June 2017

Yellagonga Regional Park wetlands water quality monitoring 2016/17 report

By, Jay Gonzalez-Pinto
Mark Lund
Marilyn Quintero Vasquez

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

Mine Water and Environment Research Centre

Final Report No. 2017-5

1. MINE WATER AND ENVIRONMENT RESEARCH CENTRE

Founded at Edith Cowan University in 2008, the Mine Water and Environment Research (MiWER) Centre is headed by A/Prof Mark Lund. The research group has a focus on mine waters; particularly pit lakes formed from open-cut mining. The group's research also extends to the ecology and rehabilitation of all inland water bodies, natural and constructed. MiWER's aim is to further understanding of freshwater science using creative, cutting-edge technologies and innovative approaches for practically improving resource sustainability and environmental condition.

MiWER is also a member of the Centre for Ecosystem Management at Edith Cowan University. More information on MiWER and our current and previous projects can be found at www.miwer.org.

MiWER Centre

Associate Professor Mark Lund can be contacted at:

School of Science
Edith Cowan University
270 Joondalup Drive
Joondalup WA 6027

2. ACKNOWLEDGEMENTS

The support of the Yellagonga Integrated Catchment Management team (Cities of Wanneroo and Joondalup) in funding this project is gratefully acknowledged. Particular thanks to Lara O'Neill (City of Joondalup) and Tristan Bruyn (City of Wanneroo) for their support. Thanks to Edith Cowan University for the provision of in-kind and infrastructure support for the project. The project team would also like to acknowledge the assistance of Mark Bannister at Edith Cowan University who undertook the chemical analyses at the Natural Sciences Analytical Laboratories. Finally we would like to thank the volunteers and interns who have assisted with fieldwork throughout this study.

3. FRONTISPIECE

Plate 1: Lake Joondalup North in January 2016

This report should be referenced as follows.

Gonzalez Pinto, J., Lund, M.A. & Quintero Vasquez, M. (2017). *Yellagonga Regional Park wetlands water quality monitoring 2016/17 report.* Mine Water and Environment Research/Centre for Ecosystem Management Report No. 2017-5, Edith Cowan University, Perth, Australia. 42pp. Unpublished report to the Cities of Joondalup and Wanneroo.

4. EXECUTIVE SUMMARY

1. Kinnear, Garnett et al. (1997) undertook a fifteen month study of 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, McCullough et al. (2011) and more recently Newport and Lund (2013) 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, Lund et al. (2011), Newport and Lund (2012), Newport and Lund (2013) 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 (2013) for June 2016 to May 2017.
3. All parameters recorded were compared to the ANZECC & ARMCANZ (2000) national water quality trigger values for the 95% protection of aquatic ecosystems. In 2016/2017 water quality was improved compared to previous years with only limited exceedances of guideline concentrations over slightly fewer elements (Al, Cd, Hg, and Zn).
4. Sulphate to chloride and sulphate to alkalinity ratios suggest that there are acid sulphate soils within the catchment, but that natural buffering within the system is preventing low pH and high metal concentrations. The low rainfall in 2015/16 did not result in metal release and obvious acidity in 2016/17. Despite this, there does appear to be an ongoing trend of lower pH across the entire system as recently reported in DOW monitoring.
5. Recommendations from this report include supporting ongoing monitoring of the wetland system and further studies to improve management of water quality.

5. CONTENTS

6. INTRODUCTION

A number of studies conducted within Yellagonga Regional Park have concluded that Lake Joondalup is a eutrophic wetland (Congdon and McComb 1976, Gordon, Finlayson et al. 1981, Congdon 1985, Congdon 1986, Davis, Rosich et al. 1993, Kinnear, Garnett et al. 1997, Kinnear and Garnett 1999, Lund, Brown et al. 2000, Lund 2003, Cumbers 2004, Lund, Wyse et al. 2014). 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, McCullough et al. (2011) 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 and Lund 2013). The area around $Drain_{Goollelal}$ was mapped for ASS in Newport and Lund (2014). The 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, McCullough et al. 2011). 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, Lund 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 and Lund 2012). The fourth monitoring report concluded that water quality in the Yellagonga Regional Park were 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 and Lund 2013). In 2013-2014, low water levels throughout the system were particularly apparent due to low rainfall, despite this water quality was generally better than in previous years (Newport and Lund 2014). One concern raised in Newport and Lund (2014) was the dry conditions might result in another release of metals from the ASS around $Drain_{Goollelal}$.

The purpose of this study is to report on the ninth year (June 2016 to May 2017) 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.

7. STUDY AREA

Yellagonga Regional Park lies on the coastal limestone belt of the Swan Coastal Plain and is located in the north-west corridor of Perth approximately 20 km north of Perth's central business district. The park covers about 1,400 ha and contains a chain of wetlands beginning south of the park at Lake Goollelal through to Lake Joondalup in the north and includes Wallubuenup Swamp (divided by Woodvale Drive) and Beenyup Swamp. All the lakes are interconnected with a natural drainage line (Figure 1), where water flows northwards from the highest point of the drainage system at Lake Goollelal at ~27 m Australian Height Datum (AHD) through Wallubuenup Swamp (~19 m AHD) to Beenyup Swamp (~18 m AHD) and into Lake Joondalup at ~16 m AHD. The 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. (Kinnear et al. 1997). The park is managed by the Cities of Wanneroo and Joondalup, and Department of Environment and Conservation (now DPaW) under the Yellagonga Regional Park Management Plan (Dooley et al. 2003).

Urbanisation has increased surface flows into the wetlands through decreased infiltration in the catchment area (Kinnear et al. 1997). This, combined with increased extraction of the Gnangara groundwater mound and steady decline in rainfall, has altered the hydrology of the wetlands. Perth's Mediterranean climate of cool wet winters and hot dry summers, ensure that most of the swamps are normally dry towards the end of summer. Although occasionally dry in the past (Hamann 1992), since 1999 Lake Joondalup has dried to small pools every year. Lake Goollelal is considered a permanently inundated lake, while Wallubuenup Swamp dries annually and Beenyup Swamp dries on occasion. The trend of diminishing groundwater and rainfall is the probable cause of increased soil and water acidity (Appleyard & Cook, 2004) within the park triggered by drying of the underlying sediment and subsequent oxidation.

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

Although the surrounds and parts of Yellagonga Regional Park have been subject to agriculture and more recently urban development, Beenyup Swamp remains highly vegetated. Upton (1996) noted stands of paperbark (*M. rhaphiophylla*) dominating the landscape, whilst a large portion of the fringing vegetation of Lake Joondalup has been replaced by lawn areas. Wallubuenup Swamp has been subject to frequent fires and has no open water with most of the swamp being covered in *Typha orientalis*. February 2011 saw developers of the Chianti Estate located on the east side of Wallubuenup Swamp, begin clearing *T. orientalis* and *Populus sp*. The developers continued to spray the *T. orientalis* and *Kikuyu* until February 2012 in a bid to eradicate both weeds from the area. Lake Goollelal has private properties and public open space bounding the water's edge but fringing vegetation generally remains in reasonable condition.

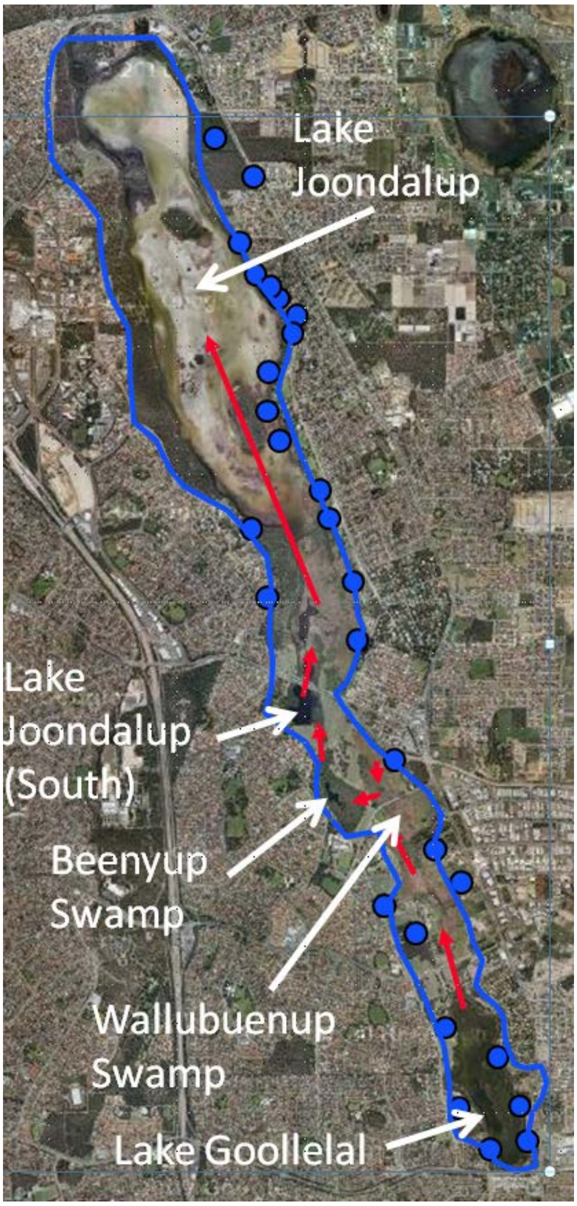


Figure 1. Direction of water flow through the Yellagonga Regional Park wetlands. Blue dots indicate drains entering the system; taken from Ove Arup & Partners (1994) and GoogleMaps (2014).

The following sites, listed from south to north within Yellagonga Regional Park waters, were sampled monthly from June to October, and in December and April (Figure3.):

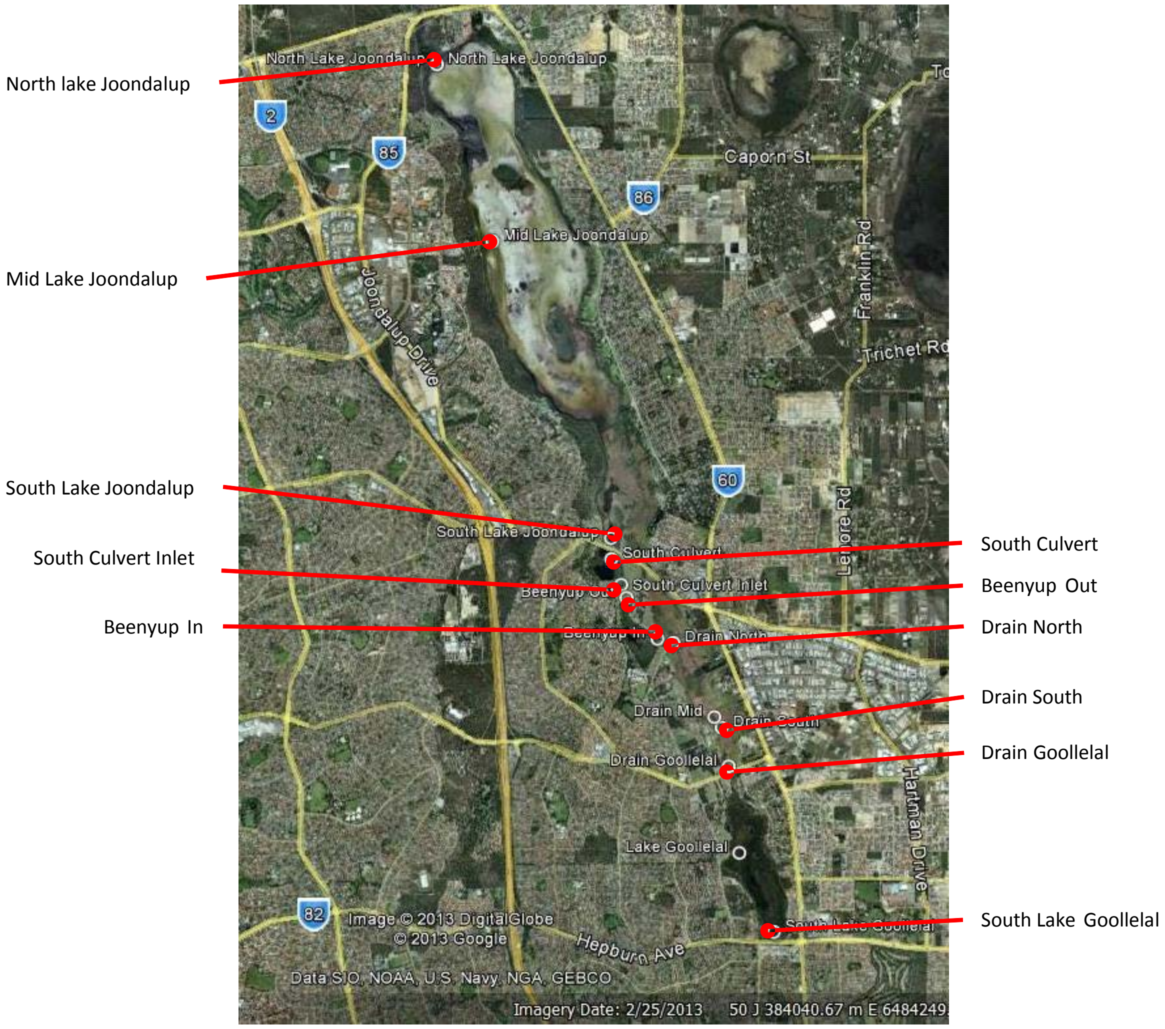


Figure 2. Locations of the thirteen study sites in Yellagonga Regional Park (adapted from Google Earth).

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

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

Drain$_{south}$ (Site 6) – Drain near Della Rd.

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

Been$_{in}$ (Site 3) – Drain between Wallubuenup Swamp and Beenyup Swamp.

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.

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 Lund (2007). An additional seven sites were been added to improve understanding of changes in water quality along the flow path from south to north. After July 2014, the sites Lake Goollelal and $Drain_{mid}$ were removed from the program due to similarities to nearby sites and difficulty in accessing them. Figure 4 shows seasonal changes in water regimes at each of the eleven sites.

a) South Lake Goollelal

October 2016 (wet)

February 2017 (dry)

b) $Drain_{Goollelal}$ (Site 5)

October 2016 (wet)

February 2017 (dry)

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

October 2016 (wet)

February 2017 (dry)

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

October 2016 (wet)

February 2017 (dry)

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

October 2016 (wet)

February 2017 (dry)

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

October 2016 (wet)

February 2017 (dry)

g) South Culvert Inlet

October 2016 (wet)

February 2017 (dry)

h) South Culvert

October 2016 (wet)

February 2017 (dry)

i) South Lake Joondalup

October 2016 (wet)

February 2017 (dry)

j) Mid Lake Joondalup

October 2016 (wet)

February 2017 (dry)

k) North Lake Joondalup

October 2016 (wet)

February 2017 (dry)

Figure 3. Photographs of the eleven sites used in this study, showing seasonal changes in water regimes.

8. METHODS

This report covers monthly sampling in July to October, December 2016 and February in 2017 at the eleven 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 surface 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). Alkalinity was measured on an unfiltered aliquot for each site according to the titration methodology in APHA (1999).

All analyses were performed at the School of Science 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.

In data analysis, all values that were below the detection limit were given a value of half the detection limit in calculations.

9. RESULTS AND DISCUSSION

Rainfall during the period of this study (June - May) in 2016/17 totalled 769.4 mm which was higher than in 2015/16 at 595.6 mm, 2014/15 at 651.9 mm, 2012/13 at 737.6 mm, 2011/12 at 709.5 mm, and 2010/2011 at 433.9 mm, but lower than 2013/14 at 841.7 mm (data from Bureau of Meteorology, Wanneroo and Tamala Park stations; Figure 4). Unusually, in 2016/17, a large proportion of the rain occurred in February.

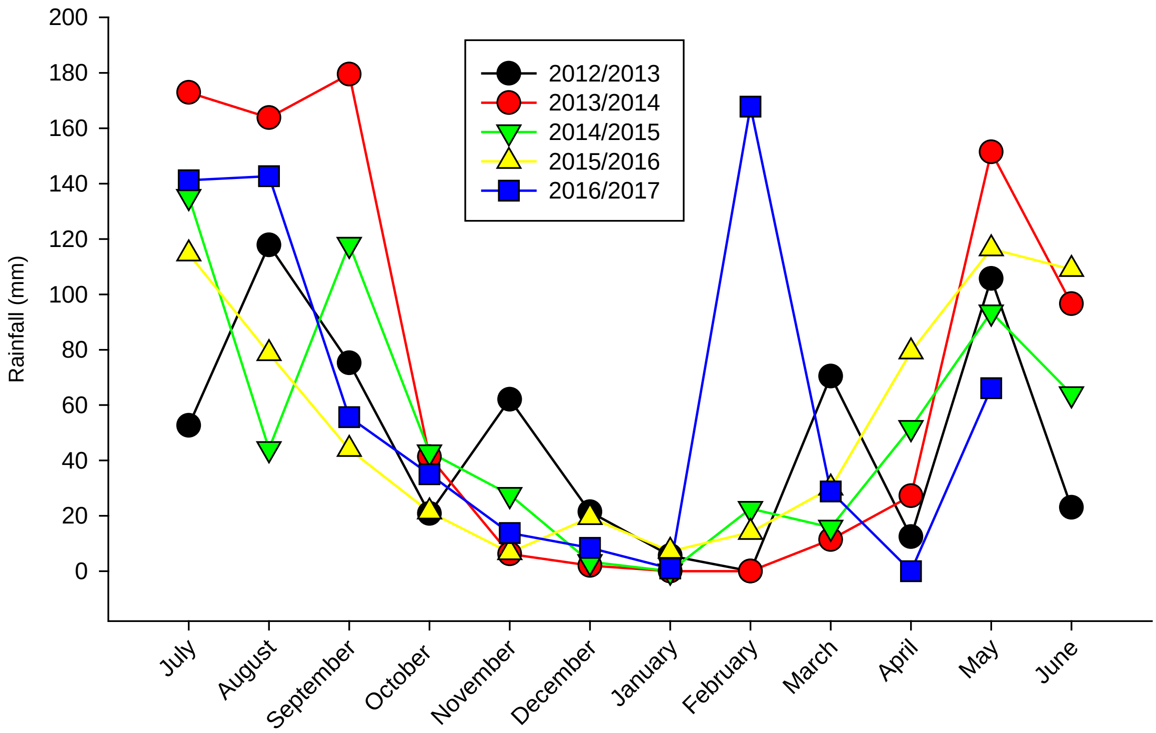


Figure 4. Monthly rainfall totals for 2012/13, 2013/14, 2014/15, 2015/16 and 2016/17 monitoring periods from data obtained from the Bureau of Meteorology, climate data from Wanneroo and Tamala Park.

All sites were sampled throughout the study except for $\text{Drain}_{\text{Goollelal}}$ in December 2016 (Table 1). South Lake Goollelal and $\text{Drain}_{\text{Goollelal}}$ were too dry to sample throughout most of the year. June 2016 was not sampled as part of the transition from the bimonthly approach of 2015/16 to the targeted times of this year. The high rainfall in February ensured that all sites were sampled, whereas we were expecting to only sample 4 sites.

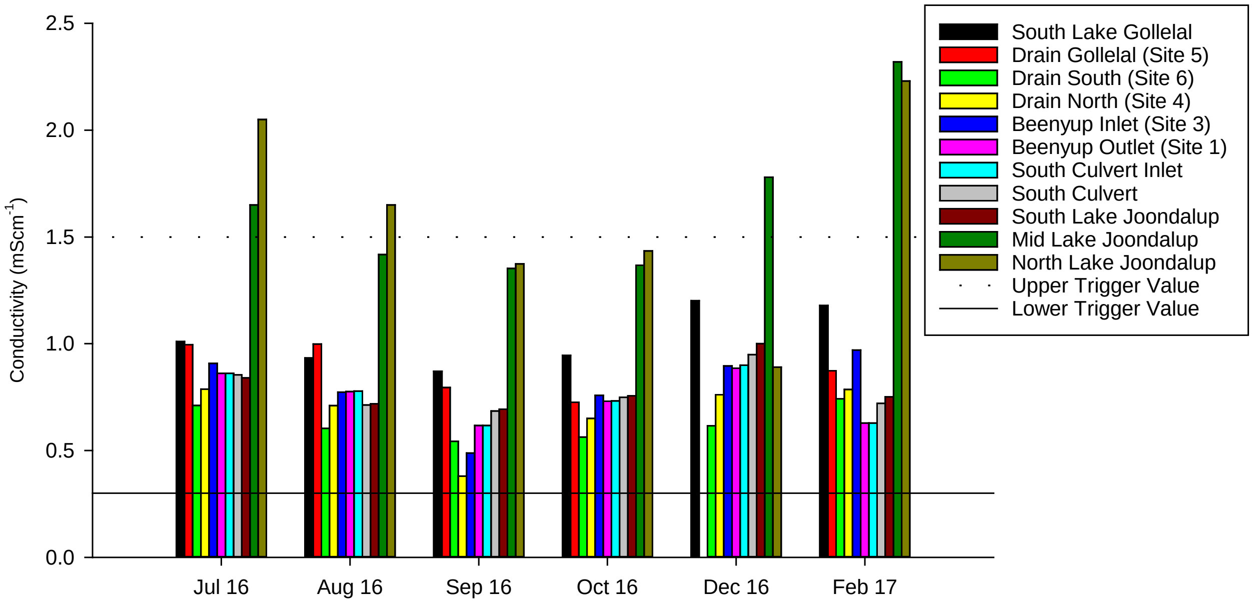
Table 1. Occasions when sites were sampled between June 2016 and May 2017 (S= sampled).

	July	August	September	October	December	February
South Lake Goollelal	S	S	S	S	S	S
Beenyup Out (Site 1)	S	S	S	S	S	S
Beenyup In (Site 3)	S	S	S	S	S	S
Drain North (Site 4)	S	S	S	S	S	S
Drain Goollelal (Site 5)	S	S	S	S		S
Drain South (Site 6)	S	S	S	S	S	S
South Culvert Inlet	S	S	S	S	S	S
South Culvert	S	S	S	S	S	S
South Lake Joondalup	S	S	S	S	S	S
Mid Lake Joondalup	S	S	S	S	S	S
North Lake Joondalup	S	S	S	S	S	S

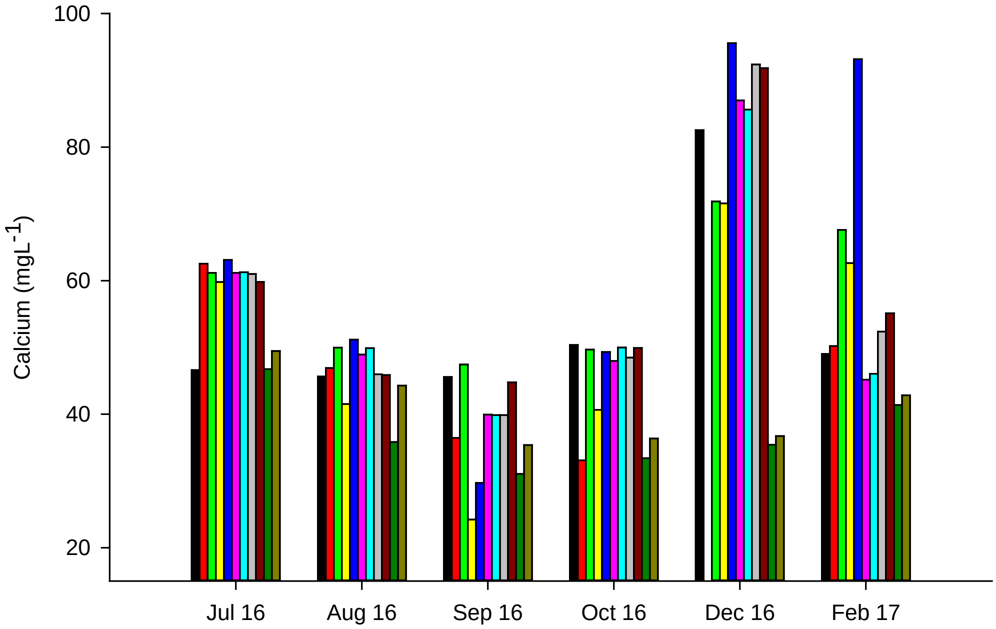
9.1 PHYSICO-CHEMISTRY

The high rainfall in 2016/17 reduced electrical conductivity (EC) across the system compared to 2015/16. The highest EC was recorded in the Lake Joondalup (Mid and North), interestingly despite the high rainfall in February this did not dramatically reduce EC (Figure 5a). Evapoconcentration of solutes in the water is evident at the time of lowest water levels (summer) and is reflected in EC, and K, Mg, Na and Cl. The greatest concentrations of these solutes tend to occur in Mid and North Lake Joondalup (Figure 5). Calcium concentrations did not reflect the patterns seen in EC, with the lowest concentrations generally in Lake Joondalup (Mid and North). Calcium followed a strong seasonal cycle, low in winter higher in summer, with the rainfall in February appearing to reduce concentrations below what could be expected based on 2015/16. In general, at all sites mean concentrations and ranges were similar for solutes in this year compared to 2016/17 despite the reduced rainfall (Table 2).

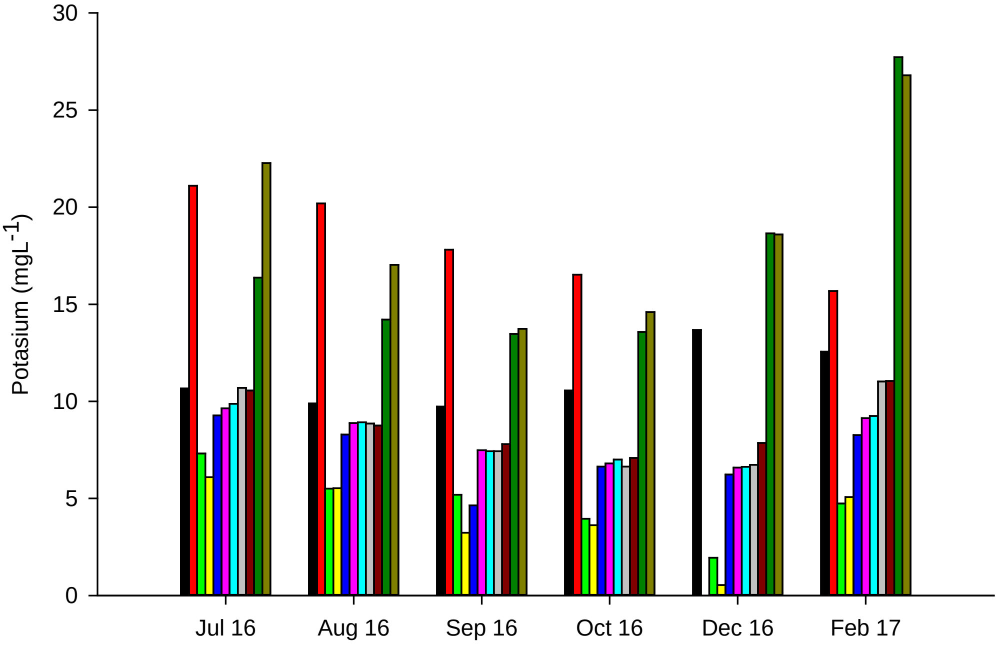
a) Electrical conductivity



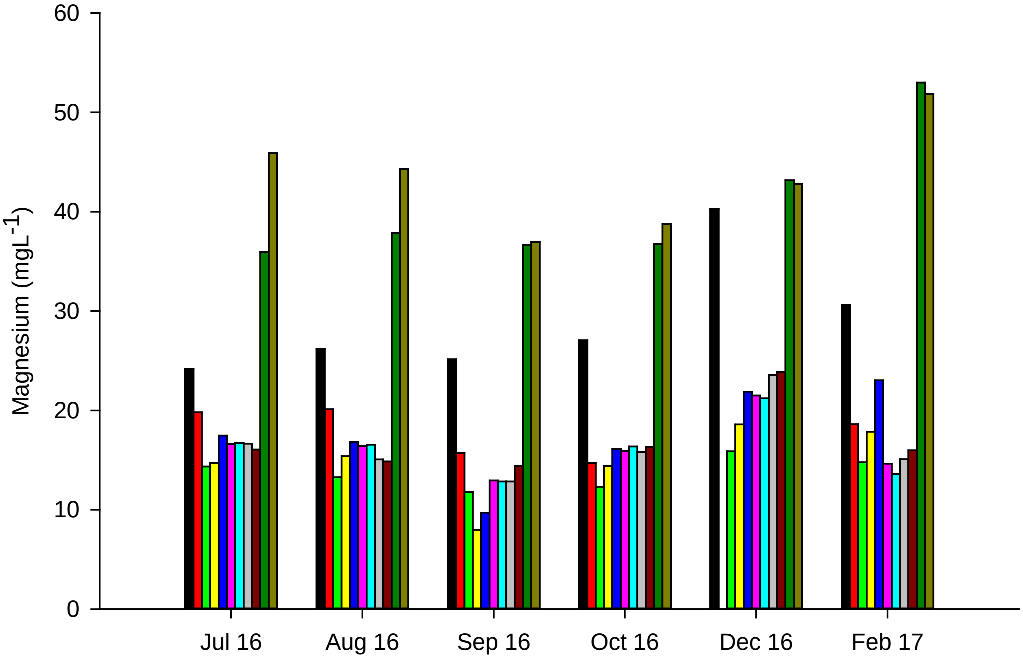
b) Calcium (Ca)



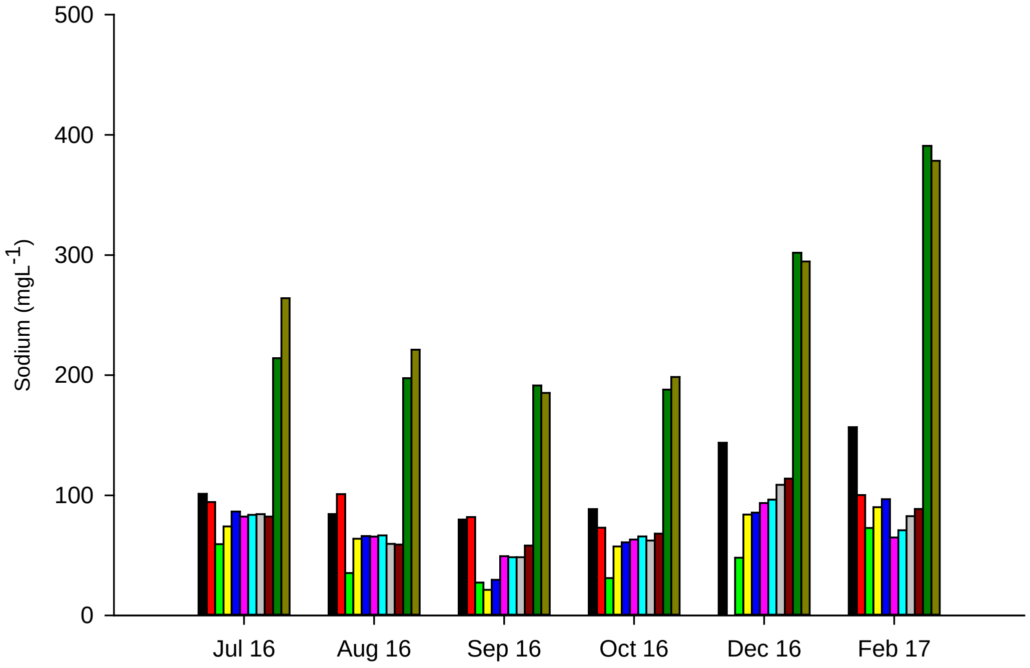
c) Potassium (K)



d) Magnesium (Mg)



e) Sodium (Na)



f) Chloride (Cl)

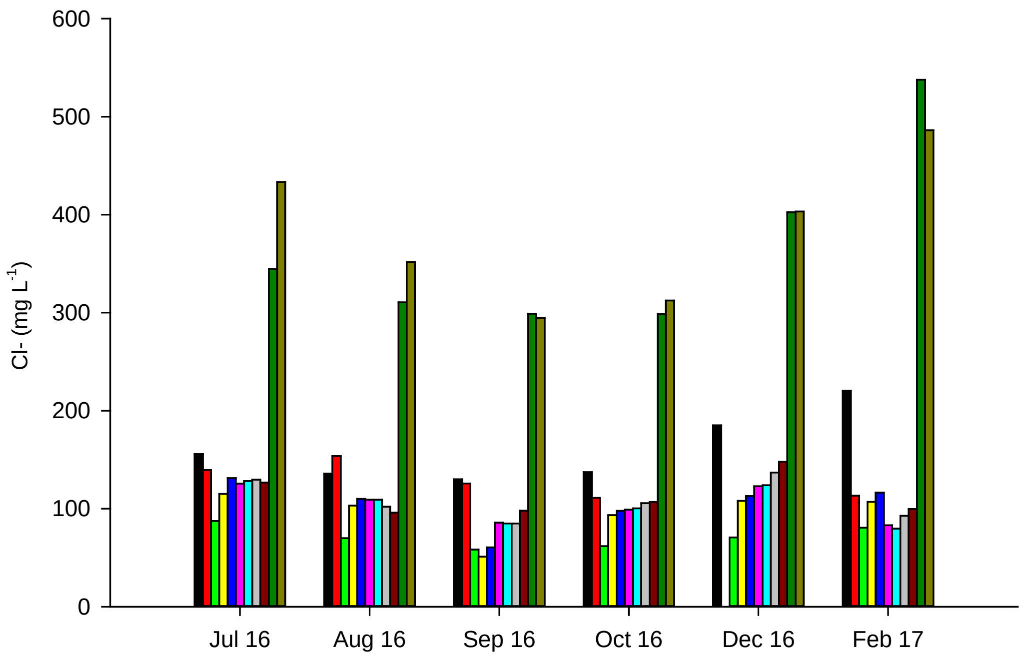


Figure 5. Changes in a) electrical conductivity, b) calcium, c) potassium, d) magnesium, e) sodium, and f) chloride over the period of monitoring at each site (June 2016- May 2017).

Table 2 Mean ±SE (range) for selected solutes (in mg L^{-1}) during the study period June 2016 to May 2016

	Ca	K	Mg	Na
Detection Limit	<0.2	<0.2	<0.2	<0.2
South Lake Goollelal	53 ± 6 (46-83)	11 ± 1 (10-14)	29 ± 2 (24-40)	109 ± 13 (80-157)
Beenyup Out (Site 1)	55 ± 7 (40-87)	8 ± 1 (7-10)	16 ± 1 (13-21)	70 ± 6 (49-94)
Beenyup In (Site 3)	64 ± 11 (30-96)	7 ± 1 (5-9)	18 ± 2 (10-23)	71 ± 10 (30-97)
Drain North (Site 4)	50 ± 7 (24-72)	4 ± 1 (1-6)	15 ± 2 (8-19)	65 ± 10 (21-90)
Drain Goollelal (Site 5)	46 ± 5 (33-63)	18 ± 1 (16-21)	18 ± 1 (15-20)	90 ± 5 (73-101)
Drain South (Site 6)	58 ± 4 (47-72)	5 ± 1 (2-7)	14 ± 1 (12-16)	46 ± 7 (27-73)
South Culvert Inlet	55 ± 7 (40-86)	8 ± 1 (7-10)	16 ± 1 (13-21)	72 ± 7 (49-96)
South Culvert	57 ± 3 (40-92)	9 ± 0 (7-11)	17 ± 1 (13-24)	74 ± 4 (49-109)
South Lake Joondalup	58 ± 7 (45-92)	9 ± 1 (7-11)	17 ± 1 (14-24)	78 ± 9 (58-114)
Mid Lake Joondalup	37 ± 1 (31-47)	17 ± 1 (13-28)	41 ± 1 (36-53)	247 ± 14 (188-391)
North Lake Joondalup	41 ± 1 (35-49)	19 ± 1 (14-27)	43 ± 1 (37-52)	257 ± 12 (185-378)

Mean water hardness was calculated for each site across the year and is shown in Figure 6. 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). When compared to the 2011-12 monitoring period the hardness has dropped slightly, all sites were still “very” to “extremely” hard. The highest hardness was 627 mg $CaCO_3L^{-1}$ in 2010-2011 monitoring period at Mid Lake Joondalup (Newport *et al.*, 2011). In contrast, the highest hardness for 2016/17 was just under half this at North Lake Joondalup (Figure 6) at 283 mg $CaCO_3L^{-1}$. Hardness of water is important for the influence it has on the toxicity of some metals, with higher hardness reducing toxicity.

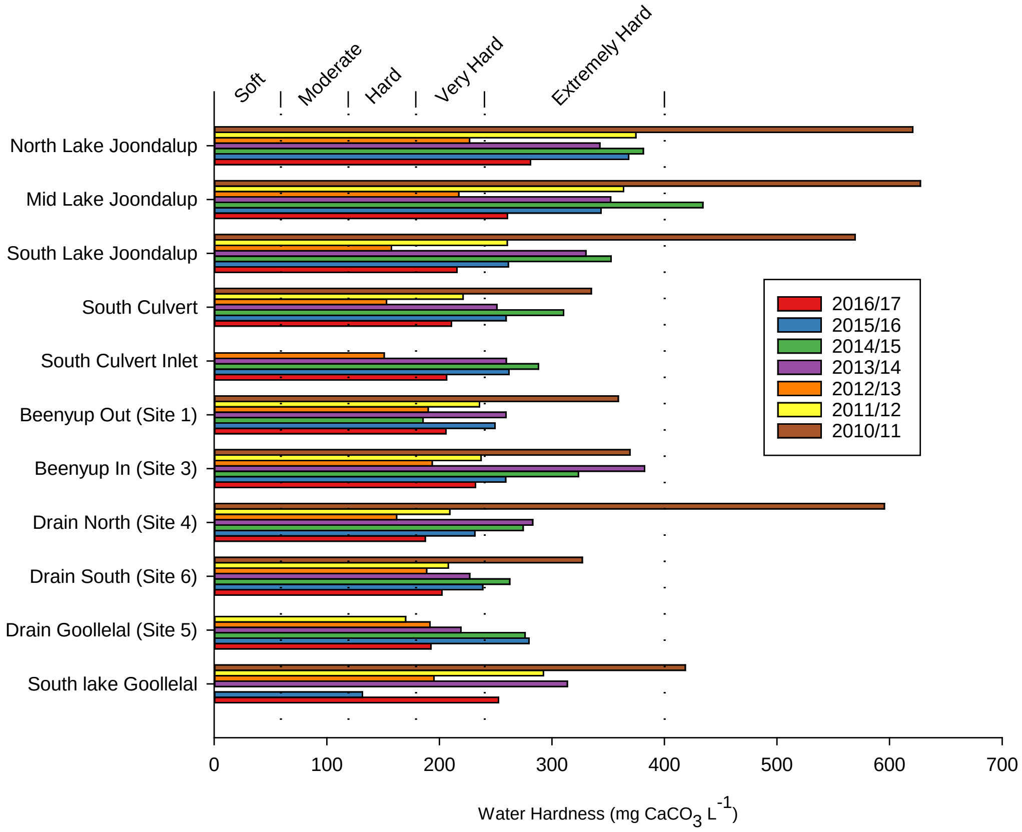
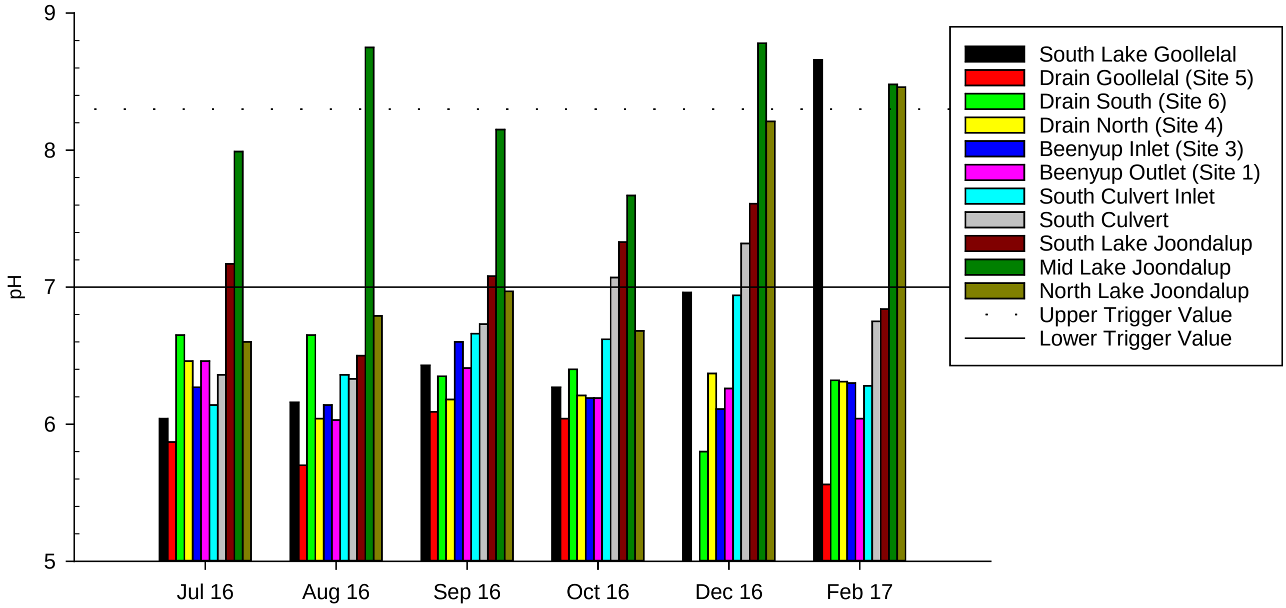


Figure 6. Calculated mean water hardness of each site for the three consecutive years of monitoring, with ANZECC/ARMCANZ (2000) categories indicated.

ANZECC/ARMCANZ (2000) water quality guidelines for the 95% protection of aquatic ecosystems recommend wetland pH levels between 7.0 and 8.5 pH at Mid and North Lake Joondalup remained in or above the guideline values, with South Lake Joondalup and South Culvert occasionally exceeding pH 7 (Figure 7). At other sites pH was <7 although typically above 6 with the exception of $Drain_{Goollelal}$ which in February 2017 dropped to 5.44. pH was generally slightly lower than in 2015/16 probably reflecting minor acidification associated with the low rainfall in that year.

a) pH



b) Sulphate (SO_4)

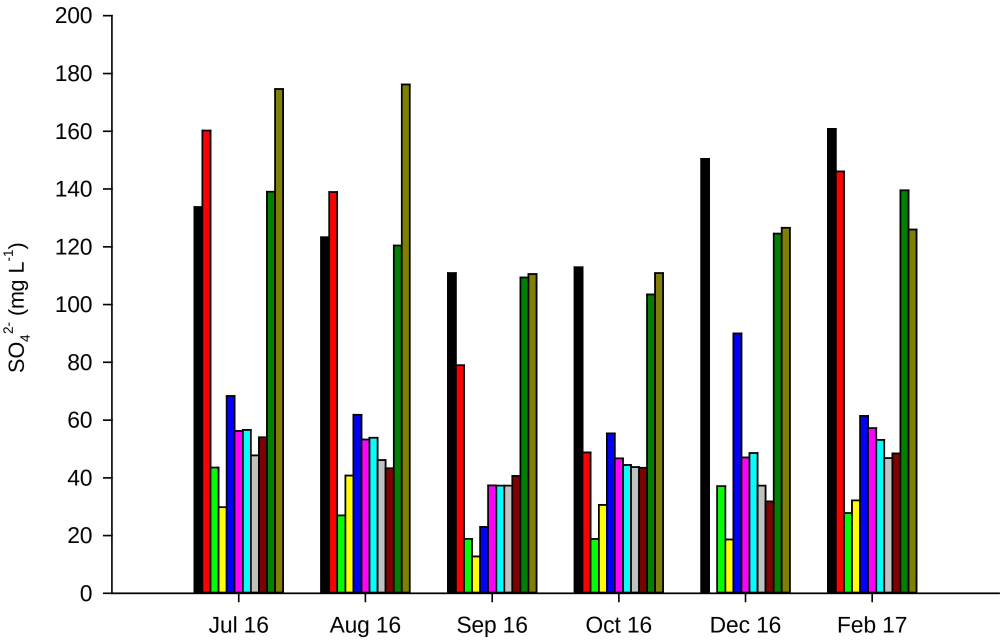


Figure 7. Changes in a) pH, and b) sulphate over the period of monitoring at each site (June 2016 – May 2017 with ANZECC & ARMCANZ (2000) trigger values for the protection of aquatic ecosystems (95%).

Chloride to sulphate molar ratios are 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 and Department of Natural Resources and Mines 2002). Best suited to saline environments, the ratio is sometimes problematic in freshwaters such as found in the Yellagonga wetlands and therefore must be treated with caution. To improve our ability to detect potential ASS, we also measured alkalinity (Table 3) as an alkalinity to sulphate ratio of <5 is considered to be a better predictor in freshwater systems (Department of Environmental Regulation 2015). Compared to previous years, there were fewer sites and occasions which had signs of ASS contamination. Low sulphate:chloride ratios were found on occasion at all sites except $Drain_{North}$, and Mid and North Lake Joondalup. Alkalinity:sulphate ratios were generally low at all sites, only rising to above 5 on a few occasions. This supports the general conclusion that there is acid sulphate soil activity within the Yellagonga catchment but currently buffering is sufficient to prevent low pH. The site around $Drain_{Goollelal}$ 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. Experimentally we have investigated the likelihood of acidification following natural drying of Lake Goollelal sediment and it appears, at least initially, unlikely as we suspect that organic matter coats the pyrite preventing it from oxidising – however under prolonged drying this may not be the case.

Table 3. Mean ±SE (range) for variables associated with acid sulphate soils (in mg L^{-1}) during the study period June 2016 to May 2017

	Cl^-	SO_4^{2-}	SO_4:Cl	Alkalinity	Alkalinity:SO_4
Detection Limit	<0.5	<0.5	Molar ratio	mg$CaCO_3$ L^{-1}	Mass ratio
South Lake Goollelal	161 ± 14 (130-220)	132 ± 8 (111-161)	3 ± 0 (3-4)	103 ± 11 (67-143)	1 ± 0 (0-1)
Beenyup Out (Site 1)	104 ± 7 (83-126)	50 ± 3 (37-57)	6 ± 0 (4-7)	137 ± 14 (100-200)	3 ± 0 (2-4)
Beenyup In (Site 3)	105 ± 10 (61-131)	60 ± 9 (23-90)	5 ± 0 (3-7)	141 ± 12 (93-177)	3 ± 0 (2-4)
Drain North (Site 4)	96 ± 9 (51-115)	27 ± 4 (13-41)	10 ± 1 (7-16)	132 ± 18 (77-183)	5 ± 1 (2-10)
Drain Goollelal (Site 5)	129 ± 8 (111-154)	115 ± 22 (49-160)	4 ± 1 (2-6)	66 ± 12 (30-90)	1 ± 0 (0-2)
Drain South (Site 6)	71 ± 4 (58-87)	29 ± 4 (19-44)	7 ± 1 (5-9)	166 ± 8 (147-200)	6 ± 1 (3-8)
South Culvert Inlet	104 ± 8 (80-128)	49 ± 3 (37-57)	6 ± 0 (4-7)	138 ± 14 (97-197)	3 ± 0 (2-4)
South Culvert	109 ± 3 (85-137)	43 ± 1 (37-48)	7 ± 0 (5-10)	149 ± 6 (120-223)	4 ± 0 (3-6)
South Lake Joondalup	112 ± 8 (96-148)	44 ± 3 (32-54)	7 ± 1 (6-13)	159 ± 15 (130-230)	4 ± 1 (3-7)
Mid Lake Joondalup	365 ± 16 (298-538)	123 ± 2 (104-140)	8 ± 0 (7-10)	113 ± 3 (93-137)	1 ± 0 (1-1)
North Lake Joondalup	380 ± 12 (295-486)	137 ± 5 (111-176)	8 ± 0 (5-10)	126 ± 2 (110-147)	1 ± 0 (1-1)

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, except Mid Lake

Joondalup (Figure 8, Table 4). At all other sites, low dissolved oxygen levels were likely due to a lack of algae or plants and the presence of oxygen demanding sediments. The lowest dissolved oxygen levels were 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

Water temperatures rose from July 2016 to February 2017. Temperatures in the drains (presumably due to shading) were noticeably lower than those in the lakes.

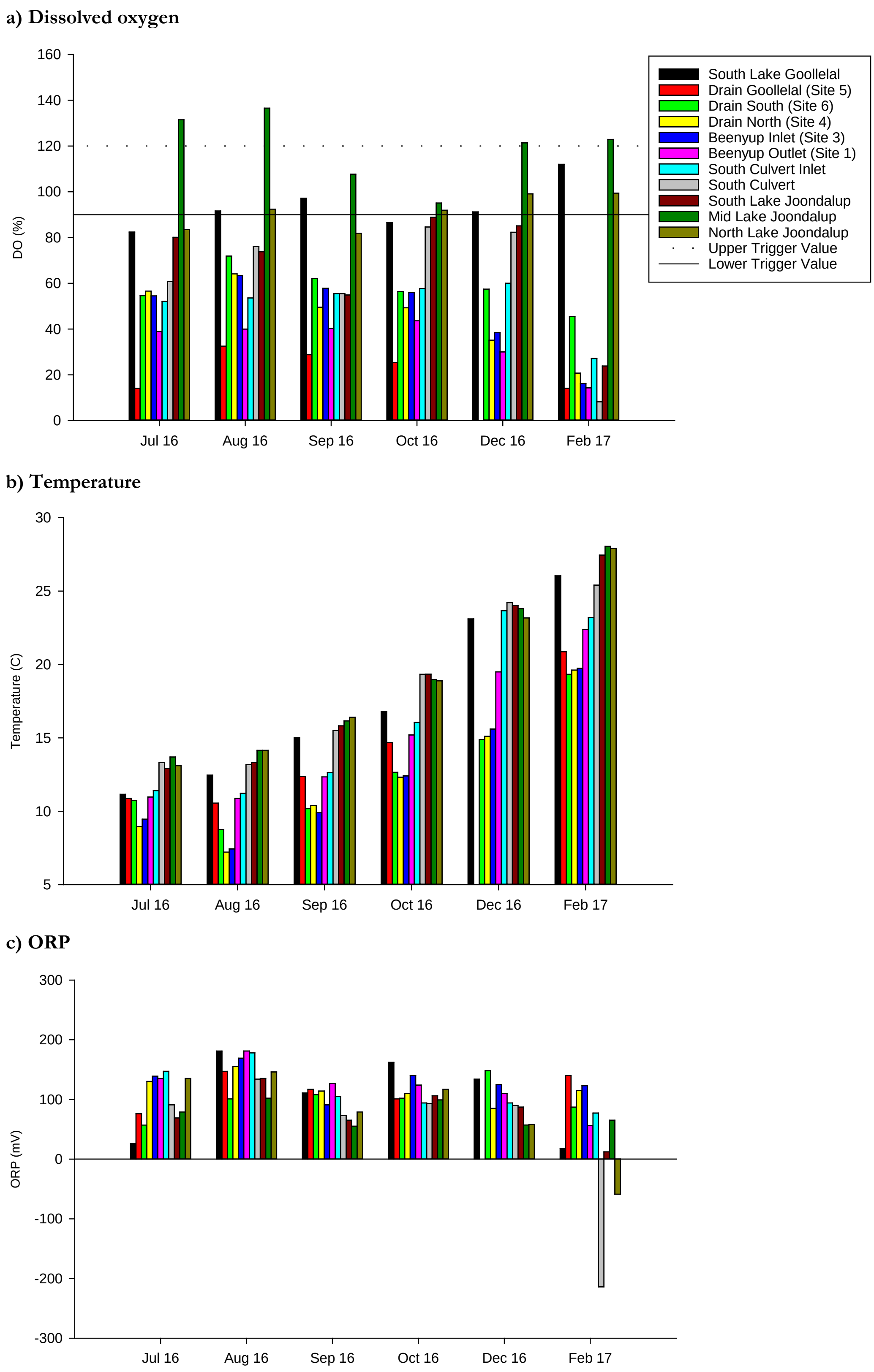


Figure 8. Changes in a) dissolved oxygen, b) temperature and c) ORP between June 2016 and May 2017 at each site with ANZECC & ARMCANZ (2000) trigger values.

Table 4. Mean ± standard error (range) for physicochemical variables over the study period (June 2016 – May 2017)

	Temperature °C	Conductivity mS/cm	Dissolved Oxygen (mgL^{-1})	%	pH	ORP mV	Turbidity NTU	Chlorophyll *a* $ug\ L^{-1}$
South Lake Goollelal	18.2 ± 3.7 (11.9-24.8)	1.05 ± 0.06 (0.95-1.15)	9.8 ± 0.8 (8.1-10.7)	104 ± 5 (97-112)	8.25 ± 0.27 (7.79-8.74)	130 ± 35 (87-199)	23 ± 0 (23-23)	5.6 ± 0.7 (4.4-6.9)
Beenyup Out (Site 1)	17.8 ± 2 (10.6-22.7)	0.73 ± 0.15 (0.07-1.15)	3.4 ± 0.5 (1.4-4.7)	35 ± 4 (17-46)	7.01 ± 0.24 (5.87-7.54)	148 ± 19 (88-221)	34 ± 0 (34-34)	5.5 ± 2.8 (0.1-18.7)
Beenyup In (Site 3)	14.3 ± 1.6 (7.6-19.7)	0.97 ± 0.07 (0.74-1.15)	4.9 ± 0.4 (3.4-6.8)	48 ± 3 (37-57)	6.88 ± 0.24 (5.87-7.78)	146 ± 24 (54-219)	26 ± 0 (26-26)	0.4 ± 0.3 (0-1.9)
Drain North (Site 4)	14.1 ± 1.6 (6.8-19.4)	0.84 ± 0.06 (0.62-1)	4.7 ± 0.9 (1.4-8.1)	44 ± 8 (16-66)	6.77 ± 0.23 (5.87-7.65)	93 ± 33 (-73-204)	59 ± 0 (59-59)	1.7 ± 0.7 (0.1-4.8)
Drain Goollelal (Site 5)	13.1 ± 1.7 (11.4-14.7)	0.83 ± 0.07 (0.76-0.9)	3.5 ± 0.9 (2.6-4.4)	37 ± 13 (24-51)	6.55 ± 0.32 (6.23-6.86)	129 ± 70 (59-199)	Too high	0.7 ± 0.1 (4.8-0.3)
Drain South (Site 6)	13 ± 1.2 (9-15.8)	0.71 ± 0.05 (0.59-0.88)	5.8 ± 0.9 (2.9-7.7)	55 ± 8 (29-78)	6.82 ± 0.3 (5.96-7.52)	139 ± 22 (88-213)	135 ± 0 (135-135)	0.2 ± 0.1 (0.1-0.5)
South Culvert Inlet	16.2 ± 1.7 (11-21.9)	0.96 ± 0.09 (0.71-1.2)	5 ± 0.4 (3.9-5.7)	51 ± 4 (39-64)	7.05 ± 0.3 (6.18-7.82)	135 ± 23 (55-192)	41 ± 0 (41-41)	1.5 ± 0.6 (0.1-3.8)
South Culvert	18.5 ± 2 (12.4-24.9)	0.84 ± 0.22 (0.08-1.29)	6.7 ± 2.4 (1.2-15.5)	75 ± 30 (13-188)	7.69 ± 0.35 (6.92-8.91)	123 ± 21 (64-182)	41 ± 0 (41-41)	3.7 ± 1.8 (0.1-9.2)
South Lake Joondalup	20.4 ± 2.7 (12.9-27.8)	1.25 ± 0.26 (0.74-1.91)	6.3 ± 0.6 (4.6-8)	70 ± 9 (43-95)	7.79 ± 0.12 (7.49-8.1)	146 ± 14 (115-192)	16 ± 0 (16-16)	2.4 ± 1.1 (0.1-6.5)
Mid Lake Joondalup	22.3 ± 2.5 (14.1-29)	2.97 ± 0.57 (1.88-4.89)	10.6 ± 0.7 (8.6-12.8)	124 ± 14 (96-170)	8.59 ± 0.15 (8.29-9.14)	146 ± 18 (103-196)	14 ± 0 (14-14)	2.3 ± 1.1 (0.1-6.4)
North Lake Joondalup	22.3 ± 3.6 (13.4-29.5)	2.57 ± 0.44 (1.9-3.84)	11.6 ± 0.8 (10.2-13.9)	136 ± 17 (102-174)	9.26 ± 0.18 (8.85-9.6)	136 ± 24 (72-179)	43 ± 0 (43-43)	2.9 ± 0.4 (2.1-3.8)

9.2 METALS AND METALLOIDS

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 5). Figure 9 shows the seasonal changes in select metal concentrations over the study period. During this year, only Al, Cd, Hg, and Zn exceeded the trigger values on some occasions, whereas in previous years both As and Se had also been problematic. Overall the number of exceedances was the lowest it has been over the 6 years of monitoring. High levels of Al can be associated with acid sulphate soils, but Al exceedances were up slightly on 2015/16 suggesting that acid sulphate soils are becoming more active. Aluminium contamination is acutely and chronically toxic to fish, amphibians, invertebrates and phytoplankton (ANZECC & ARMCANZ, 2000). Mercury concentrations were still high in 2016/17 on occasion, substantially higher than the trigger values. Short periods of high Hg concentrations are common in the system (as seen in previous years). The source of the Hg remains unknown (although the industrial area at Wangara is a probable source) and the timing of the high concentrations varies between years. Both Al and Zn occurred in high concentrations in the 2016/17 Yellagonga groundwater.

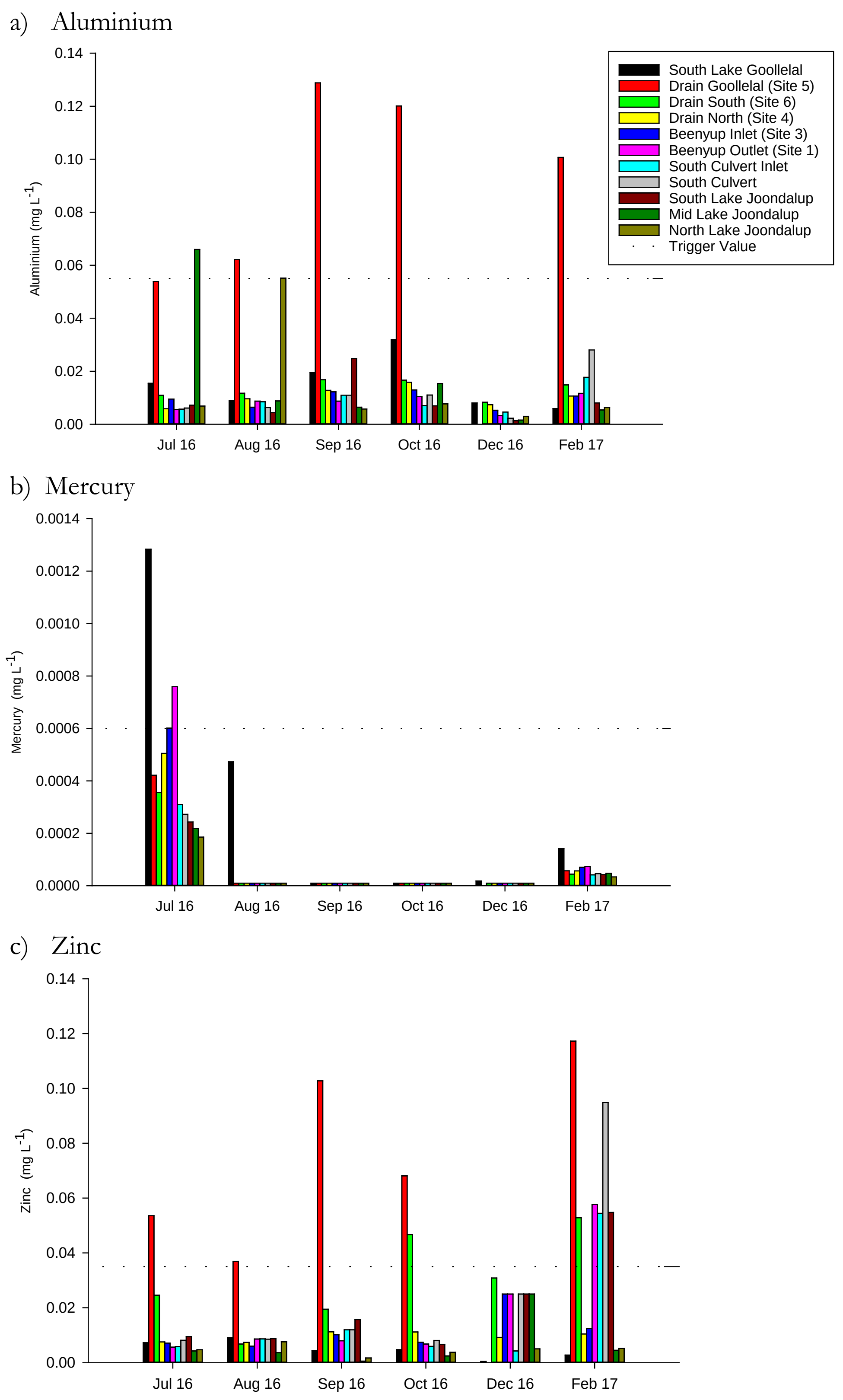


Figure 9. Occurrences of metal concentrations exceeding the ANZECC/ARMCANZ (2000) water quality trigger values for 95% protection of aquatic ecosystems between June 2016 and May 2017 (Cd not shown as only 1 exceedance and most values were below detection).

Table 5. Exceedances of ANZECC/ARMCANZ (2000) water quality trigger values for 95% protection of aquatic ecosystems for metals and metalloids recorded in this study between June 2016 and May 2017

Metal/Metalloid (mg L^{-1})	ANZECC/ ARMCANZ (2000) Trigger Value	Detection Limit	Mean ± se (maximum value)	No. exceeding detection limit (No. exceeding trigger value)
Aluminium (Al)	0.055	<0.0005	0.018 ± 0.003 (0.129)	65 (6)
Arsenic (As)	0.013 - 0.024*	<0.00001	0.0031 ± 0.0003 (0.0121)	65 (0)
Calcium (Ca)	—	<0.2	52.28 ± 2.04 (95.56)	65 (0)
Cadmium (Cd)	0.0011 – 0.0016^{H}	<0.00001	0.00003 ± 0.00002 (0.0016)	11 (1)
Cobalt (Co)	ID	<0.00002	0.0002 ± 0.0001 (0.0025)	45 (0)
Chromium (Cr)	ID - 0.006^{H}	<0.00005	0.0013 ± 0.0001 (0.0049)	65 (0)
Iron (Fe)	ID	<0.0005	0.63 ± 0.09 (4.1)	65 (0)
Mercury (Hg)	0.0006 - ID*	<0.00002	0.0001 ± 0 (0.0013)	23 (3)
Potassium (K)	—	<0.2	10.36 ± 0.7 (27.73)	65 (0)
Magnesium (Mg)	—	<0.2	22.13 ± 1.36 (53)	65 (0)
Manganese (Mn)	1.9	<0.00005	0.02 ± 0 (0.12)	65 (0)
Sodium (Na)	—	<0.2	107.54 ± 9.84 (390.86)	65 (0)
Nickel (Ni)	0.0480 – 0.0687^{H}	<0.00005	0.0017 ± 0.0004 (0.01)	65 (0)
Selenium (Se)	0.011	<0.00005	0.0001 ± 0 (0.0004)	20 (0)
Uranium (U)	0.005+	<0.00002	0.00001 ± 0 (0.00006)	6 (0)
Zinc (Zn)	0.0350 – 0.05^{H}	<0.00025	0.019 ± 0.003 (0.117)	65 (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 6. Mean ± standard error (range) for selected metals (in µg L^{-1}) over the 12 month study period (June 2016 – May 2017). Figure marked > were below detection.

	Al	As	Cd	Co	Cr	Fe
DL	>0.5	>0.01	>0.01	>0.02	>0.05	>0.5
South Lake Goollelal	15 ± 4 (5.9-32)	2.9 ± 0.3 (2.3-4.4)	0.007 ± 0.002 (>0.01-0.017)	0.119 ± 0.019 (0.063-0.194)	0.878 ± 0.079 (0.573-1.133)	221 ± 46.5 (56.7-361.1)
Beenyup Out (Site 1)	8.1 ± 1.3 (3.3-11.7)	2.7 ± 0.6 (1.6-5.7)	>0.01	0.034 ± 0.015 (>0.02-0.087)	1.205 ± 0.085 (0.96-1.499)	589.7 ± 115 (309.7-1092.7)
Beenyup In (Site 3)	9.5 ± 1.3 (5.3-13)	1.8 ± 0.3 (1.2-3.3)	>0.01	0.04 ± 0.02 (>0.02-0.123)	1.223 ± 0.109 (0.925-1.572)	543.7 ± 81.8 (279.4-790)
Drain North (Site 4)	10.4 ± 1.5 (5.9-15.9)	1.5 ± 0.2 (1.1-2.5)	>0.01	0.044 ± 0.013 (0.006-0.093)	1.441 ± 0.137 (1.144-2.024)	738.6 ± 139.7 (132-1061.6)
Drain Goollelal (Site 5)	93.1 ± 15.1 (53.9-128.8)	7.6 ± 1.4 (4-12.1)	0.326 ± 0.319 (>0.01-1.601)	1.014 ± 0.079 (0.797-1.237)	3.962 ± 0.332 (2.863-4.903)	2570.7 ± 425 (1493.1-4099.7)
Drain South (Site 6)	13.2 ± 1.4 (8.3-16.8)	1.8 ± 0.2 (1.4-2.9)	>0.01)	0.029 ± 0.01 (>0.02-0.075)	0.987 ± 0.053 (0.759-1.105)	544.6 ± 299.7 (207.6-2041.5)
South Culvert Inlet	9.1 ± 1.9 (4.7-17.7)	2.7 ± 0.6 (1.5-5.7)	0.014 ± 0 (0.014-0.014)	0.966 ± 0.495 (0.023-2.5)	1.26 ± 0.077 (1.047-1.535)	603 ± 103.4 (341.6-1014.2)
South Culvert	10.8 ± 1.5 (2.3-28)	2.8 ± 0.2 (2-5.5)	>0.01	0.043 ± 0.006 (>0.02-0.103)	1.373 ± 0.072 (0.805-2.101)	608.9 ± 31.2 (321.7-789.4)
South Lake Joondalup	8.8 ± 3.3 (1.4-24.8)	3.1 ± 0.5 (1.9-5.1)	0.007 ± 0.002 (0.005-0.018)	0.048 ± 0.015 (>0.02-0.1)	1.385 ± 0.198 (0.849-2.254)	716 ± 47.8 (543.2-821.3)
Mid Lake Joondalup	17.3 ± 4 (1.6-66)	4.1 ± 0.3 (3.2-7.6)	>0.01	0.019 ± 0.003 (0.005-0.047)	0.729 ± 0.037 (0.419-1.113)	84.9 ± 9.6 (17.2-161.5)
North Lake Joondalup	14.2 ± 3.4 (3-55.1)	4.2 ± 0.2 (3.2-7)	0.007 ± 0.001 (0.005-0.02)	0.026 ± 0.002 (>0.02-0.043)	0.752 ± 0.033 (0.389-0.982)	59.1 ± 4.4 (20.2-86.5)

Table 6 cont.

DL	Hg >0.02	Mn >0.05	Ni >0.05	Se >0.05	U >0.02	Zn <0.05
South Lake Goollelal	0.32 ± 0.21 (>0.02-1.28)	6.87 ± 1.26 (1.83-10.28)	0.44 ± 0.09 (0.23-0.83)	0.09 ± 0.05 (>0.05-0.34)	0.016 ± 0.006 (>0.02-0.047)	4.77 ± 1.27 (0.43-9.11)
Beenyup Out (Site 1)	0.15 ± 0.12 (>0.02-0.76)	22.86 ± 12.16 (7.34-83.41)	1.98 ± 1.6 (0.21-10)	0.08 ± 0.05 (>0.05-0.33)	0.011 ± 0.001 (>0.02-0.017)	18.61 ± 8.35 (5.62-57.7)
Beenyup In (Site 3)	0.12 ± 0.1 (>0.02-0.6)	31.37 ± 18.83 (4.63-124.03)	1.98 ± 1.6 (0.19-10)	0.08 ± 0.03 (>0.05-0.22)	0.013 ± 0.003 (>0.02-0.029)	11.38 ± 2.89 (6.03-25)
Drain North (Site 4)	0.1 ± 0.08 (>0.02-0.5)	21.04 ± 9.84 (5.26-67.81)	0.78 ± 0.35 (0.24-2.5)	0.05 ± 0.03 (>0.05-0.2)	0.011 ± 0.001 (>0.02-0.014)	9.49 ± 0.71 (7.38-11.26)
Drain Goollelal (Site 5)	0.1 ± 0.08 (>0.02-0.42)	61.23 ± 8.96 (45.65-93.12)	1.16 ± 0.1 (0.89-1.47)	0.17 ± 0.07 (>0.05-0.45)	0.014 ± 0.004 (>0.02-0.028)	75.71 ± 15.01 (36.91-117.21)
Drain South (Site 6)	0.07 ± 0.06 (>0.02-0.36)	11.72 ± 5.22 (5.5-37.7)	1.9 ± 1.62 (0.15-10)	0.06 ± 0.03 (>0.05-0.22)	0.018 ± 0.008 (>0.02-0.06)	30.19 ± 7.03 (6.78-52.84)
South Culvert Inlet	0.07 ± 0.05 (>0.02-0.31)	20.43 ± 9.73 (7.58-68.76)	2.03 ± 1.6 (0.17-10)	0.06 ± 0.03 (>0.05-0.21)	0.01 ± 0 (>0.02-0.013)	15.16 ± 7.93 (4.24-54.42)
South Culvert	0.06 ± 0.02 (>0.02-0.27)	20.77 ± 4.8 (3.78-79.14)	2.25 ± 0.64 (0.17-10)	0.06 ± 0.01 (>0.05-0.21)	0.01 ± 0 (>0.02-0.011)	26.1 ± 5.72 (8.09-94.85)
South Lake Joondalup	0.05 ± 0.04 (>0.02-0.24)	12.81 ± 3.51 (5.99-29.75)	2.37 ± 1.57 (0.17-10)	0.05 ± 0.02 (>0.05-0.15)	0.01 ± 0 (>0.02-0.01)	20.05 ± 7.46 (6.65-54.75)
Mid Lake Joondalup	0.05 ± 0.01 (>0.02-0.22)	1.57 ± 0.13 (0.34-2.61)	2.1 ± 0.65 (0.25-10)	0.04 ± 0.01 (>0.05-0.13)	0.012 ± 0.001 (>0.02-0.021)	6.72 ± 1.51 (0.54-25)
North Lake Joondalup	0.04 ± 0.01 (>0.02-0.19)	3.08 ± 0.25 (0.52-4.92)	1.97 ± 0.66 (0.17-10)	0.11 ± 0.02 (>0.05-0.34)	0.012 ± 0.001 (>0.02-0.022)	4.64 ± 0.32 (1.69-7.6)

Dissolved organic C concentrations were typical of Swan Coastal Plain wetlands and tended to increase slightly northwards (Figure 10). Concentrations of DOC were generally similar to 2015/16 however the rain in February 2017 appears to have increased DOC across all sites.

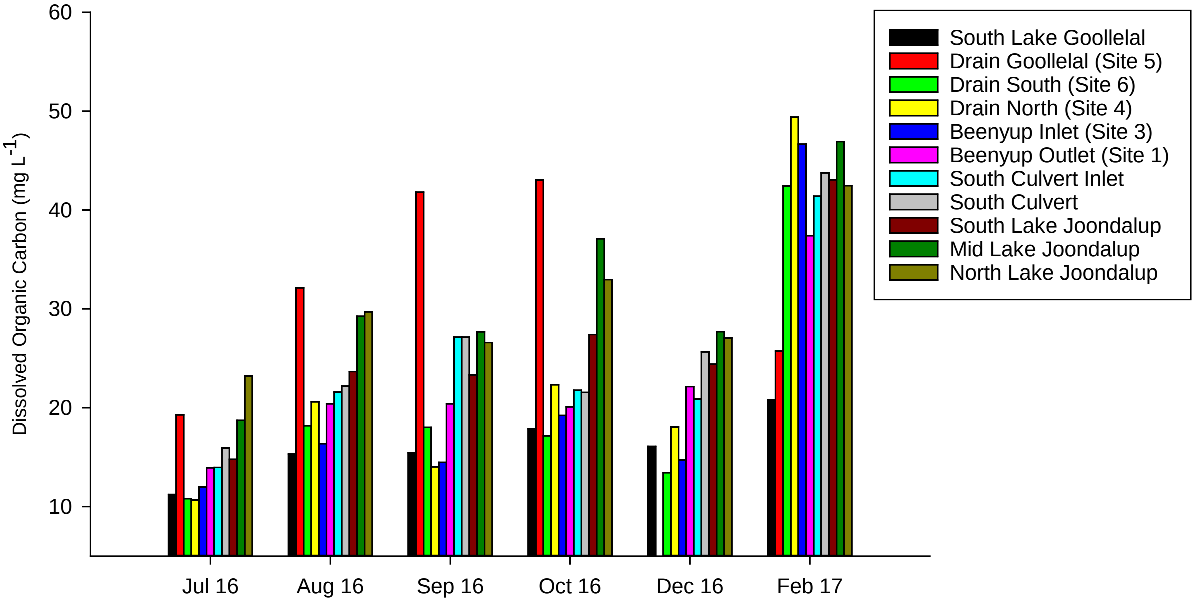


Figure 10. Dissolved organic C concentrations across the sites for the study period (June 2016 to May 2017)

Chlorophyll *a* is a measure of algal biomass and all the concentrations measured were relatively low. Chlorophyll a exceeded 10 µg L^{-1} on two occasions, September 2016 at South Culvert and February 2017 at South Lake Joondalup indicating likely blooms on these occasions (Figure 11). These blooms were not very severe (generally considered to be >100 µg L^{-1}) and would be difficult to see in the water.

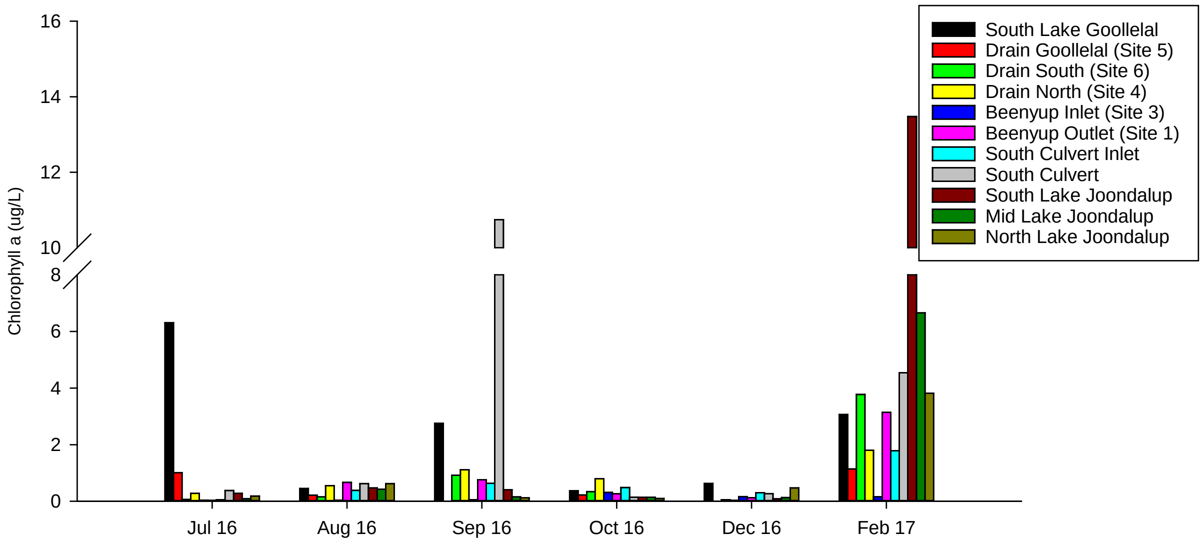


Figure 11. Chlorophyll *a* concentrations across the sites for the study period (May 2016 to June 2017).

Total phosphorus concentrations (Figure 12) exceeded the 60 µg L^{-1} ANZECC & ARMCANZ (2000) water quality guidelines for the 95% protection of aquatic ecosystems, at all sites except in Mid Lake Joondalup (Table 7). 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 8585 µg L^{-1} recorded in February 2017 again at $\text{Drain}_{\text{South}}$, this was substantially lower than in the previous year. The source of the high Total P concentrations at this drain site are not known but recur annually during the start of winter (or at times of major inflows including the unseasonal rain in February 2017).

The results show that Beenyup Swamp continues to export P (particularly as FRP) as recorded by Lund et al. (2011a). The South Culvert inlet and South Culvert had slightly higher P concentrations compared to $\text{Beenyup}_{\text{out}}$ which fits with that seen in 2014/15, where there appeared to be a source of P (assumed to be groundwater) between $\text{Beenyup}_{\text{out}}$ and the Culvert. This increase in P between $\text{Beenyup}_{\text{out}}$ and South Culvert inlet was not seen in 2015/16 - the low rainfall might have resulted in lowering of groundwater preventing it discharging P into the drain. Particularly interesting are the low concentrations of P recorded in Mid and later North Lake Joondalup in late spring and summer. Phosphorus declines from South Lake Joondalup to North/Mid Lake Joondalup, suggesting either: rapid uptake by the Lake Joondalup sediment, or the thick rushes between as the South Lake Joondalup site and Mid Lake Joondalup.

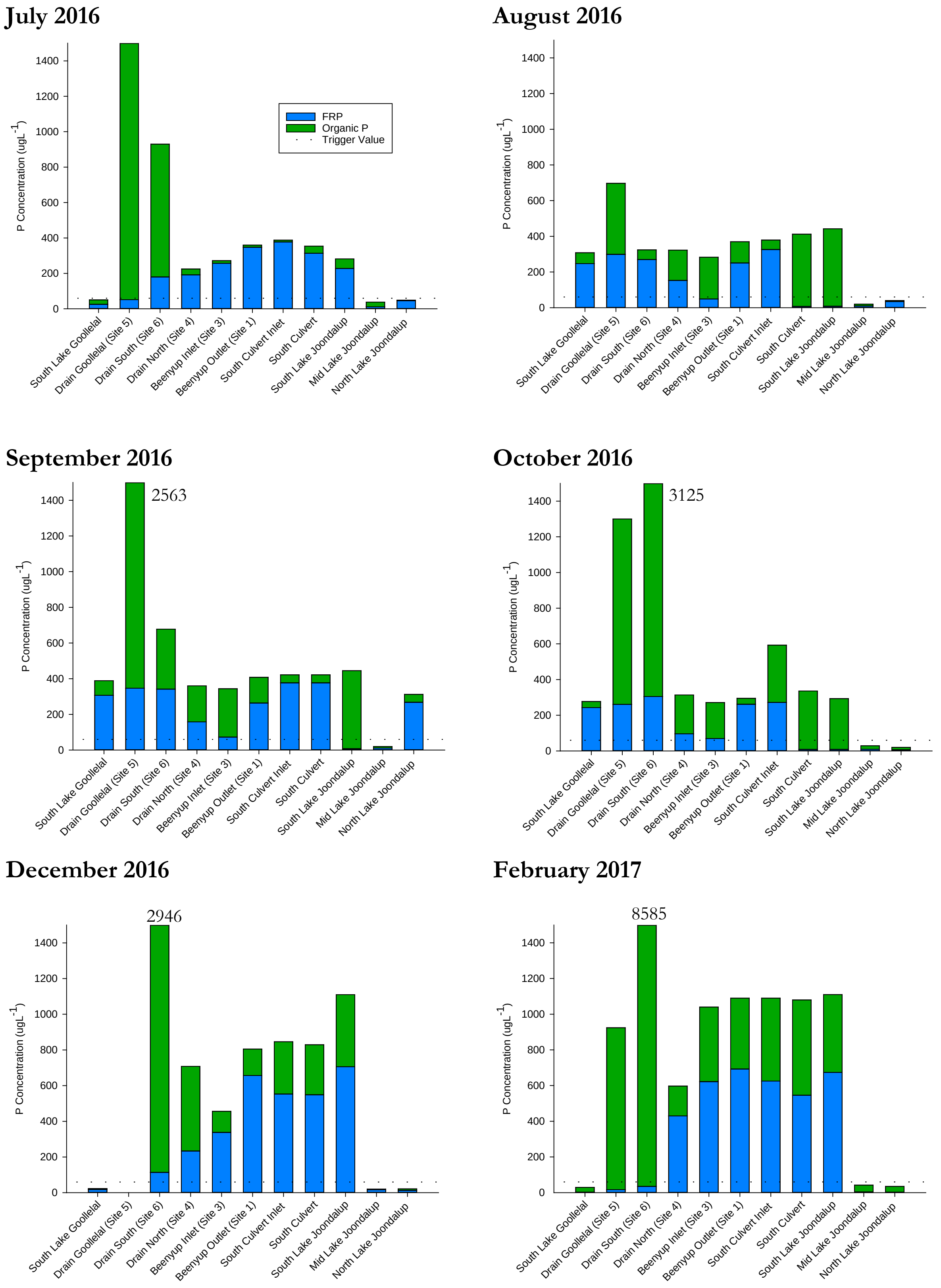


Figure 12. Breakdown of total phosphorus into chemical fractions (organic P and FRP) recorded in surface waters at each site between June 2016 and May 2017 with the ANZECC & ARMANZ (2000) trigger value for total phosphorus shown.

Total N concentrations occasionally exceeded the recommended ANZECC & ARMCANZ guidelines of 1500 μg L^{-1} (Figure 12 & Table 7), particularly during spring. The majority of the excessive N was in the form of organic N and is most likely associated with algae in the water. Algae and submerged plants in Lakes Joondalup and Goollelal probably account for the high concentrations seen in the lakes. The highest concentration recorded was 4403 μg L^{-1}, much lower than in 2015.16, for $Drain_{South}$ at the time of the peak Total P suggesting that an algal bloom was responsible – although this was not supported by chlorophyll a values. Relatively low (compared to previous years) concentrations of NOx and NH_3 were recorded throughout the system. 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. Further increases in N are apparent from $Beenyup_{out}$ through to South Lake Joondalup suggesting that there is a source of N – the most likely source is growth of plants and algae in South Lake Joondalup.

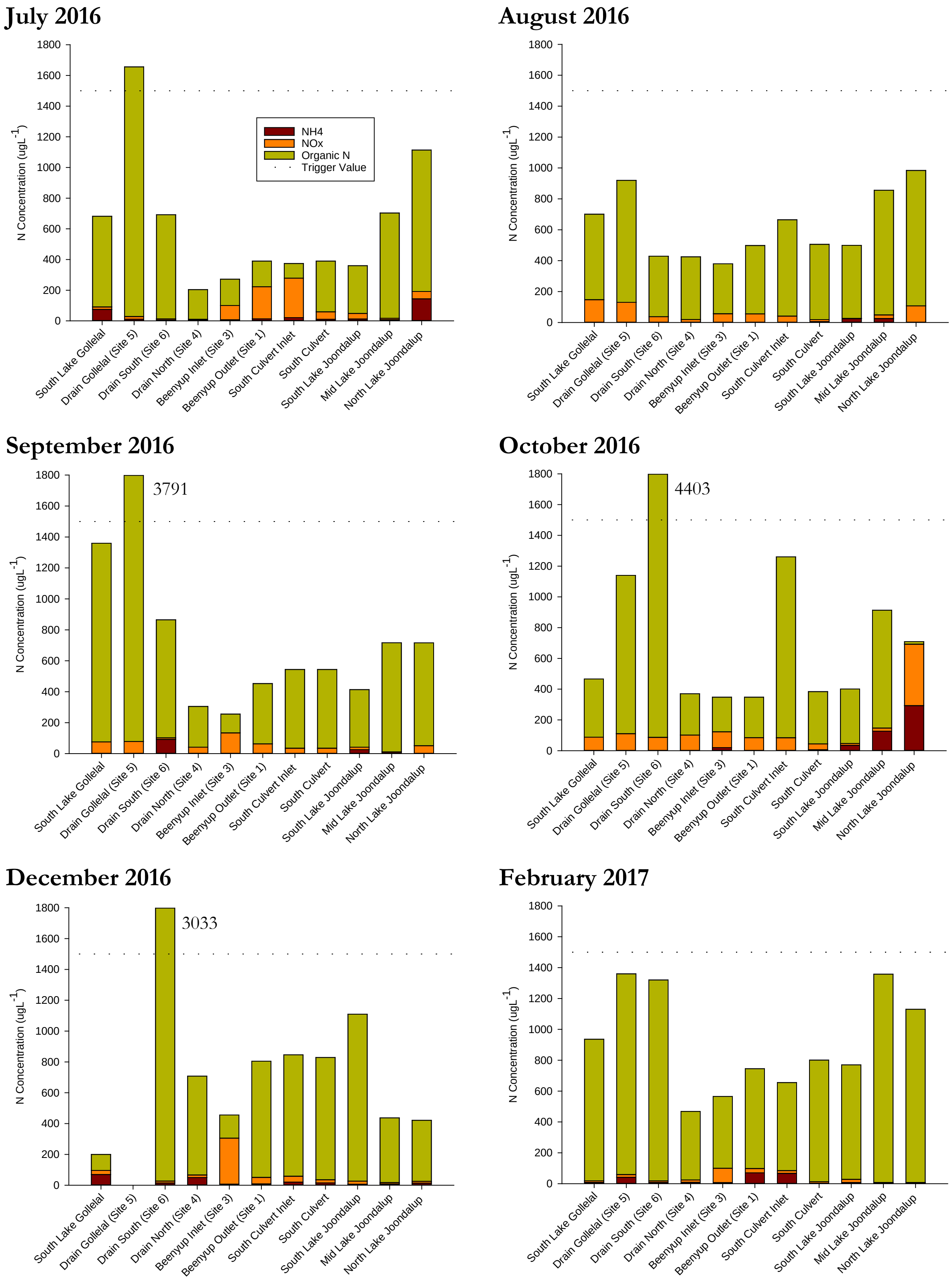


Figure 13. Breakdown of total nitrogen into chemical fractions (organic nitrogen, oxides of nitrogen and ammonia/ammonium) recorded in surface waters at each site between June 2016 and May 2017 with the ANZECC & ARMANZ (2000) trigger value for total nitrogen.

Table 7. Mean ± s.e. (range) for nutrients in water recorded at each study site over the course of the monitoring period (June 2016 - May 2017)

	NH_4-N mg.L^{-1}	NOx-N mg.L^{-1}	Total N mg.L^{-1}	Organic N mg.L^{-1}	FRP-P mg.L^{-1}	Total P mg.L^{-1}	Organic P mg.L^{-1}	DOC mg.L^{-1}
DL	>3	>2	>50		>2	>20		>0.5
South Lake Goollelal	26 ± 15 (>3-75)	60 ± 22 (9-146)	724 ± 163 (200-1360)	638 ± 169 (104-1284)	141 ± 57 (3-307)	179 ± 67 (23-389)	39 ± 11 (4-82)	16.1 ± 1.3 (11.2-20.8)
Beenyup Out (Site 1)	16 ± 11 (>3-71)	80 ± 27 (28-209)	540 ± 78 (348-805)	444 ± 91 (167-754)	413 ± 84 (251-693)	555 ± 130 (295-1090)	142 ± 56 (12-397)	22.4 ± 3.2 (13.9-37.4)
Beenyup In (Site 3)	7 ± 3 (>3-20)	129 ± 35 (55-298)	380 ± 48 (256-565)	243 ± 53 (122-465)	235 ± 91 (49-622)	444 ± 123 (271-1040)	210 ± 56 (15-418)	20.6 ± 5.3 (12-46.7)
Drain North (Site 4)	12 ± 8 (>3-50)	32 ± 14 (3-100)	413 ± 70 (204-708)	369 ± 67 (193-641)	211 ± 48 (96-430)	421 ± 77 (225-708)	211 ± 59 (33-474)	22.5 ± 5.7 (10.7-49.4)
Drain Goollelal (Site 5)	11 ± 8 (>3-41)	70 ± 23 (17-129)	1789 ± 534 (920-3870)	1708 ± 539 (790-3792)	195 ± 67 (17-347)	2158 ± 800 (697-4960)	1963 ± 820 (398-4909)	32.4 ± 4.6 (19.3-43)
Drain South (Site 6)	21 ± 14 (>3-92)	27 ± 12 (7-85)	1809 ± 659 (429-4490)	1762 ± 655 (392-4403)	208 ± 49 (35-342)	2840 ± 1271 (324-8620)	2633 ± 1307 (54-8585)	20 ± 4.6 (10.8-42.4)
South Culvert Inlet	19 ± 10 (2-67)	78 ± 37 (18-257)	724 ± 125 (374-1260)	627 ± 145 (95-1176)	422 ± 56 (272-625)	620 ± 119 (379-1090)	198 ± 76 (10-465)	24.5 ± 3.8 (14-41.4)
South Culvert	7 ± 1 (>3-16)	27 ± 3 (10-48)	576 ± 33 (384-829)	541 ± 34 (331-793)	300 ± 41 (8-549)	572 ± 51 (336-1080)	272 ± 33 (40-534)	26 ± 1.6 (15.9-43.8)
South Lake Joondalup	19 ± 5 (6-35)	18 ± 5 (2-36)	592 ± 120 (360-1110)	556 ± 123 (312-1083)	272 ± 137 (8-706)	614 ± 160 (282-1110)	341 ± 62 (54-437)	26.1 ± 3.8 (14.8-43.1)
Mid Lake Joondalup	31 ± 8 (4-127)	11 ± 1 (>2-23)	789 ± 51 (420-1350)	747 ± 53 (402-1342)	10 ± 1 (4-17)	28 ± 2 (>20-42)	18 ± 2 (3-38)	31.2 ± 1.6 (18.7-46.9)
North Lake Joondalup	76 ± 20 (>3-293)	103 ± 25 (4-399)	846 ± 46 (422-1130)	666 ± 67 (17-1122)	62 ± 17 (3-268)	80 ± 19 (>20-312)	17 ± 3 (3-44)	30.3 ± 1.1 (23.2-42.5)

10. CONCLUSION

In conclusion, this monitoring study found that there is ongoing evidence of possibly active acid sulphate soils throughout much of the park. However despite this, water quality was better than previously seen in the monitoring, with lower concentrations of most nutrients and metals. This apparent dichotomy is explained by currently natural neutralisation of acidity preventing high metal concentrations. Further although rainfall was low in 2015/16, it did not drop to the low levels seen in 2011/12 that appeared to trigger the substantial increase in metals that has lasted in the system for the last few years. Despite the lack of apparent impact on water quality, it is noted that pH seems to be dropping over time very slowly a phenomena also noted by DOW monitoring (Michael Hammond, DOW, pers. comm.). There remains a real risk that at some point the natural ability of the wetland system to buffer incoming acidity may be lost or severely reduced leading to significant problems. Active acid sulphate soils are an ongoing problem for the wetland system and currently our understanding of the location of the soils is limited. A detailed ASS mapping exercise across the park and Wanneroo catchment would allow the extent of the problem to be understood and then managed.

Apparently caused by a different phenomenon, the recurrent high concentrations of mercury seen each year, reached high levels in this monitoring year. The source of mercury remains unknown, however it appears for only a one or two months (June 2016) and then returns back to low concentrations. Selenium was noted as a contaminant in 2015/16, however this was not the case in 2016/17.

Physical parameters and nutrients also exceeded ANZECC & ARMCANZ (2000) national water quality guidelines for the protection of aquatic ecosystems (95%) throughout the flow path of Yellagonga waters on occasion. Nutrient patterns followed those of previous years, indicating high levels of enrichment up until Mid Lake Joondalup. Nutrient levels were generally lower than previous years, possibly due to dilution by the high rainfall. The wetlands remain a complex system of interacting pressures, namely drying, acidification and eutrophication. The current monitoring program provides ongoing warning of major trends within the wetland system.

11. RECOMMENDATIONS

1. It is recommended that the monitoring program continue for 2017/18 using the current parameters. Although water quality was better in some respects than in previous years, there remain concerns with evidence of ongoing acid sulphate soils and occasional peaks in mercury concentrations that warrant ongoing monitoring.
2. As mercury has been an ongoing contaminant in the wetlands, often reaching high concentrations. It is recommended that a study be instigated to attempt to track down likely sources, given that all sites showed contamination in June 2016, this would suggest either rainfall or an aerial source. The proposed study would focus on collection of local rain samples and airborne particulates during winter to confirm or eliminate this as the main source.
3. The revised monitoring schedule used in 2016/17 appears to be working yielding similar results to previous years but providing more detail when it matters (ie. when it is wet), data that will be better match the midge data.
4. The concentrations of particularly mercury in the wetlands on occasion pose a risk to humans and animals (including dogs) drinking the water. Although, the chances of any animal or person drinking a lethal dose are low, some warning signs may prevent possible problems in the future.
5. Acid sulphate soils remain an ongoing threat to the Yellagonga Lake System and it is recommended that initially a mapping of possible sources be undertaken within the park and Wanneroo catchment – to reveal the extent of the problem and opportunities for control.
6. As drying is the main threat to the Yellagonga Lake System, it is recommended to develop reliable water budgets for at least Lakes Joondalup and Goollelal would allow permit opportunities for increasing inflows and reducing losses to be explored. The Smart Cities application by the two Cities, ECU, Sensing Value and Telstra would address this recommendation.
7. Although nutrient concentrations are relatively low in Lake Goollelal, there are occasionally high concentrations that might encourage algal blooms and indirectly midge problems. It is recommended that a nutrient and water budget for Lake Goollelal would help identify the major sources (potentially septic systems on the eastern side) and provide a basis for improved management actions to maintain water quality within the lake.

12. REFERENCES

ANZECC/ARMCANZ (2000) Australian and New Zealand guidelines for fresh and marine water quality, Volume 2. Aquatic ecosystems - rationale and background Information, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

APHA (1999) Standard methods for the examination of water and wastewater, American Public Health Association, American Water Works Association, Water Environment Federation, Washington DC, USA1,220.

Boardman, L. (2000) Metaphyton in Lake Joondalup, Bachelor of Engineering (Environmental), University of Western Australia, Perth, Australia, 82.

Bryant, T. (2000) The release of phosphorus from wetland sediment: A study of Lake Joondalup., University, E.C., Edith Cowan University, Perth.

Department of Environmental Regulation (2015) Identification and investigation of acid sulfate soils and acidic landscapes. Regulation, D.o.E. (ed), p. 72, Government of Western Australia, Perth, Western Australia.

Department of Local Government and Planning and Department of Natural Resources and Mines (2002) State Planning Policy 2/02 Guideline: Planning and Managing Development involving Acid Sulfate Soils, Mines, Q.D.o.L.G.a.P.D.o.N.R.a., Indooroopilly Brisbane, QLD, Australia.

Dooley, B., Bowra, T., Cluning, D. and Thompson, P. (2003) Yellagonga Regional Park: management plan, 2003-2013, Department of Conservation and Land Management, C.o.W., City of Joondalup: Western Australia, Perth.

Goldsmith, K., Lund, M.A. and McCullough, C.D. (2008) Nutrient Loading in Sediment of Beenyup Swamp (Yellagonga Regional Park), University, E.C., MiWER/Centre for Ecosystem Management, Perth, 32.

Hamann, J.A. (1992) Lake level changes within the Yellagonga Regional Park: A historical perspective. Honours, Edith Cowan University, Perth.

Kinnear, A., Garnett, P., Bekle, H. and Upton, K. (1997) Yellagonga wetlands: A study of the water chemistry and aquatic fauna, Edith Cowan University, Perth.

Lund, M., McCullough, C. and Newport, M. (2011a) Nutrient and metal loads in and out of Beenyup Swamp, Mine Water and Environment Research Centre/Centre for Ecosystem Management, 20011-15, Perth, 55.

Lund, M.A. (2007) Midge Desktop Audit 2007, Centre for Ecosystem Management, 2007-08, Perth.

Lund, M.A., McCullough, C.D., Somesan, N., Edwards, L. and Reynolds, B. (2011b) Yellagonga wetlands nutrient and metal study, Centre for Ecosystem Management, E.C.U., City of Wanneroo, City of Joondalup and Department of Environment and Conservation, 2009-15, Perth, Western Australia, 43.

McArthur, W.M. and Bartle, G.A. (1980) landforms and soils as an aid to urban planning in the Perth metropolitan north west corridor, Western Australia, CSIRO, CSIRO, Melbourne.

Newport, M., Lund, M. and McCullough, C.D. (2011) Yellagonga Regional Park wetlands water quality monitoring 2011 report, Management, M.W.a.E.C.C.f.E., Edith Cowan University, 2011-08 Report to the City of Joondalup, Perth, 51.

Ove Arup & Partners (1994) Yellagonga Regional Park Drainage Study, Wanneroo, R.t.t.C.o., Perth.

Rose, T.W. (1979) Periphyton and metaphyton in Lake Joondalup, University of Western Australia.

Sommer, B. (2006) Drying and re-wetting of organic wetland sediments: Biogeochemistry and implications for wetland management. Ph.D. , Edith Cowan University, Perth.