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Acid Sulphate Soil Investigation of Southern Yellagonga Regional Park Report: Stage 2

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FINAL REPORT

Prepared for,
Cities of Joondalup and Wanneroo

Mine Water and Environment Research Centre

Centre for Ecosystem Management
Report No. 2013-9

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 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.

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2 ACKNOWLEDGEMENTS

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3 FRONTISPIECE

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

This report should be referenced as follows.

Newport, M.L. & Lund, M.A. (2013). *Acid Sulphate Soil Investigation of Southern Yellagonga Regional Park Report: Stage 2.* Mine Water and Environment Research/Centre for Ecosystem Management Report No. 2013-9, Edith Cowan University, Perth, Australia. 28pp. Unpublished report to the Cities of Joondalup and Wanneroo.

4 CONTENTS

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 discovered just north of Whitfords Ave. A more detailed investigation was recommended.

2. This study (Stage 2) conducted a more detailed survey of soils, in the vicinity of the potential ASS discovered in Stage 1. Twenty six profiles of the soil (down to 1.5 m) were taken at 20 m intervals across a 1 Ha site. Soil strata were identified and then a combined sample from each stratum was analysed for suite of Department of Environment and Conservation recommended analyses (pH_{ox}, SPOCAS, S_{cr}) for determination of potential ASS and ASS. Additionally all samples were tested for the concentrations of a range of metals (those regularly measured in the Yellagonga water quality monitoring program).

3. This study clearly identified that the majority of the area sampled had ASS, with levels sufficiently high in most cases to trigger the need for an ASS management plan (as per the Department of Environment and Conservation guidelines). It is clear that this area is at least partially responsible for the low pH and high metal concentrations found in Yellagonga water quality monitoring study.

4. It is recommended that further work be undertaken to determine and map all deposits of ASS around this section of Yellagonga Regional Park. As per the Department of Environment and Conservation guidelines, a management plan needs to be developed for the site. Control options need to be investigated to reduce and prevent on-going contamination of the Yellagonga wetlands.

6 INTRODUCTION

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 contaminate 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. 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 km^2 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, polices 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 is a reduction in rainfall, 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 $Fe:SO_4$ 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. The aim of this study was to begin mapping ASS (as per Department of Environment and Conservation, 2013) through the identification of 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.

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 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).

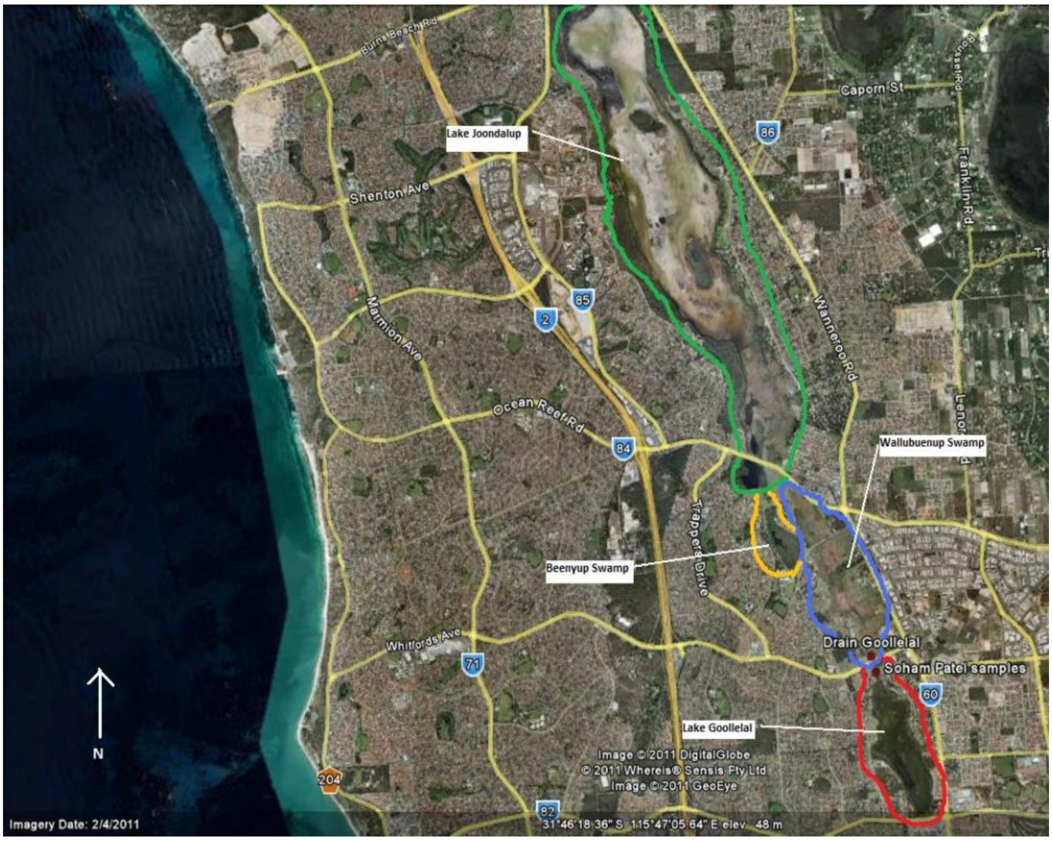


Figure 1. Map illustrating the interconnectedness of the Yellagonga Regional Park wetlands and swamps illustrating where the sampling sites were located in relation to the rest of the park.

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).

7.2 FIELD SAMPLING

A 10000 m^2 area was sampled overlaying the previous sampling sites (Newport *et al.*, 2011b) and extending westwards, eastwards and northwards, running parallel to Whitfords Avenue (Figure 2). A grid spaced at 20 m intervals was used to determine the location of sample sites. At each site, soil samples were collected to a depth of 1. 5 m.

A hand auger was used to collect the vertical profile soil samples at approximately thirty centimetre increments, with a total of one hundred and sixty six soil samples being collected. For each profile, different soil strata were identified and assigned to a broad soil classification. 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. Illustration of the sites where sediment samples were collected to a depth of 1.5 m. 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 SCR results.

7.3 LABORATORY ANALYSIS

Soil samples were combined and homogenised for each of the ten broad soil classifications. Samples were prepared in an anoxic environment for SPOCAS and S_{CR} analysis. These samples were analysed at a NATA approved laboratory (SGS Ltd). A subsample of each soil type was also analysed for metal concentrations at the Edith Cowan University laboratory.

8 RESULTS AND DISCUSSION

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 eight of the soil classifications had a low neutralising capacity (Table 1). This is in contrast to the carbonate rich Spearwood Dune systems that flank Wallubuenup Swamp and is indicative of these carbonates having been leached from the system in this location. The assessment criteria for TAA were exceeded by sandy organic material and black clay, with black clay also exceeding the TPA criteria (Table 1 & (Department of Environment and Conservation, 2013). This result demonstrated that there was a presence of PASS and ASS, with a reduced capacity for buffering, throughout the study area.

Organic material can interfere with results of the SPOCAS suite due to organic sulphurs and sulphates. This possible inaccuracy is removed by conducting the S_{CR} suite which eliminates organic background interference and is able to accurately measure inorganic sulphurs such as pyrite, iron di-sulphides and acid volatile sulphides (Ahern *et al.*, 2004). The DEC guidelines stipulate that the S_{CR} results supersede the SPOCAS results where the action criteria had been triggered (Department of Environment and Conservation, 2013). In this study three soil classifications exceeded the S_{CR} action criteria these were Sandy Organic Material, Black Clay and Clay with ferrous mottling. Organic material and Sandy Clay with Organic Material were equal to the criterion and were also considered to trigger the action criteria (Table 1). The DEC guidelines prescribe that where the action criteria is exceeded a management plan for ASS should be developed and implemented.

Table 2 illustrates detailed individual soil profiles and depth to groundwater of all sites sampled. When used in conjunction with Figure 2 it can be seen that the distribution of positive ASS soil classifications covered all but the south-west corner of the study site.

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 ten broad soil classifications with assessment and action criteria's as prescribed by the Department of Environment and Conservation (2013).

	Field Test				Lab pH		SPOCAS				S_{CR} Suite			Action Criteria	
Broad Soil Description	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	%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
Organic Material	5.7	4	1.7	M	5.9	5.6	0.02	LOR	LOR	LOR	5.9	0.02	0.006	0.02	0.03
Sandy Organic Material	6.3	3.5	2.8	S	5.9	6.8	0.24	LOR	LOR	0.04	5.9	LOR	0.006	0.24	0.21
Sand (ferrous coloured)	6.7	4.8	1.9	Sl	6	6.3	LOR	LOR	LOR	LOR	6	LOR	LOR	LOR	LOR
Sand	6.9	3.1	3.8	S	7.1	6.8	LOR	LOR	LOR	0.06	7.1	LOR	0.011	LOR	LOR
Sandy Clay (ferrous coloured)	6.9	4.7	2.2	M	6.4	6.4	LOR	LOR	LOR	LOR	6.4	LOR	LOR	LOR	LOR
Sandy Clay with Organic Material	6.5	3.2	3.3	S	5.9	6.5	LOR	LOR	LOR	LOR	5.9	LOR	0.027	LOR	0.03
Clayey Sand (ferrous coloured)	6.8	4.6	2.2	M	6.1	6.2	LOR	LOR	LOR	LOR	6.1	LOR	LOR	LOR	LOR
Clayey Sand with Organic Material	6.9	3.3	3.6	S	5.9	6.2	LOR	LOR	LOR	LOR	5.9	LOR	LOR	LOR	LOR
Black Clay	6.9	3.4	3.5	E	5	4.5	0.06	0.11	0.05	LOR	5	0.06	0.046	0.14	0.11
Clay with ferrous mottling	6.9	4	2.9	E	5.9	5	0.03	0.02	LOR	LOR	5.9	0.03	0.006	0.04	0.04

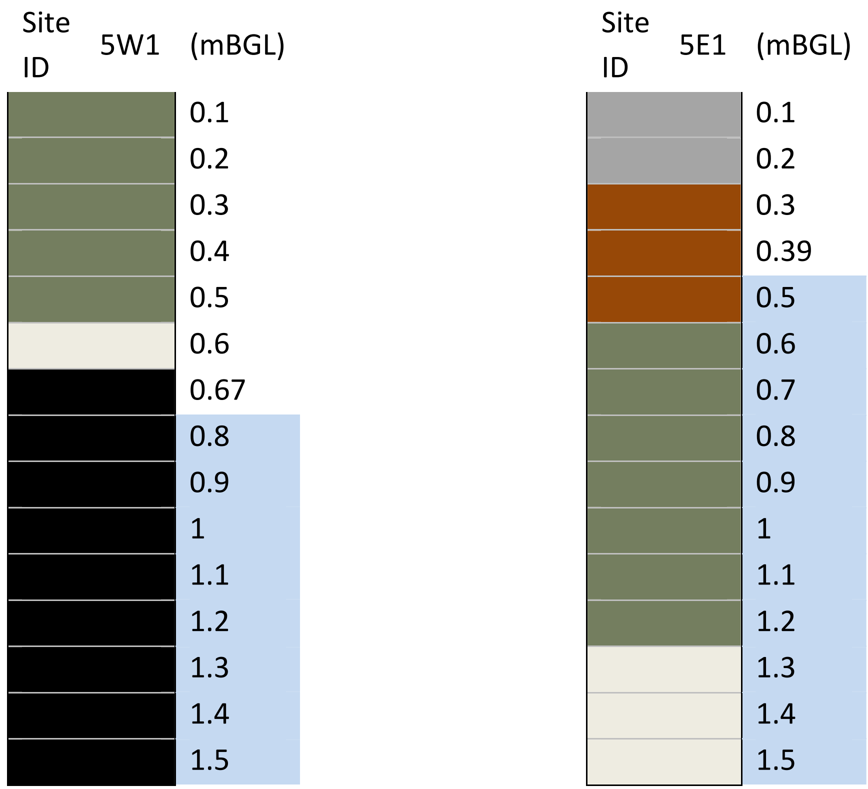
NOTE: LOR – Below Limit of Recording

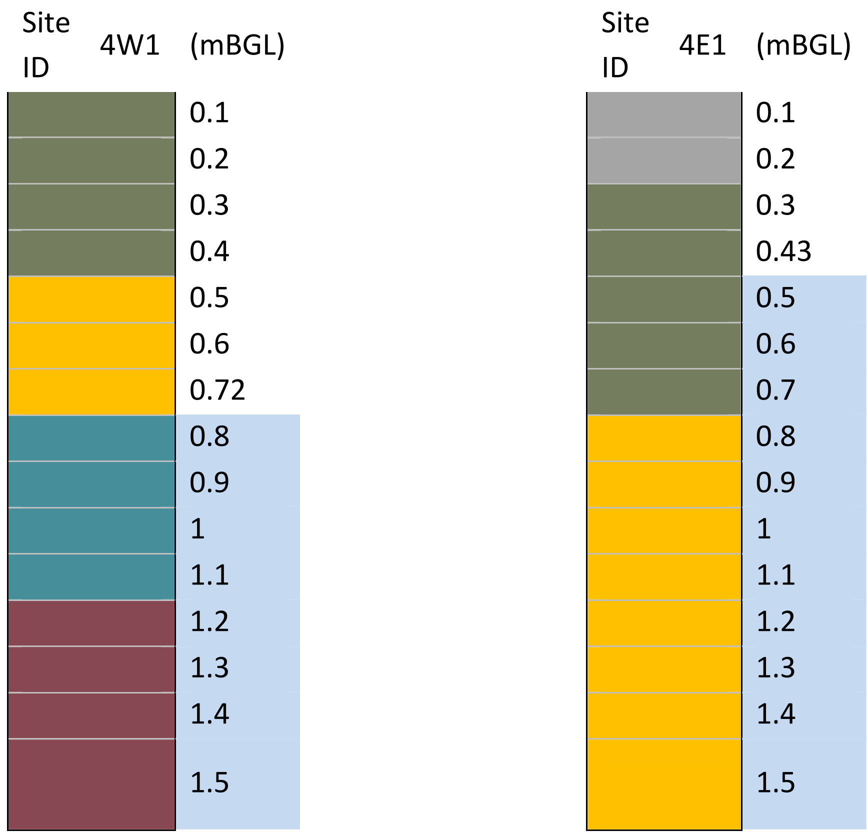
Sl – slight, M – medium, S – strong, E – extreme, these codes were used to describe the 'fizz test' reaction.

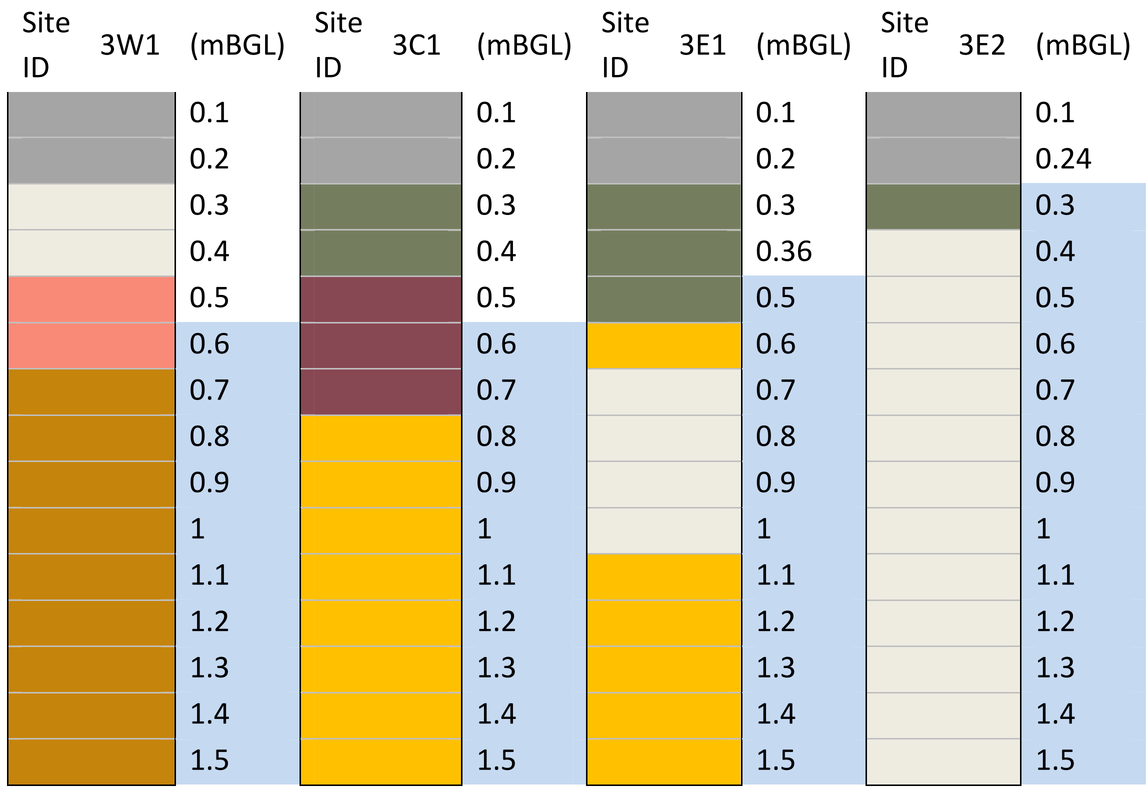
Values in red indicate levels equal to or exceeding assessment and action criteria's.

Table 2. Individual borehole soil profiles along six transects running parallel to Whitsfords Avenue with 1W1 being the south-east corner and 6E4 being the north-west corner of the sampling grid.

Site ID 6W1	(mBGL)	Site ID 6C1	(mBGL)	Site ID 6E1	(mBGL)	Site ID 6E2	(mBGL)	Site ID 6E3	(mBGL)	Site ID 6E4	(mBGL)
	0.1		0.1		0.1		0.18		0.1		0.1
	0.2		0.2		0.2		0.2		0.24		0.2
xxxxxxxx	0.3		0.3		0.26		0.3		0.3		0.3
xxxxxxxx	0.4		0.39		0.4		0.4		0.4		0.4
xxxxxxxx	0.5		0.5		0.5		0.5		0.5		0.55
	0.6		0.6		0.6		0.6		0.6		0.6
	0.7		0.7		0.7		0.7		0.7		0.7
	0.8		0.8		0.8		0.8		0.8		0.8
	0.9		0.9		0.9		0.9		0.9		0.9
	1		1		1		1		1		1
	1.1		1.1		1.1		1.1		1.1		1.1
	1.2		1.2		1.2		1.2		1.2		1.2
	1.3		1.3		1.3		1.3		1.3		1.3
	1.4		1.4		1.4		1.4		1.4		1.4
	1.5		1.5		1.5		1.5		1.5		1.5


Site ID
5W1
(mBGL)
0.1
0.2
0.3
0.4
0.5
0.6
0.67
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
Site ID
5E1
(mBGL)
0.1
0.2
0.3
0.39
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5


Site ID
4W1
(mBGL)
0.1
0.2
0.3
0.4
0.5
0.6
0.72
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
Site ID
4E1
(mBGL)
0.1
0.2
0.3
0.43
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5


Site ID
3W1
(mBGL)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
Site ID
3C1
(mBGL)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
Site ID
3E1
(mBGL)
0.1
0.2
0.3
0.36
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5
Site ID
3E2
(mBGL)
0.1
0.24
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
1.4
1.5

Site ID 2W1	(mBGL)	Site ID 2C1	(mBGL)	Site ID 2E1	(mBGL)	Site ID 2E2	(mBGL)	Site ID 2E3	(mBGL)	Site ID 2E4	(mBGL)
	0.1		0.1		0.1		0.1		0.1		0.1
	0.2		0.2		0.2		0.2		0.2		0.2
	0.3		0.3		0.3		0.3		0.3		0.3
	0.4		0.4		0.4		0.4		0.4		0.4
	0.5		0.54		0.46		0.5		0.46		0.5
	0.6		0.6		0.6		0.56	xxxxxxxx	0.6	xxxxxxxx	0.6
	0.7		0.7		0.7		0.7	xxxxxxxx	0.7	xxxxxxxx	0.73
	0.8		0.8		0.8		0.8	xxxxxxxx	0.8	xxxxxxxx	0.8
	0.9		0.9		0.9		0.9	xxxxxxxx	0.9	xxxxxxxx	0.9
	1		1		1		1	xxxxxxxx	1	xxxxxxxx	1
	1.1		1.1		1.1		1.1	xxxxxxxx	1.1	xxxxxxxx	1.1
	1.2		1.2		1.2		1.2	xxxxxxxx	1.2	xxxxxxxx	1.2
	1.3		1.3		1.3		1.3	xxxxxxxx	1.3	xxxxxxxx	1.3
	1.4		1.4		1.4		1.4	xxxxxxxx	1.4	xxxxxxxx	1.4
	1.5		1.5		1.5		1.5	xxxxxxxx	1.5	xxxxxxxx	1.5

Site ID 1W1	(mBGL)	Site ID 1C1	(mBGL)	Site ID 1E1	(mBGL)	Site ID 1E2	(mBGL)	Site ID 1E3	(mBGL)	Site ID 1E4	(mBGL)
	0.1		0.1		0.1		0.1		0.1		0.1
	0.2		0.2		0.2		0.2		0.2		0.2
	0.3		0.3		0.3		0.3		0.3	xxxxxxxx	0.3
	0.4		0.4		0.4		0.4		0.4	xxxxxxxx	0.4
	0.5		0.5		0.5		0.52		0.5	xxxxxxxx	0.5
	0.6		0.57		0.56		0.6		0.59	xxxxxxxx	0.6
	0.73		0.7		0.7		0.7		0.7	xxxxxxxx	0.7
	0.8		0.8		0.8	xxxxxxxx	0.8		0.8	xxxxxxxx	0.8
	0.9		0.9		0.9	xxxxxxxx	0.9		0.9		0.9
	1		1		1	xxxxxxxx	1		1	xxxxxxxx	1
	1.1		1.1		1.1	xxxxxxxx	1.1		1.1	xxxxxxxx	1.1
	1.2		1.2		1.2	xxxxxxxx	1.2		1.2	xxxxxxxx	1.2
	1.3		1.3		1.3	xxxxxxxx	1.3		1.3	xxxxxxxx	1.3
	1.4		1.4		1.4	xxxxxxxx	1.4		1.4	xxxxxxxx	1.4
	1.5		1.5		1.5	xxxxxxxx	1.5		1.5	xxxxxxxx	1.5

Key

	Sand		Sandy Clay with organic material
xxxx	Sand mottled		Sandy clay
	Sand with ferrous colouring		Sand + clay 50:50
xxxx	Sand with ferrous mottling		Clayey sand with peat
xxxx	Fine sand mottled		Clayey sandy ferrous colouring
	Bleached sand		Clayey sand
xxxx	Bleached sand with organic material		Black clay
	Sandy organic material		Black clayey sand
xxxx	Sandy organic material with bleached mottling	xxxx	Clay with ferrous mottling
	Sandy clay ferrous colouring		Organic material

The concentration of key metals measured in each of the major strata (where there was sufficient material) is shown in Table 3. The soils containing clay had high concentrations of Al an important component of most clay. The iron mottled samples also showed high Fe concentrations. These Fe concentrations may reflect either the presence of pyrite or deposition of Fe^{3+} following groundwater movements (Fe^{2+} occurs in reducing conditions and is soluble, Fe^{3+} is oxidised and insoluble). Arsenic concentrations were very high perhaps indicating the presence of arseno-pyrites, where arsenic is bound to the pyrite. Arseno-pyrites are common in the Stirling area (Appleyard *et al.*, 2006; Hinwood *et al.*, 2006). Calcium and Mg are typically associated with carbonates which buffer acidity, only black clay and organic material contained moderate concentrations of these elements. However, based on ANC results (Table 1) even these concentrations of Ca and Mg were insufficient to generate any substantial buffering capacity. Sand had the highest levels of Hg, with detectable levels found in another 5 soil types. There appears to be no obvious pattern to the Hg concentrations amongst the soil types. Cadmium, Se and Ni were close or below detection yet appear as contaminants of the water in Yellagonga (Newport & Lund, 2012). This may be due to ANZECC/ARMCANZ (2000) trigger values for the Protection of Aquatic Systems being below the detection limit for metals in soils and therefore unable to determine whether these soils were the source of metals in the water. Three soil types stood out as the most likely sources of metal contamination in the waters of Yellagonga Regional Park, Black clay, Clay sand ferrous coloured and Sandy clay ferrous coloured, all of which are ASS.

Table3. Select metal concentrations (mg kg^{-1}) found in major soil types found at the Yellagonga sample site.

	Al	As	Ca	Cd	Co	Cr	Fe	Hg	K	Mg	Mn	Na	Ni	Pb	S	Se	U	Zn
Reporting Limit	**<1.0**	**<0.5**	**<2.5**	**<0.1**	**<0.2**	**<0.2**	**<2.0**	**<2.0**	**<0.5**	**<0.5**	**<0.5**	**<2.0**	**<0.5**	**<2.0**	**<2.0**	**<2.0**	**<0.5**	**<0.2**
Sand	1752	23	1293	<0.1	<0.25	23	8700	8.0	57	72	21	183	<0.5	2	480	<2.0	5.7	7.1
Black clay	15120	191	3629	<0.1	6.8	216	75750	4.6	1106	1456	100	959	1.2	89	1235	<2.0	74	3.6
Clay sand, ferrous coloured	4204	145	1023	<0.1	2.4	77	59650	3.5	184	230	85	315	<0.5	52	218	<2.0	62	13.3
Sandy clay, ferrous coloured	2506	150	1007	<0.1	4.3	33	90900	2.5	136	239	122	295	0.9	110	184	<2.0	112	9.2
Sand, ferrous coloured	1035	14.3	234	<0.1	<0.25	13.3	10265	<2.0	71	48	25	161	<0.5	<2.0	57	<2.0	5.3	4.5
Organic material	2355	0.6	3388	<0.1	<0.25	14.3	7705	<2.0	149	410	37	719	2.2	15	1990	<2.0	8.4	19.5
Sandy organic material	1237	<0.5	495	<0.1	<0.25	8.4	3530	2.4	63	71	20	174	<0.5	3	303	<2.0	2.0	9.4
Sandy clay organic material	9460	1.7	1870	<0.1	<0.25	43	3961	<2.0	288	429	13	618	<0.5	9	1079	<2.0	2.8	8.6
Clay sand, organic material	3620	<0.5	774	<0.1	1.9	23	4198	2.3	119	182	23	318	6.3	3	267	<2.0	4.1	16.3

9 CONCLUSIONS

The study found that the area just north of Whitfords Avenue (around $Drain_{Goollelal}$) contained a range of soil types of which the majority were ASS or PASS. Metal analysis confirmed the presence of all the problem metals identified in the Yellagonga water quality sampling program. Therefore this site appears to be the source of both metals and acidity as recorded in the water quality study.

The results confirm the presence 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. The full extent of the ASS also needs further investigation. Options for remediation/management of the site also need to be developed.

10 RECOMMENDATIONS

1. A management plan for the site is required due to the confirmed presence of ASS and PASS.
2. Further work is recommended to determine the extent of the ASS in the locality.
3. Installation and monitoring of piezometers is recommended to identify if surface or groundwater is the main pathway of acidity and metals into drain.

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