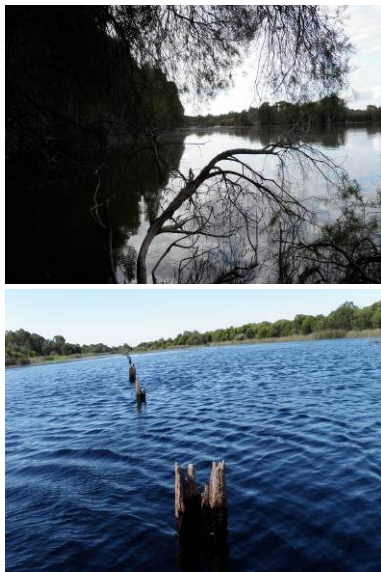


May 2014



Mine Water and
Environment
Research Centre

Acid Sulphate Soil Investigation of Southern
Yellagonga Regional Park Report: Stage 3

By, Michelle Newport
Mark Lund

DRAFT REPORT

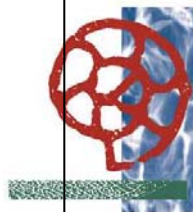
Prepared for,

Cities of Joondalup and Wanneroo

Centre for Ecosystem Management

Report No. 2014-7

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 was formed by Dr. Clint McCullough and Assoc. Prof. Mark Lund. The Centre is now lead by Mark Lund. The research group has a focus on mine waters; particularly pit lakes formed from open-cut mining. However, the group's research also covers all inland water bodies for rehabilitation, remediation and ecological assessment.

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.



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2 ACKNOWLEDGEMENTS

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Plate 1 Wallubuenup Swamp in the southern section of Yellagonga Regional Park.

This report should be referenced as follows.

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5 EXECUTIVE SUMMARY

1. In Stage 1 (October 2010 and April 2011), the immediate surrounds of the channel linking Lake Goollelal and Wallubuenup Swamp were investigated for the presence of acid sulphate soils (ASS). The likelihood of ASS had been identified in previous Yellagonga Regional Park water monitoring programs due to high metal concentrations, indicative ratios of sulphate to chloride and low pH. Using static net acidity generation tests (NAG), potential ASS was identified just north of Whitfords Ave. A more detailed investigation was recommended.
2. In Stage 2 soil profiles to a depth of 1.5 m were collected over a hectare. Soil strata were identified and then a combined sample from each stratum were analysed as per Department of Parks and Wildlife recommendations (pH_{ox} , SPOCAS, S_{cr}) and a range of metals. Stage 2 identified a majority of the area sampled as being ASS contaminated, with levels sufficiently high as to trigger the need for an ASS management plan. It was recommended that further work be undertaken to determine and map deposits of ASS within this section of Yellagonga Regional Park.
3. In this study (Stage 3), a series of four piezometers (down to 1.5 m) were installed around the known source of ASS, to confirm that metals and low pH from these sources were entering the wetland train via groundwater. Production of a contour map of the area affected by ASS and beyond provided an illustration of possible ASS pockets that may be located in the area and how groundwater moved through the soils toward the channel. Six soil profiles were collected (to a depth of 1.5 m) to confirm that the ASS edges had been located.
4. The extent of the ASS identified in Stages 1 and 2 appears to be limited to the floodplain (*Typha*) around site Drain_{Goollelal}. There is evidence of ASS in groundwater, however this appears to be generated at a distance from the drain and is neutralised before it reaches the drain. At the western piezometer very high of P were recorded that warrant further investigation.
5. It is recommended that a management plan be developed and implemented in the area identified in this study as required by Department of Parks and Wildlife guidelines. As part of the management plan control options need to be investigated to mitigate on-going contamination of the Yellagonga wetlands.

Acid sulphate soil (ASS) is the term used to describe soils and sediments containing oxidising iron sulphides, predominately iron pyrites (Department of Environment, 2003). In an anaerobic (no oxygen) environment these iron sulphide rich sediments remain benign (referred to as Potential ASS or PASS). However when exposed to an oxygenated environment, chemical and biological processes cause the oxidation of the sulphides resulting in the production of sulphuric acid. The acidity can cause metals in surrounding geologies to dissolve. When the buffering capacity of the receiving environment is exceeded heavy metal/metalloid contamination and acidification occur (Department of Environment and Conservation, 2013). Disturbance and exposure of PASS has the potential to convert PASS to ASS and lead to contamination of soil, water and air, causing harm to human health and ecological integrity e.g. loss of biodiversity, riparian vegetation, water quality deterioration, groundwater contamination, corrosion of infrastructure, and in humans skin irritation and respiratory problems (National Working Party on Acid Sulfate Soils, 2000).

Fifty six years ago, it was acknowledged that ASS were present in Australia (Sammut *et al.*, 1996). Twenty six years ago, concern was raised in relation to the potential impacts of ASS after it was found to be responsible for the occurrence of massive fish kills in Tweed River, NSW (Sammut *et al.*, 1996). More recently it has been estimated that there are 40 000 km² of pyritic sediments in coastal regions of Australia (National Working Party on Acid Sulfate Soils, 2000). In response to the multi-dimensional threat that ASS potentially poses, there are National and State level legislation, policies and guidelines detailing how ASS should be investigated, identified, managed and treated (Department of Environment and Conservation, 2013).

The Swan Coastal Plain, situated on the Western Australian coastline is of particular concern for ASS. The organically, pyritic rich sediments of lands that were historically wetlands and existing groundwater dependant wetlands present massive sources of potential ASS (Appleyard *et al.*, 2004). The two main activities threatening the release of ASS sources into wetland ecosystems on the northern Swan Coastal Plain is urban development and draw down from groundwater extraction (Appleyard *et al.*, 2004). Further compounding the effect of draw down from groundwater extraction has been a series of below average rainfall years over the last couple of decades (Bureau of Meteorology), reducing recharge of the superficial aquifer. These circumstances led to the drying event of Lake Jandabup in the late 1990s causing acidification and consequential loss of ecological integrity (Sommer & Horwitz, 2001). Another example of ASS exposure on the Swan Coastal Plain is Spoonbill Reserve in the City of Stirling, where urban development caused acidification of

groundwater and resulted in risk to human health from metal exposure (Hinwood *et al.*, 2006; Lund *et al.*, 2010).

Previous studies of water quality in Yellagonga regional park by the authors (Lund *et al.*, 2011; Newport *et al.*, 2011a; Newport & Lund, 2012) have identified high levels of metal contamination of waters around the southern end of Wallubuenup Swamp (close to Whitfords Avenue), with low pH and Cl:SO₄ ratios that all suggest the presence of ASS.

In a preliminary investigation (Stage 1) by the authors (Newport *et al.*, 2011b) the presence of ASS was identified north of Whitfords Avenue, in the southern section of Yellagonga Regional Park. Stage 2 analysed major soil types and their spatial distribution both horizontally and vertically within the landscape. Fingerprinting sources through suspension peroxide oxidation combined acidity and sulphate (SPOCAS) analysis, chromium reducible sulphur analysis (S_{CR}) and metal analysis of those major soil types identified (Newport & Lund, 2013a). The aim of this study (Stage 3) was to identify movement of acidic metallic water into the drain, produce a contour map which, in combination with soil profiling and analysis, would determine the extent of ASS in this section of the Yellagonga system.

7 METHODS

7.1 STUDY SITE

Yellagonga Regional Park is situated approximately 20 km north of Perth CBD and 6 km east of the Indian Ocean, on the Swan Coastal Plain. Yellagonga consists of a series of groundwater fed interdunal wetlands and swamps (Figure 1). These wetlands and swamps are linked throughout the park via a natural drainage line where surface waters flow northward and groundwater flows north-westerly. Lake Goollelal lies at the southern boundary, and is connected by a drain leading northwards into Wallubuenup Swamp through to Beenyup Swamp and then into Lake Joondalup at the northern boundary. Initial European colonisation of Wanneroo and Joondalup focused on agriculture both in the current park and the surrounds. In the last 30 years, there has been rapid replacement of agriculture with urban development. The park was formed in 1989 and a management plan developed in 2003 (Dooley *et al.*, 2003).

Wallubuenup Swamp is regionally significant as it contains the oldest deposits of organic material (Pleistocene) on the Swan Coastal Plain. These Pleistocene sediments have been preserved by the laying down of a sulphate rich seawater sediment during the Holocene period (Dooley *et al.*, 2003). The sediment origins mean that they should be treated with

great caution due to PASS when conducting activities which could potentially result in exposing or disturbing the sediments (National Working Party on Acid Sulfate Soils, 2000).

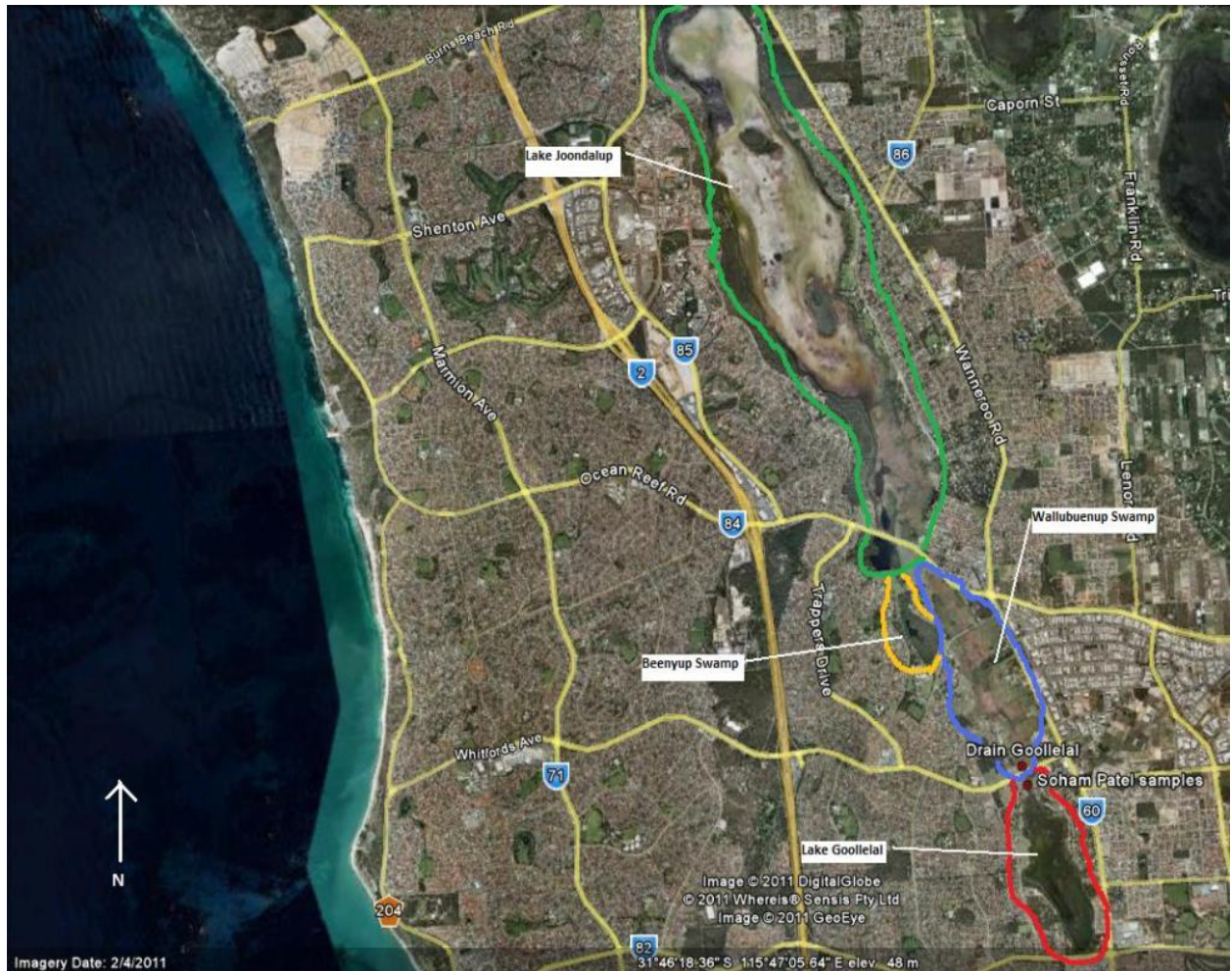


Figure 1. Map illustrating the interconnectedness of the Yellagonga Regional Park wetlands and swamps illustrating where the sampling sites (purple dots) were located in relation to the rest of the park.

7.2 FIELD SAMPLING

Four piezometers were placed in strategic locations outside the beds of *Typha* to capture the movement of water, with three (1-3) on the east side of the channel and one (4) on the west side, and sunk to just intercept (approximately 1.5 m deep) the top of the water table (Figure 2). The piezometers were sampled once a month for six months (November 2013 to

April 2014), with each sampling event physical parameters was taken *in-situ* and a water sample collected for later analysis.

Six soil profiles (7W1, 7E4, 6E5, 2E5, 5W2 & 2W2) were taken to capture the edges of ASS over the area, using a hand auger to collect the vertical profile to a depth of 1.5 m (Figure 2). For each profile, different soil strata were identified and assigned to a broad soil classifications used in Newport and Lund (2013a). Each soil type was then sealed in labelled plastic zip lock bags and frozen to avoid oxidation. The depth from the surface to groundwater level was also recorded for each site.



Figure 2. Aerial photograph of the study site showing where sediment samples were collected down to a depth of 1.5 m (blue pins). Piezometers indicated in light blue. Green indicates sites where soil types throughout the profile did not exceed the action criteria, amber indicates sites where soil types throughout the profile were equal to the action criteria and red indicates sites where soil types throughout the profile exceeded the action criteria. The action criteria were based on SPOCAS and S_{CR} results.

7.3 LABORATORY ANALYSIS

In the laboratory, water samples collected from the piezometers were divided into three aliquots. An unfiltered aliquot (subsample) 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 ($\text{NO}_x\text{-N}$), filterable reactive phosphorus ($\text{PO}_4\text{-P}$), ammonia ($\text{NH}_3\text{-N}$) and dissolved organic carbon (DOC; measured as non-purgeable organic carbon). Another filtered aliquot was acidified with nitric acid (to 1% v/v) and then kept at 4°C for later determination by ICP-AES 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 (1998).

For each of the six soil profile samples the fraction of Sandy Organic Material were sent to a NATA approved laboratory (SGS Ltd) for Suspension Peroxide Oxidation Combined Acidity and Sulphate (SPOCAS) and Chromium Reducible Sulphur (S_{CR}) suite analysis to identify if the edge of the ASS deposit had been determined. Also the field tests pH_F and pH_{FOX} are able to be conducted in the laboratory (NATA accredited laboratory, SGS). The pH_F is a measurement of soil pH, where a value less than four is an indication of Actual Acid Sulphate Soils (AASS). The pH_{FOX} measurement is where a known volume of 30% peroxide is added to a known quantity of soil sample. The reaction elicited by the peroxide is noted and the pH value is recorded and used to indicate presence of ASS. The field tests are not stand alone tests and are only used as indicators to the presence of ASS (Ahern *et al.*, 2004)

Using desktop software programs (SigmaPlot v12), elevation contour maps were produced with all previous and current soil profile sites overlaid to determine extent of ASS.

8 RESULTS AND DISCUSSION

8.1 SOIL PROFILES

The soil profiles taken in this study were selected to try and identify the edges of the main source of ASS into the wetlands. All sites (except 7E4 and 7W1) were outside of the *Typha* stand associated with the drain floodplain. Compared to the soil profiles taken from the floodplain, there were fewer soil types with most sites dominated by Sandy Organic (Figure 3). Sandy Organic soils were found to be PASS in previous studies and so were chosen as the focus for subsequent ASS testing.

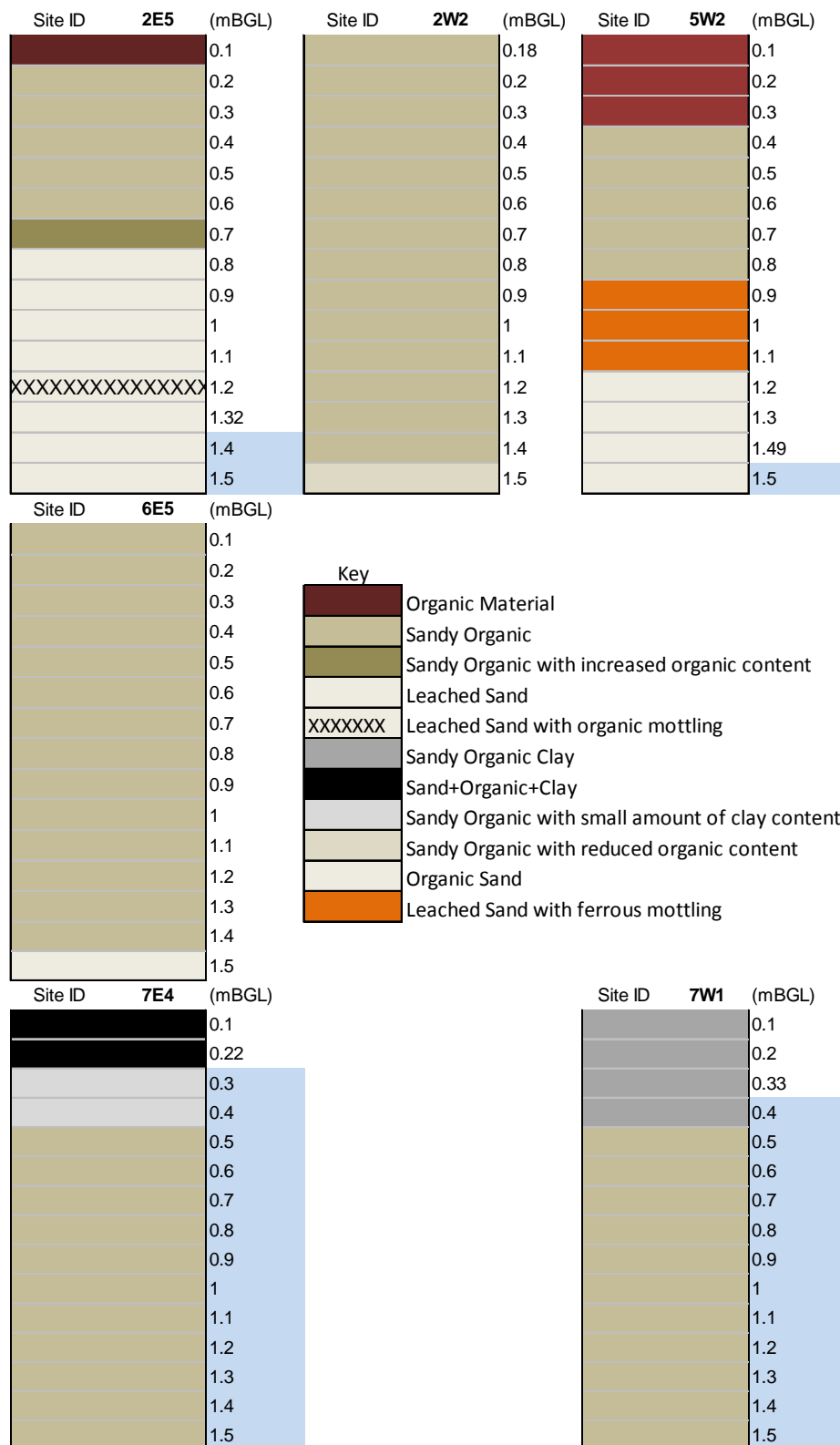


Figure 3. The six soil profiles illustrating soil classifications, fraction and depth to water for each profile collected.

The SPOCAS suite consists of three measurements and is a comprehensive Acid Base Accounting (ABA) procedure. Titratable Actual Acidity (TAA) which is representative of the soil's actual acidity, Titratable Potential Acidity (TPA) the sum of both potential sulphidic acidity and actual acidity and the soil's acid neutralising capacity (ANC) are the three measurements carried out by SPOCAS (Ahern *et al.*, 2004).

The results for this study found that the six sites sampled were negative for ASS, demonstrating that the ASS boundaries had been identified within the area under investigation. Field tests indicated that all six sites were positive for PASS and that site 6E5 and site 7W1 had the strongest positive PASS result with a moderate reaction rate, a pH_{FOX} less than 3 and a difference between pH_{F} and pH_{FOX} greater than one unit (Table 1). This was in contrast to the SPOCAS and S_{Cr} results which concluded that all six sites were negative for PASS and ASS. The false positive field tests may have been a result of interference from the organic content in the samples (Ahern *et al.*, 2004). These results suggest that these soil sampling sites lay outside the main ASS hotspot identified in previous studies.

Table 1. The results for field pH, 'Fizz Test', Suspension Peroxide Oxidation Combined Acidity and Sulphate (SPOCAS) and Chromium Reducible Sulphur (S_{CR}) analysis for each of the six profiles Sandy Organic Material fractions with assessment and action criteria's as prescribed by the Department of Environment and Conservation (2013).

| Soil Profile ID | Field Test | | | | Lab pH | | SPOCAS | | | | S_{CR} Suite | | | Action Criteria | |
|---------------------|-----------------|-------------------|------------------------------------|---------------|-------------------|------------------|--------|------|-----|------------------|-------------------|------|----------|----------------------|--------------------------|
| | pH _F | pH _{FOX} | pH _F -pH _{FOX} | Reaction Rate | pH _{KCl} | pH _{OX} | TAA | TPA | TSA | ANC _E | pH _{KCl} | TAA | S_{CR} | Net Acidity (SPOCAS) | Net Acidity (S_{CR}) |
| | | | | | | | %S | %S | %S | %S | | | | %S | %S |
| Assessment Criteria | 4 | 4 | 1 | NV | NV | NV | 0.03 | 0.03 | NV | NV | NV | 0.03 | 0.03 | 0.03 | 0.03 |
| 2E5 3-67cm | 5.5 | 2.9 | 2.7 | SI | 6.5 | 7.6 | LOR | LOR | LOR | 0.06 | 6.5 | LOR | LOR | LOR | LOR |
| 6E5 0-149cm | 5.6 | 3.3 | 2.4 | M | 7.2 | 7.5 | LOR | LOR | LOR | 0.05 | 7.2 | LOR | LOR | LOR | LOR |
| 7E4 27-46cm | 7.1 | 3.7 | 3.5 | SI | 7.1 | 7.1 | LOR | LOR | LOR | 0.03 | 7.1 | LOR | 0.019 | LOR | LOR |
| 2W2 0-75cm | 6.6 | 4.5 | 2.2 | SI | 7.2 | 7.3 | LOR | LOR | LOR | 0.05 | 7.2 | LOR | LOR | LOR | LOR |
| 5W2 38-87cm | 6.2 | 3.5 | 2.7 | SI | 6.9 | 6.9 | LOR | LOR | LOR | 0.05 | 6.9 | LOR | LOR | LOR | LOR |
| 7W1 48-158cm | 6.4 | 2.4 | 4 | M | 7.4 | 5.5 | LOR | LOR | LOR | LOR | 7.4 | LOR | LOR | LOR | LOR |

NOTE: LOR – Below Limit of Recording

SI – slight, M – medium, S – strong, E – extreme, these codes were used to describe the 'fizz test' reaction.

8.2 CONTOUR MAPPING

The location of sampling sites (excluding piezometers) in relation to the land elevation is shown in Figure 4. There is a 6 m decline in elevation from the wetland just below Whitfords Avenue to the 7E4 and 7W1 sites. Although, some caution is required as elevations were determined from GoogleMaps rather than direct measurement. The bulk of the sample sites from this and previous investigations are located in the upper elevations (>25 m). Higher elevations may be more prone to drying out than lower ones, which could result in more ASS.

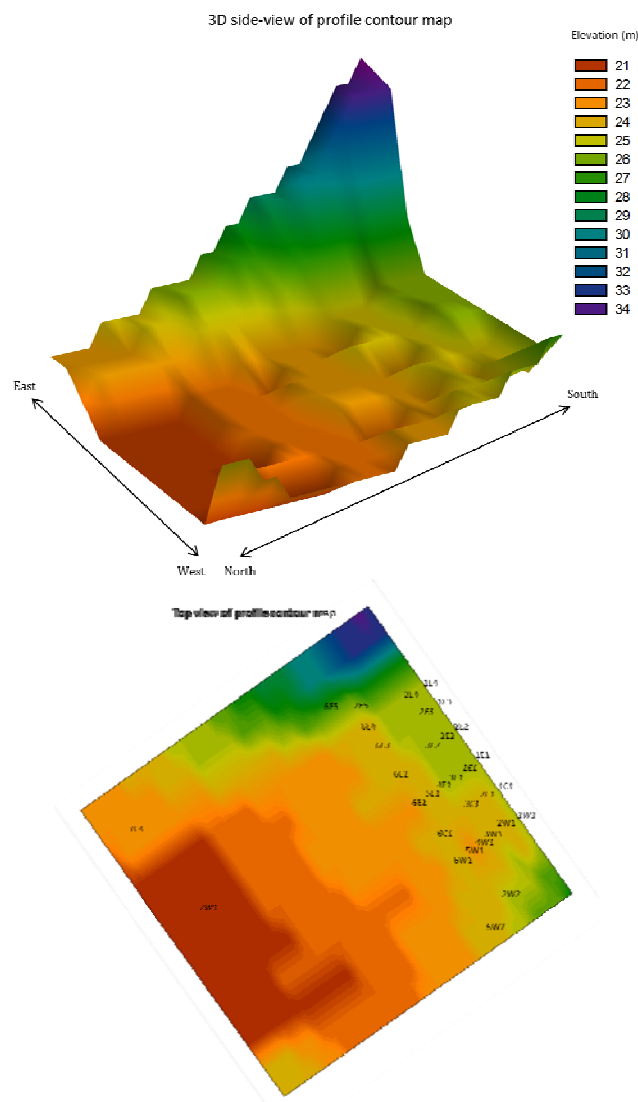
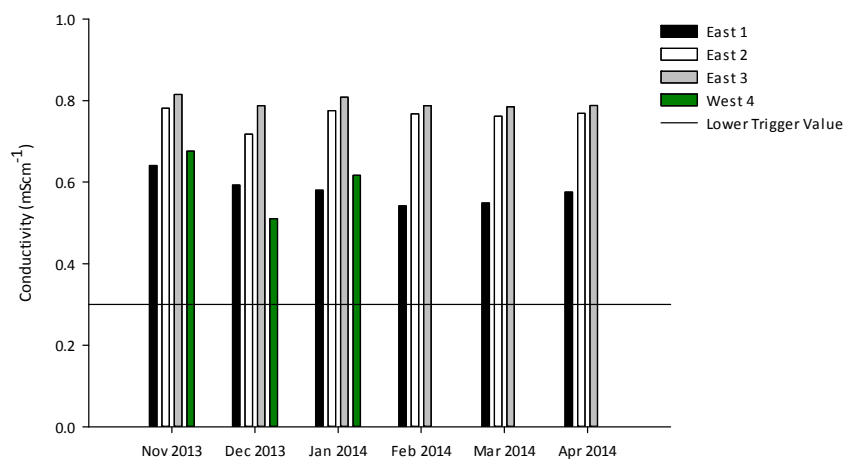


Figure 4. Three dimensional side-view and top view with soil profile sites overlaid on the ASS area at DrainGoollelal under investigation. Elevations were taken from GoogleMaps May 2014.

8.3 PEIZOMETER WATER QUALITY

For three months of six the piezometer 4 on the west side was dry. Temperature of the groundwater varied no more than 2 °C between sites on any occasion and by no more than 2 °C across the 6 months of the study. Dissolved oxygen in the bores was always oxidic, but on many occasions was slightly <4 mg L⁻¹. It is somewhat surprising that the dissolved oxygen concentrations were as high as they were and this might reflect oxygenation through exposure of the groundwater to air via the bore casing. Conductivity of the groundwater similar across the 6 months of the study and typically lower in the East 1 and West 4 bores. Conductivity indicated the water was fresh and varied between 0.5 and 0.8 mS cm⁻¹ (Figure 5). pH of the groundwater was always >6 and reached 7.5 (West 4 only), there was little variability in the pH between East sites, but the East sites had the pH increase over the 6 months of the study from around 6 to 7 (Figure 5). The pH recorded in the bores does not suggest that the acidity seen at Drain_{Goollelal} is caused by this groundwater. ORP remained positive in East 1, but was negative (except in November 2013) at all sites and across the study period. The low ORP was not correlated with low dissolved oxygen suggesting that it was chemically derived rather than determined by oxygen availability. All the eastern bores show a drop of approximately 0.4 m in water depth, with the lowest depth occurring in March 2014. The western bore had a more extreme drop of nearly 0.9 m between January and February 2014.

a) Conductivity



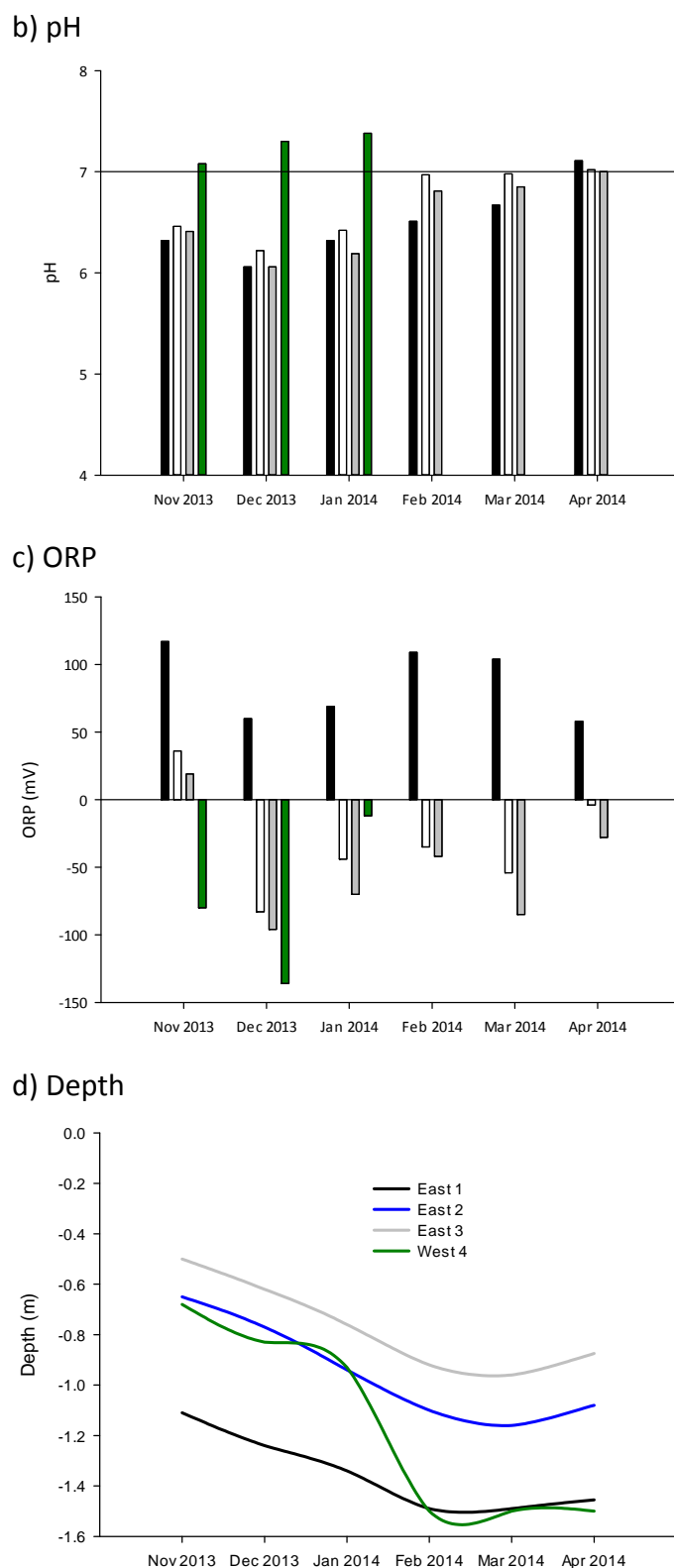


Figure 5. Selected physico-chemical variables a) conductivity, b) pH, c) ORP and d) depth recorded from piezometers at Yellagonga Regional Park between November 2013 and April 2014

Metal concentrations in the bore waters are shown in Table 2. Metal concentrations were reasonably variable across sampling occasions and between sites, although there were no strong trends with no bores appearing to have consistently higher or lower concentrations. Comparison to the mean and ranges of concentrations recorded in the same months in 2012/13 (Newport & Lund, 2013b) for Drain_{Goollelal} surface water reveals that metal concentrations in the bores were similar for As, Al, and Zn, but substantially lower for the other metals measured. Particularly, Fe and Mn concentrations were an order of magnitude lower in the bores compared to Drain_{Goollelal}. The bore samples were taken in summer when Drain_{Goollelal} was dry and have been compared to 2012/13 data, however these findings do not support this groundwater being the source of the metal contamination seen at Drain_{Goollelal}.

Table 2. Selected metal concentrations recorded in the 4 piezometers (East 1-3 and West 4) over the six month sampling period (Limit of reporting in brackets) with values in red exceeding ANZECC/ARMCANZ guidelines (2000).

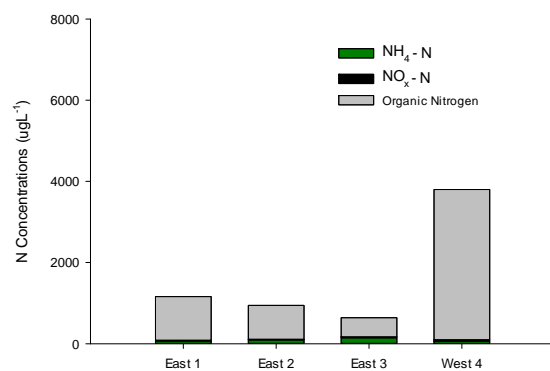
| | 28/11/2013 | 17/12/2013 | 16/01/2014 | 11/02/2014 | 13/03/2014 | 3/04/2014 |
|--|------------|------------|------------|------------|------------|-----------|
| Al ($\mu\text{g L}^{-1}$) (<0.5) | | | | | | |
| East 1 | 14.0 | 7.1 | 8.1 | 46.0 | 35.1 | 5.7 |
| East 2 | 6.7 | 81.5 | 42.0 | 5.1 | 5.9 | 15.1 |
| East 3 | 239.1 | 7.2 | 7.8 | 134.8 | 5.5 | 7.0 |
| West 4 | 67.5 | 6.5 | 7.1 | | | |
| Cr ($\mu\text{g L}^{-1}$) (<0.03) | | | | | | |
| East 1 | 1.20 | 1.20 | 1.18 | 1.48 | 1.48 | 1.24 |
| East 2 | 1.17 | 1.27 | 1.80 | 1.30 | 1.13 | 1.00 |
| East 3 | 3.20 | 1.21 | 1.06 | 2.64 | 1.24 | 1.17 |
| West 4 | 2.03 | 1.12 | 1.14 | | | |
| Mn ($\mu\text{g L}^{-1}$) (<0.05) | | | | | | |
| East 1 | 3.3 | 7.4 | 11.3 | 16.8 | 1.9 | 7.6 |
| East 2 | 15.0 | 4.6 | 2.2 | 7.3 | 26.2 | 4.9 |
| East 3 | 0.5 | 8.5 | 27.9 | 0.5 | 11.5 | 24.3 |
| West 4 | 1.3 | 11.0 | 23.6 | | | |
| Fe ($\mu\text{g L}^{-1}$) (<0.1) | | | | | | |
| East 1 | 32.0 | 126.9 | 335.1 | 233.6 | 38.2 | 111.5 |
| East 2 | 374.8 | 102.0 | 86.9 | 146.6 | 151.1 | 41.2 |
| East 3 | 229.2 | 276.6 | 106.2 | 207.3 | 59.4 | 92.8 |
| West 4 | 135.6 | 277.9 | 76.7 | | | |
| Co ($\mu\text{g L}^{-1}$) (<0.02) | | | | | | |
| East 1 | 0.28 | 0.06 | 0.05 | 0.16 | 0.28 | 0.04 |
| East 2 | 0.03 | 0.13 | 0.31 | 0.04 | 0.03 | 0.12 |
| East 3 | 0.23 | 0.04 | 0.03 | 0.31 | 0.05 | 0.04 |
| West 4 | 0.18 | 0.04 | 0.04 | | | |

| | 28/11/2013 | 17/12/2013 | 16/01/2014 | 11/02/2014 | 13/03/2014 | 3/04/2014 |
|--|------------|------------|------------|------------|------------|-----------|
| Ni ($\mu\text{g L}^{-1}$) (<0.05) | | | | | | |
| East 1 | 1.33 | 0.74 | 0.85 | 1.45 | 1.27 | 0.55 |
| East 2 | 0.71 | 1.16 | 1.85 | 0.86 | 0.77 | 1.44 |
| East 3 | 1.53 | 0.94 | 0.87 | 1.42 | 1.01 | 1.01 |
| West 4 | 1.08 | 0.88 | 0.83 | | | |
| Zn ($\mu\text{g L}^{-1}$) (<0.25) | | | | | | |
| East 1 | 23.2 | 61.3 | 60.7 | 128.6 | 8.8 | 67.5 |
| East 2 | 62.8 | 70.6 | 16.4 | 63.6 | 54.1 | 98.1 |
| East 3 | 10.6 | 57.1 | 58.7 | 16.7 | 57.2 | 64.3 |
| West 4 | 14.1 | 50.9 | 51.3 | | | |
| As ($\mu\text{g L}^{-1}$) (<0.01) | | | | | | |
| East 1 | 7.8 | 7.6 | 4.0 | 14.3 | 5.9 | 7.2 |
| East 2 | 2.9 | 22.0 | 4.8 | 6.9 | 2.2 | 12.4 |
| East 3 | 4.7 | 7.1 | 2.3 | 7.3 | 5.0 | 2.7 |
| West 4 | 3.9 | 4.6 | 3.0 | | | |
| Se ($\mu\text{g L}^{-1}$) (<0.05) | | | | | | |
| East 1 | 0.27 | 0.26 | 0.23 | 0.46 | 0.14 | 0.13 |
| East 2 | 0.18 | 0.35 | 0.21 | 0.12 | 0.10 | 0.33 |
| East 3 | 0.74 | 0.13 | 0.11 | 0.62 | 0.20 | 0.10 |
| West 4 | 0.58 | 0.20 | 0.21 | | | |
| Cd ($\mu\text{g L}^{-1}$) (<0.01) | | | | | | |
| East 1 | 0.06 | 0.06 | 0.05 | 0.06 | 0.05 | 0.08 |
| East 2 | 0.12 | 0.05 | 0.10 | 0.10 | 0.09 | 0.06 |
| East 3 | 0.10 | 0.34 | 0.14 | 0.14 | 0.37 | 0.28 |
| West 4 | 0.06 | 0.31 | 0.31 | | | |
| Hg ($\mu\text{g L}^{-1}$) (<0.02) | | | | | | |
| East 1 | 0.48 | 0.37 | 0.34 | 0.26 | 0.23 | 0.21 |
| East 2 | 0.16 | 0.14 | 0.13 | 0.12 | 0.10 | 0.09 |
| East 3 | 0.09 | 0.08 | 0.07 | 0.07 | 0.06 | 0.06 |
| West 4 | 0.06 | 0.05 | 0.04 | | | |
| U ($\mu\text{g L}^{-1}$) (<0.02) | | | | | | |
| East 1 | 0.03 | <0.02 | <0.02 | 4.68 | 0.02 | <0.02 |
| East 2 | <0.02 | 8.99 | 0.02 | <0.02 | <0.02 | 8.67 |
| East 3 | 0.05 | <0.02 | <0.02 | 0.03 | <0.02 | <0.02 |
| West 4 | 0.02 | <0.02 | <0.02 | | | |

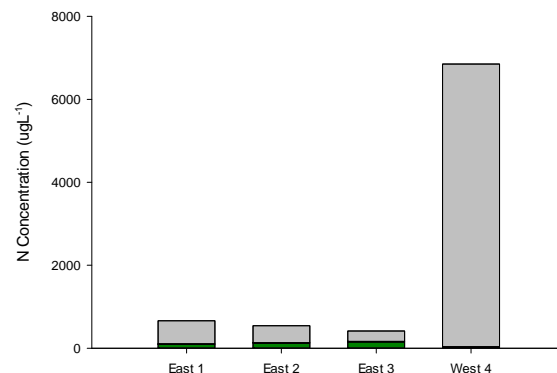
Nitrogen concentrations in bores over the sample period are shown in Figure 6. Total N was dominated by particulate (organic N) with relatively low NO_x in the eastern bores (<30 $\mu\text{g L}^{-1}$), except for East 1 in February 2014 where it reached 65 $\mu\text{g L}^{-1}$). In contrast NO_x ranged between 30 and 40 $\mu\text{g L}^{-1}$ in West 1 on all the occasions water was present (November to January). The low dissolved oxygen environment typical of groundwater tends to keep NO_x

concentrations low, due to lack of nitrification and denitrification. NO_x concentrations tended to be highest in East 1 compared to the other eastern sites. Ammonia concentrations were highest at eastern sites 2 and 3, in a reversal of the trend seen for NO_x. This reversal suggests that it is low dissolved oxygen concentrations limiting ammonia conversion to NO_x by nitrification. Organic N (or particulate) was highest in W4, with slightly high records in East 1 in November and January.

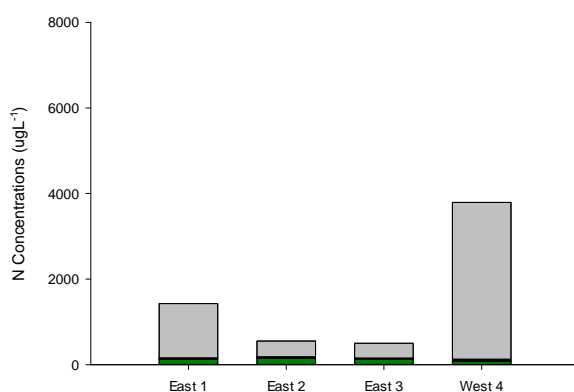
a) November 2013



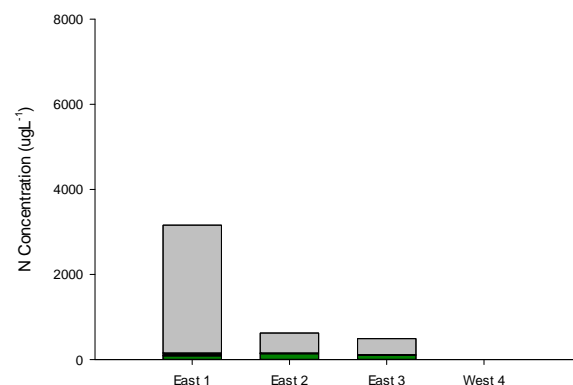
b) December 2013



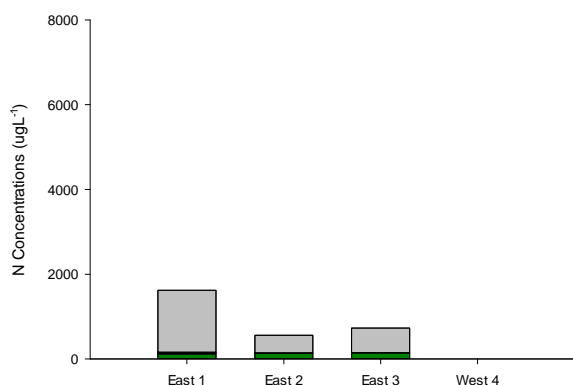
c) January 2014



d) February 2014



e) March 2014



f) April 2014

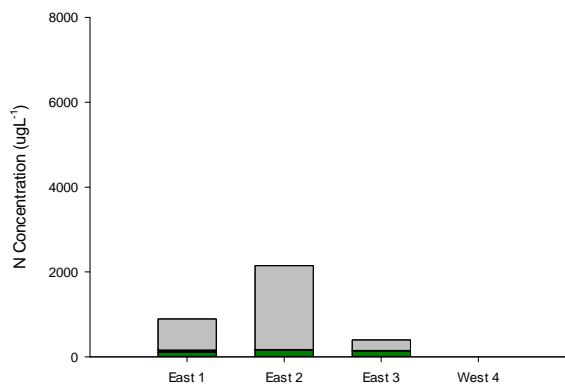
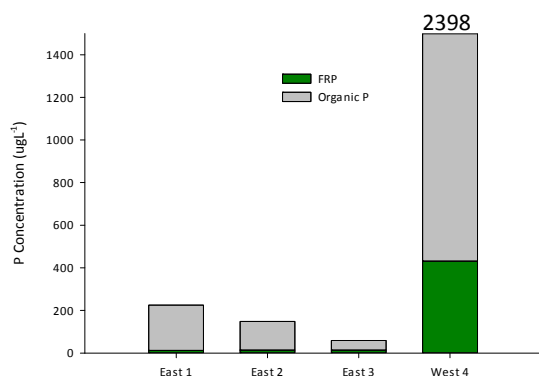


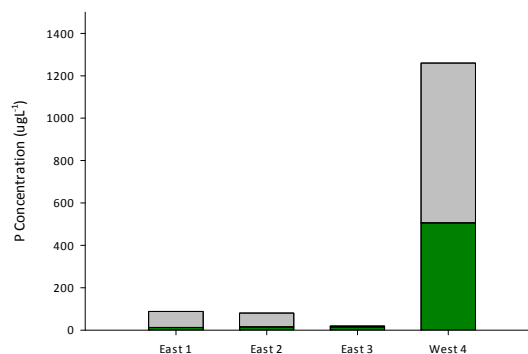
Figure 6. Nitrogen concentrations in groundwater across the study period (a-f) and between sites.

Total P was very high in West 4 ranging from 883 to 2830 $\mu\text{g L}^{-1}$ with very high FRP concentrations of 432 to 529 $\mu\text{g L}^{-1}$. The eastern sites had much lower levels of both total P (<289 $\mu\text{g L}^{-1}$) and FRP (<17 $\mu\text{g L}^{-1}$). East 1 had the highest Total P concentrations of the eastern sites, although East 2 also had high concentrations on a few occasions. The source of the high P in the West is not known and warrants further investigation.

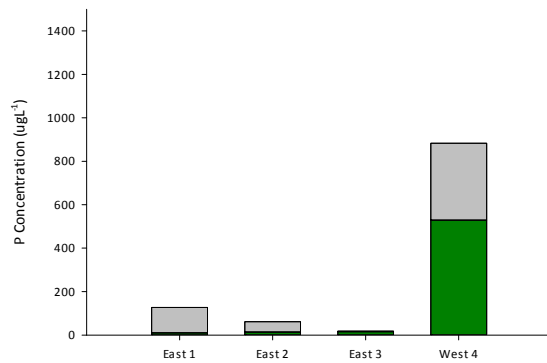
a) November 2013



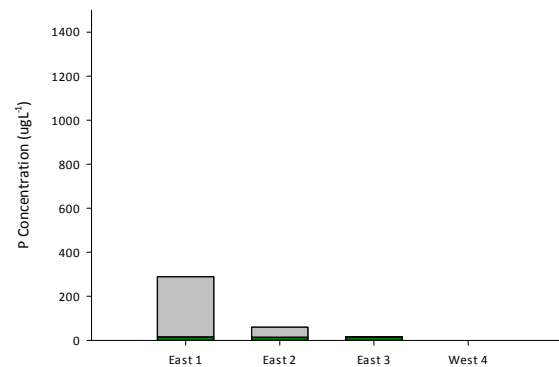
b) December 2013



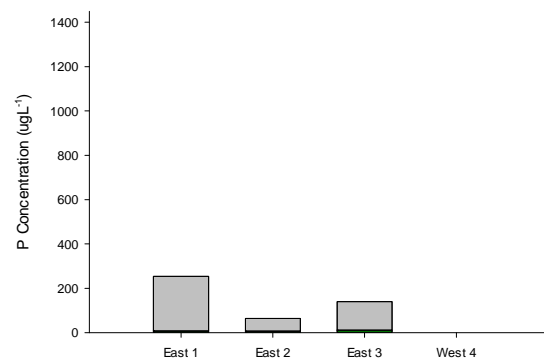
c) January 2014



d) February 2014



e) March 2014



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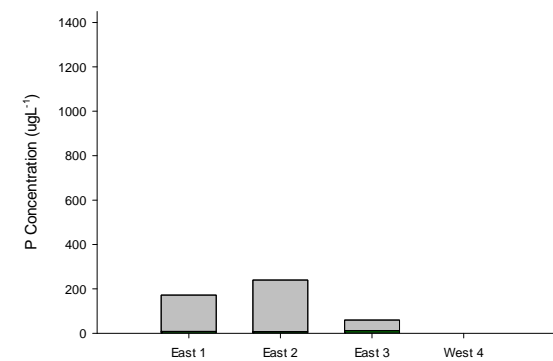


Figure 7. Phosphorus concentrations in groundwater across the study period (a-f) and between sites.

The western bore showed no signs of the presence of ASS with $\text{Cl}:\text{SO}_4$ well above the indicative 4 (Figure 8). All the Eastern sites had very low $\text{Cl}:\text{SO}_4$ ratios, well below 4 suggesting that there was elevated SO_4 concentrations which is a potential sign of ASS. As these elevated SO_4 concentrations were not matched by elevated metals or low pH, it is possible that the ASS is located at a distance from the site and that the limestone underlying the dune ridge to the east of Yellagonga is neutralising any acidity and causing the metals to precipitate out.

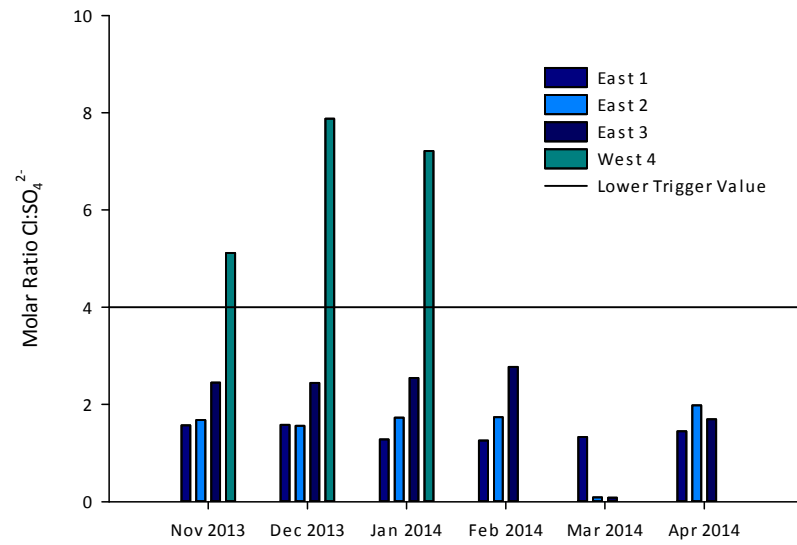


Figure 8. Molar ratio of Cl:SO₄ calculated for the four bore sites across the study time period

9 CONCLUSIONS

The study found that the area that had previously been sampled in Stages 1 and 2 represented the critical ASS areas that were most likely responsible for poor water quality seen in the Yellagonga wetlands monitoring studies. The area appeared to be limited to the extent of the floodplain (as demarcated by the presence of *Typha*). The extent of the area northwards is still unknown although it appears to have stopped by site 7. It is possible that the construction of Whitfords Avenue may have been responsible for the disturbance or relocation of ASS that have become a problem at Drain_{Goollelal}. If this is the case then it is likely that ASS do not extend very far northwards. The groundwater sampling confirms that there are traces of ASS impacts above the *Typha* as determined through Cl:SO₄ ratios. These ASS impacts are not reflected in low pH or excessively high metal concentrations. A possible explanation, is that the low ratios of Cl:SO₄ are caused by ASS much higher in the landscape, that are being neutralised by limestone in the catchment. The neutralisation causes many of the metals to precipitate out leaving simply high sulphate in the waters close to Drain_{Goollelal}.

The results confirm the extent of ASS and PASS in the area and under the Department of Environment and Conservation Guidelines this should trigger the development of a management plan for the area. Options for remediation/management of the site also need to be developed.

10 RECOMMENDATIONS

1. A management plan be developed and implemented for the site as is required due to the confirmed presence of ASS and PASS.
2. Investigate control options to mitigate contamination of Yellagonga aquatic system.

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