June 2016

Yellagonga Regional Park wetlands water quality monitoring 2015/16 report

By, Jay Gonzalez-Pinto
Mark Lund

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

Mine Water and Environment Research Centre

Report No. 2016-5

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. (2016). *Yellagonga Regional Park wetlands water quality monitoring 2015/16 report.* Mine Water and Environment Research/Centre for Ecosystem Management Report No. 2016-5, Edith Cowan University, Perth, Australia. 44pp. Unpublished report to the Cities of Joondalup and Wanneroo.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 May 2015 to 2016.
3. All parameters recorded were compared to the ANZECC & ARMCANZ (2000) national water quality trigger values for the 95% protection of aquatic ecosystems. In 2015/2016 water quality was improved compared to previous years with only limited exceedances of guideline concentrations over slightly more elements (Al, As, Hg, Se and Zn). Exceedances of selenium are a new development and given concerns with selenium toxicity around the world, this is an important development that requires ongoing monitoring. The source of the selenium is unknown.
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 may result in metal release and acidity in 2016/17. These metals are detrimental to the ecological integrity of Yellagonga wetlands and potentially the groundwater west of the regional park.
5. Recommendations from this report include supporting ongoing monitoring of the wetland system, with a revised monitoring schedule that should better represent conditions in the lakes.

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 $\text{Drain}_{\text{Goollelal}}$ in this project (Newport and Lund 2013). The area around $\text{Drain}_{\text{Goollelal}}$ 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 $\text{Drain}_{\text{Goollelal}}$ 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 $\text{Drain}_{\text{Goollelal}}$.

The purpose of this study is to report on the seventh year (July 2015 to June 2016) 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.

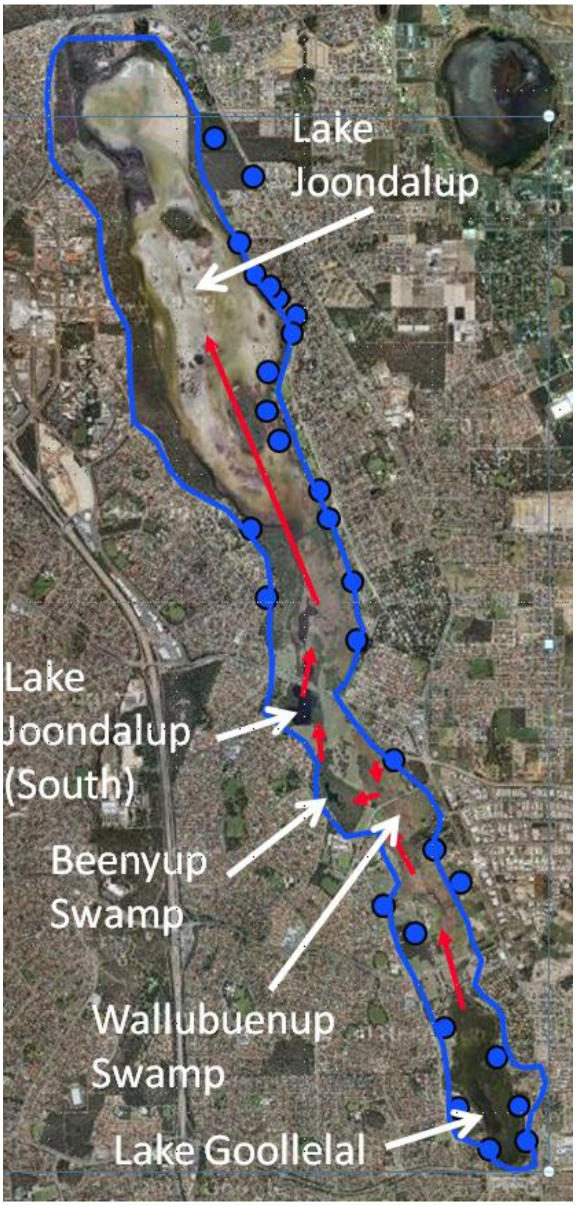


Figure 1. Direction of water flow through the Yellagonga Regional Park wetlands. Blue dots indicate drains entering the system; taken from Ove Arup & Partners (1994) and GoogleMaps (2014).

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

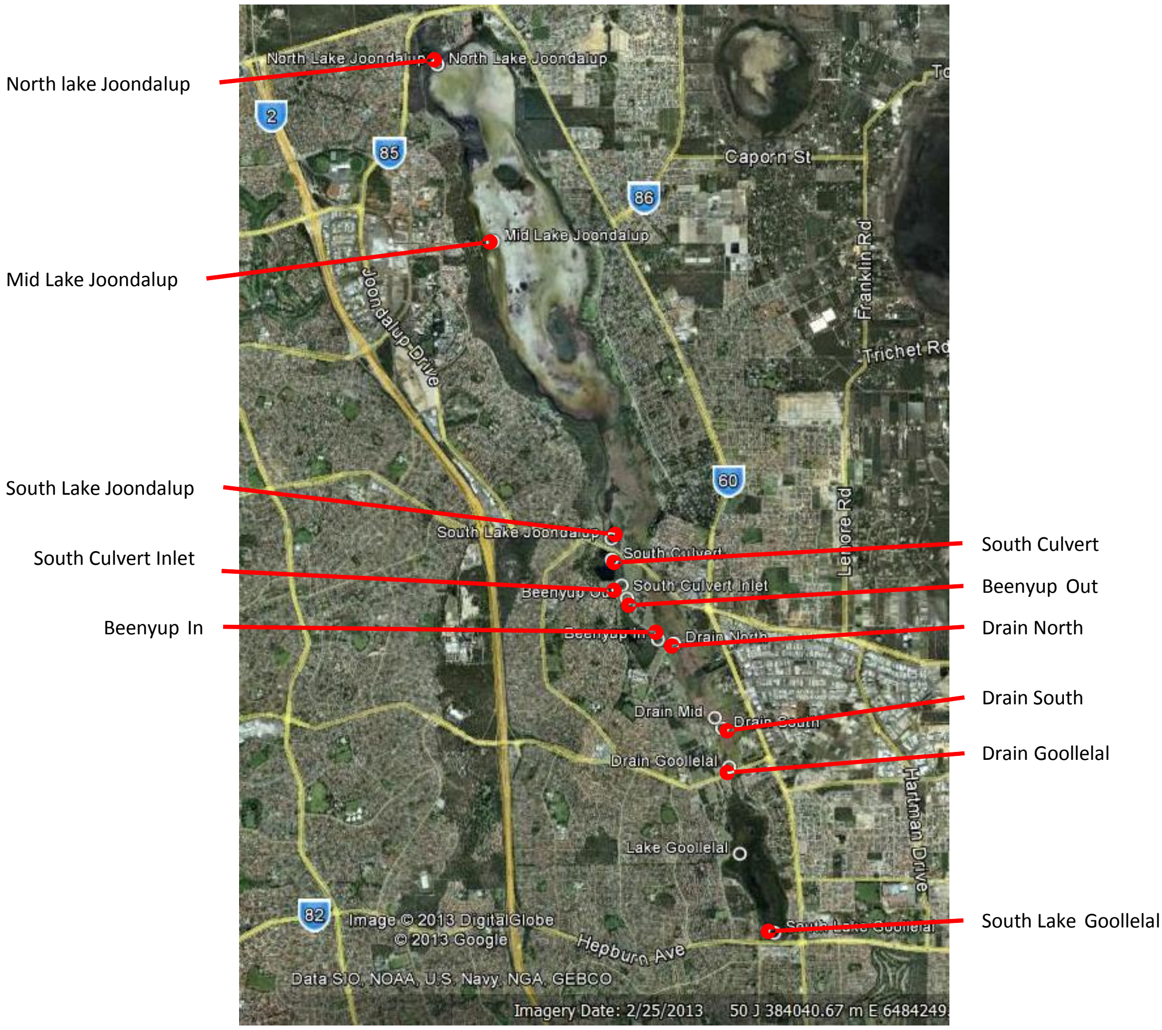


Figure 2. Locations of the thirteen study sites in Yellagonga Regional Park (adapted from Google Earth).

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.

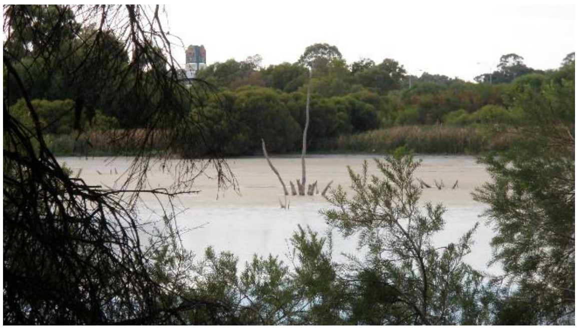
Mid Lake Joondalup – Neil Hawkins Park.
North Lake Joondalup – The northernmost site of the study area.

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 thirteen sites.

a) South Lake Goollelal

November 2015 (wet)

March 2016 (dry)



b) $\text{Drain}_{Goollelal}$ (Site 5)

November 2015 (wet)

March 2016 (dry)

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

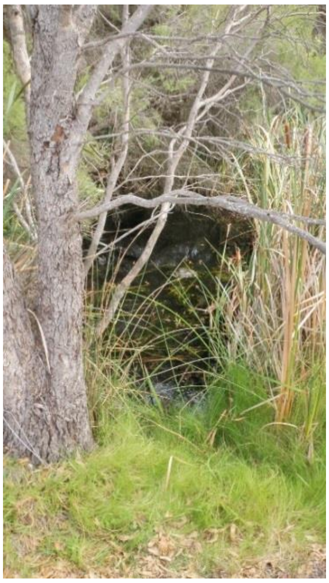
September 2015 (wet)

March 2016 (dry)

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

September 2015 (wet)

March 2016 (dry)



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

September 2015 (wet)

March 2016 (dry)

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

September 2015 (wet)

March 2016 (dry)

g) South Culvert Inlet

September 2015 (wet)

March 2016 (dry)

h) South Culvert

September 2015 (wet)

March 2016 (dry)

i) South Lake Joondalup

September 2015 (wet)

March 2016 (dry)

j) Mid Lake Joondalup

September 2015 (wet)

March 2016 (dry)

k) North Lake Joondalup

September 2015 (wet)

March 2016 (dry)

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

8. METHODS

This report covers bi-monthly sampling between the July 2014 and June 2015, 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 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.

9. RESULTS AND DISCUSSION

Rainfall during the period of this study (July 2015- June 2016) totalled 640.6 mm which was higher than in 2014-15 (619.3 mm), but lower than 2013-14 (852.3 mm), 2012-13 (743.2 mm), 2011-12 (761.9 mm) but greater than 2010-2011 (507.1 mm) monitoring period (Figure 4).

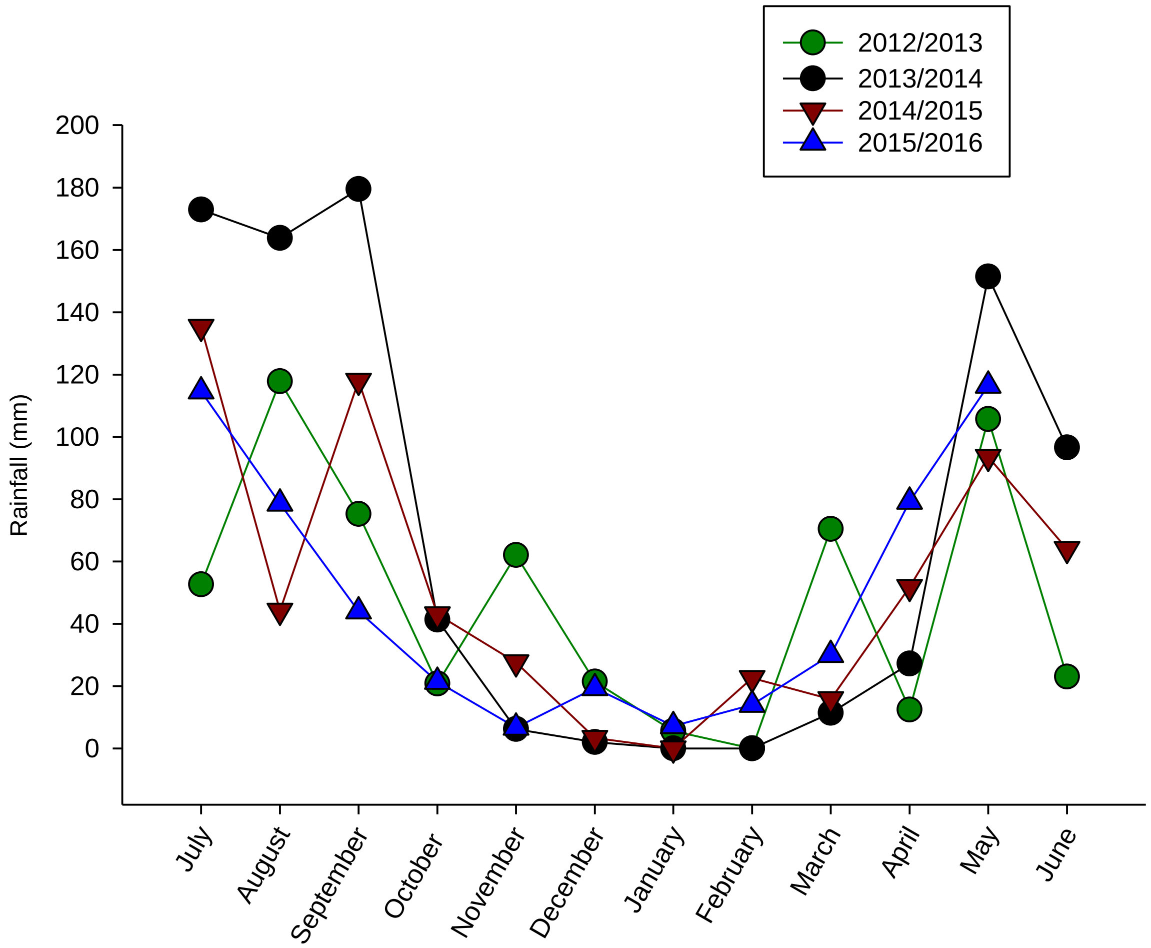


Figure 4. Monthly rainfall totals for 2012/13, 2013/14, 2014/15 and 2015/16 monitoring periods from data obtained from the Bureau of Meteorology, climate data from Wanneroo.

All sites were sampled in July, September and November ($Drain_{Goollelal}$ excepted) 2015 (Table 1), Lake Joondalup was too dry in March and May 2016 to sample. South Lake Goollelal and $Drain_{Goollelal}$ were too dry to sample throughout most of the year. South Culvert was also too dry to sample in January and March 2016. The low rainfall of 2015/16 resulted in one of the driest sampling periods in Yellagonga monitoring history.

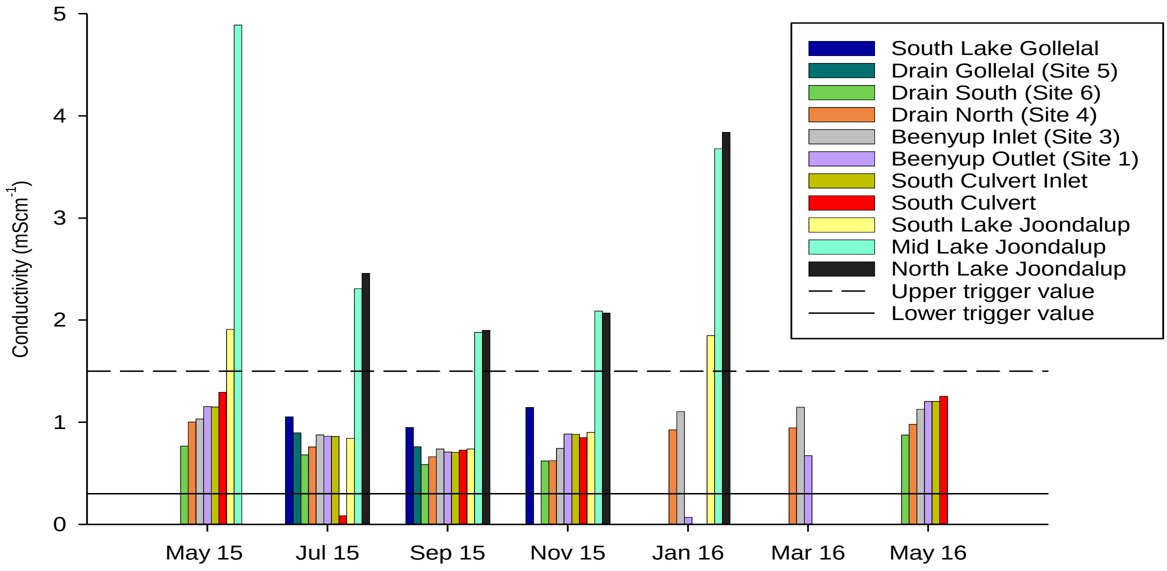
Table 1. Occasions when sites were sampled between May 2015 and 2016 (S= sampled).

	May	July	September	November	January	March	May
South Lake Goollelal		S	S	S			
Beenyup Out (Site 1)	S	S	S	S	S	S	S
Beenyup In (Site 3)	S	S	S	S	S	S	S
Drain North (Site 4)	S	S	S	S	S	S	S
Drain Goollelal (Site 5)		S	S				
Drain South (Site 6)	S	S	S	S			S
South Culvert Inlet	S	S	S	S			S
South Culvert	S	S	S	S			S
South Lake Joondalup	S	S	S	S	S		
Mid Lake Joondalup	S	S	S	S	S		
North Lake Joondalup		S	S	S	S		

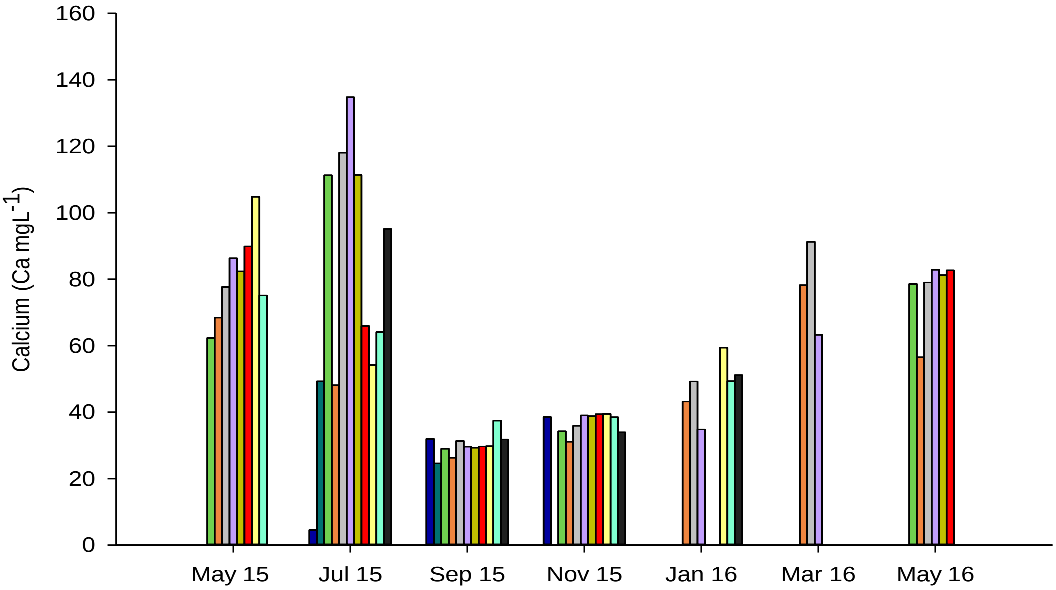
9.1 PHYSICO-CHEMISTRY

The low rainfall in 2015/16 reduced water in the system leading to high electrical conductivities (EC) across the system, slightly higher than in 2014/15. The highest EC was recorded in the Lake Joondalup (Mid and North), although unlike in 2014/15, March and May in 2016 values were low (probably due to higher rainfall in these months) (Figure 5a). Evapoconcentration of solutes in the water is evident at the time of lowest water levels (summer) and is reflected in EC, and Ca, K, Mg, Na and Cl. The greatest concentrations of these solutes tend to occur in Mid and North Lake Joondalup (Figure 5). In general, at all sites mean concentrations and ranges were similar for solutes in this year compared to 2015-2016 despite the reduced rainfall.

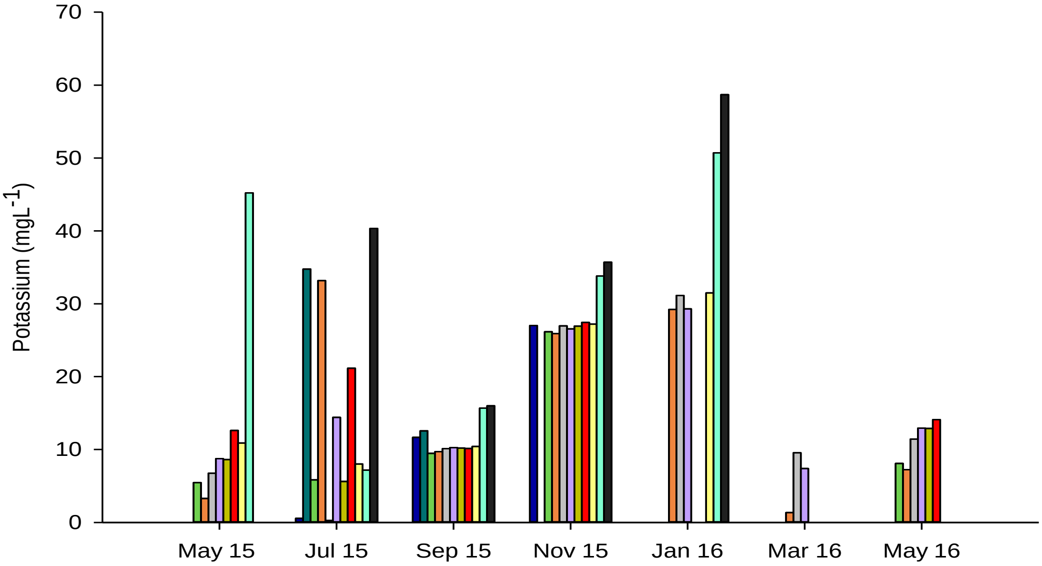
a) Electrical conductivity



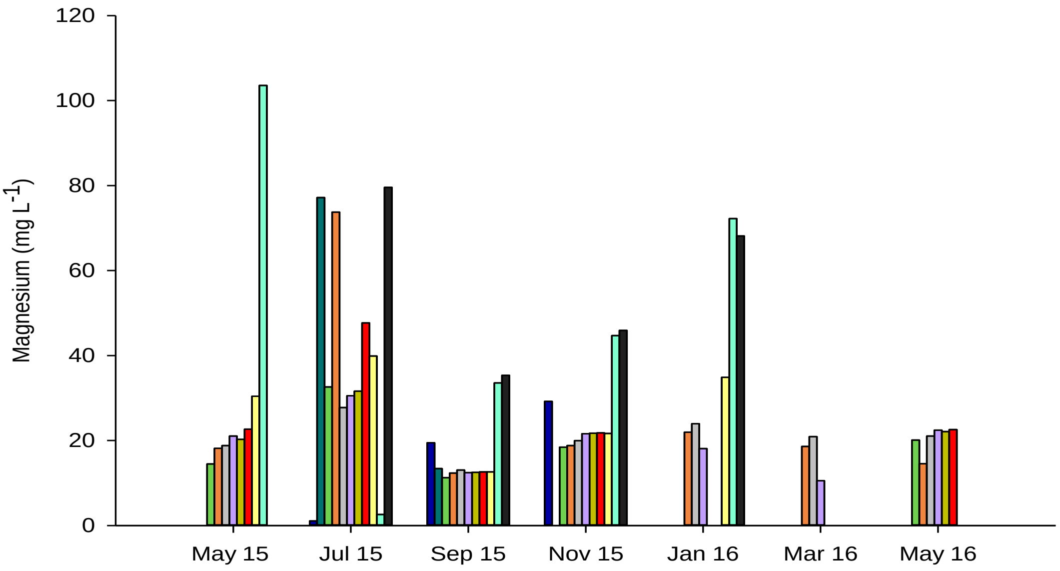
b) Calcium (Ca)



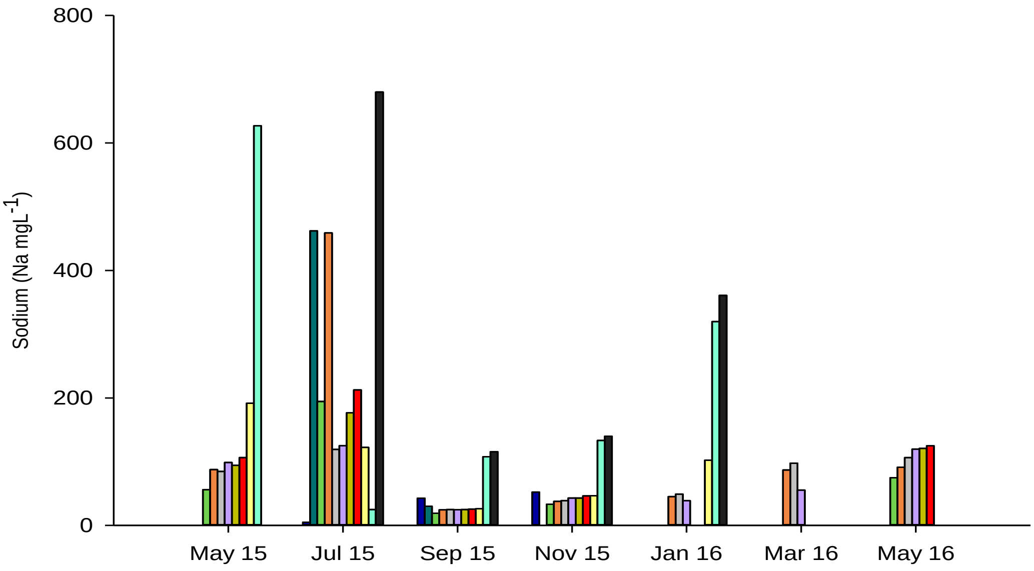
c) Potassium (K)



d) Magnesium (Mg)



e) Sodium (Na)



f) Chloride (Cl)

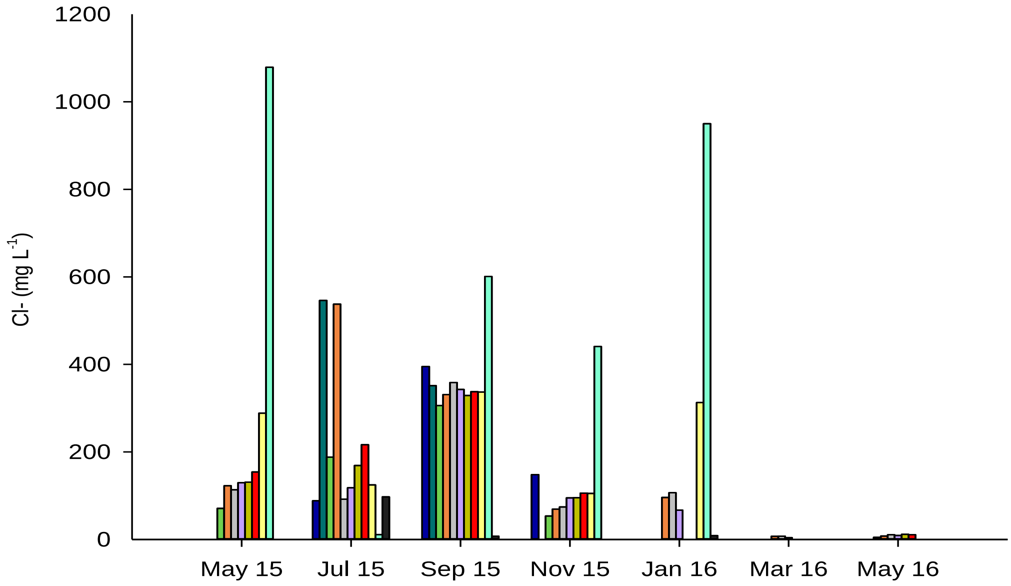


Figure 5. Changes in a) electrical conductivity, b) calcium, c) potassium, d) magnesium, e) sodium, and f) chloride over the period of monitoring at each site (May 2015- 2016).

Table 2 Mean ±SE (range) for selected solutes (in mg L^{-1}) during the study period May 2015 to 2016

	Ca	K	Mg	Na
DL	**<0.2**	**<0.2**	**<0.2**	**<0.2**
South Lake Goollelal	25 ± 10 (5-72)	13 ± 8 (1-21)	17 ± 8 (1-48)	33 ± 14 (5-213)
Beenyup Out (Site 1)	67 ± 14 (30-135)	16 ± 3 (7-29)	20 ± 3 (11-31)	72 ± 16 (25-125)
Beenyup In (Site 3)	69 ± 12 (31-118)	14 ± 4 (0-31)	21 ± 2 (13-28)	74 ± 14 (25-119)
Drain North (Site 4)	50 ± 7 (26-78)	16 ± 5 (1-33)	25 ± 8 (12-74)	119 ± 58 (25-459)
Drain Goollelal (Site 5)	37 ± 12 (25-49)	24 ± 11 (13-35)	45 ± 32 (13-77)	246 ± 216 (30-462)
Drain South (Site 6)	63 ± 15 (29-111)	11 ± 4 (5-26)	19 ± 4 (11-33)	76 ± 31 (19-195)
South Culvert Inlet	69 ± 15 (29-111)	13 ± 4 (6-27)	22 ± 3 (13-32)	92 ± 27 (25-177)
South Culvert	62 ± 5 (30-90)	17 ± 1 (10-27)	25 ± 3 (13-48)	103 ± 15 (26-213)
South Lake Joondalup	58 ± 13 (30-105)	18 ± 5 (8-31)	28 ± 5 (13-40)	98 ± 29 (26-192)
Mid Lake Joondalup	53 ± 3 (37-75)	31 ± 4 (7-51)	51 ± 8 (3-104)	243 ± 48 (25-627)
North Lake Joondalup	53 ± 7 (32-95)	38 ± 4 (16-59)	57 ± 5 (35-80)	324 ± 65 (116-680)

Mean water hardness was calculated for each site across the year. 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 had significantly dropped across all sites (Figure 6). In 2012-2013, the hardness has continued to drop, with most sites now 'hard' to 'very 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 2011-2012 was just over half this at North Lake Joondalup (Figure 6). The maximum hardness was recorded at North Lake Joondalup at 227 mg $CaCO_3L^{-1}$. In 2014-2015, hardness increased slightly for all sites except $Beenyup_{In}$ over last year reflecting the lower rainfall and possibly the reduced sampling frequency. In 2015/16 was very similar to 2014/15, although it dropped substantially in South Lake Goollelal, although the reason for this is unknown. The drains and Lake Goollelal were generally hard rather than very hard as Lake Joondalup. Hardness of water is important for the influence it has on the toxicity of some metals, with higher hardness reducing toxicity.

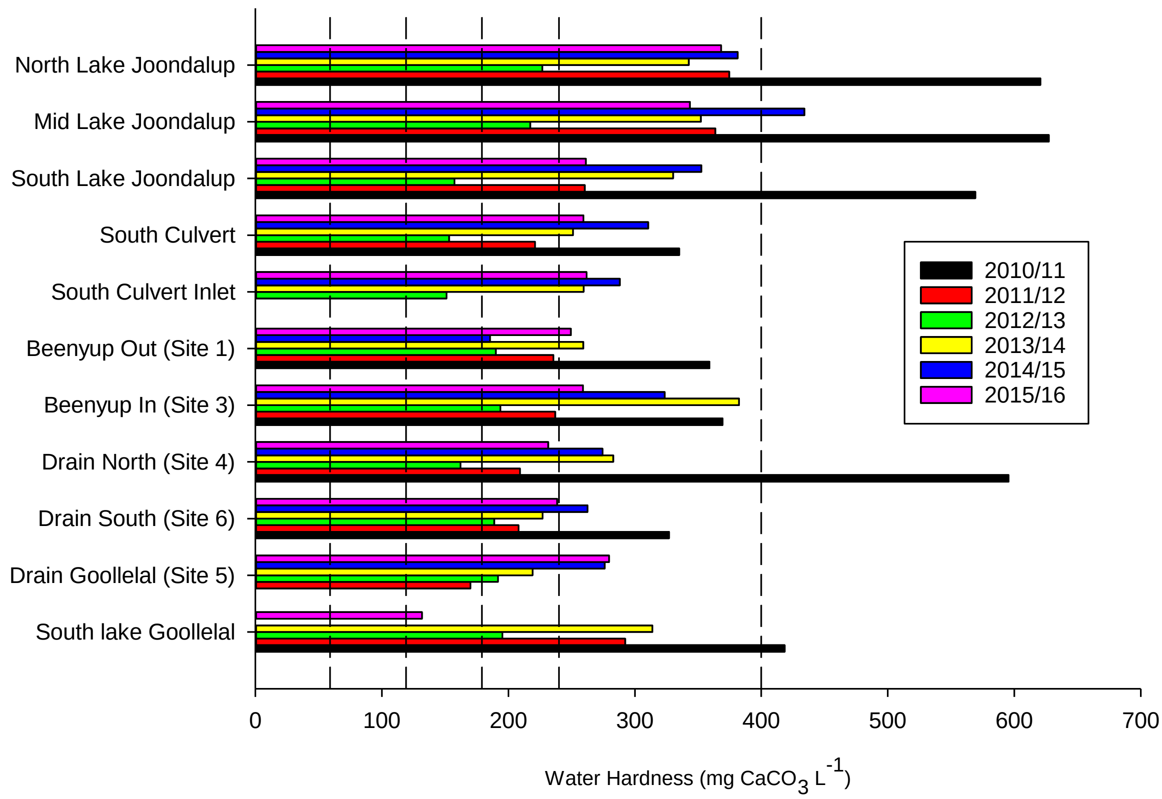
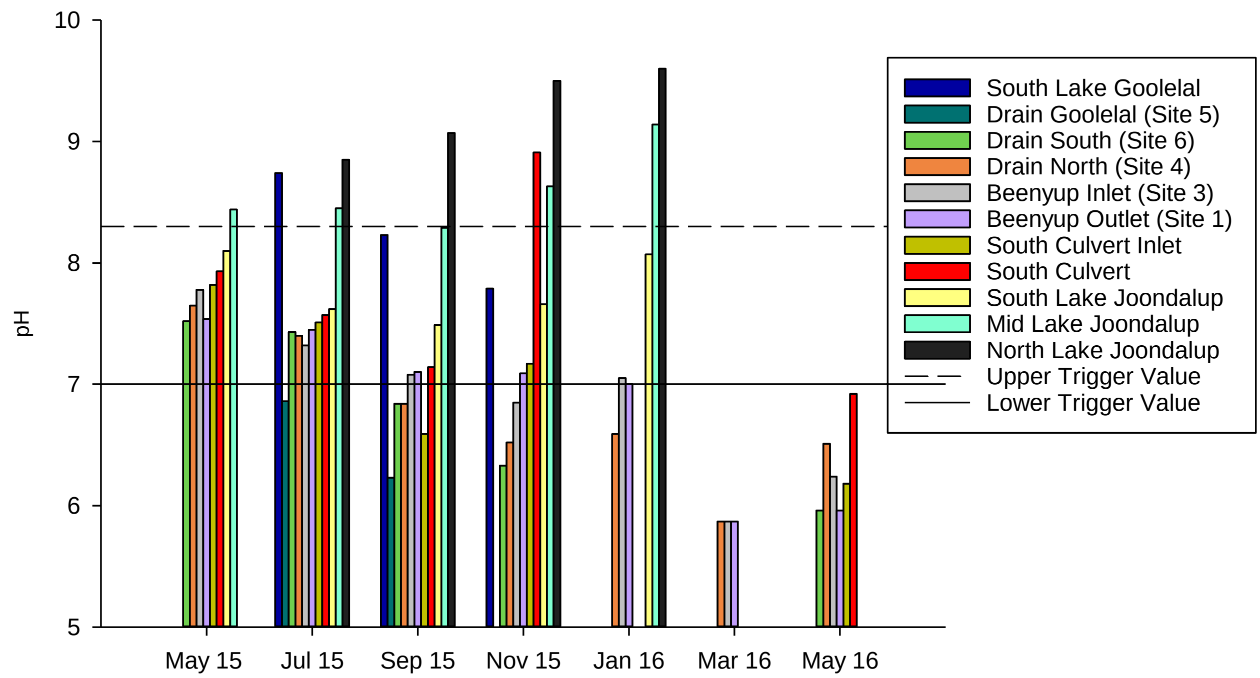


Figure 6. Calculated mean water hardness of each site for the three consecutive years of monitoring, with ANZECC/ARMCANZ (2000) categories indicated.

ANZECC/ARMCANZ (2000) water quality guidelines for the 95% protection of aquatic ecosystems recommend wetland pH levels between 7.0 and 8.5 (Figure 7). Although pH remained in or above the guideline values until January 2016 for most sites and particularly Lake Joondalup (presumably driven by evapo-concentration or algal blooms). At the drain sites and Lake Goollelal, pH slowly dropped to just below 6 in March 2016, although appeared to be increasing with winter rainfall in May 2016. Although pH in 2016 dropped, it did not reach critical levels but was suggestive of acid sulphate soils.

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 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, this year 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 $\text{Drain}_{\text{Goollelal}}$ 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 $\text{Drain}_{\text{Goollelal}}$ 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. Experimentally we have investigated the likelihood of acidification following natural drying of Lake Goollelal sediment and it appears to be unlikely as we suspect that organic matter coats the pyrite preventing it from oxidising.

a) pH



b) Sulphate (SO_4)

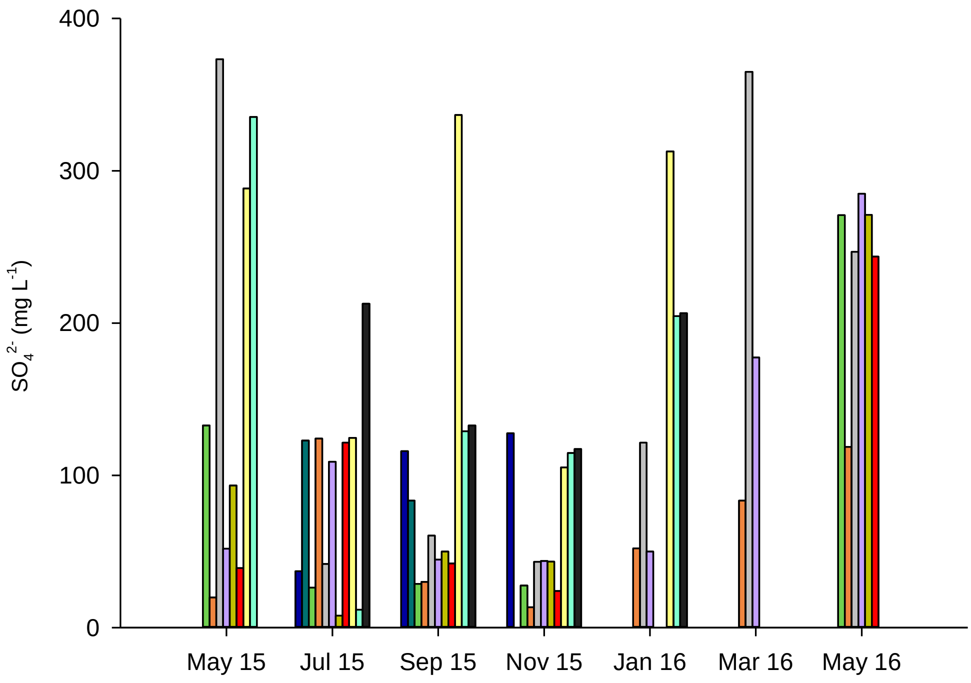


Figure 7. Changes in a) pH, and b) sulphate over the period of monitoring at each site (May 2015 – May 2016) with ANZECC & ARMCANZ (2000) trigger values for the protection of aquatic ecosystems (95%).

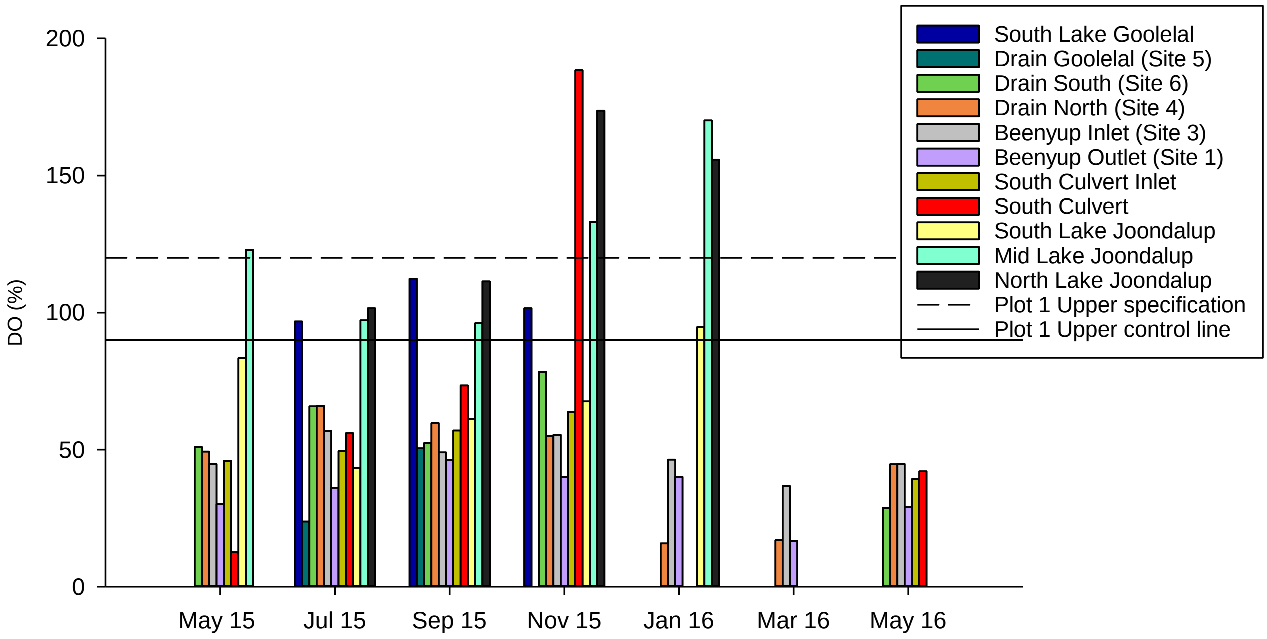
Table 3. Mean ±SE (range) for variables associated with acid sulphate soils (in mg L^{-1}) during the study period May 2015 to 2016

DL	Cl^- <0.5	SO_4^{2-} <0.5	SO_4:Cl Molar ratio	Alkalinity mg$CaCO_3$ L^{-1}	Alkalinity:SO_4 Mass ratio
South Lake Goollelal	210 ± 94 (88-189)	94 ± 28 (37-138)	6 ± 2 (3-21)	93 ± 12 (77-0)	1 ± 0 (1-0)
Beenyup Out (Site 1)	109 ± 43 (4-343)	109 ± 35 (44-285)	6 ± 3 (0-21)	162 ± 19 (120-240)	2 ± 1 (1-4)
Beenyup In (Site 3)	109 ± 45 (7-359)	179 ± 56 (42-373)	4 ± 2 (0-16)	158 ± 14 (103-200)	2 ± 1 (1-3)
Drain North (Site 4)	167 ± 74 (7-538)	63 ± 17 (14-124)	11 ± 4 (0-30)	171 ± 13 (133-213)	4 ± 1 (1-10)
Drain Goollelal (Site 5)	449 ± 98 (351-546)	103 ± 20 (84-123)	12 ± 0 (11-12)	87 ± 20 (67-107)	1 ± 0 (1-1)
Drain South (Site 6)	125 ± 54 (5-306)	97 ± 48 (26-271)	11 ± 6 (0-29)	180 ± 21 (143-240)	4 ± 1 (0-7)
South Culvert Inlet	147 ± 52 (12-329)	93 ± 47 (8-271)	17 ± 11 (0-58)	158 ± 18 (127-210)	6 ± 4 (1-18)
South Culvert	165 ± 24 (11-337)	94 ± 18 (24-244)	10 ± 2 (0-22)	160 ± 6 (140-197)	3 ± 1 (1-6)
South Lake Joondalup	234 ± 49 (105-337)	59 ± 25 (20-155)	18 ± 7 (2-42)	197 ± 43 (140-323)	7 ± 3 (1-16)
Mid Lake Joondalup	616 ± 85 (11-1079)	159 ± 24 (12-335)	9 ± 1 (3-13)	148 ± 5 (120-163)	4 ± 2 (1-14)
North Lake Joondalup	703 ± 59 (435-986)	167 ± 12 (117-213)	11 ± 0 (10-13)	187 ± 34 (100-387)	1 ± 0 (0-2)

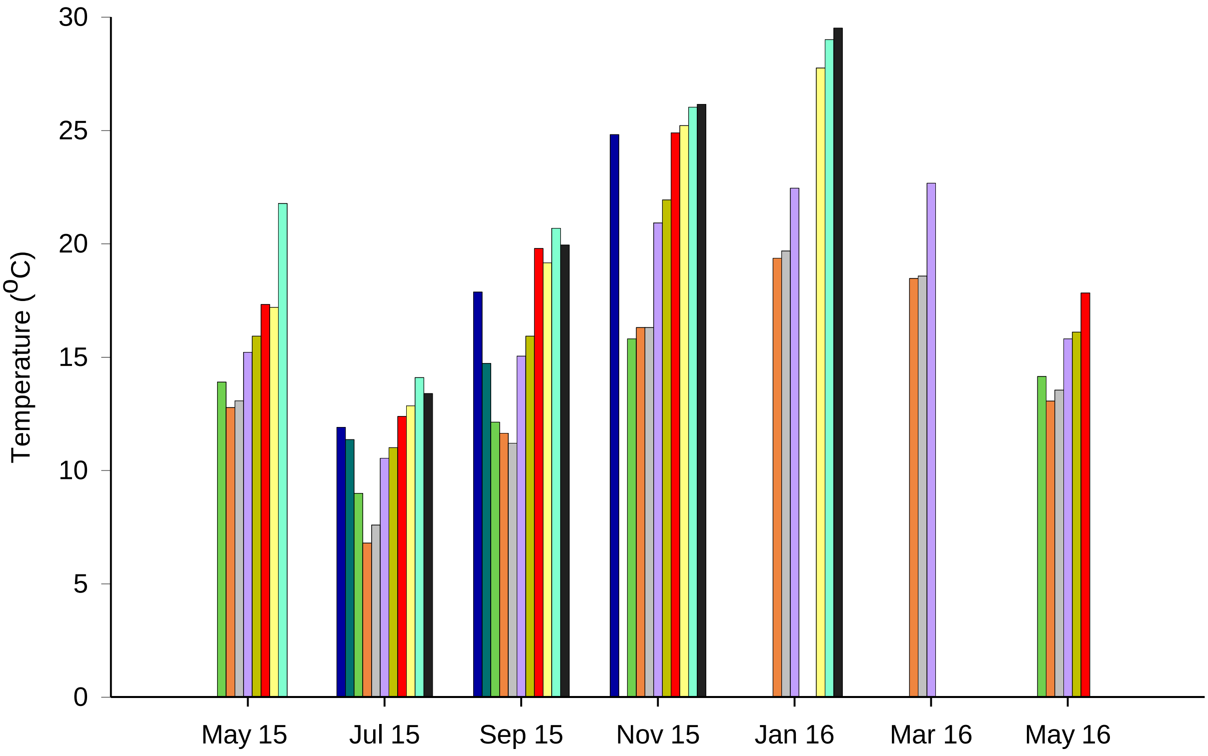
The ANZECC and ARMCANZ (2000) trigger values for dissolved oxygen are set at above 90% and below 120%. During the period of this study all sites breached trigger values, except Mid Lake Joondalup and Lake Goollelal (Figure 8, Table 4). The lakes Goollelal and Joondalup generally exceeded the upper trigger value; this is most likely due to algae or aquatic plants in the water producing oxygen through photosynthesis. 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 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, unlike in previous years when only one negative ORP value was recorded.

Water temperatures rose from July 2015 to January 2016 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

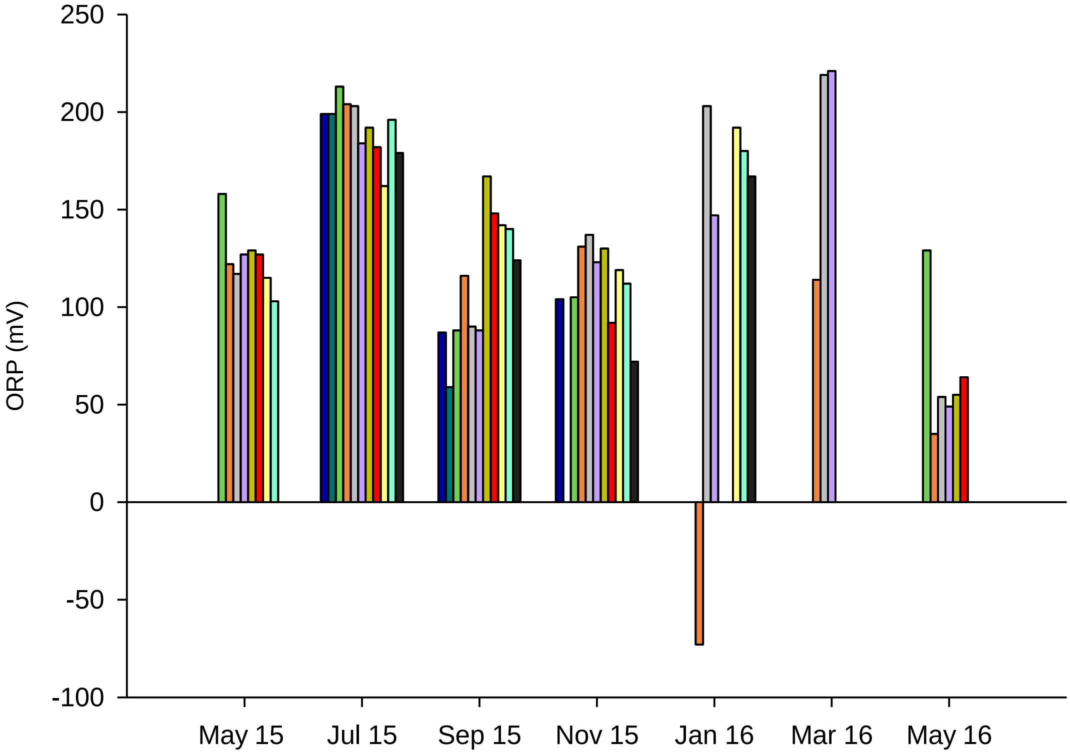


Figure 8. Changes in a) dissolved oxygen, b) temperature and c) ORP between May 2015 and 2016 at each site with ANZECC & ARMCANZ (2000) trigger values.

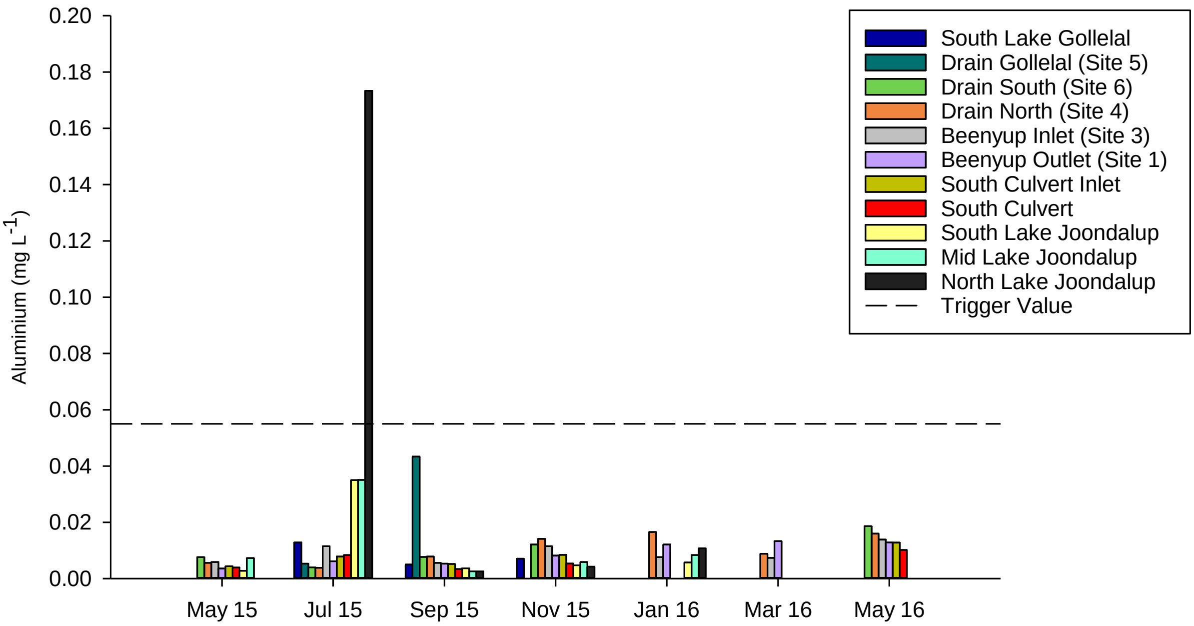
Table 4. Mean ± standard error (range) for physicochemical variables over the study period (May 2015 - 2016)

	Temperature	Conductivity	Dissolved Oxygen		pH	ORP	Turbidity	Chlorophyll *a*	Alkalinity
	°C	mS/cm	(mgL^{-1})	%		mV	NTU	ug L^{-1}	mg $CaCO_3$ L^{-2}
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)	93.3 ± 12 (76.7-116.7)
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)	146 ± 12.1 (120-180)
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)	158.3 ± 14.2 (103.3-200)
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)	170.6 ± 13 (133.3-213.3)
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)	-	0.7 ± 0.1 (4.8-0.3)	86.7 ± 20 (66.7-106.7)
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)	180 ± 21.1 (143.3-240)
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)	158.3 ± 18.3 (126.7-210)
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)	160 ± 12.5 (140-196.7)
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)	196.7 ± 43.4 (140-323.3)
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)	148.3 ± 9.7 (120-163.3)
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)	186.7 ± 67.1 (100-386.7)

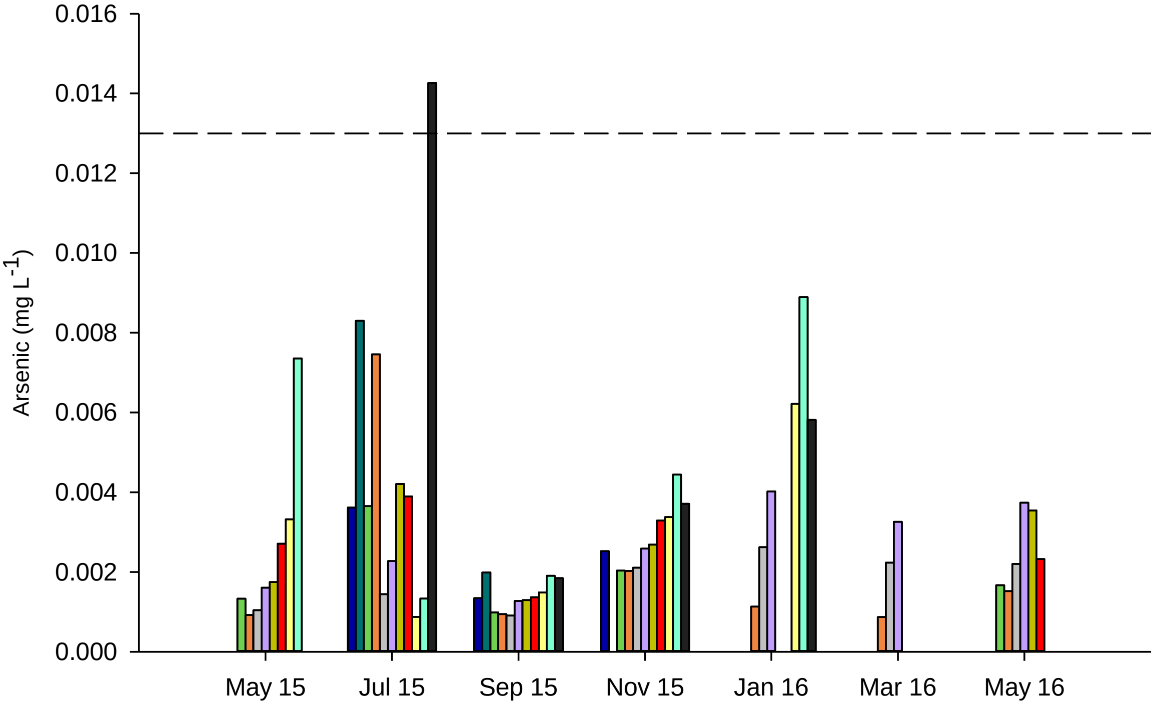
9.2 METALS AND METALLOIDS

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, Al, As, Hg, Se and Zn exceeded the trigger values on some occasions. Overall the number of exceedances was the lowest it has been over the 5 years of monitoring, although involving slightly more elements. High levels of Al can be associated with acid sulphate soils, but Al exceedances were much lower than in 2014/15 suggesting that acid sulphate soils although present in the catchment are not of immediate concern. Aluminium contamination is acutely and chronically toxic to fish, amphibians, invertebrates and phytoplankton (ANZECC & ARMCANZ, 2000). Mercury concentrations were still unusually high on occasion in 2015/16 but less frequently than in 2014/15. These Hg concentrations were 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 probably source) and the timing of the high concentrations varies between years. Selenium is increasingly being recognised as a serious pollutant and the high number of exceedances this year compared to previous years is concerning especially as the source is unknown. Selenium exceedances were seen in Beenyup Swamp and Lake Joondalup.

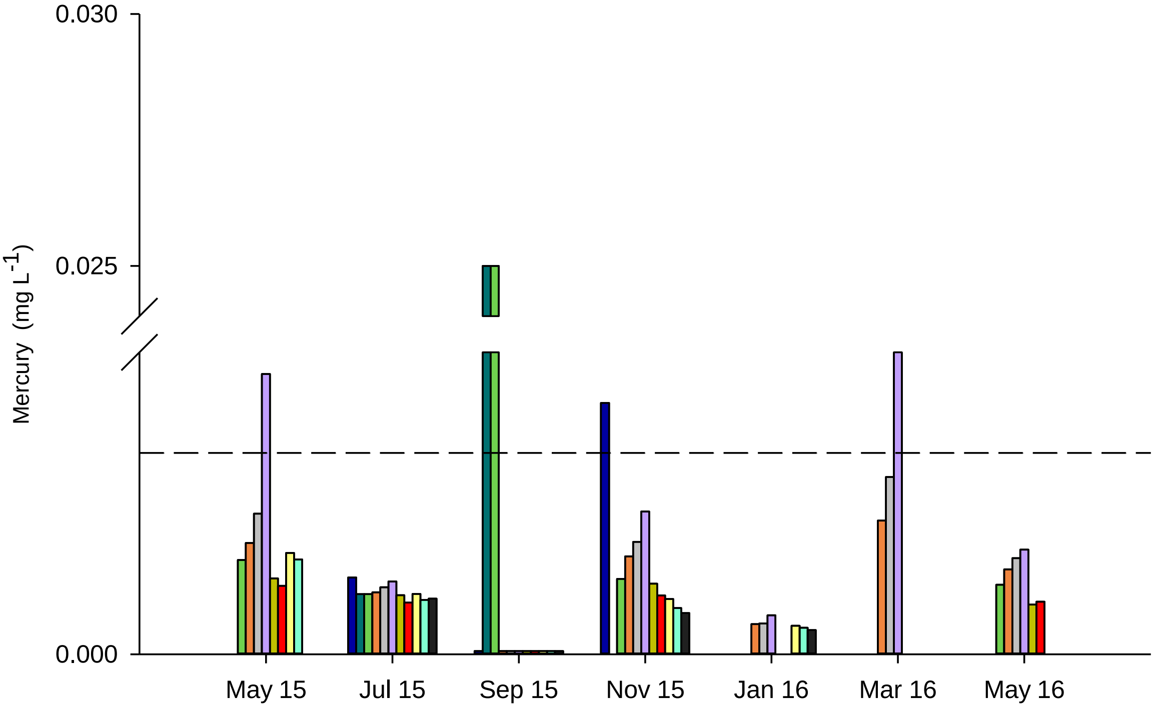
a) Aluminium



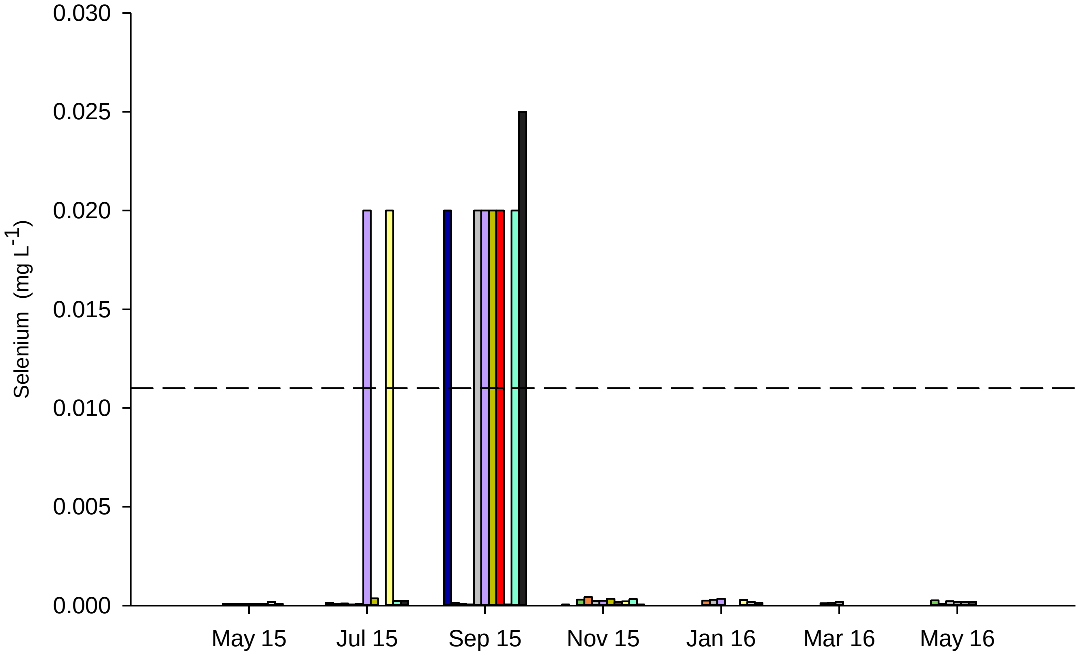
b) Arsenic



c) Mercury



d) Selenium



e) Zinc

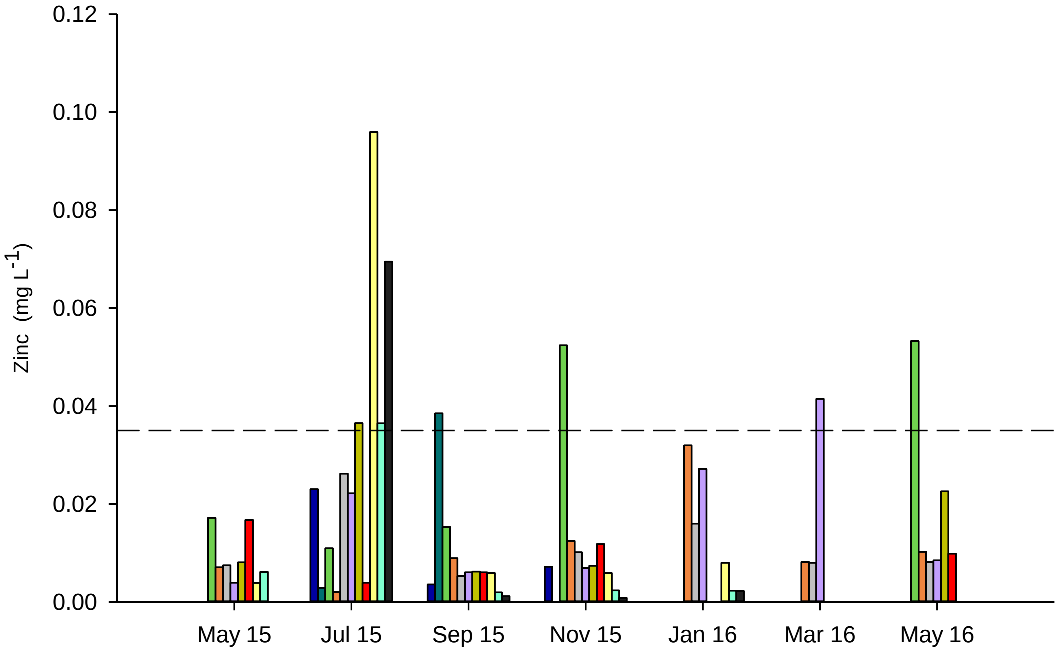


Figure 9. Occurrences of select metal and metalloid concentrations exceeding the ANZECC/ARMCANZ (2000) water quality trigger values for 95% protection of aquatic ecosystems between May 2015 and 2016.

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 May 2015 and 2016

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	0.013 ± 0.003 (0.173)	55 (1)
Arsenic (As)	0.013 - 0.024*	<0.00001	0.003 ± 0.0003 (0.0143)	55 (0)
Calcium (Ca)	—	<0.2	57.9 ± 3.83 (134.77)	55 (0)
Cadmium (Cd)	0.0011 – 0.0016[H]	<0.00001	0.00016 ± 0.00004 (0.001)	44 (0)
Cobalt (Co)	ID	<0.00002	0.0002 ± 0.0001 (0.0025)	55 (0)
Chromium (Cr)	ID - 0.006[H]	<0.00005	0.001 ± 0.0001 (0.0024)	55 (0)
Iron (Fe)	ID	<0.0005	0.56 ± 0.12 (6.01)	55 (0)
Mercury (Hg)	0.0006 - ID*	<0.00002	0.0011 ± 0.0006 (0.025)	46 (5)
Potassium (K)	—	<0.2	18.15 ± 1.79 (58.69)	55 (0)
Magnesium (Mg)	—	<0.2	28.33 ± 2.78 (103.57)	55 (0)
Manganese (Mn)	1.9	<0.00005	0.03 ± 0.01 (0.27)	55 (0)
Sodium (Na)	—	<0.2	123.72 ± 19.29 (679.97)	55 (0)
Nickel (Ni)	0.0480 – 0.0687[H]	<0.00005	0.0005 ± 0 (0.0016)	55 (0)
Selenium (Se)	0.011	<0.00005	0.0035 ± 0.001 (0.025)	54 (9)
Uranium (U)	0.005+	<0.00002	0.00002 ± 0 (0.00011)	14 (0)
Zinc (Zn)	0.0350 – 0.05[H]	<0.00025	0.016 ± 0.002 (0.096)	55 (2)

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 (May 2015 –2016). Values under the detection limit were given a value of half the detection limit in the calculations. Figure marked < were below detection.

DL	Al >0.5	As >0.01	Cd >0.01	Co >0.02	Cr <0.05	Fe <0.5
South Lake Goollelal	8.4 ± 2.4 (5.1-29.6)	2.5 ± 0.7 (1.3-3.9)	0.407 ± 0.301 (0.026-0.014)	0.096 ± 0.036 (0.059-0.118)	0.772 ± 0.207 (0.496-0.76)	405.1 ± 261.1 (122.9-180.7)
Beenyup Out (Site 1)	8.8 ± 1.5 (3.6-13.3)	2.7 ± 0.4 (1.3-4)	0.135 ± 0.069 (0.005-0.482)	0.076 ± 0.013 (0.033-0.12)	1.124 ± 0.149 (0.549-1.578)	526.4 ± 97.3 (235.3-893.1)
Beenyup In (Site 3)	9.1 ± 1.2 (5.6-13.9)	1.8 ± 0.2 (0.9-2.6)	0.2 ± 0.134 (0.029-1)	0.078 ± 0.011 (0.033-0.12)	1.064 ± 0.115 (0.805-1.499)	612.7 ± 262.2 (162.6-2134.7)
Drain North (Site 4)	10.4 ± 1.9 (3.9-16.6)	2.1 ± 0.9 (0.9-7.5)	0.176 ± 0.084 (0.023-0.5)	0.07 ± 0.013 (0.022-0.113)	1.258 ± 0.168 (0.503-1.902)	582.3 ± 152.2 (21.9-1206.6)
Drain Goollelal (Site 5)	24.4 ± 19 (5.3-43.4)	5.1 ± 3.2 (2-8.3)	0.02 ± 0.002 (0.017-0.022)	0.237 ± 0.214 (0.023-0.451)	1.166 ± 0.698 (0.468-1.864)	403.1 ± 374.4 (28.6-777.5)
Drain South (Site 6)	10 ± 2.5 (4-18.7)	1.9 ± 0.5 (1-3.7)	0.018 ± 0.009 (0.005-0.053)	0.055 ± 0.012 (0.028-0.092)	0.885 ± 0.126 (0.545-1.278)	579.3 ± 226.5 (229.2-1415.7)
South Culvert Inlet	7.8 ± 1.5 (4.4-12.8)	2.7 ± 0.5 (1.3-4.2)	0.031 ± 0.007 (0.013-0.048)	0.147 ± 0.08 (0.036-0.462)	1.4 ± 0.301 (0.807-2.447)	677 ± 188.3 (356.9-1343.9)
South Culvert	6.3 ± 0.6 (3.4-10.2)	2.7 ± 0.2 (1.4-3.9)	0.015 ± 0.003 (0.005-0.044)	0.089 ± 0.008 (0.039-0.14)	1.014 ± 0.077 (0.509-1.549)	441.6 ± 55.6 (42.3-820.9)
South Lake Joondalup	10.4 ± 6.2 (2.8-35)	3.1 ± 0.9 (0.9-6.2)	0.063 ± 0.045 (0.005-0.243)	0.086 ± 0.018 (0.038-0.147)	0.909 ± 0.146 (0.383-1.172)	1497 ± 1128.6 (272.3-6009)
Mid Lake Joondalup	11.9 ± 2.6 (2.6-35.1)	4.8 ± 0.7 (1.3-8.9)	0.618 ± 0.105 (0.035-1)	0.549 ± 0.218 (0.021-2.5)	0.645 ± 0.048 (0.402-0.973)	56.9 ± 2.9 (34-71.5)
North Lake Joondalup	47.8 ± 20.9 (2.6-173.3)	6.4 ± 1.4 (1.8-14.3)	0.016 ± 0.002 (0.005-0.029)	0.665 ± 0.306 (0.035-2.5)	0.875 ± 0.174 (0.388-1.906)	55.2 ± 16.2 (19.2-151.9)

Table 5 cont.

DL	Hg <0.02	Mn <0.05	Ni <0.05	Se <0.05	U <0.02	Zn <0.05
South Lake Goollelal	0.33 ± 0.22 (0.01-5.4)	96 ± 87.43 (4.53-7.24)	0.37 ± 0.05 (0.27-0.62)	6.73 ± 6.64 (0.05-0.86)	0.01 ± 0 (0.01-0.02)	11.27 ± 5.97 (3.59-10.2)
Beenyup Out (Site 1)	0.41 ± 0.14 (0.01-0.97)	52.1 ± 20.72 (5.08-157.04)	0.56 ± 0.1 (0.19-0.88)	5.87 ± 3.65 (0.09-20)	0.018 ± 0.003 (0.01-0.032)	16.6 ± 5.33 (3.94-41.47)
Beenyup In (Site 3)	0.27 ± 0.07 (0.01-0.53)	37.68 ± 13.39 (5.44-105.95)	0.44 ± 0.05 (0.27-0.68)	3.01 ± 2.83 (0.08-20)	0.019 ± 0.005 (0.01-0.039)	11.61 ± 2.74 (5.29-26.18)
Drain North (Site 4)	0.22 ± 0.05 (0.01-0.4)	30.12 ± 11.47 (0.96-83.91)	0.49 ± 0.08 (0.27-0.92)	0.15 ± 0.05 (0.05-0.42)	0.011 ± 0.001 (0.009-0.018)	11.56 ± 3.61 (2.04-31.97)
Drain Goollelal (Site 5)	12.59 ± 12.41 (0.18-25)	15.73 ± 14.05 (1.68-29.79)	0.59 ± 0.12 (0.47-0.71)	0.1 ± 0.03 (0.07-0.14)	0.01 ± 0 (0.01-0.01)	20.7 ± 17.8 (2.9-38.5)
Drain South (Site 6)	5.18 ± 4.96 (0.18-25)	19.6 ± 8.73 (4.15-53.09)	0.4 ± 0.1 (0.22-0.79)	0.17 ± 0.05 (0.08-0.3)	0.015 ± 0.005 (0.01-0.036)	29.83 ± 9.44 (10.96-53.27)
South Culvert Inlet	0.15 ± 0.04 (0.01-0.23)	16.31 ± 5.11 (5.09-35.41)	0.47 ± 0.09 (0.23-0.68)	4.19 ± 3.95 (0.08-20)	0.012 ± 0.002 (0.01-0.019)	16.15 ± 5.9 (6.21-36.5)
South Culvert	0.14 ± 0.02 (0.01-0.2)	11.77 ± 2.04 (1.1-25.99)	0.43 ± 0.03 (0.23-0.65)	4.09 ± 1.78 (0.02-20)	0.026 ± 0.007 (0.01-0.092)	9.68 ± 1 (3.93-16.74)
South Lake Joondalup	0.15 ± 0.05 (0.01-0.3)	12.96 ± 2.8 (5.67-20.7)	0.51 ± 0.14 (0.24-1.03)	4.15 ± 3.96 (0.06-20)	0.014 ± 0.004 (0.01-0.031)	23.94 ± 18 (3.91-95.9)
Mid Lake Joondalup	0.13 ± 0.02 (0.01-0.28)	2.22 ± 0.21 (1.49-3.94)	0.51 ± 0.07 (0.24-1.08)	4.16 ± 1.77 (0.09-20)	0.045 ± 0.009 (0.01-0.115)	9.84 ± 2.99 (1.94-36.45)
North Lake Joondalup	0.09 ± 0.02 (0.01-0.17)	1.36 ± 0.28 (0.35-2.98)	0.7 ± 0.16 (0.24-1.64)	6.36 ± 3.11 (0.06-25)	0.01 ± 0 (0.01-0.01)	18.42 ± 8.51 (0.82-69.47)

9.3 NUTRIENTS

Dissolved organic C concentrations were typical of Swan Coastal Plain wetlands and tended to increase slightly northwards (Figure 10). Concentrations of DOC were generally higher than in 2014/15 especially between May and November 2015, possibly due to lower water levels.

Total phosphorus concentrations (Figure 11) 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 12660 µg L^{-1} recorded in May 2015 at $Drain_{South}$, this was substantially higher 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.

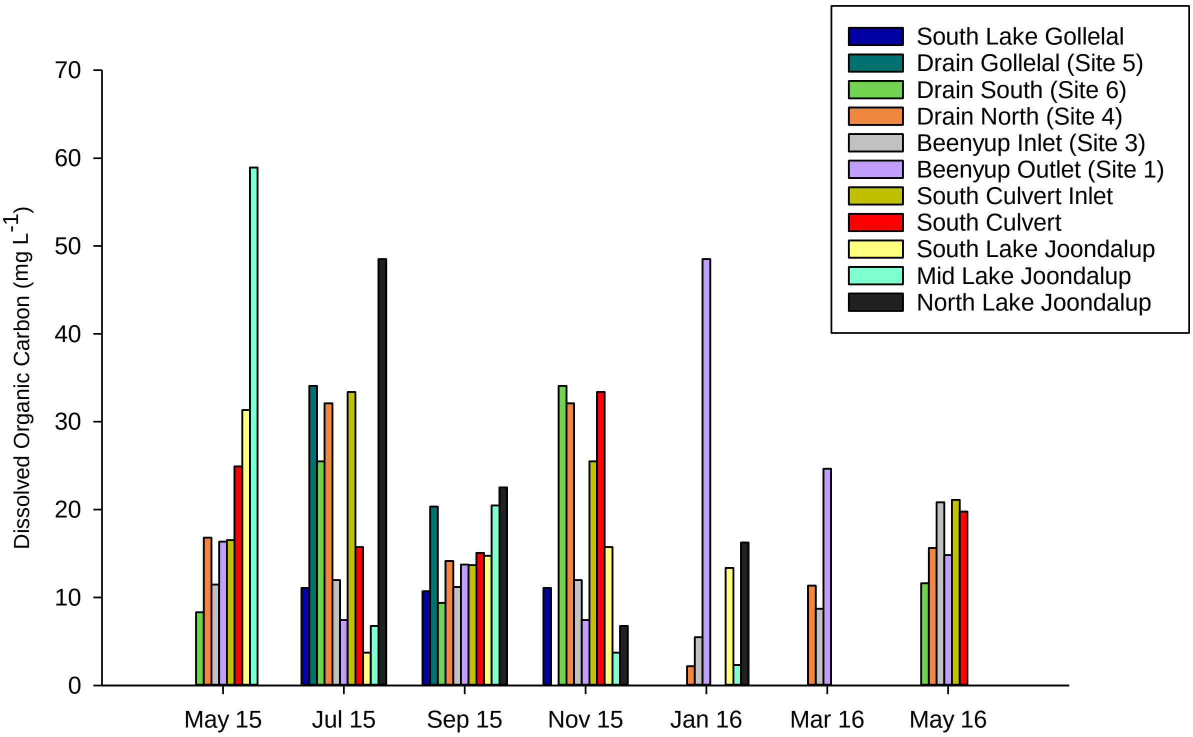
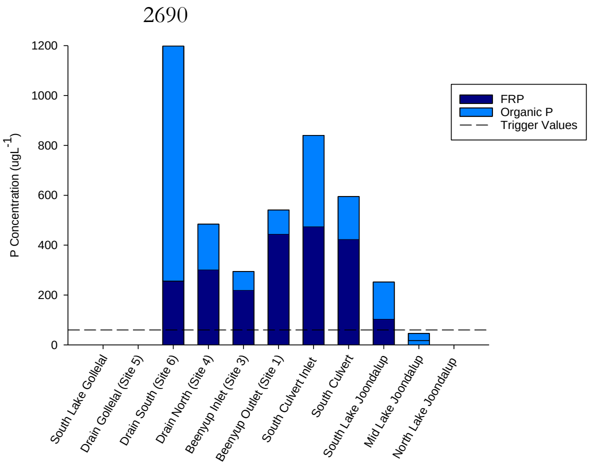


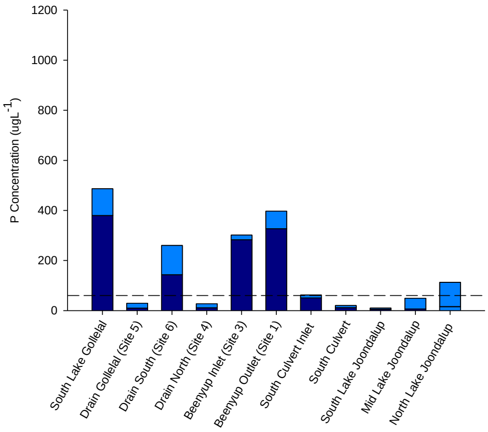
Figure 10. Dissolved organic C concentrations across the sites for the study period (May 2015 to 2016)

The results show that Beenyup Swamp continues to export P as recorded by Lund et al. (2011a). Particularly interesting are the low concentrations of P recorded in the South Culvert inlet and South Culvert compared to $Beenyup_{out}$ in 2015/16. This latter finding runs contrary to that seen in 2014/15, where there appeared to be a source of P (assumed to be groundwater) between $Beenyup_{out}$ and the Culvert. The low rainfall might have resulted in lowering of groundwater preventing it discharging P into the drain. Phosphorus then declines from South Lake Joondalup to North/Mid Lake Joondalup, suggesting either rapid uptake by the Lake Joondalup sediment or as the South Lake Joondalup site is just north of Ocean Reef Rd that the thick rushes between there and Mid Lake Joondalup are effective at removing the P.

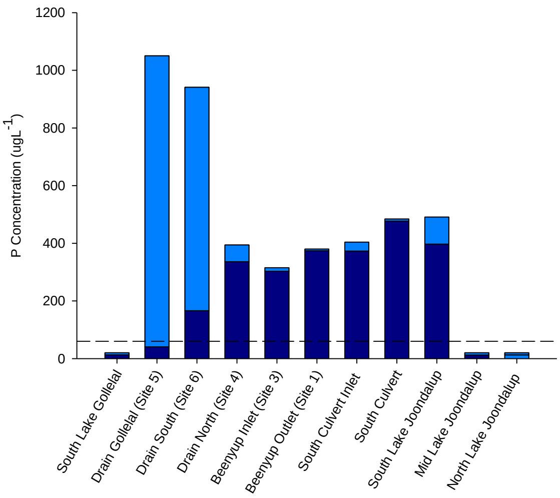
May 2015



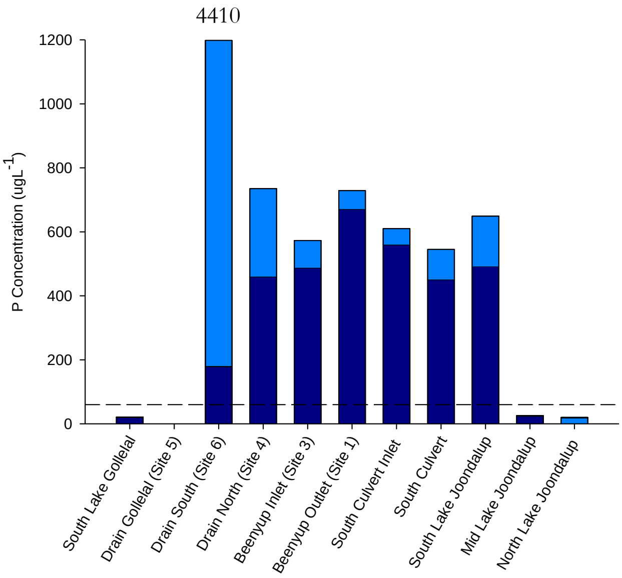
July 2015



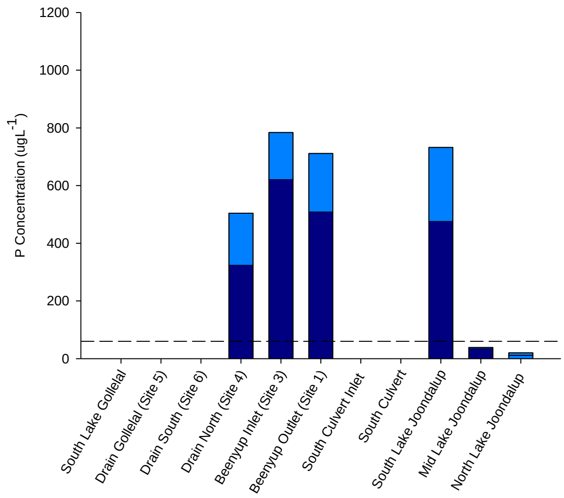
September 2015



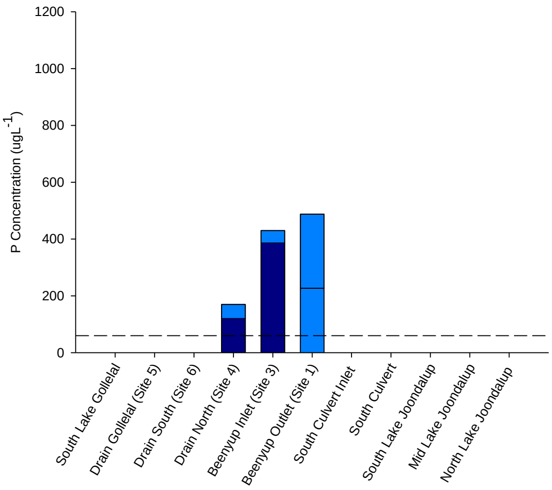
November 2015



January 2016



March 2016



May 2016

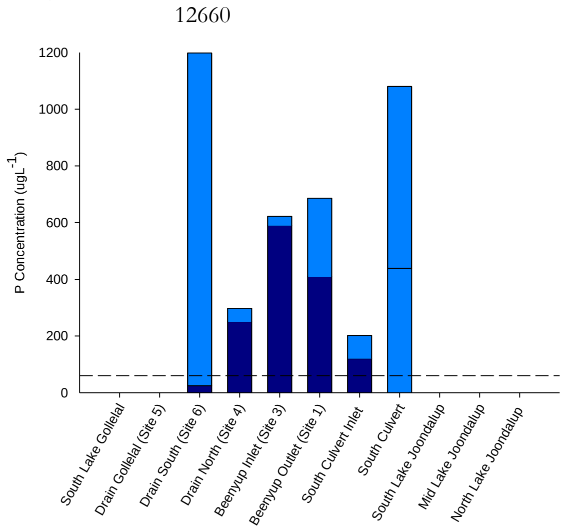
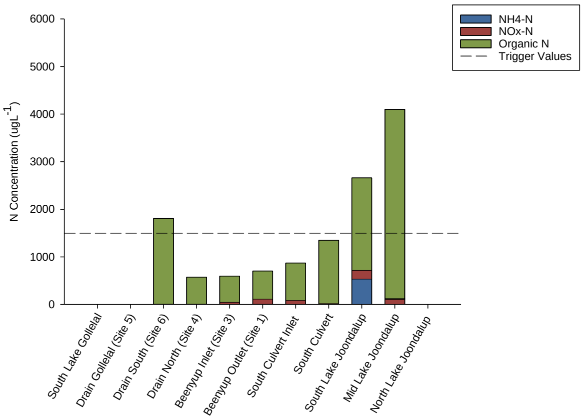


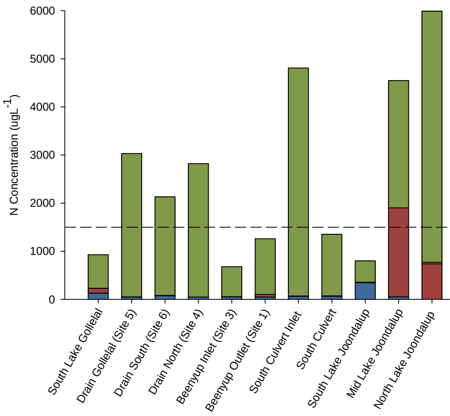
Figure 11. Breakdown of total phosphorus into chemical fractions (organic P and FRP) recorded in surface waters at each site between May 2015 and 2016 with the ANZECC & ARMANZ (2000) trigger value for total phosphorus shown.

Total N concentrations occasionally exceeded the recommended ANZECC & ARMCANZ guidelines of 1500 µg L^{-1} (Figure 12 & Table 7), particularly during July 2015. 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 25367 µg L^{-1} for $Drain_{South}$ at the time of the peak Total P suggesting that an algal bloom was responsible. 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.

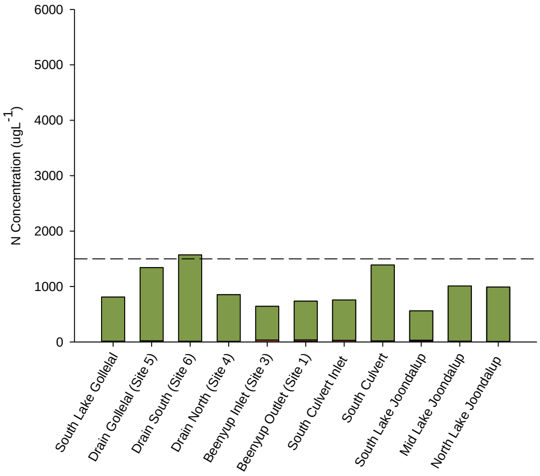
May 2015



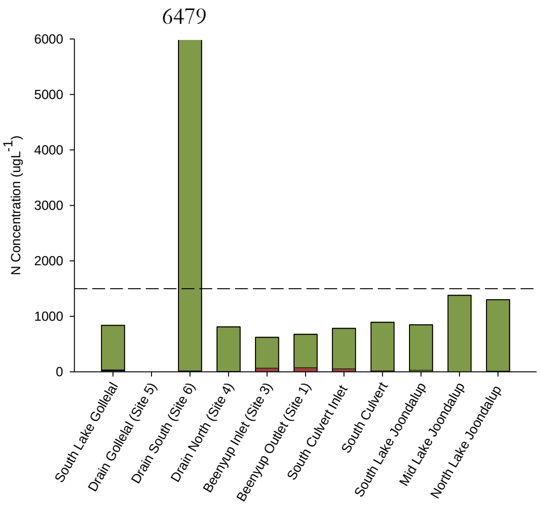
July 2015



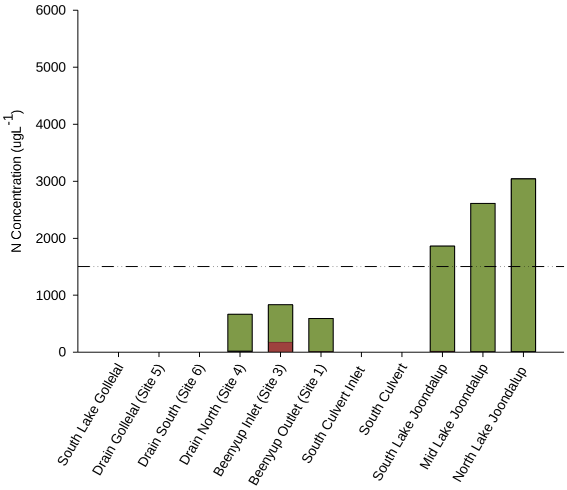
September 2015



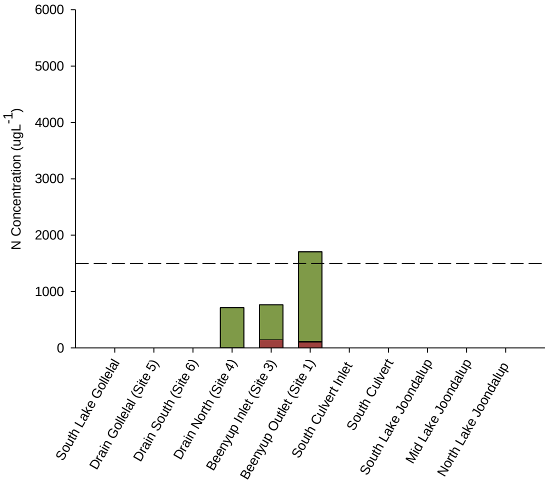
November 2015



January 2016



March 2016



May 2016

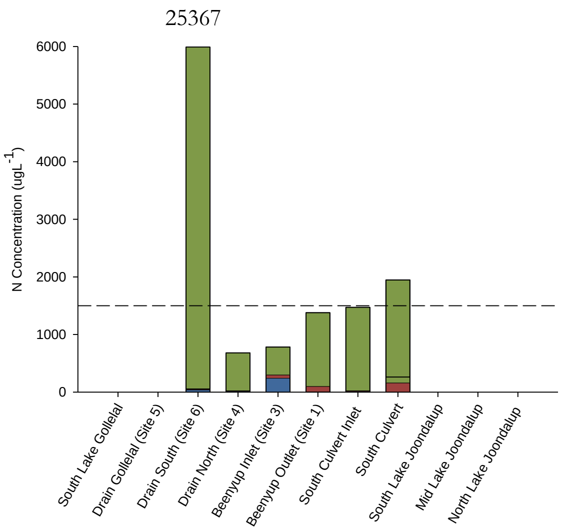


Figure 12. Breakdown of total nitrogen into chemical fractions (organic nitrogen, oxides of nitrogen and ammonia/ammonium) recorded in surface waters at each site between May 2015 and 2016 with the ANZECC & ARMANZ (2000) trigger value for total nitrogen.

Table 7. Mean ± s.e. (range) for nutrients in water recorded at each study site over the course of the monitoring period (May 2015 - 2016)

DL	**NH_4-N** **mg.L^{-1}** **<3**	**NOx-N** **mg.L^{-1}** **<2**	**TN** **mg.L^{-1}** **<50**	**Org N** **mg.L^{-1}**	**FRP-P** **mg.L^{-1}** **<2**	**TP** **mg.L^{-1}** **<20**	**Org P** **mg.L^{-1}**	**DOC** **mg.L^{-1}** **<0.5**
South Lake Goollelal	52 ± 39 (2-129)	40 ± 30 (7-100)	858 ± 35 (811-927)	766 ± 34 (698-804)	138 ± 121 (13-380)	176 ± 155 (20-486)	38 ± 34 (1-107)	11 ± 0.1 (10.7-17.7)
Beenyup Out (Site 1)	28 ± 14 (4-104)	54 ± 15 (8-107)	1007 ± 165 (592-1706)	926 ± 156 (574-1594)	423 ± 53 (227-671)	562 ± 56 (380-729)	138 ± 40 (6-277)	19 ± 5.4 (7.4-48.5)
Beenyup In (Site 3)	45 ± 34 (1-245)	76 ± 24 (4-179)	702 ± 33 (597-826)	581 ± 22 (480-647)	413 ± 59 (220-622)	474 ± 72 (294-784)	61 ± 20 (12-162)	11.7 ± 1.8 (5.5-20.8)
Drain North (Site 4)	13 ± 6 (2-48)	9 ± 1 (1-12)	1017 ± 303 (575-2820)	995 ± 298 (562-2771)	258 ± 56 (12-460)	373 ± 88 (27-735)	115 ± 37 (16-275)	17.8 ± 4.1 (2.2-32.1)
Drain Goollelal (Site 5)	31 ± 17 (14-48)	6 ± 2 (4-8)	2185 ± 845 (1340-3030)	2148 ± 830 (1318-2978)	25 ± 15 (10-41)	540 ± 510 (29-1050)	514 ± 495 (19-1009)	27.2 ± 6.9 (20.3-34.1)
Drain South (Site 6)	25 ± 15 (1-77)	10 ± 1 (5-13)	7478 ± 4571 (1570-25400)	7443 ± 4567 (1558-25347)	154 ± 37 (25-256)	4192 ± 2237 (260-12660)	4038 ± 2264 (116-12635)	17.8 ± 5.1 (8.3-34.1)
South Culvert Inlet	18 ± 11 (2-61)	38 ± 15 (9-90)	1739 ± 779 (757-4810)	1683 ± 776 (724-4740)	316 ± 99 (51-560)	424 ± 139 (62-840)	108 ± 65 (11-365)	22 ± 3.5 (13.7-33.4)
South Culvert	49 ± 14 (2-163)	31 ± 8 (6-98)	1386 ± 75 (894-1946)	1306 ± 58 (870-1685)	361 ± 39 (12-477)	545 ± 75 (20-1080)	184 ± 53 (7-641)	21.8 ± 1.5 (15.1-33.4)
South Lake Joondalup	185 ± 109 (11-537)	48 ± 35 (8-186)	1345 ± 397 (561-2660)	1112 ± 323 (442-1937)	295 ± 101 (5-492)	427 ± 132 (10-732)	132 ± 41 (5-255)	15.8 ± 4.4 (3.7-31.3)
Mid Lake Joondalup	36 ± 10 (1-113)	377 ± 165 (8-1850)	2730 ± 316 (1010-4550)	2318 ± 236 (995-3979)	19 ± 2 (7-36)	36 ± 3 (20-49)	17 ± 4 (2-43)	18.4 ± 4.7 (2.3-58.9)
North Lake Joondalup	185 ± 92 (0-737)	13 ± 3 (6-31)	2831 ± 573 (992-5990)	2632 ± 487 (983-5222)	15 ± 1 (11-19)	43 ± 12 (20-113)	29 ± 11 (1-97)	23.5 ± 4.5 (6.8-48.5)

10. CONCLUSION

In conclusion, this monitoring study found that there is probable evidence of acid sulphate soils throughout much of the park at various times. However despite this, water quality was better than previously seen in the monitoring. 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. 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 few months and then returns back to low concentrations. Additionally this year, selenium also appeared as a contaminant in the northern parts of the park, the source of this is unknown.

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. The ongoing poor water quality within the system highlights the importance of ongoing monitoring.

11. RECOMMENDATIONS

1. It is recommended that the monitoring program continue for 2016/17 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 and selenium concentrations that warrant ongoing monitoring. A revised monitoring schedule to maximise the usefulness of the monitoring to both midge management and understanding of the system that sampling should be conducted in Feb, Jun to Oct and Dec (7 times). The recommended times ensure high sampling density when the lake is wet and limited sampling as it dries out. Failure to monitor during the dry period may mean that issues with acid sulphate soils are missed so it is recommended to sample in February whatever sites have water.
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. Additionally, a small study could attempt to locate the source of the selenium noted this year.
3. The concentrations of particularly mercury and selenium 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.

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.