

June 2016



Yellagonga Regional Park wetlands groundwater monitoring 2015/16 report

By, Jay Gonzalez-Pinto
Mark Lund

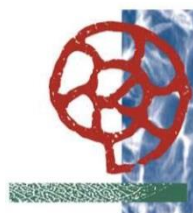
Prepared for,

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

Mine Water and
Environment Research
Centre

Report No. 2016-4

MiWERCentre



CENTRE *for*
ECOSYSTEM
MANAGEMENT

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.



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 Goollelal

This report should be referenced as follows.

Gonzalez-Pinto, J. & Lund, M.A. (2016). *Yellagonga Regional Park wetlands groundwater monitoring 2015/16 report*. Mine Water and Environment Research/Centre for Ecosystem Management Report No. 2016-4, Edith Cowan University, Perth, Australia. 37pp. Unpublished report to the Cities of Joondalup and Wanneroo.

4. EXECUTIVE SUMMARY

1. In 2012, MiWER completed a review of available groundwater data for the area surrounding the Yellagonga Regional Park. It identified the paucity of information relevant to management of the Park. In response, the City of Joondalup installed two bores on the eastern side of Lake Goollelal. In August 2012, MiWER commenced a groundwater monitoring program utilising the new bores and existing bores that were best located to gain an understanding of groundwater impacts on the Yellagonga wetlands. In 2014, two further bores were provided at Neil Hawkins Park and Ariti Avenue by the Cities.
2. Monitoring was conducted monthly and involved measurement of groundwater height, physico-chemical parameters, nutrient concentrations and selected metal/metalloid concentrations. Three bores were located on the eastern side of Lake Joondalup, two on the western side. Wallubuenup Swamp had one bore sampled on its eastern side and one on the western side. Two bores were sampled on the eastern side of Lake Goollelal and one on the western side. A total of ten bores throughout Yellagonga were sampled. Sampling commenced in July 2013. This report covers monitoring from May 2015 to May 2016.
3. The bores on the western side of the park show an increase in conductivity and related parameters in late summer, following evapo-concentration of solutes in the lakes.
4. There was evidence of ASS impacts in most bores based on molar ratios of sulphate to chloride and alkalinity to sulphate. This was not reflected in pH (>5), but in metal concentrations such as Al, As, Hg, and Zn which exceeded ANZECC & ARMCANZ (2000) guidelines for the 95% protection of aquatic systems by up to an order of magnitude (10 times) on occasion. Concentrations of Al were however not at levels indicative of active ASS, although Fe concentrations were very high on occasion. The groundwater should continue to be monitored to keep a watch out for possible ASS problems which might necessitate management action. It appeared that groundwater was a source of Al and Hg identified in the wetlands.
5. High concentrations of P and N were recorded in a number of the eastern bores (particularly Mid E Joondalup), suggesting groundwater is an important source of nutrients into the northern end of Lake Joondalup.
6. Key recommendations from the study are to continue monitoring, although the frequency can be decreased to bimonthly - still allowing clarification of seasonal effects and a better understanding of processes.

5. CONTENTS

1. MINE WATER AND ENVIRONMENT RESEARCH CENTRE	I
2. ACKNOWLEDGEMENTS	I
3. FRONTISPIECE	II
4. EXECUTIVE SUMMARY	III
5. CONTENTS.....	IV
6. INTRODUCTION	5
7. METHODS	6
7.1 STUDY SITE.....	6
7.2 SAMPLING	7
8. RESULTS AND DISCUSSION	7
8.1 PHYSICO-CHEMISTRY.....	7
8.2 METALS AND METALLOIDS	17
8.3 NUTRIENTS.....	23
9. CONCLUSIONS	32
10. RECOMMENDATIONS	32
11. REFERENCES.....	33

6. INTRODUCTION

Underlying part of the Swan Coastal Plain of Western Australia, between the Darling Range fault line and Indian Ocean is a shallow unconfined aquifer known as the Gnangara Mound (Appleyard and Cook 2009). The Gnangara Mound covers an area of approximately 2,200 km² and is the most significant water resource utilised by the population of Perth, providing up to 85% of its total domestic water requirements (Elmahdi and McFarlane 2009).

The Gnangara Mound is one component of a highly interdependent and complex hydrological system named the Gnangara groundwater system. It comprises of the Gnangara Mound, Leederville aquifer (confined and at a depth of 500 m), Yarragadee aquifer (confined and at a depth of 1000 m), rivers, wetlands (permanent and seasonal) and ocean (Wilson and Valentine 2009). Consequently it is important that the Gnangara hydrological system is maintained at a sustainable level in order to support water supply capacity, groundwater dependent ecosystems, vegetation communities and biodiversity on the Swan Coastal Plain (Wilson and Valentine 2009).

Yellagonga Regional Park occupies an area of around 1,400 ha overlying the Gnangara Mound and consists of Lake Goollelal, Wallubuenup Swamp, Beenyup Swamp, and Lake Joondalup. This interdunal chain of wetlands is a surface expression of the unconfined aquifer which flows in an east to west direction through the park (Newport et al. 2011a).

Over the past thirty five years, numerous studies have been conducted around the Yellagonga wetlands, investigating nutrient enrichment, metal contamination and the presence of Acid Sulphate Soils (Congdon and McComb 1976a, Congdon 1985, 1986, Congdon and McComb 1976b, Cumbers 2004, Davis et al. 1993, Gordon et al. 1981, Khwanboonbumpen 2006, Kinnear and Garnett 1999, Kinnear et al. 1997, Lund 2003, 2007, Lund et al. 2000). More recently, a water quality monitoring program has produced results that support previous findings of nutrient enrichment and metal contamination, which exceed ANZECC/ARMCANZ (2000) national water quality guidelines (Lund et al. 2011, Newport et al. 2011a, Newport and Lund 2012b, 2013b, 2014b). An investigation in the southern section of Wallubuenup Swamp identified the presence of ASS (Newport et al. 2011b, Newport and Lund 2013a, 2014a).

Newport and Lund (2012a) undertook a review of groundwater data in the vicinity of Yellagonga Regional Park. They identified a series of groundwater bores that might be suitable for regular monitoring. These bores have been supplemented with two new groundwater bores on the eastern side of Lake Goollelal and bores at Ariti Avenue and Neil Hawkins Park. This report details the results of third annual monthly monitoring of these groundwater bores from May 2015 –2016.

7. METHODS

7.1 STUDY SITE

Three bores are located on the eastern side of Lake Joondalup and two on the western side. There are two bores (east and west) of Wallubuenup and two eastern and one western bore around Lake Goollelal (Figure 1.).The bores sampled on a monthly basis are listed below with their corresponding AWRC reference number or identifying number:

S.E. Goollelal – CoJ2

Mid W. Goollelal – AWRC ref: 61611870

N.E. Goollelal – CoJ1

Mid E. Wallubuenup – WN12

W. Wallubuenup – AWRC ref: 61610679

S.E. Joondalup – Ariti Avenue

Mid E. Joondalup – AWRC ref: 61610661

Mid W. Joondalup – Neil Hawkins

N.E. Joondalup – AWRC ref: 61610629

N.W. Joondalup – AWRC ref: 61611423



Figure 1. Location of the ten groundwater bores used for monthly monitoring in Yellagonga Regional Park (adapted from Google Earth 2013).

7.2 SAMPLING

This report covers monthly sampling of the groundwater bores between the July 2014 and June 2015. At each bore, the depth was measured from top of the PVC casing to water level using a dipper-T. A bailer was then used to purge each bore of three times its volume before extracting the water sample. On each occasion, pH, oxidation reduction potential (ORP), electrical conductivity (EC), temperature and dissolved oxygen (% saturation and mg L⁻¹) were measured *in situ* using a Datasonde 5a (Hydrolab) instrument.

In the laboratory, an unfiltered aliquot of each water sample was frozen for later determination of total nitrogen (TN¹) and phosphorus (TP). A 0.5 µm filtered (Pall Metrigard) aliquot was then frozen for later determination of sulphate (SO₄), chloride (Cl), nitrate/nitrite (NO_x), filterable reactive phosphorus (FRP), ammonia (NH₄) and dissolved organic carbon (DOC; measured as non-purgeable organic carbon). Another filtered aliquot was acidified with nitric acid to ensure a final pH <2 (approx. 1% v/v) and then kept at 4°C for later determination by ICP-AES/MS for a range of metals (Al, As, Ca, Cd, Co, Cr, Fe, Hg, K, Mg, Mn, Na, Ni, Se, U & Zn). All analyses were performed at the Natural Sciences Analytical Laboratory (Edith Cowan University) as per APHA (1999). Alkalinity was measured on an unfiltered aliquot of water, according to the methods of APHA (1999).

The analysis conducted for groundwater monitoring mirrored that of surface water monitoring (see Newport and Lund 2014b) so as to be effective in evaluating inputs/outputs associated with nutrient enrichment and metal contamination in the Yellagonga system.

In the data analysis, concentrations that were below detection limits were assigned a value of half the detection limit and included in the calculation. This approach tends to strike a middle ground between being overly conservative and not conservative.

8. RESULTS AND DISCUSSION

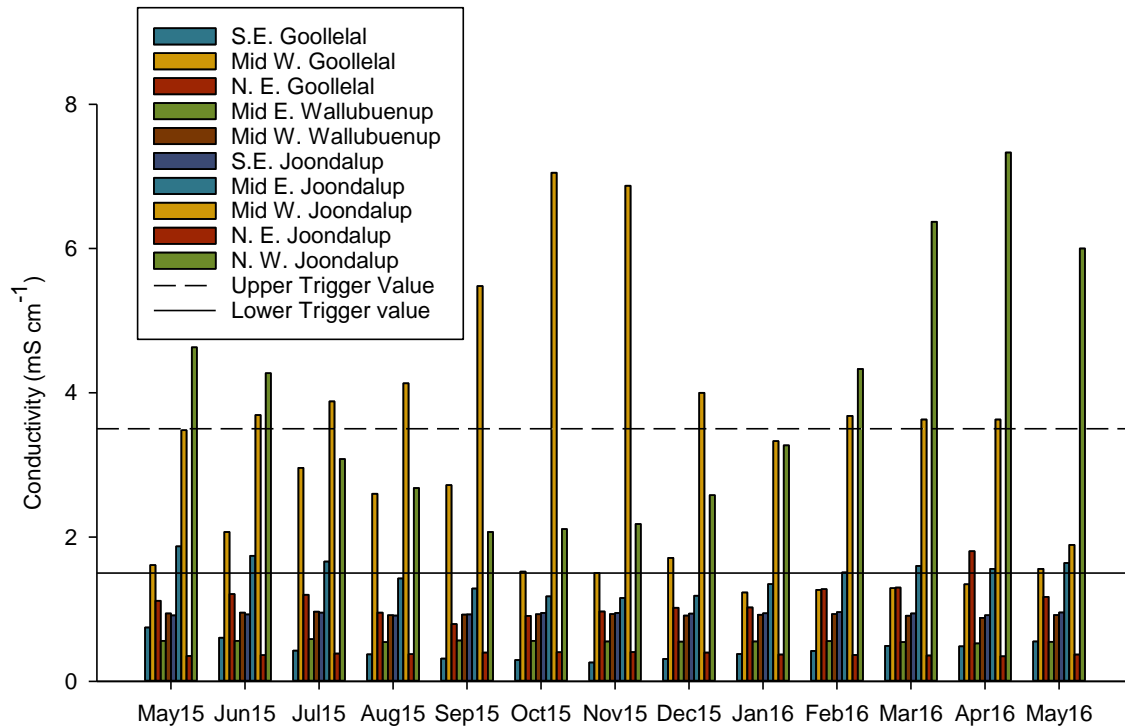
8.1 PHYSICO-CHEMISTRY

The EC followed a trend of typically higher values in western bores compared to eastern ones, the only exception was Mid W Wallubuenup (Figure 1). Evapoconcentration of salts in the lakes is reflected in high EC in Mid W Joondalup in spring, N.W. Joondalup and Mid W. Goollelal in winter. The difference in the timing of peak EC between the western bores probably reflects time taken for the lake water to move from the lake through to the bore. Similar trends can be seen in Ca, K, Mg, Na and Cl across all sites and times reflecting their contribution to EC and evapoconcentration in the lake. Table 1 illustrates the mean and ranges for each of the common

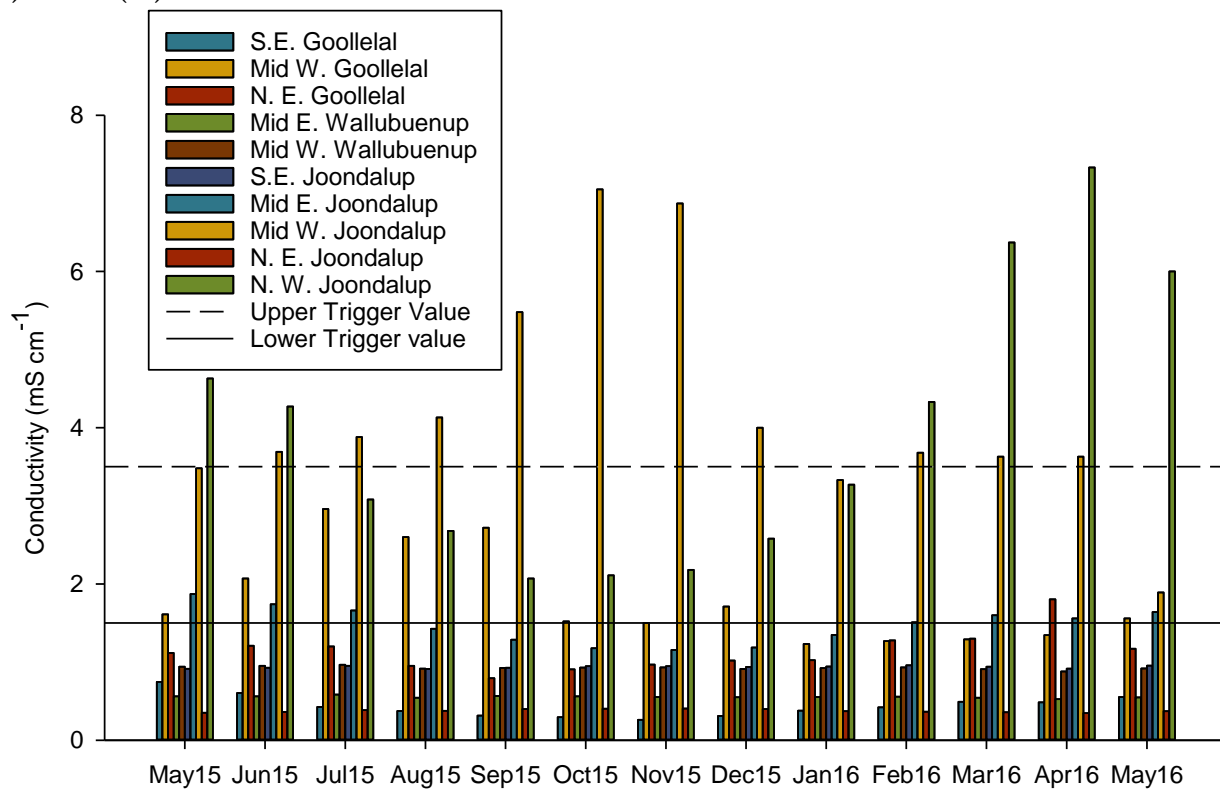
¹ All nutrients are measured as the key elements ie. TN-N, TP-P, NO_x-N, FRP-P and NH₄-N (includes NH₃)

ions. Mid w. Goollelal had some unusually high concentrations of K, Mg, Na and Cl in August 2015, this appears to be one-off and concentrations returned to more normal levels in September. The exact cause of the high concentrations seen in August 2015 is unknown.

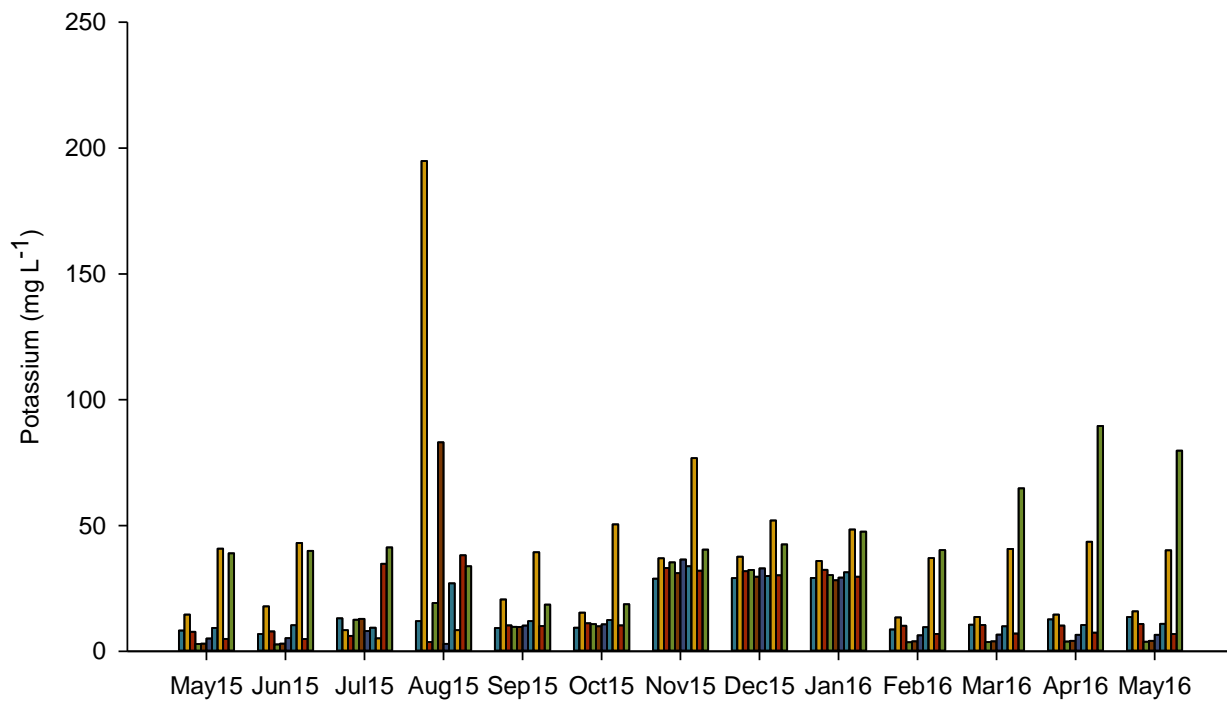
a) Electrical conductivity



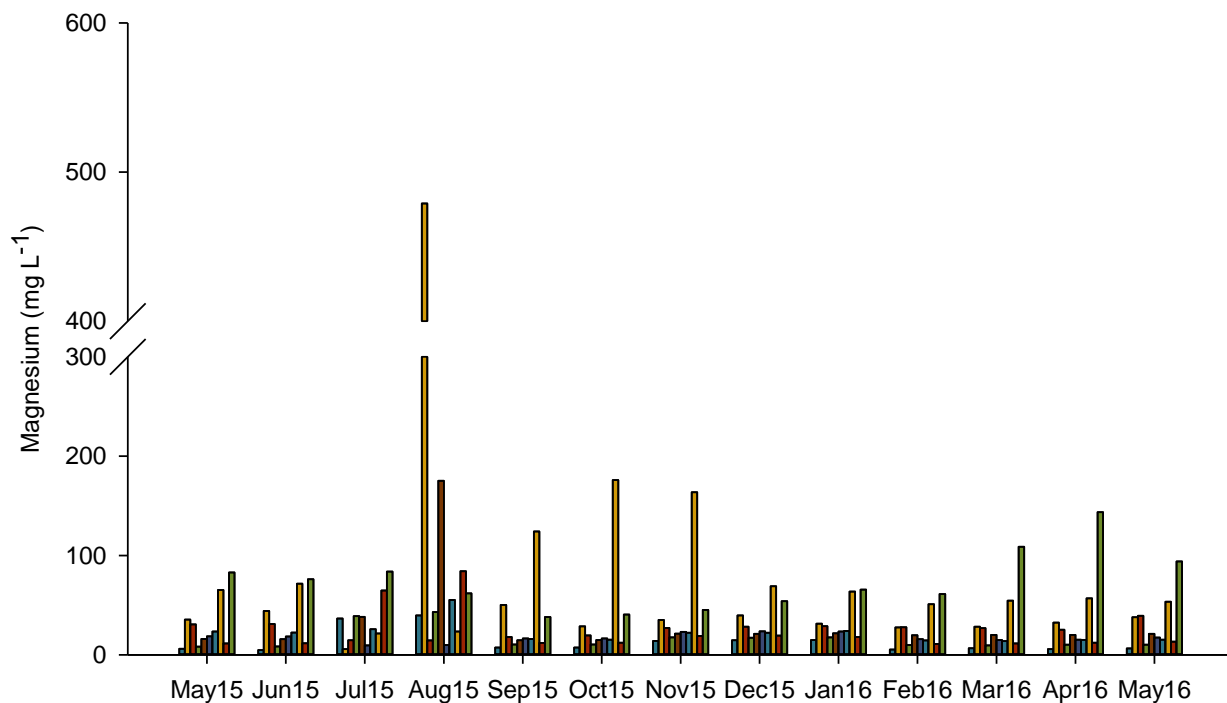
b) Calcium (Ca)



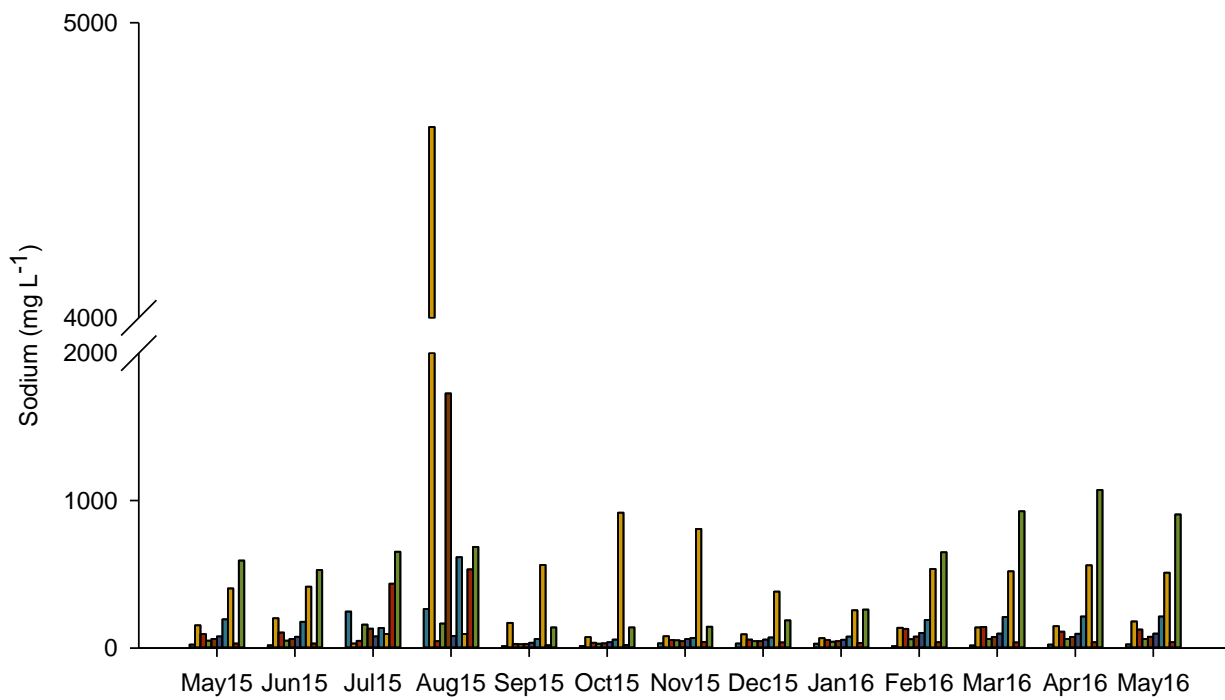
c) Potassium (K)



d) Magnesium (Mg)



e) Sodium (Na)



f) Chloride (Cl^-)

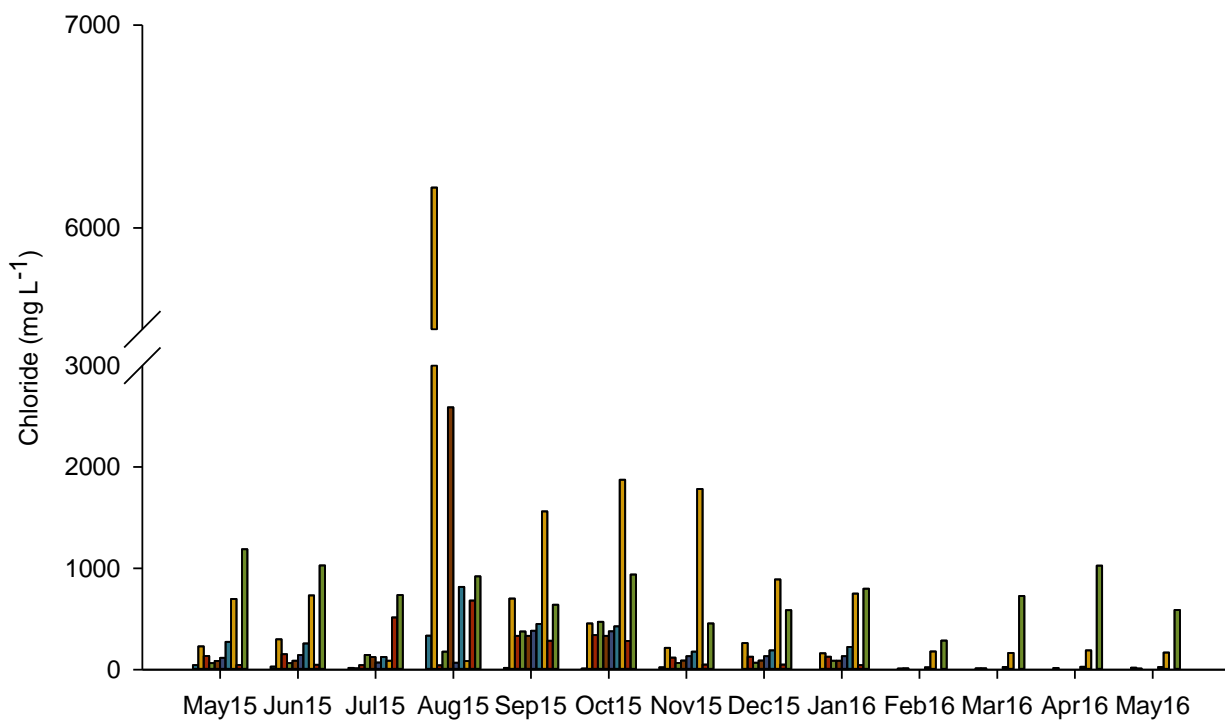


Figure 1. Changes in a) electrical conductivity, b) calcium, c) potassium, d) magnesium, e) sodium and f) chloride over the period of monitoring at each site (May 2015–2016).

Table 1 Mean \pm standard error (range) for selected solutes during the monitoring period May 2015 to 2016

DL	Ca <0.2	K <0.2	Mg <0.2	Na <0.2	Cl ⁻ <0.5	SO ₄ ²⁻ <0.5
S.E. Goollelal	88 \pm 17 (20-208)	16 \pm 2 (9-29)	14 \pm 3 (5-40)	61 \pm 24 (12-264)	45 \pm 25 (0-336)	107 \pm 44 (11-601)
Mid W. Goollelal	77 \pm 14 (38-192)	36 \pm 14 (8-195)	73 \pm 34 (6-479)	498 \pm 347 (31-4646)	703 \pm 463 (12-6199)	412 \pm 145 (16-2099)
N.E. Goollelal	37 \pm 7 (8-87)	16 \pm 3 (4-33)	30 \pm 4 (15-62)	94 \pm 17 (28-209)	136 \pm 37 (10-343)	503 \pm 129 (32-1707)
Mid E. Wallubuenup	43 \pm 5 (20-70)	14 \pm 3 (4-35)	17 \pm 3 (9-43)	74 \pm 12 (25-166)	129 \pm 40 (4-473)	42 \pm 6 (17-91)
W. Wallubuenup	75 \pm 11 (39-149)	18 \pm 6 (4-83)	35 \pm 12 (15-175)	200 \pm 128 (29-1726)	310 \pm 193 (5-2590)	319 \pm 49 (157-557)
S.E. Joondalup	49 \pm 7 (30-107)	14 \pm 3 (3-36)	20 \pm 2 (9-37)	85 \pm 11 (35-156)	143 \pm 38 (8-386)	137 \pm 25 (15-251)
Mid E. Joondalup	63 \pm 13 (33-170)	18 \pm 3 (9-34)	25 \pm 4 (14-55)	204 \pm 46 (57-615)	277 \pm 70 (24-818)	167 \pm 31 (59-310)
Mid W. Joondalup	101 \pm 14 (51-180)	47 \pm 7 (5-86)	87 \pm 15 (22-176)	530 \pm 75 (95-918)	816 \pm 198 (86-1876)	368 \pm 44 (126-575)
N.E. Joondalup	23 \pm 7 (7-82)	18 \pm 3 (7-38)	25 \pm 6 (11-84)	108 \pm 47 (18-533)	163 \pm 61 (2-684)	130 \pm 31 (44-463)
N.W. Joondalup	71 \pm 11 (31-151)	52 \pm 7 (19-90)	86 \pm 12 (38-166)	616 \pm 110 (139-1186)	935 \pm 169 (288-2378)	382 \pm 88 (58-920)

Calculated hardness of water samples from the bores are shown in Figure 3. Hardness was generally slightly lower than in 2014/2015, but higher than previous years, reflecting the low annual rainfall which increased concentrations of key components of the water hardness. The only exception was the very high hardness of Mid E Joondalup in 2013/14, the exact cause of which is unknown. Hardness was highest in western bores, reflecting evapo-concentration of solutes passing through the lake. Eastern bores around Lake Joondalup tend to contain harder water than around Lake Goollelal reflecting differences in the catchments, with more limestone around Lake Joondalup.

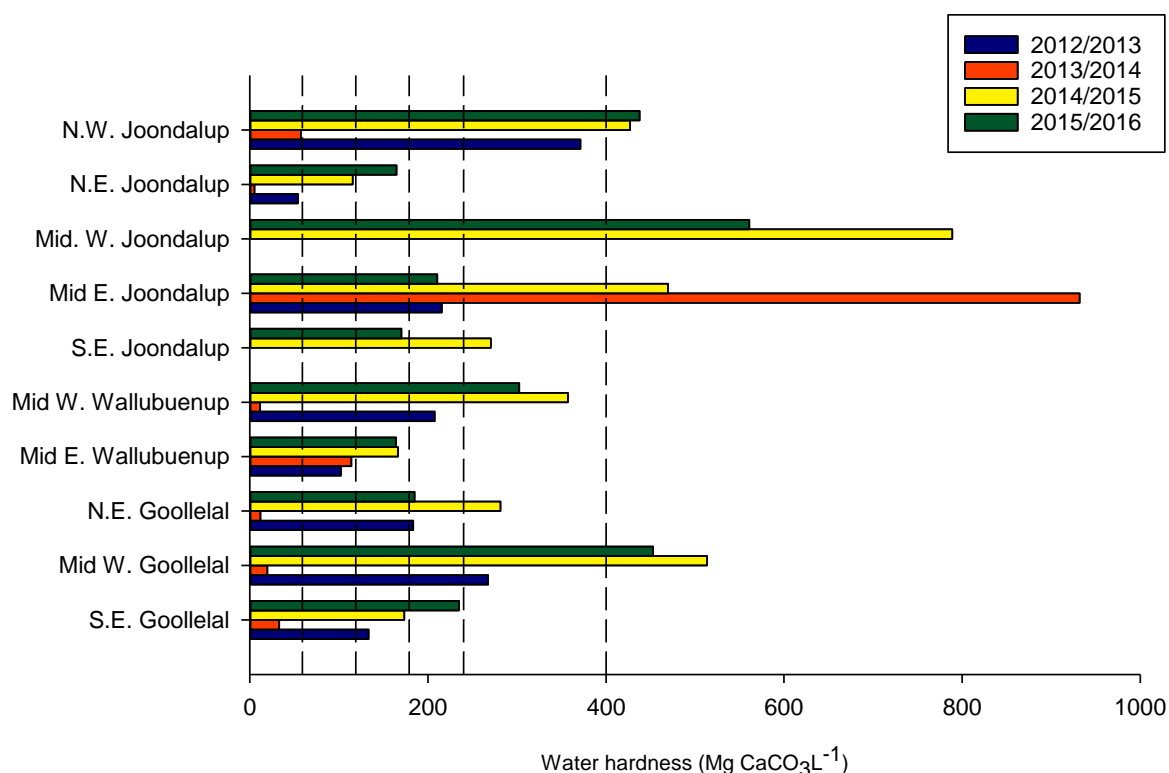
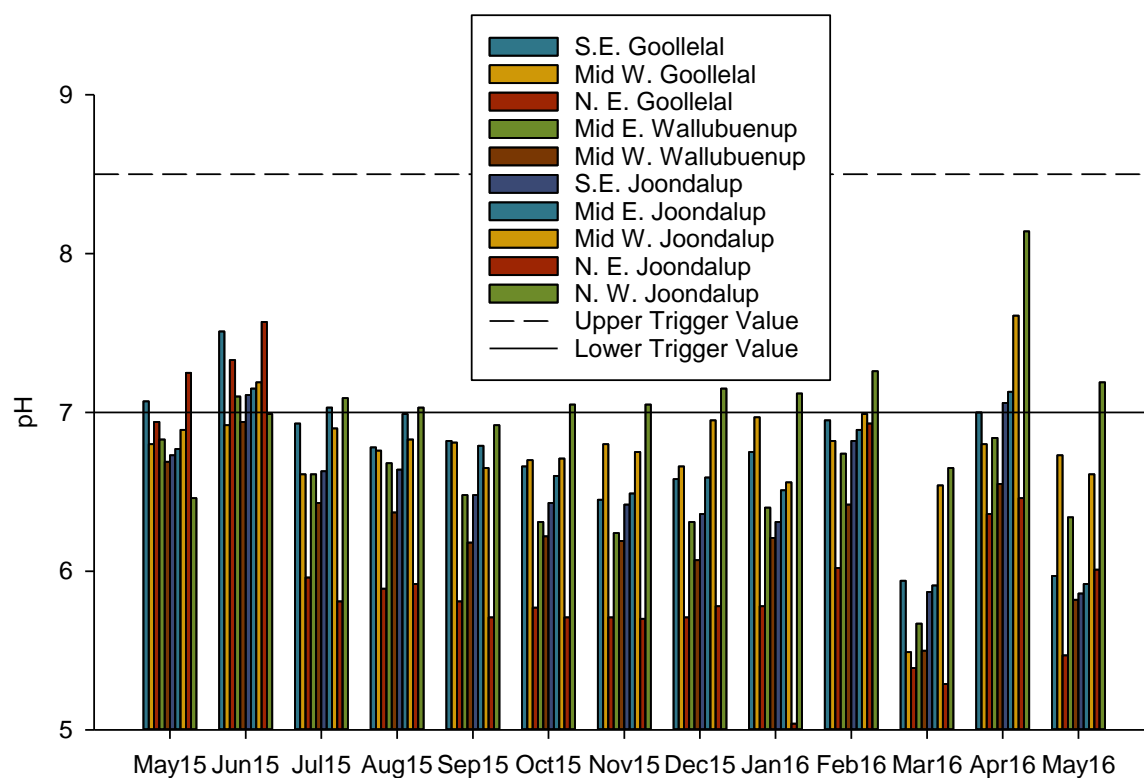


Figure 2. Calculated mean water hardness for the period of monitoring at each bore (May 2015 –2016) with ANZECC & ARMCANZ (2000) categories indicated.

Chloride to sulphate molar ratios is commonly used to indicate the presence of acid sulphate soils (ASS). Oxidation of metal sulphides (typically pyrites) in soils and sediments leads to the production of sulphuric acid. The oxidation increases concentrations of sulphate relative to the 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 bores and therefore must be treated with caution. To improve the ability to detect potential ASS, this year we also measured alkalinity (Table 2) as an alkalinity to sulphate ratio of <5 is considered to be a better predictor in freshwater systems (Department of Environmental Regulation 2015). pH of the groundwater ranged from circum-neutral to <6 (N.E. Goollelal) as in previous years and was highest in December to February. Overall pH at all sites was relatively constant across the year varying by <2 units. Sulphate concentrations were generally highest in the western sites (Mid W. Joondalup and Mid W. Goollelal). Ratios indicated the possible presence of ASS contamination at all sites, although pH was not <5 or aluminium concentrations >1 mg L⁻¹, although very high iron concentrations were noted. Overall, there is suggestion that oxidation of acid sulphate soils is occurring within the catchment, but not all criteria are met to confirm this is occurring (Department of Environmental Regulation 2015).

a) pH



b) Sulphate (SO_4)

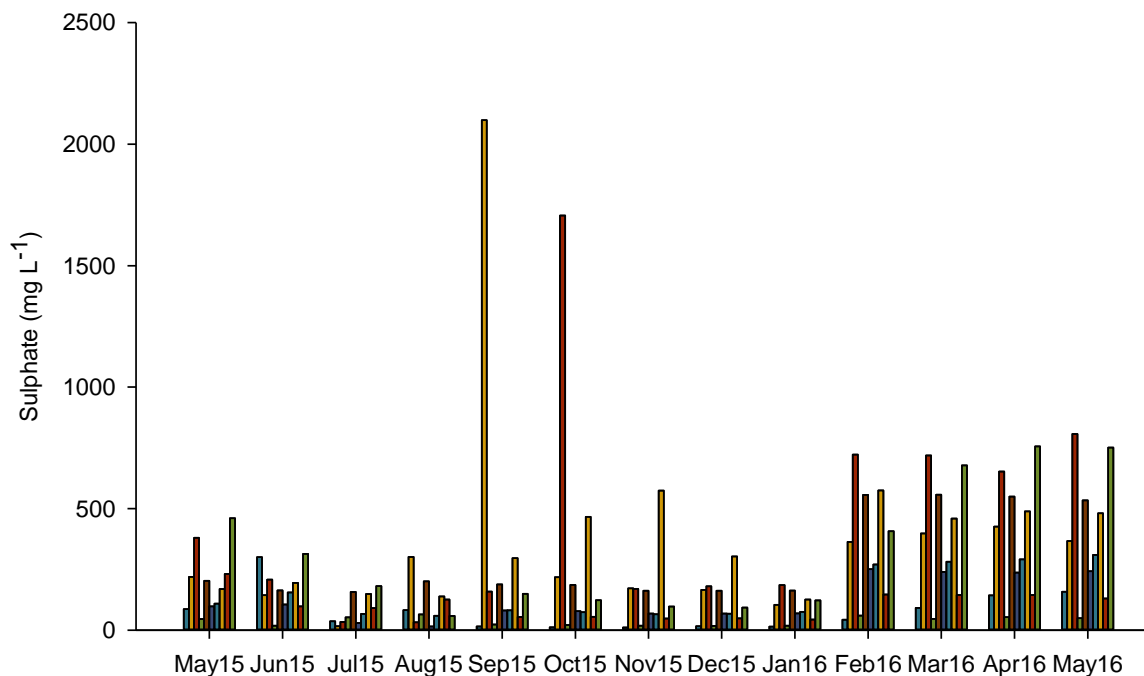


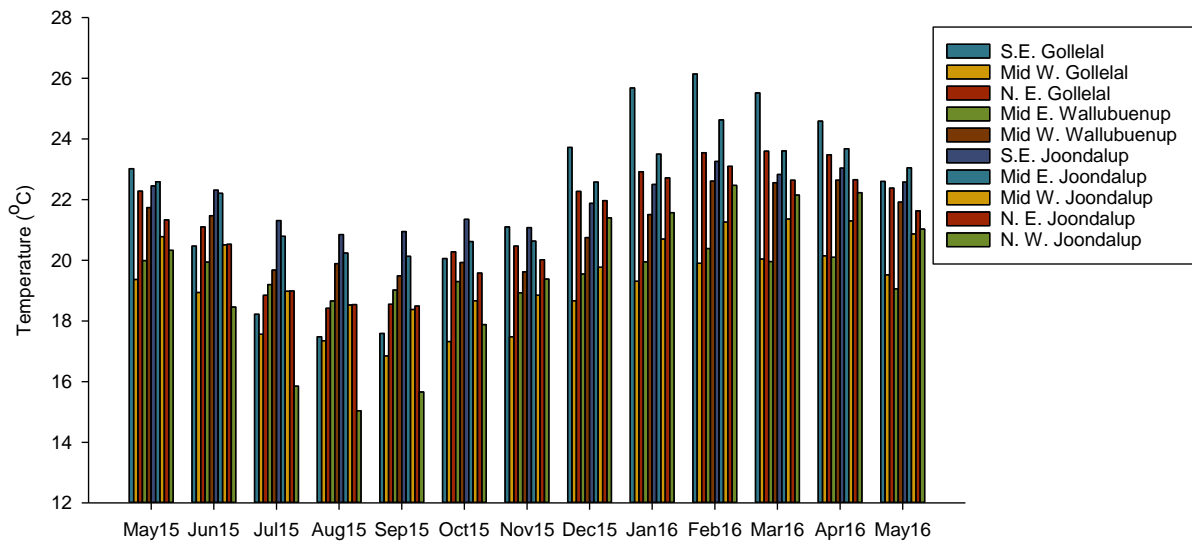
Figure 4. Changes in a) pH and b) sulphate over the period of monitoring at each bore (May 2015 –2016) with ANZECC & ARMCANZ (2000) trigger values for the protection of aquatic ecosystems (95%).

Table 2 Mean \pm standard error (range) for chloride to sulphate ratios, alkalinity and alkalinity to sulphate ratios during the monitoring period May 2015 to 2016

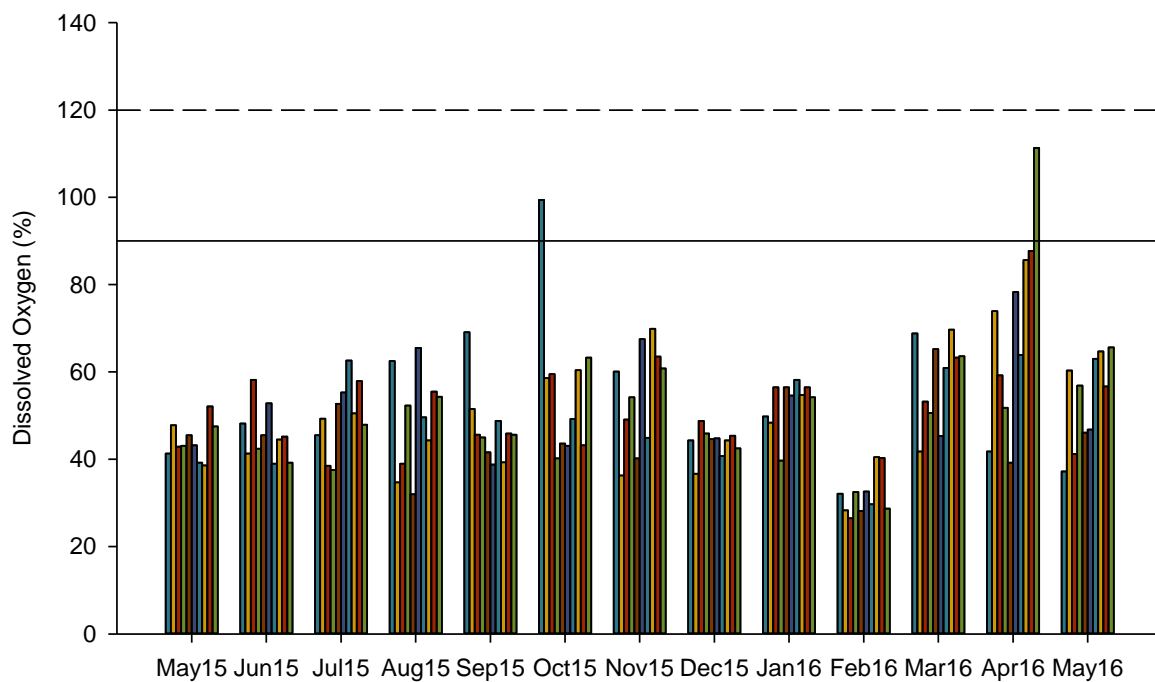
DL	Cl:SO ₄ ²⁻ molar ratio	Alkalinity	Alkalinity : SO ₄ ²⁻ Mass ratio
S.E. Goollelal	2 \pm 1 (0-11)	100 \pm 13 (40-157)	4 \pm 1 (1-9)
Mid W. Goollelal	7 \pm 4 (0-56)	162 \pm 10 (120-240)	1 \pm 0 (0-1)
N.E. Goollelal	2 \pm 1 (0-6)	23 \pm 4 (10-53)	0 \pm 0 (0-1)
Mid E. Wallubuenup	14 \pm 5 (0-61)	95 \pm 2 (87-103)	3 \pm 1 (1-6)
W. Wallubuenup	4 \pm 3 (0-35)	71 \pm 6 (60-127)	0 \pm 0 (0-1)
S.E. Joondalup	6 \pm 1 (0-13)	98 \pm 5 (53-107)	2 \pm 1 (0-7)
Mid E. Joondalup	9 \pm 3 (0-38)	121 \pm 7 (97-163)	1 \pm 0 (0-2)
Mid W. Joondalup	8 \pm 2 (1-22)	258 \pm 6 (223-283)	1 \pm 0 (0-2)
N.E. Joondalup	5 \pm 2 (0-15)	20 \pm 4 (10-50)	0 \pm 0 (0-1)
N.W. Joondalup	14 \pm 3 (2-43)	241 \pm 38 (130-473)	1 \pm 0 (1-2)

Water temperatures varied by approximately 10 °C over the year, highest in summer and lowest in winter (Figure 5, Table 2). Dissolved oxygen was measured in all bores at >25% saturation. Despite low dissolved oxygen concentrations, ORP was generally >0 mV across the year and for eastern sites. Western sites had very low ORP, generally <-100 mV, probably reflecting low water levels within the lakes in 2015/2016. These low ORP values indicated chemical processes rather than oxygen as the driver for ORP changes. Water levels in the bores illustrated little seasonal variation (<0.5 m), highest in October and lowest in May, with almost no change in Mid W. Wallubuenup.

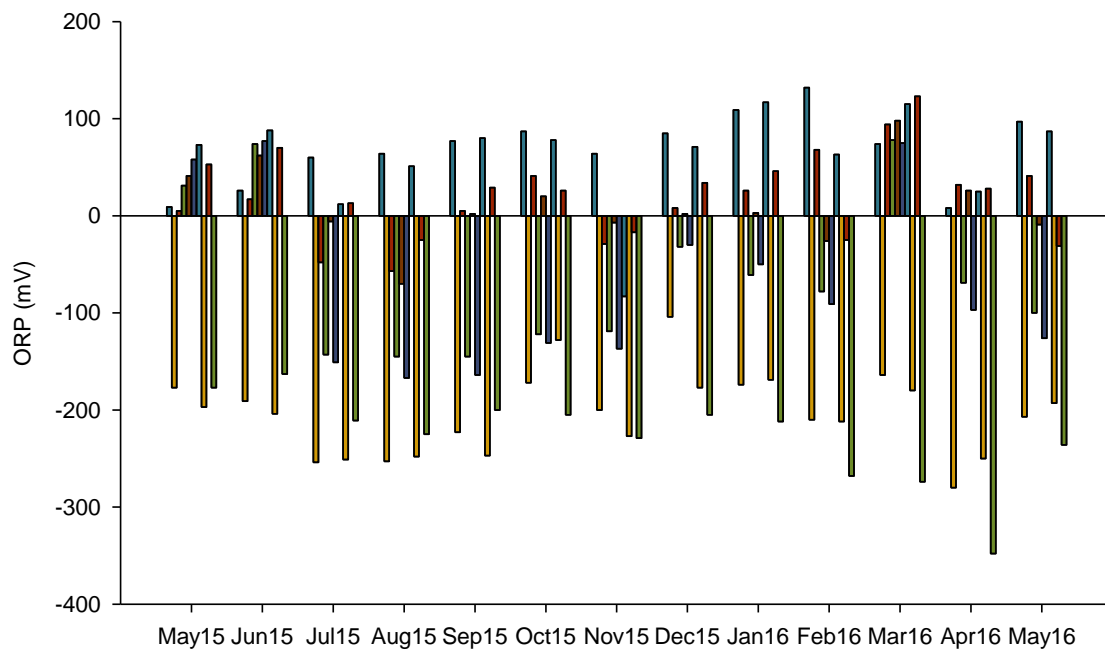
a) Temperature



b) Dissolved Oxygen



c) ORP



d) Depth to Water from Top of Casing (ToC)

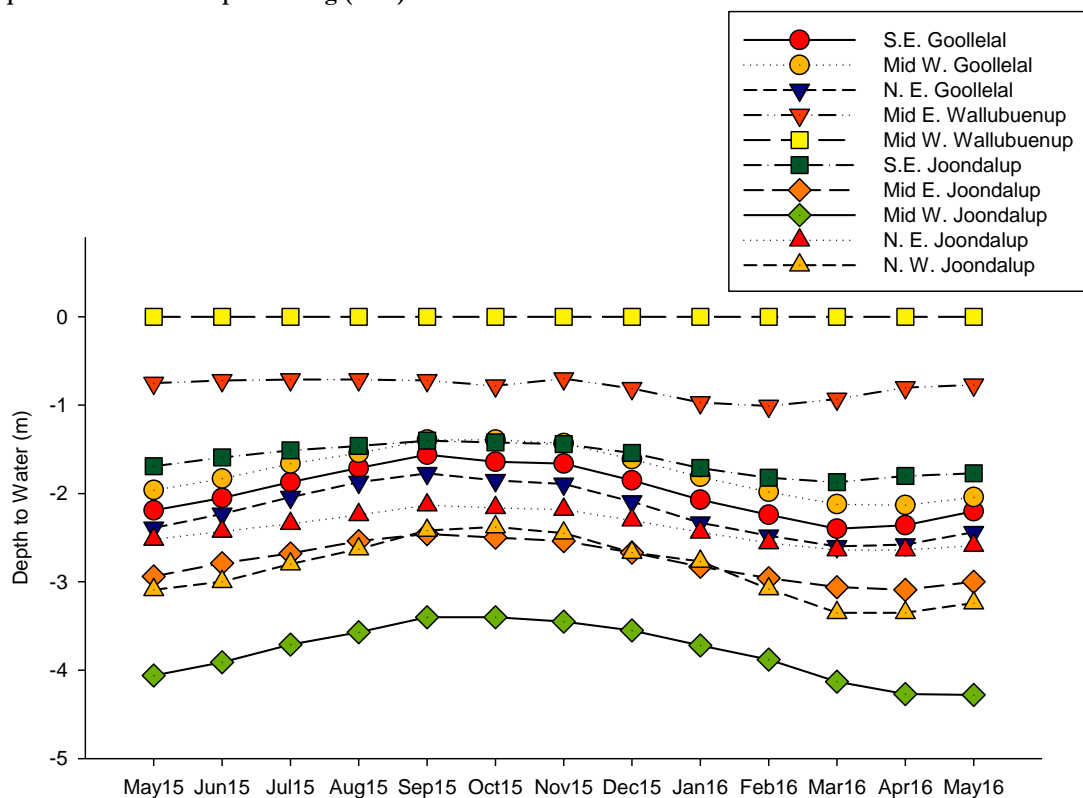


Figure 3. Variation throughout groundwater monitoring period for a) temperature, b) dissolved oxygen, c) ORP and d) depth to water between May 2015 and 2016 at each bore.

Table 3. Mean \pm standard error (range) for physicochemical variables over the monitoring period (May 2015- 2016)

	Temperature (°C)	Conductivity (mS cm ⁻¹)	Dissolved Oxygen (mg L ⁻¹)	Dissolved Oxygen (%)	pH	ORP (mV)
Goollelal SE	22 \pm 0.9 (17.5-26.1)	0.44 \pm 0.04 (0.26-0.75)	4.8 \pm 0.5 (2.6-9)	53.9 \pm 5 (32.1-99.4)	6.72 \pm 0.12 (5.94-7.51)	69 \pm 10 (8-132)
Goollelal Mid W	18.7 \pm 0.3 (16.9-20.2)	1.8 \pm 0.17 (1.23-2.96)	4.3 \pm 0.3 (2.6-6.7)	46.8 \pm 3.4 (28.3-73.9)	6.68 \pm 0.1 (5.49-6.97)	-201 \pm 13 (-280--104)
Goollelal NE	21.4 \pm 0.5 (18.4-23.6)	1.13 \pm 0.07 (0.79-1.8)	4.2 \pm 0.2 (2.2-5.4)	47.6 \pm 2.7 (26.5-59.5)	6.01 \pm 0.16 (5.39-7.33)	16 \pm 12 (-57-94)
Wallubuenup Mid E	19.5 \pm 0.2 (18.7-20.4)	0.55 \pm 0 (0.53-0.58)	4.2 \pm 0.2 (2.9-5.2)	45.5 \pm 2 (32.5-56.9)	6.5 \pm 0.1 (5.67-7.1)	-64 \pm 22 (-145-78)
Wallubuenup W	21.7 \pm 0.4 (19.5-22.6)	1.02 \pm 0.06 (0.88-0.97)	4.6 \pm 0.3 (2.4-5.6)	52.2 \pm 3.1 (28.2-65.2)	6.47 \pm 0.11 (5.5-6.94)	39 \pm 15 (-70-98)
Joondalup SE	22 \pm 0.2 (20.9-23.3)	0.94 \pm 0 (0.91-0.96)	4.5 \pm 0.3 (2.8-6.7)	51.4 \pm 3.5 (32.6-78.3)	6.52 \pm 0.11 (5.86-7.11)	-72 \pm 25 (-167-77)
Joondalup Mid E	22.2 \pm 0.3 (20.1-24.6)	1.47 \pm 0.01 (1.16-1.87)	4.3 \pm 0.2 (2.4-5.6)	50 \pm 2.7 (29.7-63.9)	6.67 \pm 0.1 (5.91-7.15)	60 \pm 11 (-83-117)
Joondalup Mid W	20 \pm 0.3 (18.4-21.4)	4.21 \pm 0.4 (1.89-7.05)	4.9 \pm 0.4 (3.4-7.5)	54.4 \pm 4.1 (38.6-85.6)	6.86 \pm 0.08 (6.54-7.61)	-206 \pm 10 (-251--128)
Joondalup NE	20.9 \pm 0.5 (18.5-23.1)	0.38 \pm 0.01 (0.35-0.41)	4.9 \pm 0.3 (3.4-7.6)	54.9 \pm 3.5 (40.3-87.7)	6.09 \pm 0.21 (5.04-7.57)	25 \pm 12 (-31-123)
Joondalup NW	19.5 \pm 0.7 (15-22.5)	3.92 \pm 0.49 (2.07-7.33)	5 \pm 0.5 (2.4-9.4)	55.7 \pm 5.5 (28.7-111.3)	7.08 \pm 0.11 (6.46-8.14)	-227 \pm 13 (-348--163)

8.2 METALS AND METALLOIDS

Table 3 shows the number of samples from all the bores that exceeded ANZECC & ARMCANZ (2000) guidelines for the protection of aquatic ecosystems. It should be noted that these guidelines were not designed for groundwater, but assuming that this groundwater discharges into the lake it provides an indicator of potential issues. Aluminium, As, Cd, Hg and Zn all had concentrations that on occasion were higher than guideline levels (often by an order of magnitude) indicating potential problems for the lakes. Aluminium, Hg and Zn concentrations were particularly problematic affecting over 25% of samples exceeding guidelines. Mercury can biomagnify up food chains when methylated and pose a risk to higher organisms and birds. All the metals detected at high concentrations were also identified as problematic in the Yellagonga surface water monitoring program, suggestive that a major source might be groundwater.

Table 4. Exceedances of ANZECC & ARM CANZ (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/ ARM CANZ (2000) Trigger Value	Detection Limit	Mean \pm se (maximum value)	No. exceeding detection limit (No. exceeding trigger value)
Aluminium (Al)	0.055	<0.0005	0.057 \pm 0.008 (0.602)	130 (31)
Arsenic (As)	0.013 - 0.024*	<0.00001	0.0052 \pm 0.0005 (0.0333)	130 (2)
Calcium (Ca)	—	<0.2	62.69 \pm 3.98 (207.66)	130 (0)
Cadmium (Cd)	0.0011 – 0.0016 ^H	<0.00001	0.00023 \pm 0.00003 (0.00194)	117 (1)
Cobalt (Co)	ID	<0.00002	0.0003 \pm 0.0001 (0.0154)	129 (0)
Chromium (Cr)	ID - 0.006 ^H	<0.00005	0.0013 \pm 0.0001 (0.0038)	130 (0)
Iron (Fe)	ID	<0.0005	1.04 \pm 0.18 (8.42)	130 (0)
Mercury (Hg)	0.0006 - ID*	<0.00002	0.0001 \pm 0 (0.006)	96 (5)
Potassium (K)	—	<0.2	24.82 \pm 2.2 (194.88)	130 (0)
Magnesium (Mg)	—	<0.2	41.24 \pm 4.74 (478.94)	130 (0)
Manganese (Mn)	1.9	<0.00005	0.02 \pm 0 (0.57)	130 (0)
Sodium (Na)	—	<0.2	247 \pm 42.53 (4645.95)	130 (0)
Nickel (Ni)	0.0480 – 0.0687 ^H	<0.00005	0.0014 \pm 0.0002 (0.0207)	130 (0)
Selenium (Se)	0.011	<0.00005	0.0004 \pm 0 (0.0025)	97 (0)
Uranium (U)	0.005+	<0.00002	0.00008 \pm 0.00001 (0.00074)	128 (0)
Zinc (Zn)	0.0350 – 0.05 ^H	<0.00025	0.084 \pm 0.004 (0.222)	130 (77)

^H Value corrected for hardness (increases trigger) as per ANZECC/ARM CANZ (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.

ID Insufficient data to derive a reliable trigger value.

— No trigger provided in ANZECC/ARM CANZ (2000)

+ Low reliability, interim working level as prescribed in ANZECC/ARM CANZ (2000)

Aluminium concentrations in bores in 2014/15 behaved very differently to 2015/16, with less export to the west and higher concentrations around the lower part of Lake Joondalup (Table 4). Arsenic, Cd, Cr and Co concentrations show no particular trends spatially. Iron concentrations were high in the north east of Lake Goollelal and Mid W. Joondalup and W. Wallubuenup, in a pattern similar to that seen in 2014/15.

In 2014/15 Hg concentrations were substantially higher than in previous years, exceeding guideline levels at all bores. In 2015/16 Hg concentrations remained high but were lower than 2014/15. Concentrations of Mn, Ni, Se, U and Zn were relatively similar across all the bores, although high one-off values were common.

Table 5. Mean \pm standard error (range) for selected metals over the May 2015 to 2016 monitoring period with ANZECC & ARMCANZ (2000) water quality trigger values for 95% protection of aquatic ecosystems for metals and metalloids for reference.

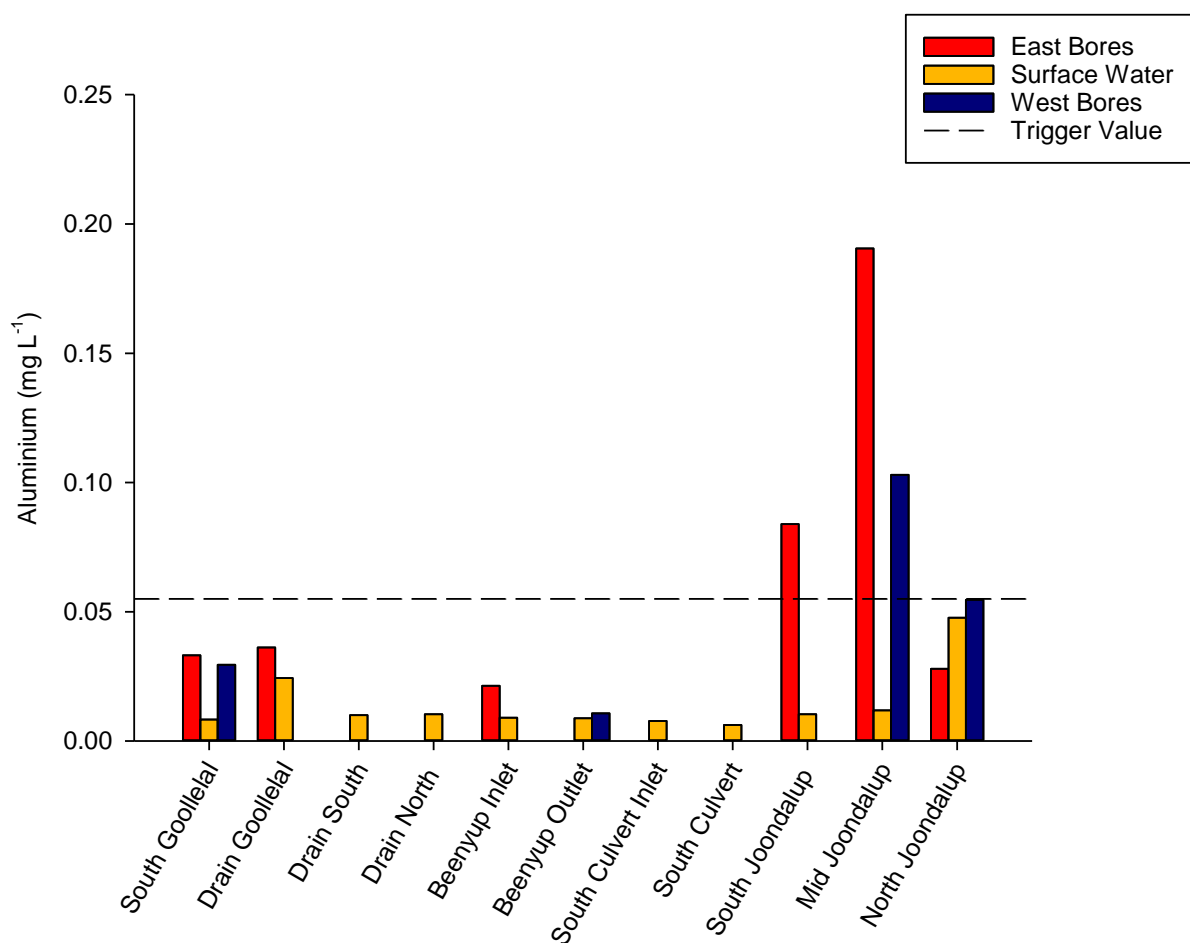
	Al	As	Cd	Co	Cr	Fe
DL	>0.5	>0.01	>0.01	>0.02	>0.05	>0.5
Trigger Value	>55	>13-24	>0.3-1.7 ^H	ID	ID-4*	ID
S.E. Goollelal	33 \pm 9 (8-137)	1.65 \pm 0.39 (0.88-6.25)	0.33 \pm 0.07 (0.1-1.12)	0.19 \pm 0.03 (0.08-0.4)	0.59 \pm 0.06 (0.26-1.08)	54 \pm 7 (33-130)
Mid W. Goollelal	28 \pm 5 (11-66)	5.61 \pm 0.76 (1.31-10.37)	0.1 \pm 0.03 (0.01-0.42)	0.09 \pm 0.01 (0.03-0.21)	0.83 \pm 0.08 (0.36-1.46)	355 \pm 109 (58-1386)
N.E. Goollelal	40 \pm 10 (12-135)	0.79 \pm 0.09 (0.3-1.31)	0.52 \pm 0.15 (0.11-1.94)	1.34 \pm 1.17 (0.06-15.37)	0.64 \pm 0.05 (0.34-0.86)	4994 \pm 827 (100-8423)
Mid E. Wallubuenup	21 \pm 3 (10-42)	10.62 \pm 0.97 (6.36-18.07)	0.06 \pm 0.01 (0.01-0.15)	0.08 \pm 0.01 (0.05-0.12)	2.65 \pm 0.28 (0.75-3.83)	73 \pm 19 (32-271)
W. Wallubuenup	10 \pm 2 (4-27)	1.49 \pm 0.14 (0.76-2.54)	0.4 \pm 0.1 (0.06-1.46)	0.25 \pm 0.19 (0.02-2.5)	1.67 \pm 0.2 (0.34-2.52)	3876 \pm 381 (107-5477)
S.E. Joondalup	86 \pm 33 (16-459)	3.13 \pm 0.95 (1.02-11.1)	0.07 \pm 0.02 (0.01-0.27)	0.2 \pm 0.08 (0.04-1.07)	1.08 \pm 0.26 (0.38-3.5)	36 \pm 9 (18-124)
Mid E. Joondalup	180 \pm 53 (13-602)	1.95 \pm 0.42 (1.13-6.94)	0.17 \pm 0.05 (0.03-0.63)	0.46 \pm 0.07 (0.02-0.85)	1.16 \pm 0.2 (0.28-2.66)	70 \pm 9 (28-151)
Mid W. Joondalup	97 \pm 28 (5-326)	15.2 \pm 2.63 (1.17-33.31)	0.07 \pm 0.02 (0.01-0.28)	0.11 \pm 0.02 (0.03-0.21)	1.8 \pm 0.17 (0.91-2.79)	688 \pm 357 (92-4058)
N.E. Joondalup	27 \pm 7 (9-93)	2.47 \pm 0.91 (0.6-11.29)	0.44 \pm 0.12 (0.04-1.19)	0.1 \pm 0.02 (0.04-0.24)	0.97 \pm 0.1 (0.53-1.79)	138 \pm 35 (43-447)
N.W. Joondalup	51 \pm 20 (12-281)	8.87 \pm 1.71 (1.04-17.51)	0.13 \pm 0.05 (0.01-0.62)	0.09 \pm 0.02 (0.02-0.26)	1.67 \pm 0.2 (0.39-3.01)	149 \pm 24 (70-416)

Table 54. cont.

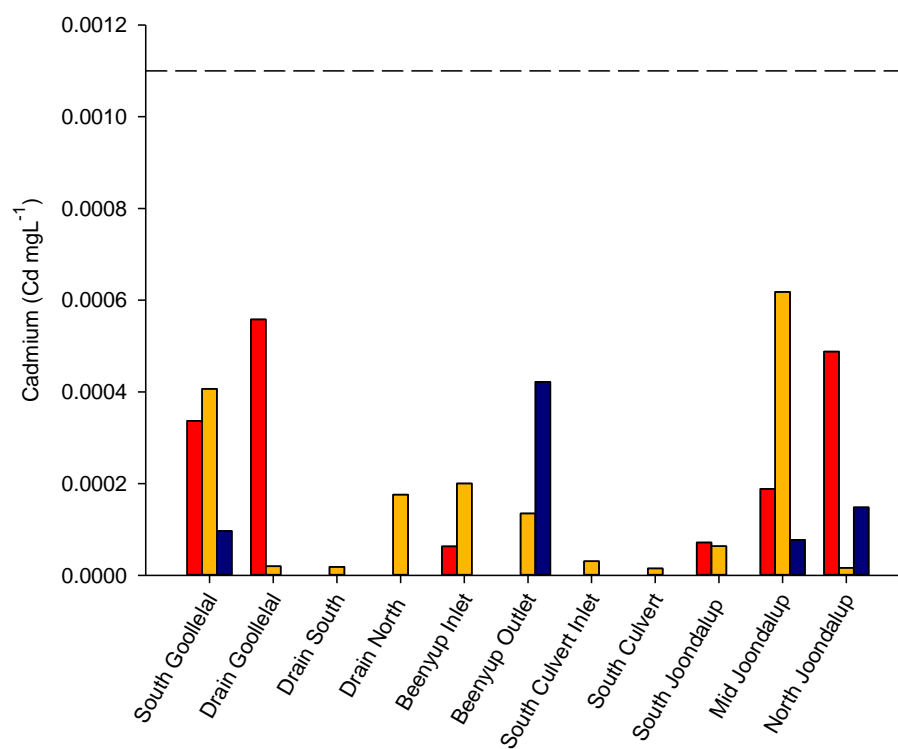
DL	Hg	Mn	Ni	Se	U	Zn
	>0.02	>0.05	>0.05	>0.05	>0.02	>0.05
Trigger Value	>0.6-ID*	>1.9	>18.1-88.5 ^H	>11	>5 ⁺	>13.2-64.3 ^H
S.E. Goollelal	0.05 ± 0.01 (0.01-0.14)	4.52 ± 1.01 (0.68-12)	1.47 ± 0.19 (0.6-2.63)	0.35 ± 0.07 (0.14-1.07)	0.3 ± 0.07 (0.06-0.74)	111.38 ± 10.25 (36.93-160.33)
Mid W. Goollelal	0.1 ± 0.05 (0.01-0.65)	13.47 ± 7.92 (1.6-107.9)	0.96 ± 0.1 (0.49-1.57)	0.55 ± 0.24 (0.06-2.5)	0.05 ± 0.03 (0.01-0.34)	37.61 ± 3.51 (15.04-63.89)
N.E. Goollelal	0.06 ± 0.01 (0.01-0.17)	59.01 ± 42.48 (2.42-566.09)	2.92 ± 1.51 (0.66-20.67)	0.3 ± 0.18 (0.05-2.5)	0.01 ± 0 (0.01-0.03)	141.21 ± 18.02 (27.17-222.49)
Mid E. Wallubuenup	0.05 ± 0.01 (0.01-0.13)	7.83 ± 0.74 (3.98-10.98)	0.93 ± 0.1 (0.5-1.6)	0.66 ± 0.19 (0.08-1.92)	0.12 ± 0.01 (0.01-0.18)	95.38 ± 9.37 (42.66-140.38)
W. Wallubuenup	0.09 ± 0.05 (0-0.73)	24.01 ± 2.46 (12.25-45.18)	1.01 ± 0.1 (0.52-1.69)	0.29 ± 0.19 (0.03-2.5)	0.04 ± 0.01 (0.01-0.15)	82.25 ± 8.04 (13.81-119.24)
S.E. Joondalup	0.07 ± 0.02 (0.01-0.19)	19.55 ± 4.39 (5.64-58.75)	1.04 ± 0.15 (0.43-2.36)	0.42 ± 0.13 (0.12-1.94)	0.08 ± 0.01 (0.01-0.15)	88.04 ± 13.39 (24.66-166.62)
Mid E. Joondalup	0.17 ± 0.13 (0.01-1.77)	12.7 ± 3.34 (5.16-50.31)	1.88 ± 0.29 (0.58-5.05)	0.46 ± 0.07 (0.07-1.04)	0.02 ± 0 (0.01-0.05)	91.68 ± 14.06 (12.38-161.89)
Mid W. Joondalup	0.11 ± 0.05 (0.01-0.74)	7.38 ± 1.89 (2.42-22.37)	1.66 ± 0.21 (0.75-3.57)	0.3 ± 0.09 (0.05-1.13)	0.05 ± 0.01 (0.01-0.11)	81.85 ± 16.44 (29.37-176.43)
N.E. Joondalup	0.52 ± 0.46 (0.01-6.04)	3.65 ± 0.41 (1.71-6.29)	0.9 ± 0.09 (0.43-1.37)	0.18 ± 0.04 (0.05-0.45)	0.01 ± 0.09 (0.13-0.01)	54.18 ± 4.38 (35.47-93.96)
N.W. Joondalup	0.12 ± 0.04 (0.01-0.49)	16.01 ± 9.22 (2.13-125.81)	1.24 ± 0.18 (0.48-2.54)	0.62 ± 0.18 (0.05-2.5)	0.05 ± 0.01 (0.01-0.08)	51.61 ± 6.27 (23.15-97.49)
^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.					
ID	Insufficient data to derive a reliable trigger value.					
+	Low reliability, interim working level as prescribed in ANZECC/ARMCANZ (2000)					

Figure 6 shows average concentrations of metals/metalloids that had individual values that exceeded guideline levels in eastern and western bores compared to the nearest surface water, from the annual Yellagonga surface water monitoring program. Aluminium concentrations were generally higher in the groundwater around the lakes but not through the centre of the park. Aluminium concentrations were very similar to 2014/15 except at Mid Joondalup where the east bore had a much higher concentration. Mercury concentrations were higher in surface waters suggesting that there were other sources of this metal in the system alongside groundwater. The Hg concentrations were lower than in 2014/15 with fewer exceedances and low peak values. For Cd concentrations were generally higher in the surface waters, in contrast to 2013/14. Zinc concentrations were similar between eastern and western bores but significantly higher than found in the surface waters. Zinc concentrations were also worse in terms of frequency of exceedances and peak concentrations than in 2014/15.

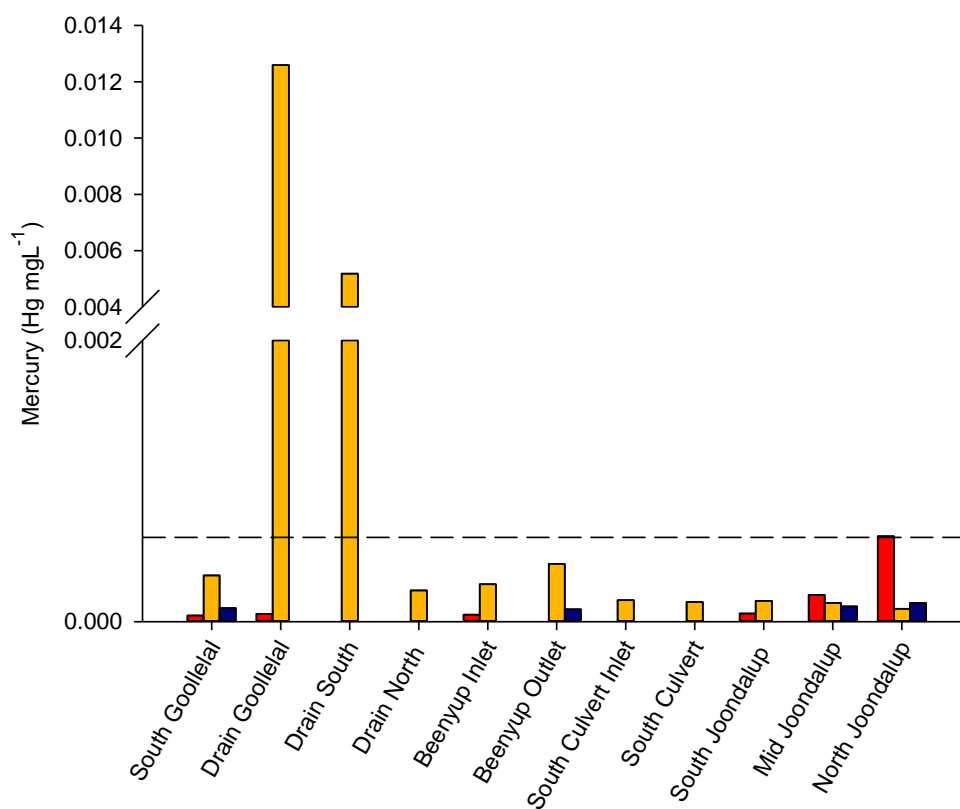
a) Aluminium



b) Cadmium



c) Mercury



d) Zinc

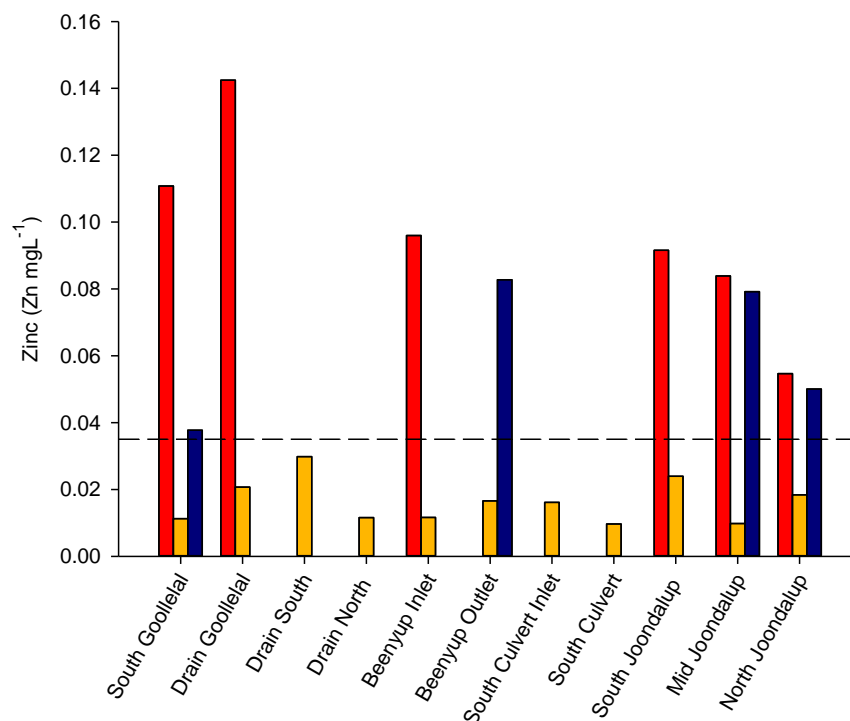


Figure 6. Mean (May 2015 to 2016) metal concentrations for groundwater and surface water. Dotted lines indicate the ANZECC & ARM CANZ (2000) trigger value ranges for the protection of aquatic ecosystems (95%).

8.3 NUTRIENTS

The highest DOC concentrations were found in water leaving Lake Joondalup at N.W. Joondalup, Mid W. Joondalup and Mid W. Goollelal (Figure 7). The western Joondalup concentrations were highest in Feb to June, while for Mid W. Goollelal it was August to October. This pattern is almost identical to that seen for EC (Figure 2), and therefore probably an evapo-concentration effect. The concentrations of DOC were similar to 2014/15.

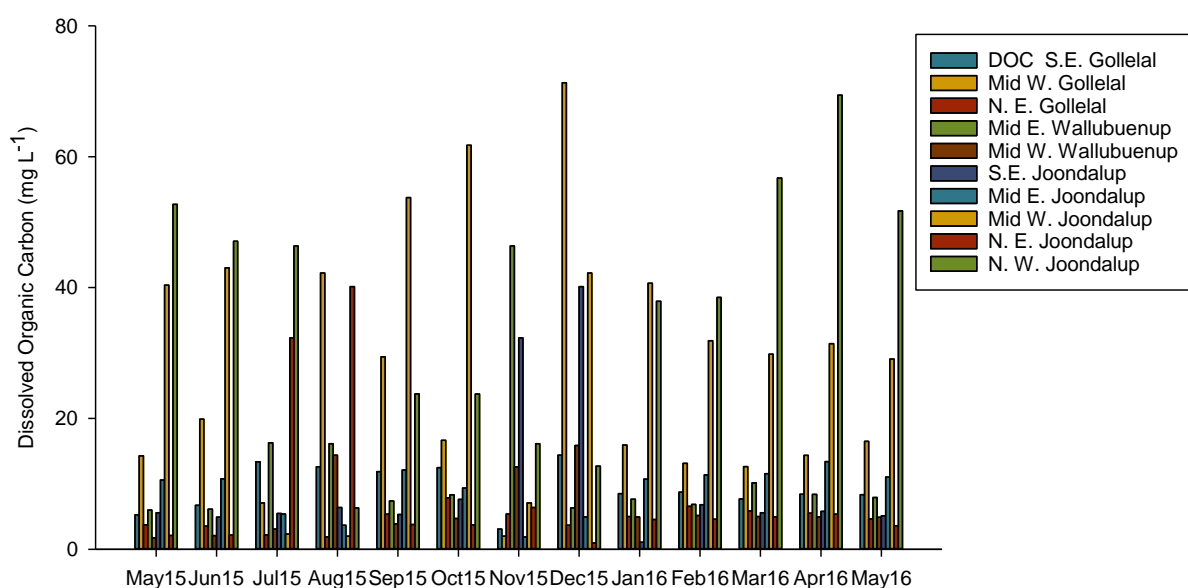
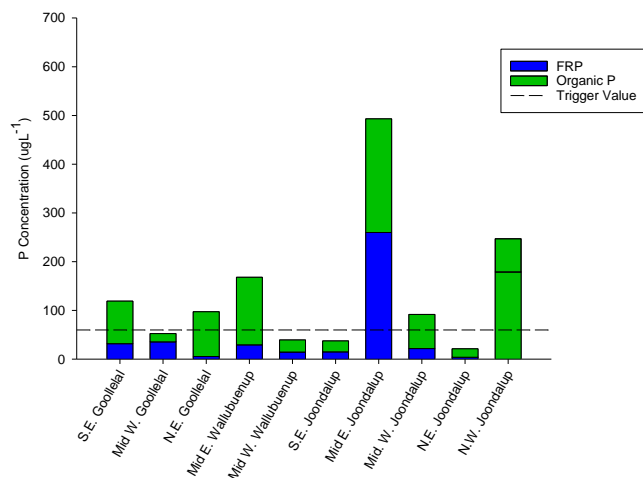


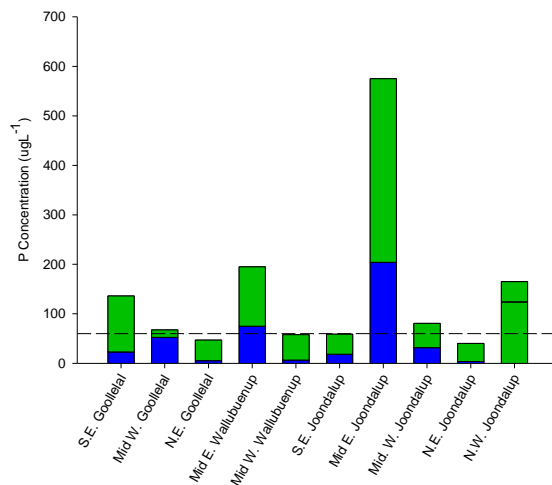
Figure 7. Dissolved organic C concentrations recorded in groundwater bores from May 2015 to 2016.

Mid E Joondalup had the highest concentrations of FRP exceeding $400 \mu\text{g L}^{-1}$, in all months except July and August 2015. All sites were dominated by organic P (probably inorganic particulates, as the analysis does not discriminate between organic and inorganic forms). S.E. Goollelal, Mid E. Wallubuenup and Mid E. Joondalup were consistently high in P suggesting that these bores were sources of P in wetland system. These sites also had high P concentrations in 2013/14 and 2014/15. The N.W. Joondalup bore was usually higher in P than N.E. Joondalup and was the only western site that showed significant P levels. Phosphorus concentrations were similar to those recorded in the surface water study suggesting that groundwater is an important source of P.

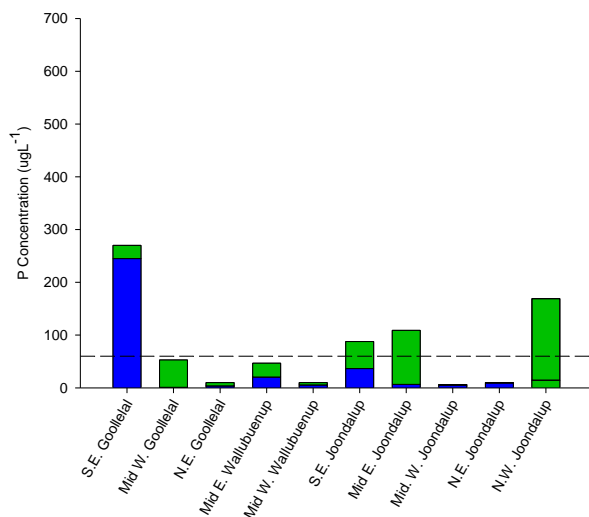
May 2015



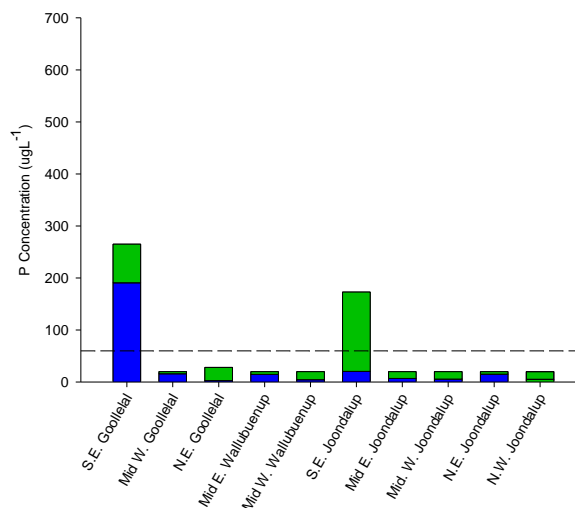
June 2015



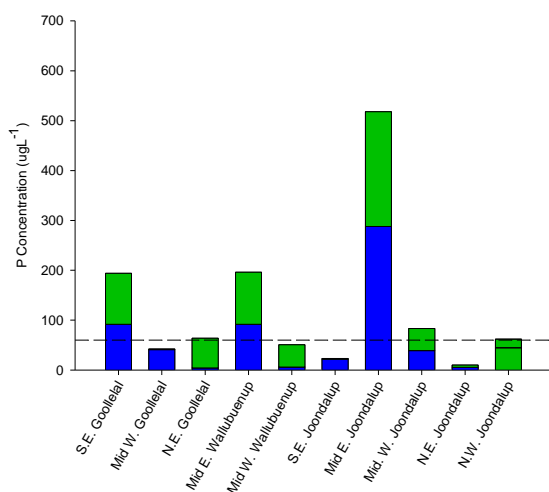
July 2015



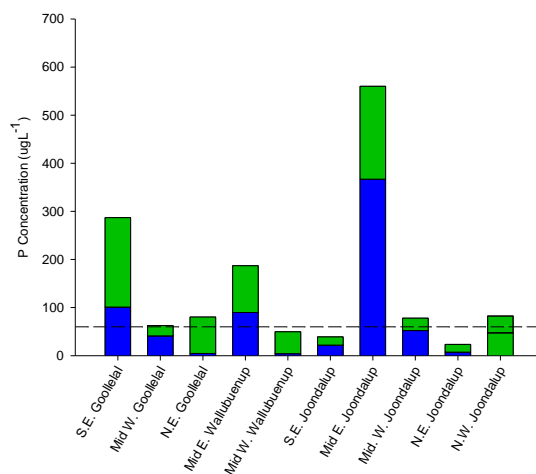
August 2015



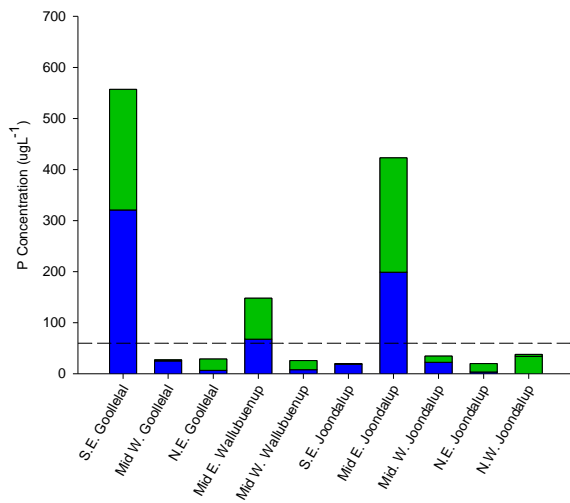
September 2015



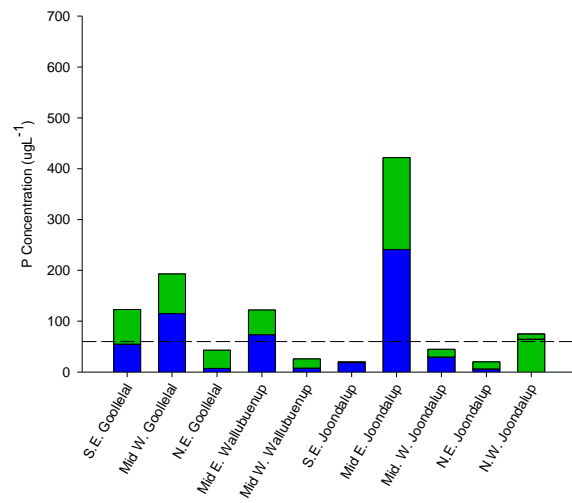
October 2015



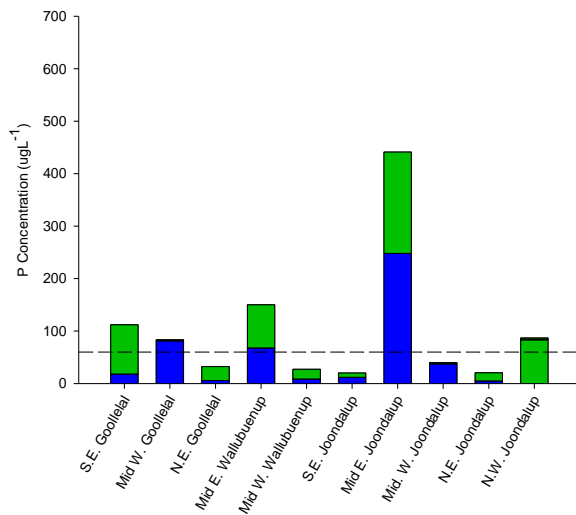
November 2015



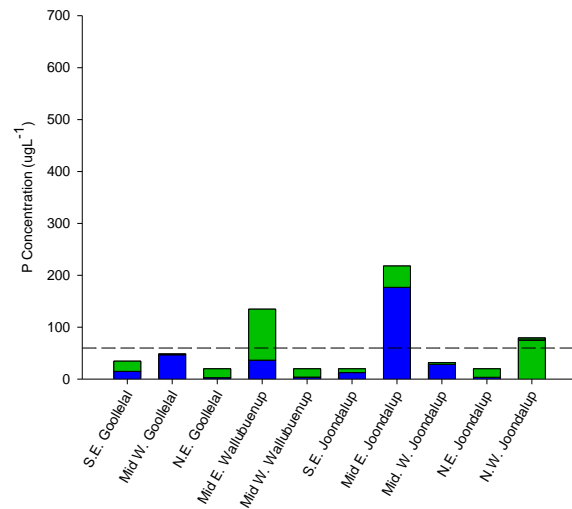
December 2015



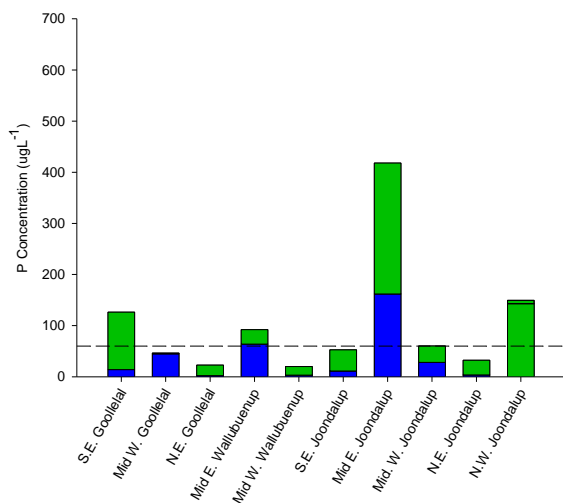
January 2016



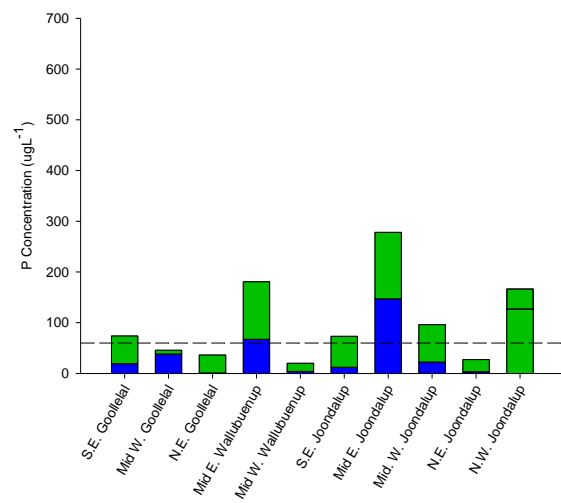
February 2016



March 2016



April 2016



May 2016

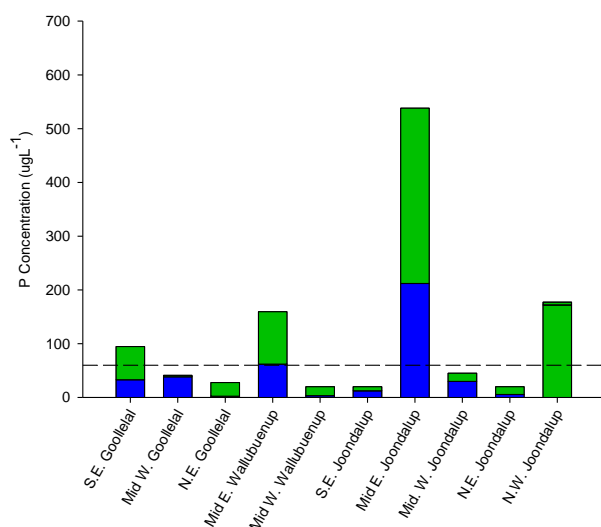
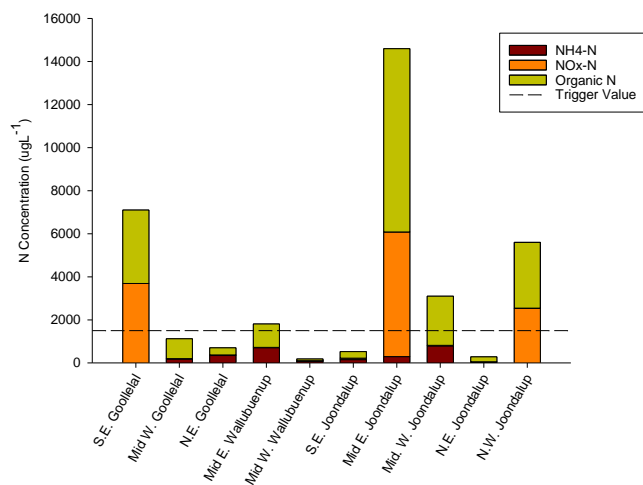


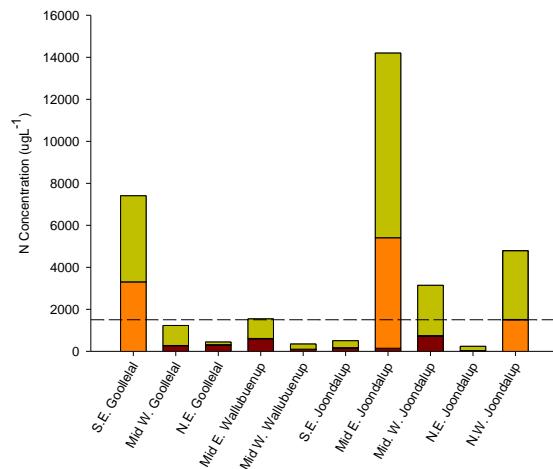
Figure 4. Breakdown of total phosphorus into chemical fractions (organic P and FRP) recorded in groundwater at each bore between May 2015 and 2016 with the ANZECC & ARMANZ (2000) trigger value for total phosphorus shown.

Nitrogen concentrations in the groundwater were dominated by organic N (the analysis used does not discriminate between organic and inorganic forms), most probably N associated with colloidal particles. In 2013/14 this domination of organic N lasted from August 2012 to February 2013, after which this form of N was almost absent. This loss of organic N was unusual and was not repeated in 2014/15 or in 2015/16. Mid E. Joondalup and S.E. Goollelal consistently had very high NO_x concentrations; these may be from the former landfill areas on the eastern side of Lake Joondalup, fertiliser use on lawns, septic tanks east of Kingsley or a legacy of former agricultural activities on the eastern side of the lakes. Occasional spikes of NH₄ are seen in western bores. Generally very little NO_x is exported from the lakes, presumably being used by plants in the lakes. However when water levels are very low in the lakes we see significant export of ammonia into the groundwater. Ammonia is probably being produced in the lakes in the shallow water as organic matter is broken down (ammonification). Similar patterns were seen in nitrogen in bores in 2015/16 compared to 2014/15.

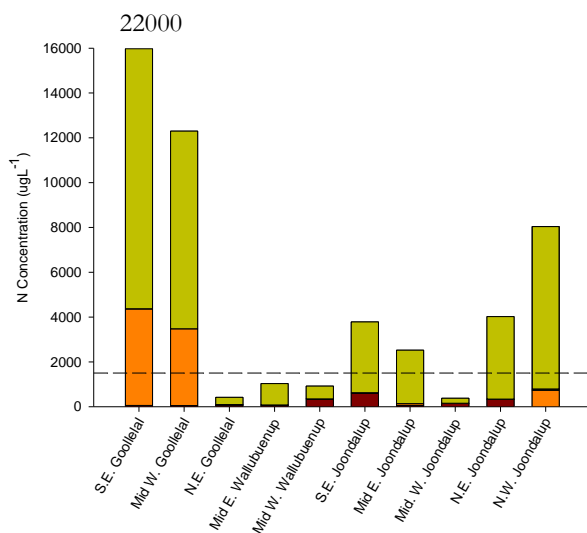
May 2015



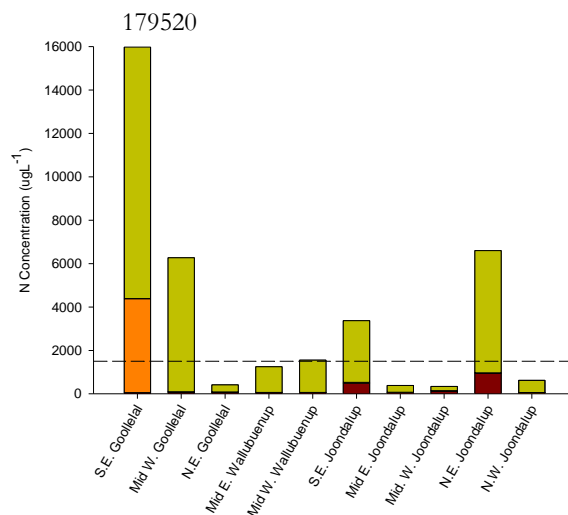
June 2015



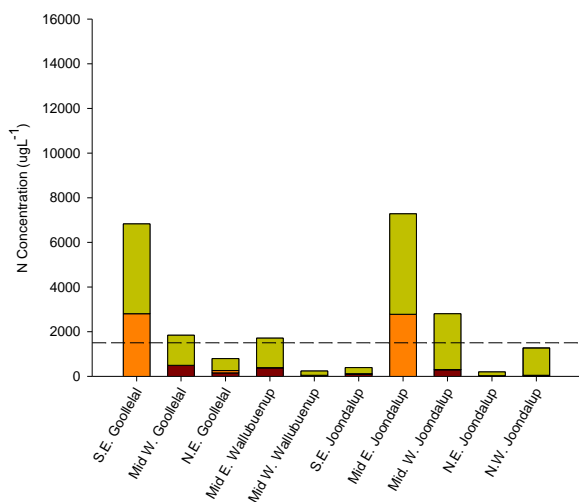
July 2015



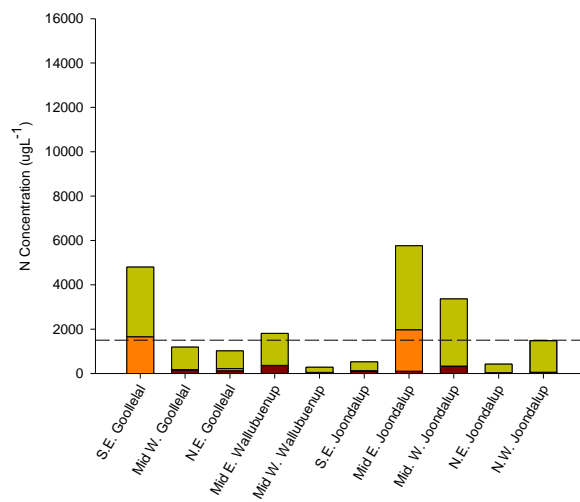
August 2015



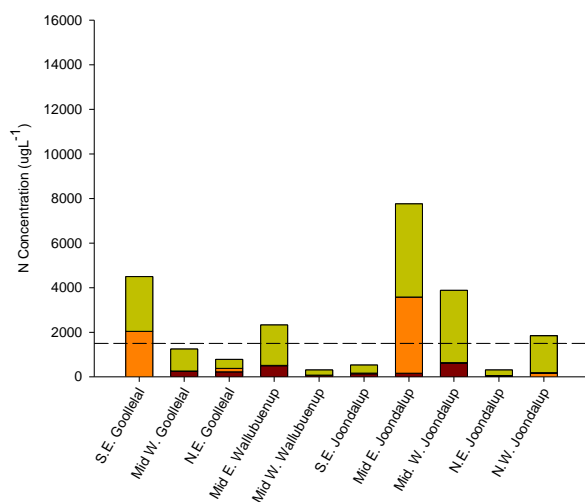
September 2015



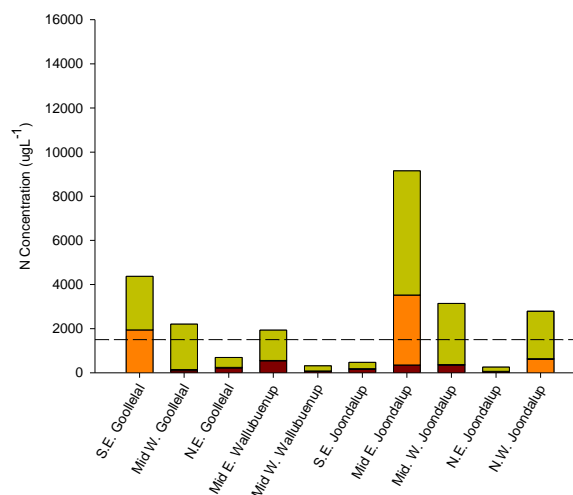
October 2015



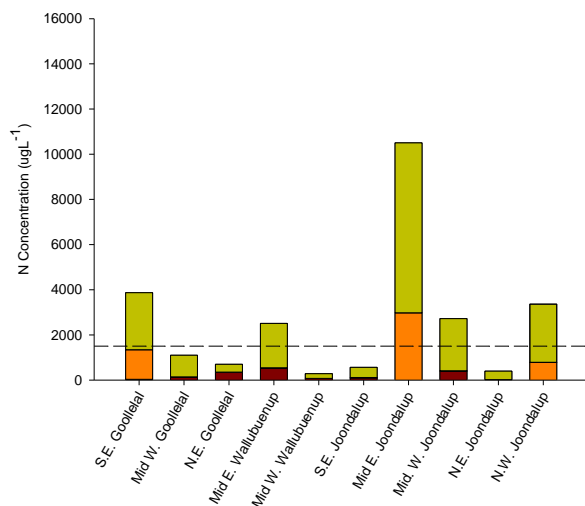
November 2015



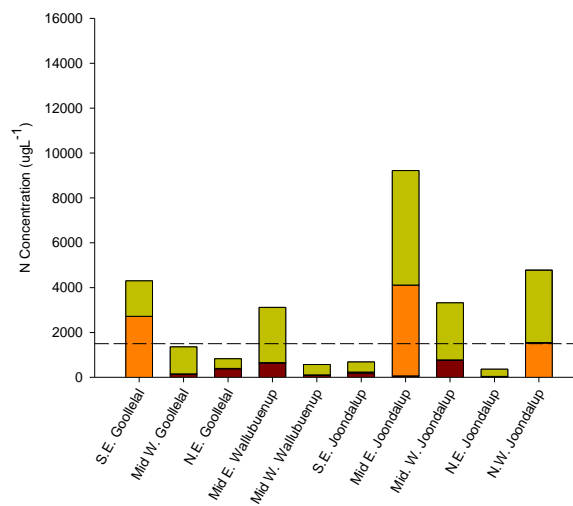
December 2015



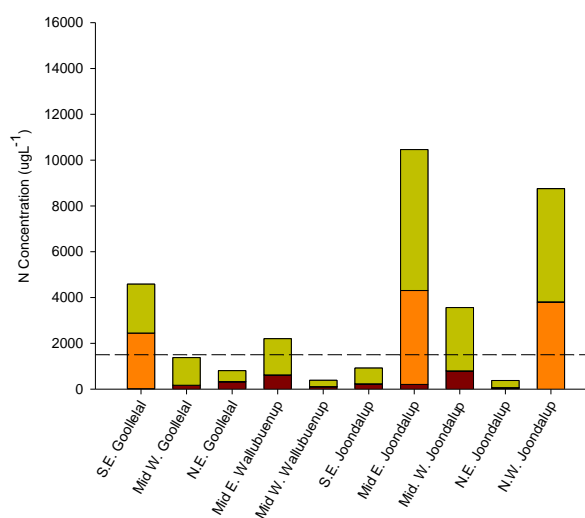
January 2016



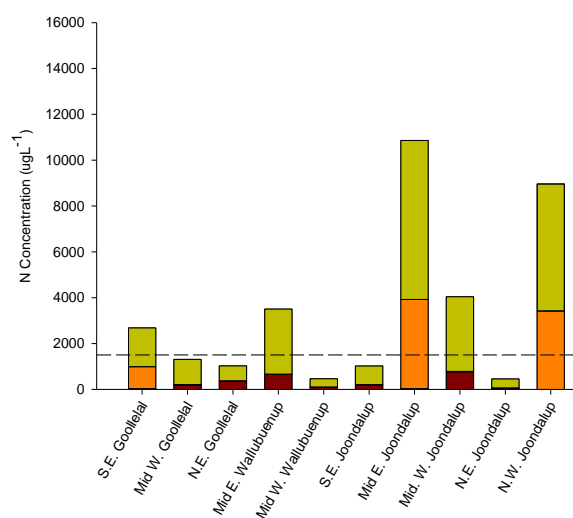
February 2016



March 2016



April 2016



May 2016

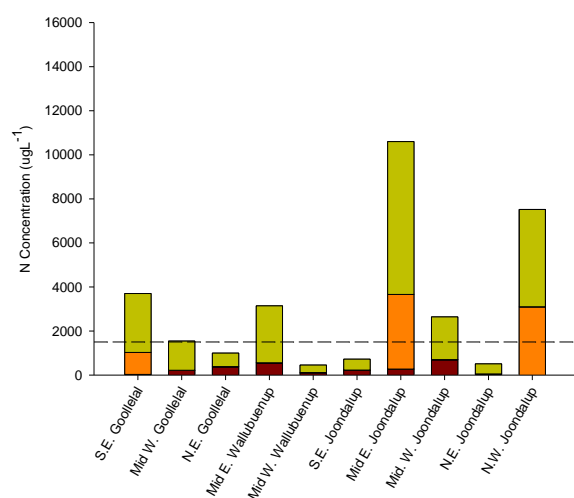


Figure 5. Breakdown of total nitrogen into chemical fractions (organic nitrogen, nitrate/nitrite (NO_x) and ammonium (NH₄)) recorded in groundwater at each bore between May 2015 and 2016 with the ANZECC & ARMANZ (2000) trigger value for total nitrogen.

Table 6. Mean \pm s.e. (range) for nutrients in water recorded at each bore over the course of the monitoring period (May 2015-2016), concentrations recorded as < were below the detection limit.

	NH ₄ $\mu\text{g L}^{-1}$	NO _x $\mu\text{g L}^{-1}$	TN $\mu\text{g L}^{-1}$	FRP $\mu\text{g L}^{-1}$	TP $\mu\text{g L}^{-1}$	DOC mg L^{-1}
Detection Limit	<3	<0.05	<0.5	<0.5	<0.5	<2
ANZECC & ARMCANZ (2000) Trigger Value	40 $\mu\text{g L}^{-1}$	100 $\mu\text{g L}^{-1}$	1500 $\mu\text{g L}^{-1}$	30 $\mu\text{g L}^{-1}$	60 $\mu\text{g L}^{-1}$	-
SE Goollelal	25 \pm 5 (3-57)	3032 \pm 571 (956-7380)	8658 \pm 1953 (2680-22000)	93 \pm 27 (14-321)	204 \pm 38 (35-557)	10.3 \pm 0.9 (3.1-14.4)
Mid W Goollelal	223 \pm 42 (50-534)	278 \pm 263 (3-3430)	2802 \pm 876 (1100-12300)	51 \pm 9 (1-115)	69 \pm 14 (20-193)	23.8 \pm 5.2 (2-71.3)
NE Goollelal	301 \pm 52 (69-692)	47 \pm 13 (8-156)	828 \pm 72 (413-1400)	5 \pm 1 (1-11)	52 \pm 14 (10-195)	5.3 \pm 0.5 (1.9-7.9)
Mid E Wallubuenup	578 \pm 105 (57-1422)	14 \pm 2 (7-30)	2402 \pm 234 (1030-3620)	67 \pm 9 (15-150)	166 \pm 28 (20-390)	12.8 \pm 2.9 (6.3-46.4)
Mid W Wallubuenup	114 \pm 23 (46-346)	10 \pm 2 (2-29)	525 \pm 101 (236-1550)	8 \pm 2 (3-29)	37 \pm 8 (10-116)	6.7 \pm 1.2 (3.1-15.9)
SE Joondalup	239 \pm 42 (92-599)	36 \pm 9 (9-131)	1156 \pm 305 (392-3780)	21 \pm 3 (11-37)	57 \pm 13 (20-173)	11 \pm 3.2 (1.1-40.1)
Mid E mid Joondalup	172 \pm 47 (8-590)	3985 \pm 947 (3-11580)	10931 \pm 2372 (388-29200)	229 \pm 40 (7-520)	468 \pm 87 (20-1150)	10.6 \pm 1.7 (1.9-21.5)
Mid W Joondalup	640 \pm 126 (133-1598)	18 \pm 3 (6-45)	3281 \pm 484 (341-6280)	31 \pm 5 (5-63)	68 \pm 15 (6-183)	38.4 \pm 7.5 (2-86)
NE Joondalup	129 \pm 73 (9-965)	20 \pm 4 (6-61)	1149 \pm 533 (196-6600)	7 \pm 1 (3-15)	27 \pm 5 (10-80)	9.1 \pm 3.4 (1-40.1)
NW Joondalup	1718 \pm 479 (29-5060)	13 \pm 4 (1-52)	5401 \pm 1031 (621-11200)	109 \pm 28 (5-358)	148 \pm 37 (20-494)	44.8 \pm 8.5 (6.3-105.5)

9. CONCLUSIONS

Ten bores (4 western, 6 eastern) were sampled for a broad range of physico-chemical parameters, nutrient and metal/metalloid concentrations between May 2015 and 2016. All the western bores showed a strong evapo-concentration effect for conductivity and related solutes reflecting changes in the nearest lake. There was evidence that certain bores such as Mid E. Joondalup and both eastern Goollelal bores tended to be highly contaminated with metals/metalloids. It appears that groundwater was a source of Al and Hg identified in the wetlands. High concentrations of P and N were recorded in a number of the eastern bores (particularly Mid E Joondalup and both Lake Goollelal bores), suggesting groundwater is an important source of nutrients into both lakes. It is likely that landfill around the edge of Lake Joondalup, former agricultural practices or lawn fertilization are responsible for the contamination of these eastern bores. The high level of contamination seen in Mid E. Joondalup bore is reflected in the northern section of Lake Joondalup but the size and volume of Lake Joondalup means that contamination is heavily diluted. The monitoring of the groundwater bores is starting to show areas of likely contamination of the Yellagonga wetlands, but also shows contaminants leaving the wetland system. The bores show evidence of oxidised acid sulphate soils in very low sulphate to chloride/alkalinity ratios but this was tempered by high pH and moderate levels of Al – the low rainfall of 2015 might see this situation worsen in 2016.

10. RECOMMENDATIONS

1. It is recommended that groundwater monitoring continue in conjunction with surface water monitoring throughout Yellagonga Regional Park. It is suggested that the frequency of sampling (monthly) could be reduced to bimonthly with patterns similar between years. As the groundwater monitoring data set now extends over several years, it is revealing a detailed picture of how the groundwater is contributing to the contamination of the wetlands but also is responsible for the loss of contaminants leaving the wetlands. Improving the understanding of how groundwater interacts with the wetland chain is vital to better manage these groundwater dependent systems. Groundwater monitoring also is useful in detecting potential acid sulphate soil issues in the catchment.

11. 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, USA, 220.
- Appleyard, S. and Cook, T. (2009) Reassessing the management of groundwater use from sandy aquifers: acidification and base cation depletion exacerbated by drought and groundwater withdrawal on the Gngangara Mound, Western Australia. *Hydrogeology Journal* 17(3), 579-588.
- Congdon, R. and McComb, A. (1976a) The nutrients and plants of Lake Joondalup, a mildly eutrophic lake experiencing large seasonal changes in volume. *Journal of the Royal Society of Western Australia* 59, 14-23.
- Congdon, R.A. (1985) The water balance of Lake Joondalup, Western Australian Department of Conservation and Environment, 183.
- Congdon, R.A. (1986) Nutrient loading and phytoplankton blooms in Lake Joondalup, Wanneroo, Western Australia, Department of Conservation and Environment, Western Australia, 6.
- Congdon, R.A. and McComb, A.J. (1976b) The nutrients and plants of Lake Joondalup, a mildly eutrophic lake experiencing large seasonal changes in volume. *Journal of the Royal Society of Western Australia* 59(1), 14-23.
- Cumbers, M. (2004) Improving nutrient management at Lake Joondalup, Western Australia, through identification of key sources and current trajectories. Honours, Edith Cowan University, Perth.
- Davis, J.A., Rosich, R.S., Bradley, J.S., Growns, J.E., Schmidt, L.G. and Cheal, F. (1993) Wetland classification on the basis of water quality and invertebrate community data, Water Authority of Western Australia and the Western Australian Department of Environmental Protection, Perth 242.
- 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.
- Elmahdi, A. and McFarlane, D. (2009) Water Resources Management V. Brebbia, C.A. and Popov, V. (eds), pp. 327-339, Wessex Institute of Technology, UK.
- Gordon, D.M., Finlayson, C.M. and McComb, A.J. (1981) Nutrients and phytoplankton in three shallow freshwater lakes of different trophic status in Western Australia. *Australian Journal of Marine and Freshwater Research* 32, 541-553.

- Khwanboonbumpen, S. (2006) Sources of nitrogen and phosphorus in stormwater drainage from established residential areas and options for improved management. Ph.D. , Edith Cowan University, Perth.
- Kinnear, A. and Garnett, P. (1999) Water chemistry of the wetlands of the Yellagonga Regional Park, Western Australia. *Journal of the Royal Society of Western Australia* 82, 79-85.
- 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.A. (2003) Midge Monitoring Program of the Cities of Joondalup and Wanneroo: A Review, Centre for Ecosystem Management, Edith Cowan University, Report No. 2003-02, Perth.
- Lund, M.A. (2007) Midge Desktop Audit 2007, Centre for Ecosystem Management, 2007-08, Perth.
- Lund, M.A., Brown, S. and Lee, G. (2000) Controlling midges at Lake Joondalup and Lake Goolelall, Centre for Ecosystem Management, Edith Cowan University, 2000-10, Perth.
- Lund, M.A., McCullough, C.D., Somesan, N., Edwards, L. and Reynolds, B. (2011) 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.
- Newport, M., Lund, M. and McCullough, C.D. (2011a) 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.
- Newport, M., Lund, M., McCullough, C.D. and Patel, S. (2011b) Acid Sulphate Soil Investigation of Southern Yellagonga Regional Park, Management, M.W.a.E.C.C.f.E., Edith Cowan University, 2011-12 Report to the City of Joondalup, Perth, 21.
- Newport, M. and Lund, M.A. (2012a) Review of Yellagonga Regional Park wetlands groundwater data, University, E.C., Mine Water and Environment Research Centre/Centre for Ecosystem Management, CEM Report 2012-14, Perth, Australia, 160.
- Newport, M. and Lund, M.A. (2012b) Yellagonga Regional Park wetlands water quality monitoring 2012 report, Centre for Ecosystem Management, E.C.U., Centre for Ecosystem Management, Edith Cowan University, Mine Water and Environment Research Centre/Centre for Ecosystem Management Report 2012-10, Perth, Western Australia, 47.
- Newport, M. and Lund, M.A. (2013a) Acid Sulphate Soil Investigation of Southern Yellagonga Regional Park Report: Stage 2, Mine Water and Environment Research Centre/Centre for Ecosystem Management, Edith Cowan University, 2013-9, Perth, Western Australia, 28.
- Newport, M. and Lund, M.A. (2013b) Yellagonga Regional Park wetlands water quality monitoring 2013 report, Centre for Ecosystem Management, E.C.U., Centre for Ecosystem Management, Edith Cowan University, Mine Water and Environment Research Centre/Centre for Ecosystem Management Report 2013-11, Perth, Western Australia, 51.
- Newport, M. and Lund, M.A. (2014a) Acid Sulphate Soil Investigation of Southern Yellagonga Regional Park Report: Stage 3, Mine Water and Environment Research Centre/Centre for Ecosystem Management, Edith Cowan University, 2014-7, Perth, Western Australia, 29.
- Newport, M. and Lund, M.A. (2014b) Yellagonga Regional Park wetlands water quality monitoring 2013-2014 report, Centre for Ecosystem Management, E.C.U., Centre for Ecosystem Management, Edith Cowan

University, Mine Water and Environment Research Centre/Centre for Ecosystem Management Report 2014-08, Perth, Western Australia, 49.

Wilson, B.A. and Valentine, L.E.E. (2009) Biodiversity values and threatening processes of the Gnamptara Groundwater System, Conservation, D.o.E.a., Department of Environment and Conservation, Perth, Western Australia, 626.