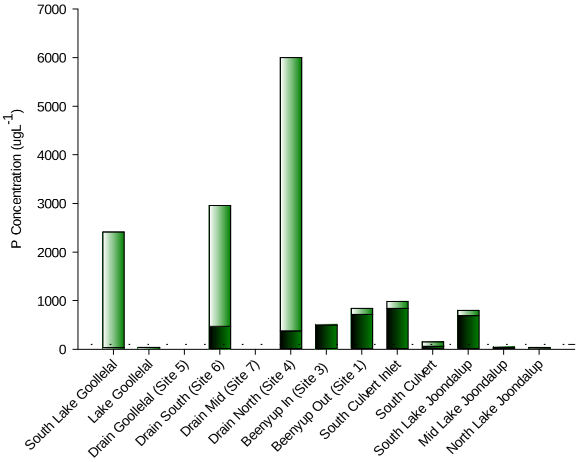
September 2013



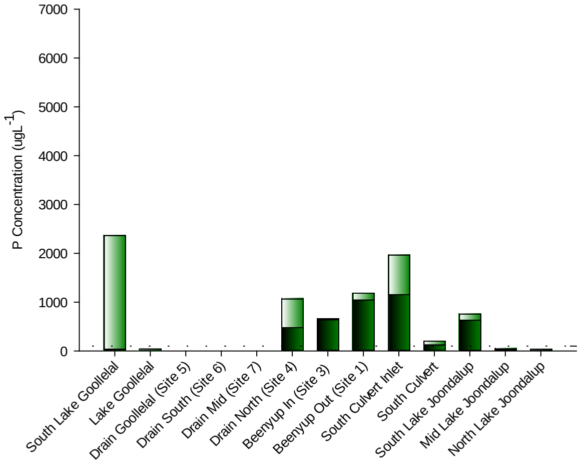
October 2013



November 2013



December 2013



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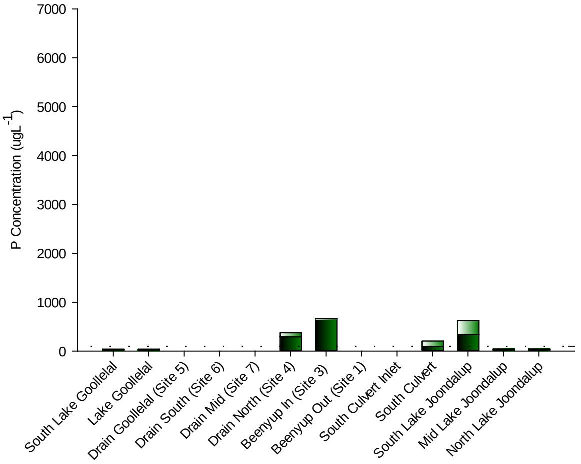

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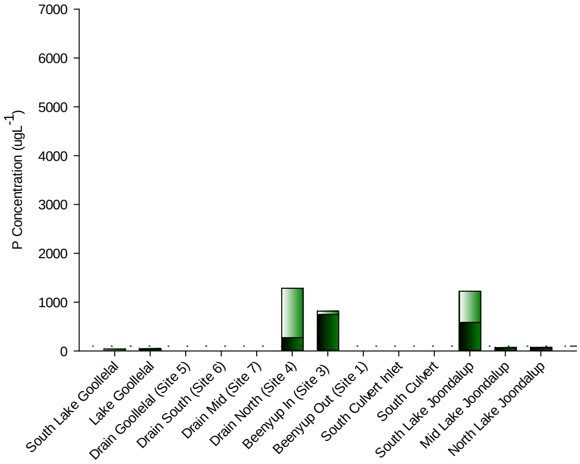

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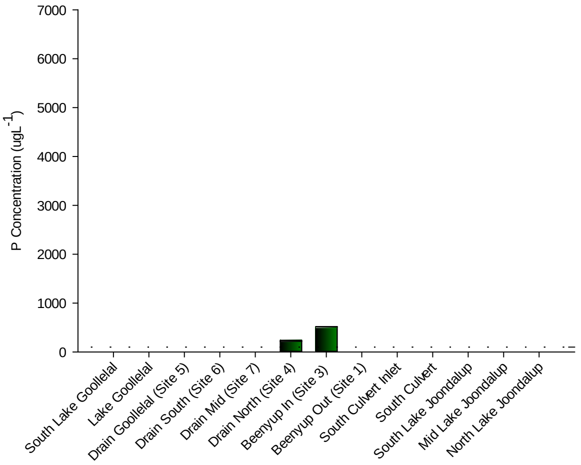

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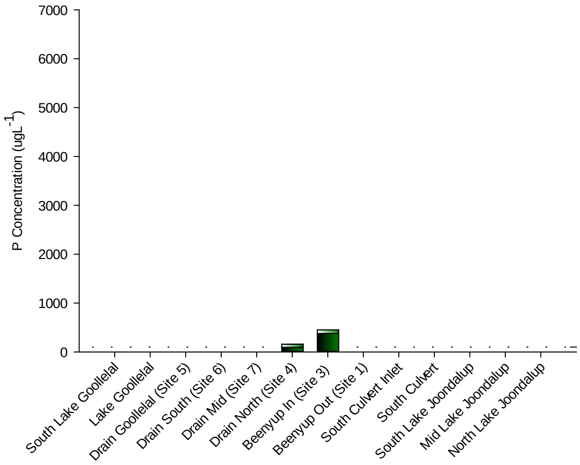

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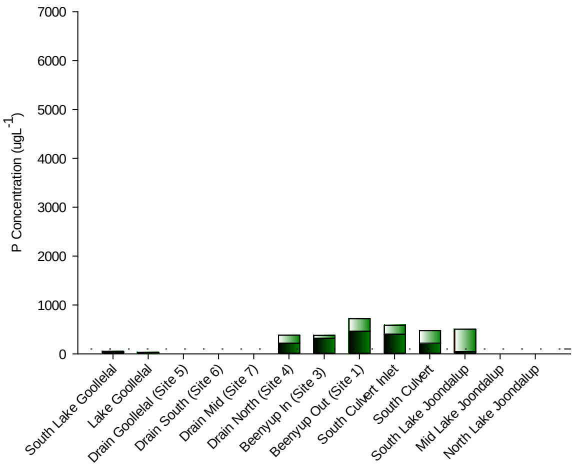

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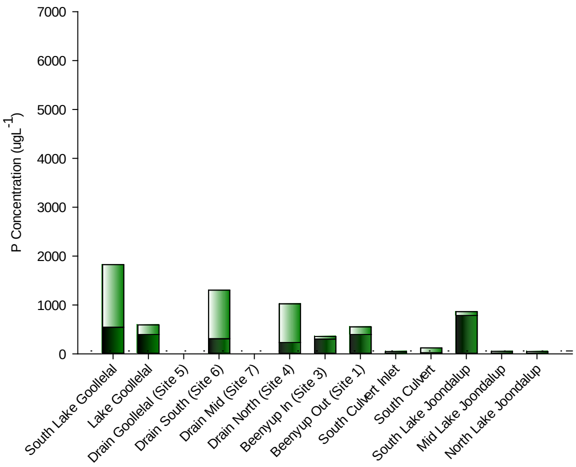
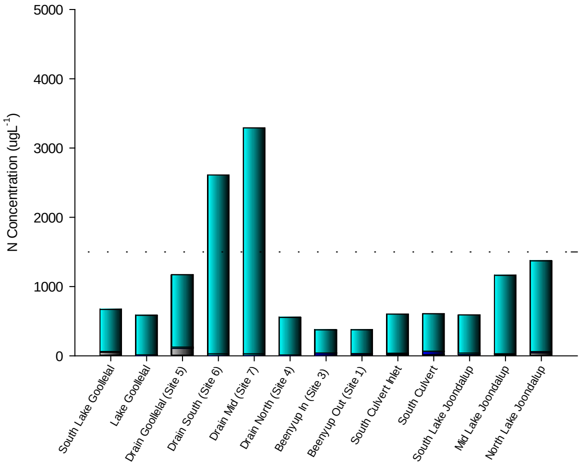


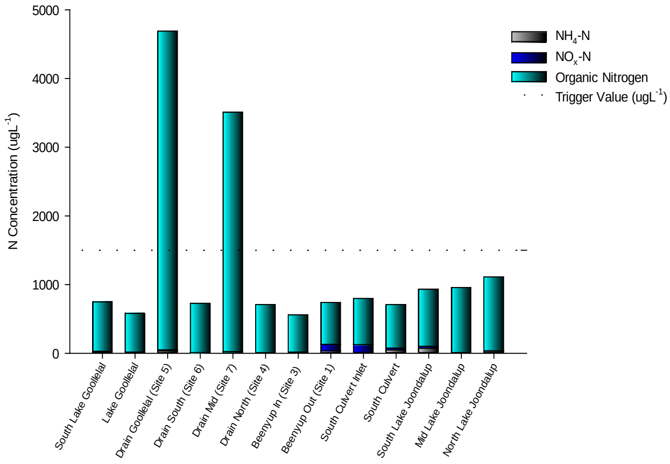
Figure 8. Breakdown of total phosphorus into chemical fractions (organic P and FRP) recorded in surface waters at each site between July 2013 and June 2014 with the ANZECC & ARMANZ (2000) trigger value for total phosphorus shown.

Total N concentrations occasionally exceeded the recommended ANZECC & ARMCANZ guidelines of 1500 µg L^{-1} (Figure 9 & Table 5). The majority of the excessive N was in the form of organic N and is most likely associated with algae in the water. Algal blooms in Lakes Joondalup and Goollelal probably account for the high concentrations seen in the lakes. The highest concentration recorded was 4,690 µg L^{-1} for $Drain_{Goollelal}$ in August 2013. High concentrations of ammonia and to a less extent NOx were measured from $Been_{out}$ to South Lake Joondalup, and in Lake Goollelal and South Lake Goollelal. As ammonia and NOx are soluble they might be sourced from groundwater. Over time through nitrification this ammonia will be converted to NOx or taken up by algae. As recorded in Lund et al (2011a) there was continued evidence of nitrogen export from Beenyup Swamp with on most occasions outputs higher than inputs.

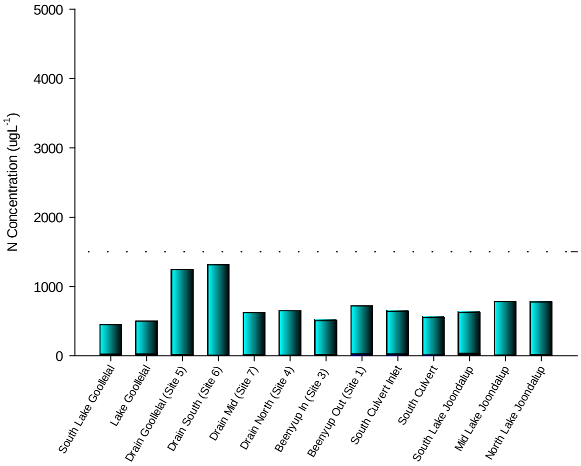
July 2013



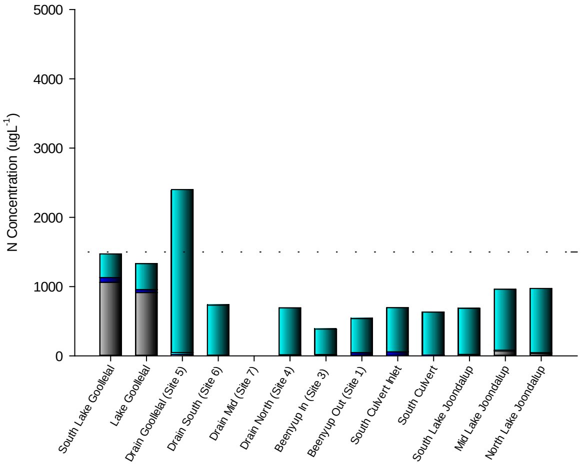
August 2013



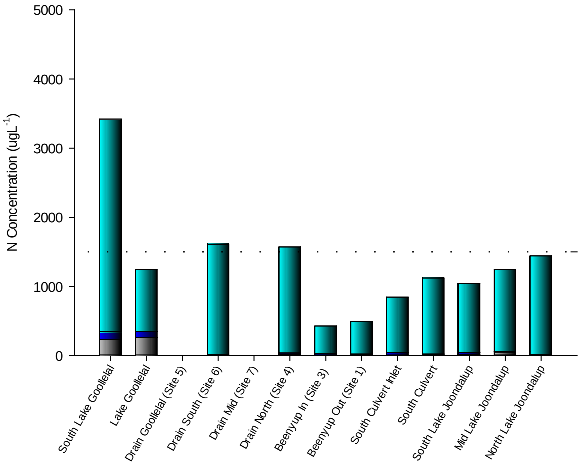
September 2013



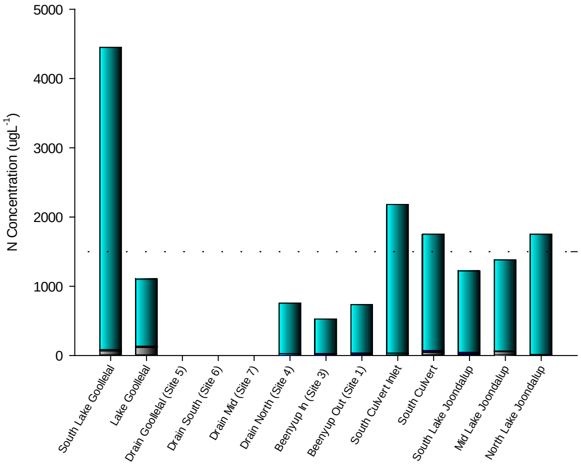
October 2013



November 2013



December 2013



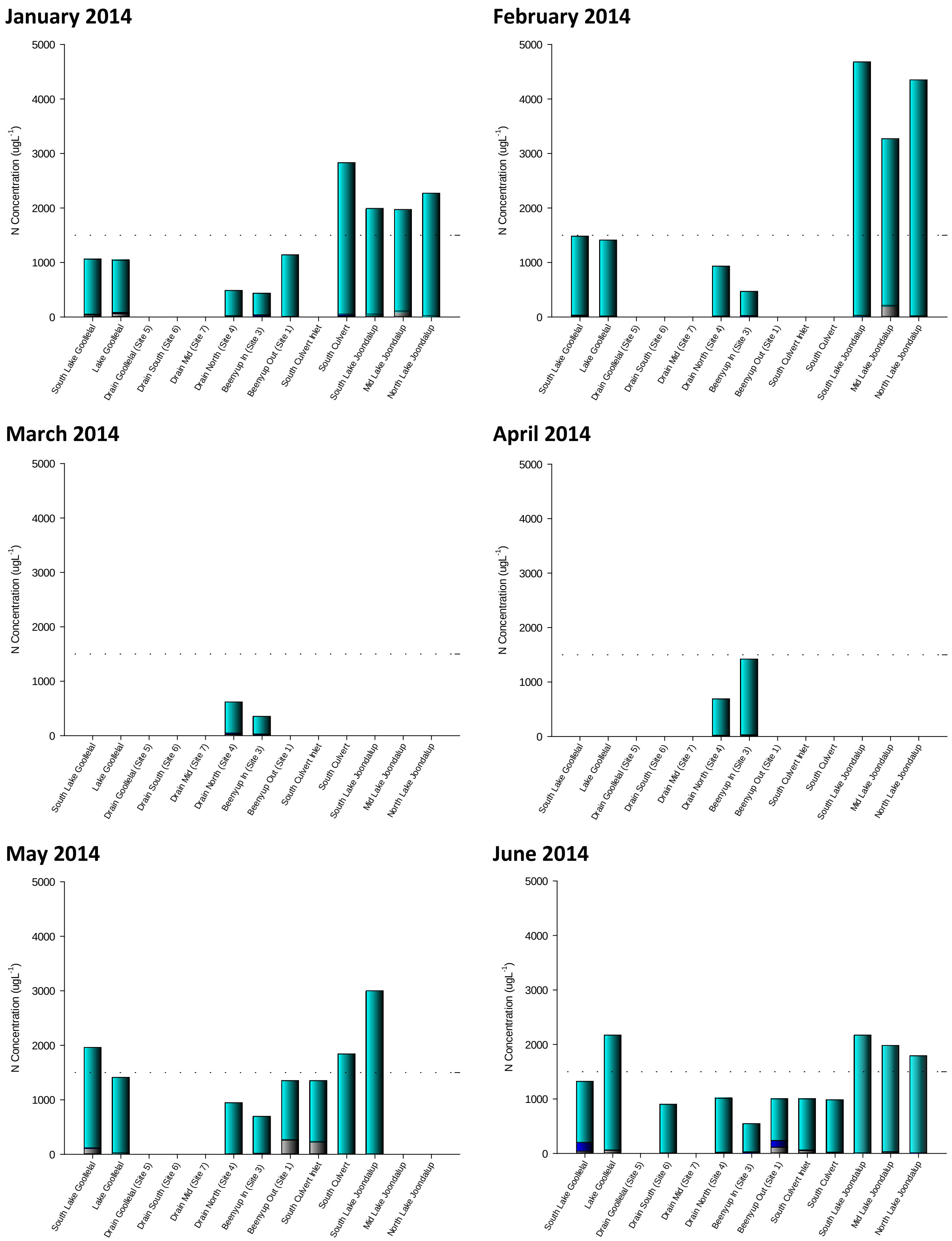


Figure 9. Breakdown of total nitrogen into chemical fractions (organic nitrogen, oxides of nitrogen and ammonia/ammonium) recorded in surface waters at each site between July 2013 and June 2014 with the ANZECC & ARMANZ (2000) trigger value for total nitrogen.

Table 5 Mean ± s.e. (range) for nutrients in water recorded at each study site over the course of the monitoring period (July 2013-June 2014)

	NH_4-N	**NOx-N**	**TN**	**FRP-P**	**TP**	**DOC**
	µg.L^{-1}	**µg.L^{-1}**	**µg.L^{-1}**	**µg.L^{-1}**	**µg.L^{-1}**	**mg.L^{-1}**
Detection Limit	**<3**	**<2**	**<50**	**<2**	**<20**	**<0.5**
South Lake Goollelal	177 ± 113 (5-1060)	28 ± 12 (4-110)	1717 ± 510 (447-4450)	21 ± 3 (12-33)	558 ± 345 (26-2410)	9.1 ± 1.1 (5.1-16.8)
Lake Goollelal	155 ± 99 (<3-911)	22 ± 9 (<2-88)	972 ± 130 (498-1410)	22 ± 3 (13-33)	35 ± 3 (25-59)	9.1 ± 1.3 (5.3-17.9)
Beenyup Out (Site 1)	44 ± 36 (<3-260)	33 ± 11 (4-92)	729 ± 100 (514-1170)	610 ± 84 (399-1040)	712 ± 95 (446-1180)	14.6 ± 2.4 (7.4-26.4)
Beenyup In (Site 3)	3 ± 1 (<3-16)	22 ± 3 (14-37)	446 ± 24 (351-556)	498 ± 40 (313-742)	531 ± 39 (374-812)	9.8 ± 1.4 (4.2-18.8)
Drain North (Site 4)	5 ± 2 (<3-23)	12 ± 2 (<2-24)	772 ± 108 (483-1570)	319 ± 37 (90-480)	1061 ± 505 (153-6000)	13.8 ± 1.8 (4.2-23.7)
Drain Goollelal (Site 5)	38 ± 24 (<3-107)	20 ± 5 (15-35)	2375 ± 822 (1170-4690)	69 ± 21 (30-107)	1291 ± 586 (380-2870)	25.9 ± 5.4 (13.1-39)
Drain South (Site 6)	<3 (<3)	11 ± 4 (2-25)	1397 ± 348 (723-2610)	470 ± 71 (206-622)	2920 ± 828 (1120-5940)	10.5 ± 1.5 (4.8-12.6)
Drain Mid (Site 7)	3 ± 2 (<3-6)	17 ± 3 (12-20)	2469 ± 928 (616-3500)	532 ± 63 (417-633)	1390 ± 375 (659-1900)	14.7 ± 0.4 (13.9-15.2)
South Culvert Inlet	36 ± 31 (<3-221)	42 ± 15 (11-124)	959 ± 247 (600-2180)	629 ± 110 (315-1150)	860 ± 196 (417-1960)	15 ± 2.6 (7.3-28)
South Culvert	16 ± 2 (<3-46)	21 ± 2 (<2-49)	1170 ± 121 (549-2830)	299 ± 26 (58-647)	399 ± 27 (147-796)	15.5 ± 0.8 (7.5-30.1)
South Lake Joondalup	19 ± 7 (<3-71)	19 ± 3 (<2-28)	1469 ± 486 (588-4680)	456 ± 71 (40-685)	679 ± 88 (315-1220)	16.3 ± 2 (8.9-28)
Mid Lake Joondalup	65 ± 9 (<3-189)	11 ± 1 (5-22)	1507 ± 124 (780-3270)	23 ± 3 (6-57)	38 ± 2 (26-59)	15.5 ± 0.6 (9.6-22.4)
North Lake Joondalup	15 ± 2 (4-36)	11 ± 1 (6-21)	1754 ± 144 (773-4350)	23 ± 2 (9-51)	44 ± 2 (24-68)	12 ± 0.9 (4.3-19.7)

8 CONCLUSION

In conclusion, this monitoring study found that the issues associated with acid sulphate soils around site $Drain_{Goollelal}$ have largely ended. This can be seen in improved $Cl:SO_4$ ratios, higher pH and reduced metal concentrations. There are still some exceedances of ANZECC & ARMCANZ (2000) national water quality guidelines for the protection of aquatic ecosystems (95%) of metal concentrations, particularly for Al, As, Hg, and Zn. However, these exceedances were for a very few occasions. Physical parameters, nutrients and chlorophyll *a* also exceeded guideline levels throughout the flow path of Yellagonga waters on occasion.

Low water levels in Lake Joondalup appear to have favoured the growth of rushes between South Lake Joondalup and Mid Lake Joondalup, closing off former clear flow pathways between the two areas. As a result, the rushes appear to be acting in a similar manner to a constructed wetland effectively stripping the high concentrations of Total P that occurred at the South Culvert Inlet preventing them substantially contaminating the main part of the lake, which currently shows low nutrient concentrations. This is a very positive development and if sustained reduces the necessity of the constructed wetland recommended in previous reports. This year, we also found that there was an additional source of P (probably groundwater) between the outlet of Beenyup Swamp and the inlet to lake south of Ocean Reef Rd which would potentially undermine any constructed wetlands effectiveness. The on-going issues with water quality within the system highlight the importance of on-going monitoring.

9 RECOMMENDATIONS

1. It is recommended that the monitoring program continue for at least another year as the impact of acid sulphate soils around $Drain_{Goollelal}$ appears to have greatly reduced. The extended dry period experienced in 2013/14 means there might be a reoccurrence of acidity release in 2014/15. It is now possible given that 4 years of data have been collected to reduce to sampling frequency - every two months is recommended.
2. It is recommended that Lake Goollelal be prevented from drying out, even to the level it reached in 2011. This may require artificial maintenance as used at Lake Jandabup. This is to prevent potential acidification from the acid sulphate soils in the lake sediment.
3. Although the source of acid sulphate soils has been identified and mapped, an ASS Management Plan is still recommended. Although the system has largely recovered from the acidification event that took place in 2011/2012 at site $Drain_{Goollelal}$, another acidification event is still possible due to the confirmed presence of ASS and PASS. As part of the management plan, control options need to be investigated to mitigate any on-going or future contamination of the Yellagonga wetlands.
4. It appears that the thick band of rushes growing between Mid and South Lake Joondalup is responsible for removing the high nutrient concentrations coming northwards through the park. At present, these rushes are preventing on-going degradation of northern Lake Joondalup. It is recommended that this area be investigated to confirm that it is responsible for the nutrient removal and to understand why it has become effective only in the last few years. Understanding the mechanisms of nutrient removal will enable management of this area to ensure that it continues to perform – reducing the necessity of nutrient controls further south such as a constructed wetland. The flow of nutrients continues northwards and it remains the largest potential source of nutrients into Lake Joondalup. The rushes have currently reduced the necessity for a constructed wetland; however it would be advisable to enhance nutrient stripping capacity of Lake Joondalup prior to Ocean Reef Rd. A potential low-cost approach would be to build a bund to deflect water incoming

into the lake away from the culvert to north Lake Joondalup. This bund would increase residence time in the southern lake allowing more opportunity for nutrient stripping. Vegetating the bund would help stabilise the structure and increase potential for nutrient stripping and enhance aesthetic values.

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