

www.csiro.au

Monitoring and Assessment of Reflooded Acid Sulfate Soil Materials in Currency Creek and Finniss River Region, South Australia

RW Fitzpatrick, GJ Grealish, P Shand and NL Creeper

May 2011

Prepared for: Department of Environment and Natural Resources (DENR)
Murray Futures Lower Lakes & Coorong Recovery Acid Sulfate Soils Research Program

Project Report Number R-325-8-6

Enquiries should be addressed to:

Dr Rob Fitzpatrick: CSIRO Land and Water,
Private Bag No 2, Glen Osmond, South Australia
Email: rob.fitzpatrick@csiro.au
Phone: 08 8303 8511; Mobile: 0408 824 215

Copyright and Disclaimer

© 2010 CSIRO / Department of Environment and Natural Resources (DENR). Photographs, cover artwork and logos are not to be reproduced, copied or stored by any process without the written permission of the copyright holders or owners. All commercial rights are reserved and no part of this publication covered by copyright may be reproduced, copied or stored in any form or by any means for the purpose of acquiring profit or generating monies through commercially exploiting ('including but not limited to sales) any part of or the whole of this publication except with the written permission of the copyright holders.

However, the copyright holders permit any person to reproduce or copy the text and other graphics in this publication or any part of it for the purposes of research, scientific advancement, academic discussion, record-keeping, free distribution, educational use or for any other public use or benefit provided that any such reproduction or copy (in part or in whole) acknowledges the permission of the copyright holders and its source ('Monitoring and assessment of reflooded Acid Sulfate Soil materials in Currency Creek and Finniss River Region, South Australia) is clearly acknowledged.

To the extent permitted by law, the copyright holders (Including its employees and consultants) exclude all liability to any person for any consequences, including but not limited to all losses, damages, costs, expenses and any other compensation, arising directly or indirectly from using this report (in part or in whole) and any information or material contained in it.

The contents of this publication do not purport to represent the position of CSIRO / SA Department of Environment and Natural Resources (DENR) in any way and are presented for the purpose of informing and stimulating discussion for improved management of Basin natural resources.

Citation:

Fitzpatrick, RW, Grealish, GJ, Shand, P and Creeper, NL. (2011). Monitoring and assessment of reflooded Acid Sulfate Soil materials in Currency Creek and Finniss River Region, South Australia. Prepared for the South Australia Department of Environment and Natural Resources (DENR), Adelaide. Client Report R-325-8-6. CSIRO: Sustainable Agriculture Research Flagship, 103 pp.

Cover Photograph:

Description: Clockwise from top left.

1. Soil pore water sampler prepared for installation into the soil below the surface water.
2. Surface water in December 2009, which covers an area surrounded by reeds that was previously (November 2008) a dry, sulfuric cracking clay at site FIN28. The "orange" reddish-brown colouration of water is due to the presence of iron rich mineral precipitates comprising mostly schwertmannite, an iron-oxyhydroxysulfate mineral.
3. A soil core extracted from this Finniss River site showing clear soil layer variations with depth.
4. (Below photograph) Upper 25 cm of soil extracted from a Currency Creek site (CUR 25) below about 50cm of surface water, showing reddish-brown gel material comprising schwertmannite as a thin surface layer, over grey clay sulfuric material that still contains concentrations of the bright yellow mineral jarosite.

Photographer: Rob Fitzpatrick © 2008 CSIRO

CONTENTS

Executive Summary.....	viii
1. Introduction	1
1.1. Aims and Objectives.....	1
1.2. Background	3
1.3. Summary of Previous Work	4
1.4. Classification of Acid Sulfate Soil Material	7
2. Field Sampling and Laboratory Methods.....	9
2.1. Field Sampling of Soil.....	10
2.2. Field Sampling of Water	11
2.3. Field Sampling of Soil Pore Water.....	11
2.4. Laboratory Analysis.....	12
2.4.1. Soil analysis methods	13
2.4.2. Water analysis methods	14
2.4.3. Soil pore water analysis.....	14
3. Soil Results and Assessment	15
3.1. Site Location.....	15
3.2. Soil Morphology	16
3.3. Soil Laboratory Data	17
3.4. Soil pH testing results (pH_w, pH_{ox}, $pH_{incubation}$)	19
3.5. Acid Base Accounting Results	23
3.6. Acid Sulfate Soil Material Assessment	25
3.6.1. Classification of Soil Layers.....	25
3.6.2. Characterisation of Sites According to the Acid Sulfate Soil Identification Key	25
3.7. Comparison of results between the 2008 and 2009 surveys	26
3.7.1. Count of results by measured parameter	26
3.7.2. Site characterisation	27
3.7.3. Laboratory results – pH and acid base accounting parameters.....	28
4. Surface Water Results and Assessment.....	30
5. Soil Pore Water Results	36
5.1. Methods	36
5.2. Results and Discussion.....	38
5.2.1. 1-D spatial variability of pH, EC and Acidity or Alkalinity.	39
5.2.2. Acidic Cations.....	42
5.2.3. Soil Pore Water Quality	45
5.3. Conclusion and knowledge gaps	50
6. Summary and Conclusions	52
References	54
Appendices	57
Appendix 1: Australian Acid Sulfate Soil Identification Key	58
Appendix 2: Site locations, Morphology, Photographs of Sites, Profiles and Samples	62

Appendix 3: Laboratory Results – Soil pH testing and Acid Base Accounting Parameters.....	81
Appendix 4: Laboratory Results – Surface Water	86
Appendix 5: Laboratory Results – Soil Pore Water	89

LIST OF FIGURES

Figure 1-1: A selection of these 2008 survey sites was revisited as part of this study. Map shows survey area and location of all detailed assessment survey sites for Finniss River (FIN 20 to 28, 30 to 42), Currency Creek (CUR 02 to 07, 20 to 28), Goolwa Channel (CUR 11 to 19) and Black Swamp (FIN29). The map also shows the location of the earlier rapid assessment survey sites.....	3
Figure 1-2: Generalised conceptual model showing the sequential transformation of four classes of acid sulfate soil due to lowering of water levels (from Fitzpatrick <i>et al.</i> 2008a,b,d).4	
Figure 1-3: Predictive scenario maps depicting changes in acid sulfate soil materials at different water levels in Lake Alexandrina (+0.5 m AHD, -0.5 m AHD and -1.5 m AHD) from Fitzpatrick <i>et al.</i> (2008a,b,d; 2009c). Finniss River, Currency Creek and Goolwa Channel are the three extensions occurring on the left side of Lake Alexandrina.	6
Figure 1-4: Graphic depiction of scenario changes in ASS material aerial extents at different water levels in Lake Alexandrina (+0.5 m AHD, -0.5 m AHD and -1.5 m AHD) from Fitzpatrick <i>et al.</i> (2008a,b,d; 2009c).	6
Figure 2-1. Soil pore water sampler (white plastic with 36 cells) carefully pushed into the sediment to a set depth.	11
Figure 3-1. Map showing the location of the soil sample sites.	15
Figure 3-2. pH data results plotted as a cumulative percentage.	18
Figure 3-3. All net acidity and chromium reducible sulfur results plotted as a cumulative percentage.....	18
Figure 3-4. Finniss River pH depth profiles.	20
Figure 3-5. Currency Creek pH depth profiles.	22
Figure 3-6. Wally's Landing pH depth profiles.	22
Figure 3-7. Finniss River depth profiles of Net Acidity (NA) shown on the right. The left side shows the components TAA (red bar), AGP as S _{CR} (pink bar).	23
Figure 3-8. Currency Creek depth profiles for Net Acidity (NA) shown on the right. The left side shows the components TAA (red bar), AGP as S _{CR} (pink bar), and ANC (blue bar).	24
Figure 3-9. Wally's Landing depth profiles for Net Acidity (NA) shown on the right. The left side shows the components TAA (red bar), AGP as S _{CR} (pink bar), and ANC (blue bar).	25
Figure 3-10. pH data comparison between 2008 and 2009 survey data for pH _W , pH _{OX} , and pH _{incubation} (dashed line shows 1:1).	29
Figure 3-11. Acid base accounting parameter comparison between 2008 and 2009 laboratory data for total actual acidity, chromium reducible sulfur and net acidity (dashed line shows 1:1)....	29
Figure 4-1. Location map showing position of surface water sampling sites.....	30

Figure 4-2. Surface water at site FC1009 / FIN20 (see Figure 4-1) showing an “orange” reddish-brown colouration of water most likely due to a mixture of iron rich mineral precipitates (e.g. oxyhydroxysulfate mineral, schwertmannite and ferrihydrite), aluminosilicate clays and possibly orange coloured algae.....	31
Figure 4-3. Piper plot showing the relative proportions of major solutes in the surface waters of Finniss River and Currency Creek.....	32
Figure 4-4. Plot of Na vs. Cl for surface waters showing typically higher concentrations in Currency Creek.....	33
Figure 4-5. Ratio plots for major element/chloride ratios plotted against Cl as an indicator of salinity.....	34
Figure 4-6. Negative correlation between SO ₄ /Cl ratio (i.e. excess SO ₄ from soil-water interaction) and alkalinity. The dissolution of hydroxysulfate minerals, which generate acidity can thus explain the variations in alkalinity across the area.....	35
Figure 5-1. 3D to-scale diagram of peepers used in this study. The polysulfone membrane is coloured yellow in diagram for clarity (usual colour is white).	36
Figure 5-2. Photo showing lower end of specialised peeper installation apparatus with peeper ready to be deployed.	37
Figure 5-3. Location map showing position of soil-pore water sampling sites.....	39
Figure 5-4. Plots of EC, pH, alkalinity, and acidity with depth for site FC1001 (FIN28).....	40
Figure 5-5. Plots of EC, pH, alkalinity, and acidity against depth for site FC1029 (CUR18). ..	40
Figure 5-6. Plots of EC, pH, alkalinity, and acidity against depth for site FC1062 (CUR25). ..	41
Figure 5-7. Plots of EC, pH, alkalinity, and acidity against depth for site FC1062.....	42
Figure 5-8. Individual acidic cation profiles for H ⁺ ,Mn ²⁺ (left), Al ³⁺ and Fe ²⁺ (middle) and summed concentrations of acidic cations against acidity (right) for site FC1001.	43
Figure 5-9. Individual acidic cation profiles for H ⁺ ,Mn ²⁺ (left) Al ³⁺ and Fe ²⁺ (middle) and summed concentrations of acidic cations against acidity (right) for site FC1029.	43
Figure 5-10. Individual acidic cation profiles for H ⁺ ,Mn ²⁺ (left) Al ³⁺ and Fe ²⁺ (middle) and summed concentrations of acidic cations against acidity (right) for site FC1062.	44
Figure 5-11. Individual acidic cation profiles for H ⁺ ,Mn ²⁺ (left) Al ³⁺ and Fe ²⁺ (middle) and summed concentrations of acidic cations against acidity (right) for site FC1074.	45
Figure 5-12 Profiles of aluminium (left), arsenic (middle), and boron (right) for each of the four sites. The black, dashed line represents the relevant ANZECC WQ guideline trigger value for 80% species protection.....	47
Figure 5-13. Profiles of cadmium (left), and chromium (right) for each of the four sites. The black, dashed line represents the relevant ANZECC WQ guideline trigger value for 80% species protection.....	48
Figure 5-14. Profiles of copper (left), manganese (middle), and nickel (right) for each of the four sites. The black, dashed line represents the relevant ANZECC WQ guideline trigger value for 80% species protection.....	49
Figure 5-15. Profiles of lead (left), and zinc (right) for each of the four sites. The black, dashed line represents the relevant ANZECC WQ guideline trigger value for 80% species protection.....	50
Figure 6-1. Photograph and conceptual cross-section diagram of Acid Sulfate Soil of the subtype “Sulfuric cracking clay soil” in the dry river bed of Currency Creek, near north Goolwa (Site No CUR 13 sampled in November 2008), looking west towards to the Adelaide	

Hills, South Australia. This shows: (i) trans-horizon polygonal cracks with very coarse columnar ped structures; the result of desiccation and dewatering of a former "Hypersulfidic subaqueous clayey soil" during drying cycles due to recent extreme drought conditions; (ii) surface coating of the reddish-brown mineral, schwertmannite, which has a pH ranging between 3.0 and 3.6 (sulfuric material), (iii) sulfuric material (pH < 4) with pale yellow mottles of natrojarosite in a dark grey clay matrix between 10 cm to 30 cm, and (iv) very dark grey hypersulfidic material (iron sulfides) at depth (> 30 cm). The lower photograph and conceptual cross-section diagram is taken at same locality in December 2009 after reflooding following winter rainfall runoff from adjacent catchments and construction of Clayton and Currency Creek water regulators..... 53

LIST OF TABLES

Table 2-1. Summary of general approach for conducting the work.....	9
Table 2-2. Laboratory analysis conducted on soil and water samples and the method used.....	12
Table 3-1. Site identification number, locality, depth to water table, and number of samples collected.....	16
Table 3-2. Laboratory data summary for pH testing and sulfate chemistry for all samples..	17
Table 3-3. Acid sulfate soil characterisation and classification for each site.....	26
Table 3-4. Comparison of data from November 2008 and December 2009 surveys, showing count of result meeting soil property criteria.....	27
Table 3-5. Site classification for November 2008 and December/*November 2009 surveys, sorted by region and then classified according 2009 subtype (Appendix 1).....	28
Table 4-1. Field parameters measured on surface waters from Finniss River and Currency Creek.....	31
Table 5-1. Summary table of for toxicants where the guideline trigger values were exceeded for 80% species protection in freshwater ecosystems (exceedance based on non-hardness corrected values for elements Cd, Cu, Ni, Zn, and Pb). (✓ = exceedance).....	45
Table 5-2. Guideline trigger values applied to data. The GTV is shown as a dashed line in Figures 5-12 through 15.	46

ACKNOWLEDGMENTS

This work was largely funded by the Department of Environment and Natural Resources (DENR), South Australia (previously Department for Environment and Heritage, South Australia), Murray Futures Lower Lakes & Coorong Recovery Acid Sulfate Soils Research Program. We would like to acknowledge the support, comment and project management provided by Dr Liz Barnett (DENR) and team.

We acknowledge the efforts of CSIRO staff: Sonia Grocke, who assisted with field work and testing of water samples, Nilmini Jayalath, who conducted the pH testing and preparation of samples for laboratory analysis and Warren Hicks for suggesting we undertake *in situ* porewater experiments using multi-chambered dialysis samplers (peepers) and also for reviewing and commenting on the report, especially the section relating to pore water sampling and geochemistry, Richard Merry, for reviewing our report. We also thank Dr Luke Mosley for constructive comments.

The field work could not have been conducted without the expertise and experience of Mr. A. Phillips who navigated his boat safely and efficiently to the site locations and assisted the field sampling team.

EXECUTIVE SUMMARY

Background and Aim

This study was commissioned by the Department of Environment and Natural Resources (DENR) to conduct field and laboratory investigations in the lower reaches of Finniss River, Currency Creek and Goolwa Channel regions in South Australia, to:

- Provide a quantitative assessment of the acid sulfate soil (ASS) and water changes that have occurred over a one year period between a survey conducted in November 2008 after drying during extreme drought conditions and after reflooding in December 2009 (due to raising water levels by construction of water regulators across the Goolwa Channel and Currency Creek). Extensive areas of acid sulfate soils with sulfuric material ($\text{pH} < 4$) were exposed in this region as a result of unprecedented low water levels. Acidification of surface waters has also occurred in some localised areas where acidity has been transported from soil profiles with sulfuric material. Increasing the water level and the other intervention measures are assumed to have assisted with mitigating increasing formation of acid sulfate soils with sulfuric material and acid waters. Consequently, the aim of this investigation is the need for detailed field and laboratory investigations at 25 representative sites that were previously characterised to quantify the impact of rewetting on ASS and water processes to better evaluate reflooding management options.
- Provide a report on the findings to underpin possible ongoing monitoring, long-term management and potential short-term mitigation options.

Scope of study

This study reports on the following three components of work:

1. Revisiting a selection of representative sites from the November 2008 study, to quantify soil properties and characterise acid sulfate soil conditions, allowing change in acid sulfate soil characteristics and impacts to be assessed.
2. Collecting water samples throughout the study area to quantify the current water conditions and water quality.
3. Using multi-chambered dialysis samplers (peepers) to collect high resolution, down-profile information of soil pore water geochemistry to quantify:
 - (i) water and sediment quality against ANZECC guidelines, and
 - (ii) depth and rates of acid neutralisation down soil profiles.

Field work for this survey was conducted mostly in December 2009. Investigation sites were distributed throughout the area to provide coverage of all areas, 25 sites (80 layers) were sampled for acid sulfate soil assessment, 11 sites were sampled for surface water quality and chemistry, and four sites were sampled to obtain soil pore water characteristics.

Key findings

The data obtained indicates that even though the 25 sites investigated in 2009 have been inundated with water, an acidification hazard remains. The most significant change to the area is that soils previously sampled in 2008 that were exposed are now covered with surface water. Consequently, all soil profiles investigated in December 2009 classify as "subaqueous" with the following summary of findings for the 80 soil samples taken:

- Mostly acidic, with 75% of samples having a pH in soil water < 7 , and 21% with a pH < 4 .
- Likely to oxidise to high acidity levels, with 79% of samples having a pH after hydrogen peroxide treatment below the critical value of 2.5.

- The data for pH after incubation identify 68% of samples as having a pH below the critical value of 4.
- Generally, all samples contain actual acidity (high median and maximum values for total actual acidity).
- Retained acidity was measured in 24 of the samples (30% of total samples).
- Acid neutralising capacity was found in 18 of the samples (22% total samples), with some samples having very high values as indicated by the maximum value measured.
- Most soil samples have potential acidity, as shown by the high median and maximum values for chromium reducible sulfur, with 77 of samples having a value greater than 0 (96% of total samples).
- Most soil samples had net acidity with 70 of the samples having a positive net acidity (88% of total samples), and only 10 samples had sufficient neutralising capacity to be net negative. As indicated by the high median and maximum values, samples generally contained high levels of net acidity.

Detailed analyses of water from the sediment-water (s-w) interface and soil pore-water to around 33 cm below the s-w interface showed that 5-8 months of inundation is insufficient time to return previously hazardous, oxidised sulfuric ASS materials to reduced benign sulfidic materials. In fact, seasonal 'flushing' and subsequent inundation had little to no effect of the types of ASS materials found. Only 5 cm or less of the uppermost sediment was neutralised to a pH > 4. Below this material that was classified as sulfuric in 2008 has remained sulfuric and unaffected by reflooding. The alkalinity of water at the s-w interface was found to be reduced relative to the water column indicating its role in neutralisation of the uppermost sediment layers. Additionally, guideline trigger values were exceeded for aluminium, arsenic, boron, cadmium, chromium, copper, manganese, nickel, lead and zinc with most being exceeded at all sites and over the majority of the depth-profile, including the top 5 cm.

The surface water chemistry indicates transport of SO₄ to the surface water, and therefore most likely acidity as well, which explains the variation in alkalinity. If there is further transportation of acidity into the surface water then buffering capacity in the surface waters will be consumed, increasing the risk of acidification of the waters.

In summary, field and laboratory data obtained in the November 2008 and December 2009 surveys were compared using changes in: (i) soil classification subtypes (ii) sample counts against key chemical criteria, (iii) chemical laboratory results with like for like soil layer data and (iv) soil morphology and cross sections at sites with information on depth of the soil cracking and the oxidation (acid mobilisation) front, which can vary from 10 cm to 1 metre below the soil surface depending on location and the soil type. Acidity remains in the sub-soil following rewetting despite more alkaline surface soils and water. Based on the 2008 and 2009 comparative studies it is likely that recovery from a severe acidification could take years to decades but this depends on many factors (e.g. how long soils have been oxidised, texture, depth of cracking, flushing rate, severity of soil and water acidification and effectiveness of sulfate reduction). Consequently, recovery processes are complex, scale dependent and controlled by a number of physical and chemical factors.

Recommendations

- Monitoring should continue during rewetting and reflooding phases caused by winter rainfall or reflooding due to increased river flows or pumping, when acidity and metal mobilisation are likely to have the most significant impact. The extent and rate change of various types of underlying acid sulfate soil materials and their impacts on the environment need to be quantified.

- The time scales for the establishment of a new equilibrium under reducing conditions remains unknown. Gaining knowledge of the time scales needed to return these profiles to their pre-drought condition (i.e. re-establishment of reducing conditions) is important for the understanding and management of rewetted ASS. By repeating detailed soil pore-water experiments following an additional 6 or more months under reflooded conditions an understanding of the time scales involved could be obtained.
- A consolidated dataset, which must be regularly updated with results of any future monitoring, will provide information to underpin management in relation to both short and long-term strategies for the lakes and wetlands. The findings of this study should be integrated with data from previous and planned future studies to enable a more complete documentation of processes.

1. INTRODUCTION

This report provides data for the soil and water properties, extent and presence (or absence) of acid sulfate soil materials in the lower reaches of Finniss River, Currency Creek, and Goolwa Channel regions for an acid sulfate soil survey conducted in December 2009. It provides an assessment of the soil changes that have occurred over approximately a one year period since the previous acid sulfate soil survey of the area was conducted in November 2008 (Fitzpatrick *et al.* 2009a, 2009b).

These areas (Figure 1-1), adjacent to Lake Alexandrina in the lower reaches of the River Murray in South Australia, have experienced falling and historically low water levels due to drought conditions in 2007 and 2008. Subsequently, a water regulator (earth dam) was placed near Clayton township to assist with raising the water level in the Finniss River, Currency Creek and Goolwa Channel areas by retaining water inflow from the tributaries and by pumping water from Lake Alexandrina. This commenced in September 2009 (DENR 2010). The water levels stabilized at approximately + 0.5 m AHD in November to December 2009.

This work fits with the on-going monitoring of acid sulfate soil conditions in the region and provides the first opportunity to assess the changes in soil condition due to inundation of large areas. The previous survey (Fitzpatrick *et al.* 2009a, 2009b), conducted at lower water levels, characterised many areas as sulfuric acid sulfate soil materials. A separate mapping project to determine the spatial heterogeneity of the Lower Lakes was commissioned by Department of Environment and Natural Resources (Fitzpatrick *et al.* 2010a). This mapping study revealed that these tributary areas have widespread occurrence of acid sulfate soil with sulfuric material, confirming the previous predictions of Fitzpatrick *et al.* (2008a,b,d; 2009a, 2009b). In November 2009 CSIRO also conducted sampling at Wally's Landing (1 November 2009) following winter rainfall reflooding of dried wetlands with sulfuric material and identified sulfuric materials persisting below 50 cm of water. This important observation has highlighted an urgent requirement for further work to quantify the nature and extent of sulfuric materials occurring below ponded water (both acidic and alkaline).

In parallel with raising the water levels, other interventions were undertaken that include liming water and shores, and building of water retaining structures (DENR 2010). Increasing the water level and the other intervention measures are assumed to have assisted with mitigating formation of sulfuric materials and ponded acid waters. What the changes are to the various types of underlying acid sulfate soil materials and their impacts have not been quantified.

This study reports on three components of work.

1. Revisiting a selection of sites from the November 2008 study (i.e. when sites were mostly exposed to air and dry) to quantify changing soil properties and characterise acid sulfate soil conditions, allowing change in acid sulfate soil characteristics to be assessed.
2. Collecting water samples throughout the study area to quantify the current water conditions and water quality.
3. Measuring at a fine level of detail the soil pore water characteristics, to assist with characterising the soil water condition (Note, this work component replaces the geostatistical mapping of soil properties, which was adequately addressed in Fitzpatrick *et al.*, 2010a).

1.1. Aims and Objectives

This work fits with the on-going monitoring of acid sulfate soil conditions in the Lower Lakes region and provides the first opportunity to assess and verify the changes in soil condition

following inundation of large areas that were previously identified as acid sulfate soils with a range of sulfuric and hypersulfidic materials and textures (i.e. sands, loams, sandy clay loams, clays and peats).

The aims of this investigation were to:

- (i) Provide a current status and update the soil and water properties, extent and presence (or absence) of the types and sub-types of acid sulfate soils in Finniss River, Currency Creek and Goolwa Channel region, South Australia.
- (ii) Identify soil property changes that have occurred over the one year period between surveys (drying during the drought in 2008 and after reflooding in September 2009).
- (iii) Characterise the soil pore-water geochemistry to determine changes with depth.
- (iv) Identify the acid sulfate soil material characteristics that will assist managers with determining potential remediation options to minimise the impact of the formation of widespread sulfuric materials to the environment and to recommend future monitoring options.
- (v) Build on prior information to assist with compiling an acid sulfate soil monitoring database and sampling program that is required to confirm and assist with predicting future scenarios either for this study area or for extrapolation to other locations that may be applicable around the Lower Lakes region.

To achieve these aims, the following objectives were identified:

- Conduct field investigations at the same sites investigated one year previously, describe and characterise the soil profile and collect soil samples for laboratory analysis (for 80 soil layers at 25 sites).
- Conduct field investigations to obtain water quality parameters and collect water samples for laboratory analysis (for 10 sites).
- Conduct field investigations to collect soil pore-water solution samples for laboratory analysis (for 4 sites).
- Conduct laboratory analysis that includes pH testing, acid-base accounting, and water quality parameter measurements.
- Assess acidification potential using peroxide testing, pH changes with incubation, and acid-base accounting. Characterise the type of acid sulfate soil material.
- Compile a database that includes soil descriptive information, soil analytical data, and photographs.
- Evaluation of changes between the two sampling events and what this means.
- Provide data on current conditions and location maps of samples to support EIS and other modelling activities.
- Provide verbal briefings and short summary reports to Department of Environment and Heritage (South Australia) based on field work, pre-laboratory testing (pH and peroxide tests), and laboratory results as completed.
- Prepare a report (this report) consolidating all data and discussing the findings and conclusions on the properties, extent and potential severity of acid sulfate soil materials and the water conditions, including recommendations for on-going monitoring.

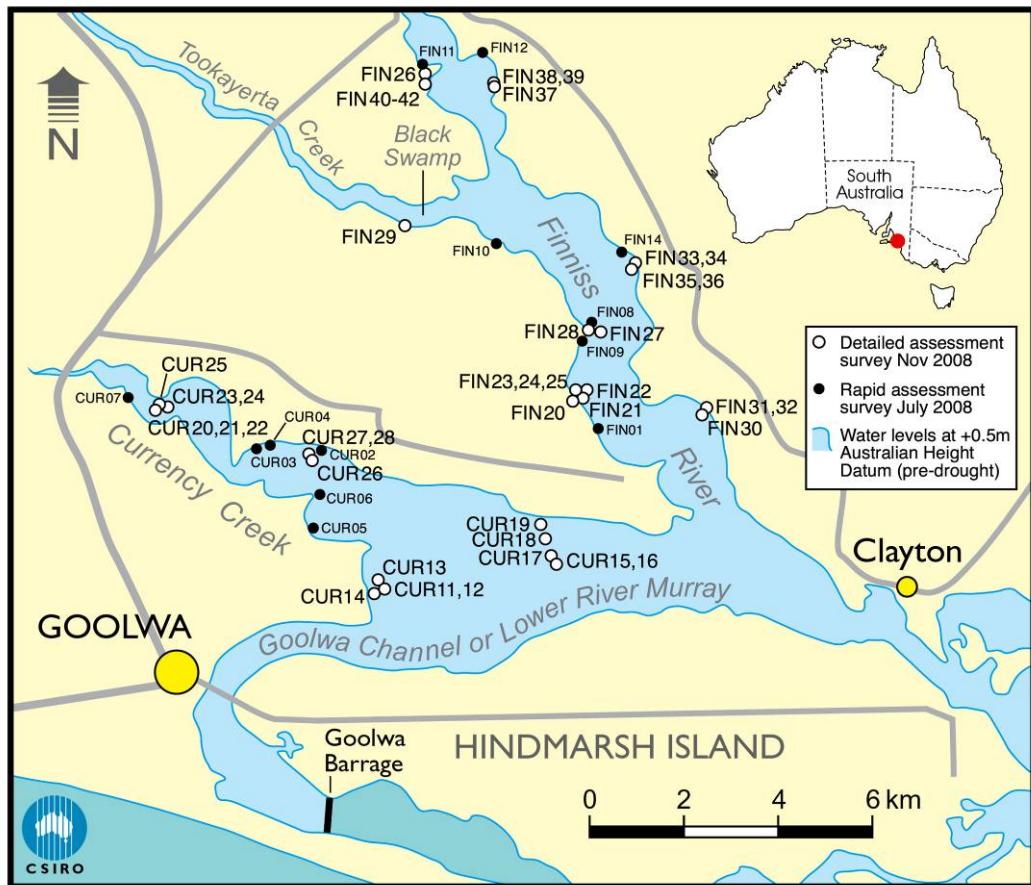


Figure 1-1: A selection of these 2008 survey sites was revisited as part of this study. Map shows survey area and location of all detailed assessment survey sites for Finniss River (FIN 20 to 28, 30 to 42), Currency Creek (CUR 02 to 07, 20 to 28), Goolwa Channel (CUR 11 to 19) and Black Swamp (FIN29). The map also shows the location of the earlier rapid assessment survey sites.

1.2. Background

Acid sulfate soils are those soils containing iron sulfide minerals (e.g. Pons 1973; Fanning 2002). These soils may either contain sulfuric acid (sulfuric material), or have the potential to form sulfuric acid (sulfidic material), or cause de-oxygenation (monosulfidic material), or release contaminants when the sulfide minerals are exposed to air (oxygen). Potential acid sulfate soils form naturally when sulfate in the water is converted to sulfide by bacteria. These sulfides react with metals, especially iron (Fe), to form sulfidic materials (typically pyrite: FeS_2) in subaqueous acid sulfate soil or sediments in rivers and wetlands.

Changes to the hydrology in regulated sections of the Murray-Darling Basin (MDB) system, and the chemistry of rivers and wetlands have caused significant accumulation of sulfidic material in subaqueous and exposed margin soils. If left undisturbed and covered with water, sulfidic material poses little or no threat. However, when sulfidic material is exposed to the air, the sulfides react with oxygen to form sulfuric acid (and potentially sulfuric soil materials with $\text{pH} < 4$). When these sulfuric materials are subsequently covered with water, significant amounts of sulfuric acid can be released into the water.

Other risks associated with acid sulfate soils include: (i) mobilisation of metals, metalloids and non-metals, (ii) decrease in oxygen in the water column when monosulfidic materials are mobilised into the water column, and (iii) production of noxious gases. In severe cases, these risks can potentially lead to damage to the environment, and have impacts on water supplies, and human and livestock health.

As water levels decline in Lake Albert and Lake Alexandrina (the Lower Lakes) and the River Murray system below Blanchetown (Lock 1), due to the current, unprecedented drought conditions, the anaerobic sulfidic materials that were once covered by water are now exposed to oxygen at the river and lake margins, and in adjacent wetlands. With continued lowering of water levels, the hypersulfidic material can become progressively oxidised to greater depths of the soil profile, potentially generating sulfuric material ($\text{pH} < 4$).

1.3. Summary of Previous Work

Previous studies by CSIRO Land and Water developed a conceptual model (Figure 1-2) to describe four sequential drying phases and the development of different acid sulfate soil subtypes (Fitzpatrick *et al.* 2008b,d; 2009c) that occur. Applying this model, Fitzpatrick *et al.* (2008b,c) integrated locally detailed field survey and laboratory data and used the Australian Soil Classification (Isbell 1996) to derive 14 subtypes of acid sulfate soil conforming to the map legend of the Atlas of Australian Acid Sulfate Soils (Fitzpatrick *et al.* 2008c; Appendix 1).

A series of conceptual process models for each of the lakes (Alexandrina and Albert) and lower River Murray systems were applied to:

- explain the sequential formation and transformation of sulfidic material to sulfuric material in various subtypes of acid sulfate soil (5,500 B.C.E to the extreme drought conditions of 2006-2008),
- explain and predict new occurrences of minerals, their formation and transformation (e.g. pyrite to sideronatrite; sideronatrite to schwertmannite; pyrite to natrojarosite), and
- predict the impacts of further drought on acid sulfate soil oxidation and impacts.

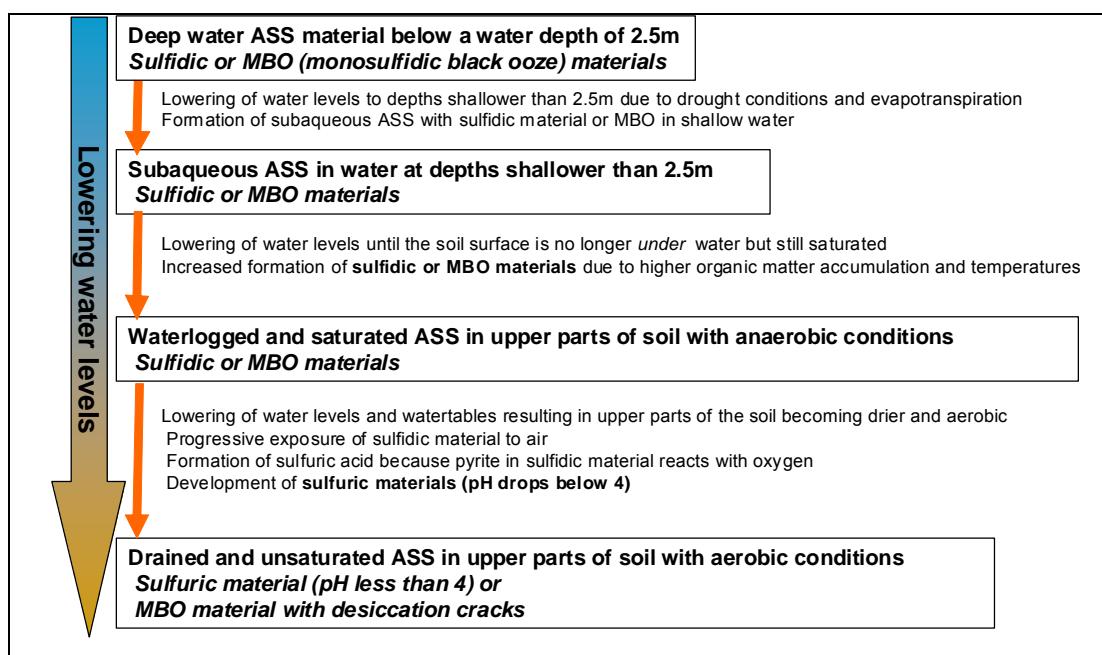


Figure 1-2: Generalised conceptual model showing the sequential transformation of four classes of acid sulfate soil due to lowering of water levels (from Fitzpatrick *et al.* 2008a,b,d).

Combined bathymetry, soil and vegetation mapping in a geographic information system (GIS) framework was used to help predict the distribution of different subtypes of acid sulfate soil according to three predictive scenario maps (Fitzpatrick *et al.* 2008a,b,d), which in Figure 1-3 depicts sequential changes in acid sulfate soil materials at different water levels in Lake Alexandrina and tributaries (e.g. Finniss River).

These predictive acid sulfate soil maps are constantly being revised as new information becomes available through site visits, field testing and the availability of new spatial data sets (e.g. Fitzpatrick *et al.* 2008b; p. 59; 2009a; 2010a).

High sulfide contents were previously measured in a subaqueous sulfidic soil in the Finniss River at site AA26 adjacent to FIN26 (Figure 1-1), which also had relatively low acid neutralising capacity in the upper soil layers [i.e., low carbonate concentrations (Fitzpatrick *et al.* 2008b; p. 118; 2009a)].

Field studies combined with the maps and predictive soil-regolith models were used to conclude that most of this region could produce widespread areas of sulfuric material if the water level fell to –1.5 m AHD (see predictive scenario shown in the acid sulfate soil maps in Figure 1-2 and Figure 1-3). As a result of these types of predictions, deep concerns grew during 2009 that without significant new lake river inflows the ASS trajectories presented in these maps and graphs (Figure 1-4) could eventually be realised. For example, at –1.5 m AHD approximately 20,000 ha of sulfuric material will be produced (Figure 1-4) along with the associated environmental degradation.

A rapid acid sulfate soil assessment conducted in July 2008 by MDB NRM staff identified significant occurrences of acid sulfate soils with sulfuric and hypersulfidic materials and very low pH water values in the Finniss River and Currency Creek region. This triggered a detailed acid sulfate soil assessment of the lower Finniss River, Currency Creek and Goolwa channel, which was conducted in November 2008 by CSIRO and documented in reports by Fitzpatrick *et al.* (2009a, 2009b). The following are some of the key findings identified:

- That more than half of the sites investigated contained sulfuric material ($\text{pH} < 4.0$). The remainder of sites have significant potential for further developing sulfuric materials from hypersulfidic materials if the water levels continue to drop, although the risk of this occurring is low to moderate provided the materials are kept under anaerobic conditions.
- The identification of acidic ($\text{pH} 3.8$ to 3.3) pond and flowing water bodies in localised areas previously identified as containing widespread sulfuric cracking clay soils.
- The metal release was rapid and dissolved concentrations of Al, Cd, Co, Cu, Cr, Mn, Ni, V and Zn greatly exceeded the Australian water quality guidelines (WQGs) for protection of ecosystem health. For Al, Cd, Co, Cu, Cr, Ni and Zn, the concentrations were often greater than $100 \times \text{WQGs}$ and Al and Co frequently exceeded $1000 \times \text{WQG}$ values. Greater concentrations of metals were released from Finniss River soils than from Currency Creek soils. In general, the concentrations of metals released increased greatly at $\text{pH} < 5$.
- At several sites, abundant occurrences of acidity indicating minerals were observed in salt efflorescences and sub-surface horizons.
- Some of the waters in soil pits of the dry river-beds and wetlands of Currency Creek (with deep cracks) and Finniss River (sands) had low pH values ranging from 3.4 to 3.9. Some river waters sampled in Currency Creek and Black Swamp in November 2008 contain moderate to low concentrations of alkalinity ($< 117 \text{ mg/L}$ and 31 mg/L respectively as HCO_3^-).
- Conceptual toposequence models were developed that described the conditions during the 2006 to 2010 extreme drought conditions and predicted future scenarios.
- 37 of the 39 sites (94%) have sufficient net acidity that, if disturbed, would be a site of concern. More than 91% of the sites assessed have a high, very high, or extra high hazard classification indicating a significant potential acid hazard.
- Recommendations were made that monitoring be conducted in this region as an essential component of acid sulfate soil assessments, not only during the 2006 to 2010 drought, but also during the re-wetting phases when acidity and metal mobilisation are likely to occur.

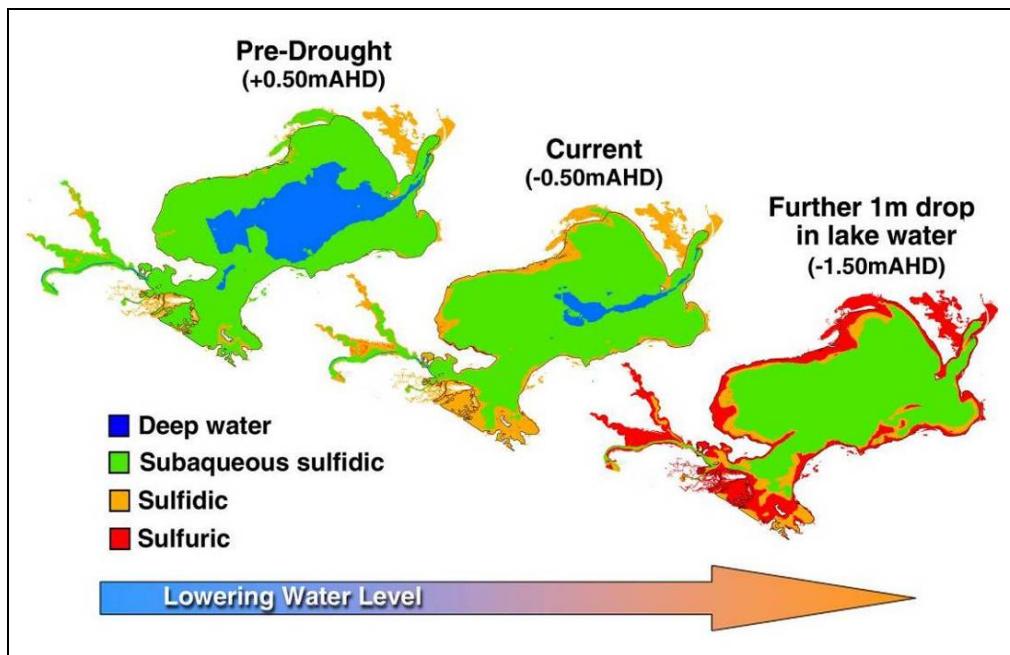


Figure 1-3: Predictive scenario maps depicting changes in acid sulfate soil materials at different water levels in Lake Alexandrina (+0.5 m AHD, -0.5 m AHD and -1.5 m AHD) from Fitzpatrick *et al.* (2008a,b,d; 2009c). Finniss River, Currency Creek and Goolwa Channel are the three extensions occurring on the left side of Lake Alexandrina.

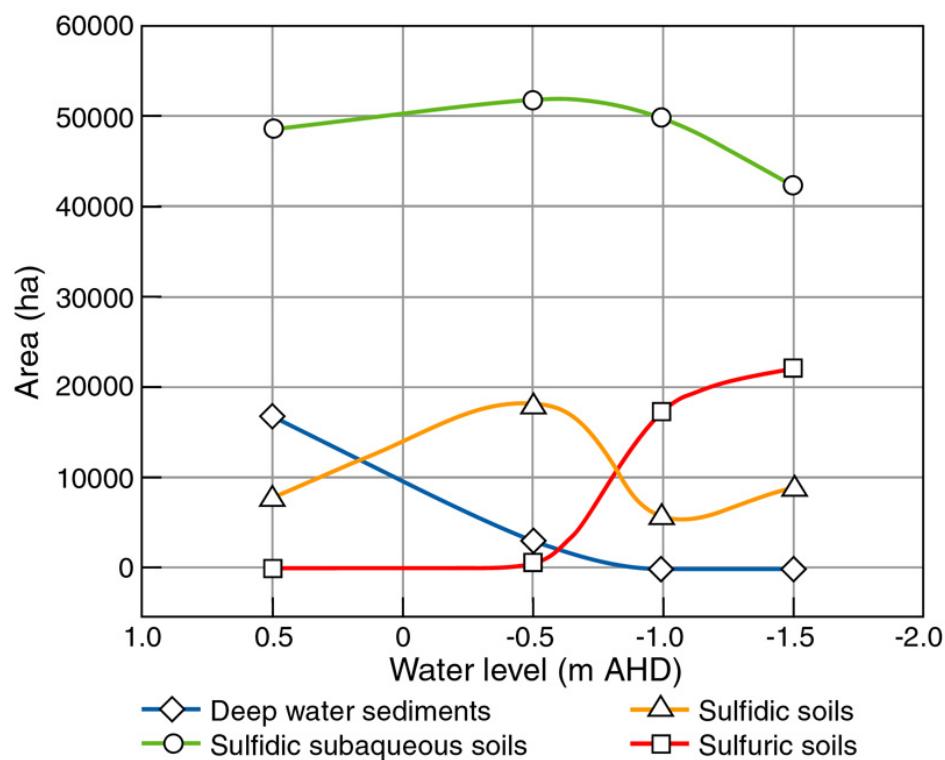


Figure 1-4: Graphic depiction of scenario changes in ASS material aerial extents at different water levels in Lake Alexandrina (+0.5 m AHD, -0.5 m AHD and -1.5 m AHD) from Fitzpatrick *et al.* (2008a,b,d; 2009c).

In August 2009 the predictions expressed in Figure 1-4 were verified based on extensive field investigations and laboratory analyses across the whole Lower Lakes region where 330 sites were described and sampled, which resulted in 706 samples being analysed for pH and

acid base accounting parameters (Fitzpatrick *et al.* 2010a). The sampling sites were selected randomly using geostatistical techniques. This information was used to produce maps of various soil parameters across the whole Lower Lakes using geostatistical techniques, which identified **approximately**:

- 80% (70,829 ha) of the total lake area (89,219 ha) had Hypersulfidic subaqueous soils with associated Hyposulfidic subaqueous soils and Hypersulfidic hydrosols.
- 20% (18,226 ha) of the total lake area (89,219 ha) had Sulfuric unsaturated soils and Sulfuric hydrosols.
- 0.2% (165 ha) of the total lake area (89,219 ha) had Sulfuric subaqueous soils

Spatial heterogeneity mapping by Fitzpatrick *et al.* (2010a) has identified:

- Tributary regions with poor connection to the main lake bodies such as Currency Creek and Finniss River to have widespread occurrence of ASS with both sulfuric and hypersulfidic materials confirming the previous predictions of Fitzpatrick *et al.* (2008a,b,d; 2009a,b).
- Considerable variation in the vertical and horizontal extent of ASS materials and their net acidity, pH and Titratable Actual Acidity (or readily available acidity), highlighting significant variation in the risk profile of ASS around the lower lakes and adjacent tributaries.

This information was used as justification to construct a temporary flow regulator (earth dam) across the Goolwa Channel at Clayton Bay, to assist with raising the water level in the Finniss River, Currency Creek and Goolwa Channel areas by retaining water inflow from the tributaries and by pumping water from Lake Alexandrina, this commenced in September 2009 (see Figure 21 in Fitzpatrick *et al.* 2009c; DENR 2010). This successfully permitted the continued saturation of sulfidic, hypersulfidic and sulfuric materials to minimise sulfide oxidation and to allow the early season flows, which will mobilise acid and heavy metals, to be held back allowing *in situ* bioremediation to proceed (DENR 2010). In parallel, other interventions were undertaken by Murray Futures Lower Lakes & Coorong Recovery Acid Sulfate Soils Program under the direction of the Department of Environment and Natural Resources (DENR) and Environment Protection Authority (EPA) that included liming water and shores and building of water retaining structures. Increasing the water level and the other intervention measures are assumed to have assisted with mitigating formation of more sulfuric materials and acid waters. What the changes are to the acid sulfate soils and their impacts has not been quantified.

1.4. Classification of Acid Sulfate Soil Material

The Acid Sulfate Soils Working Group of the International Union of Soil Sciences agreed to adopt in principle the following five descriptive terminology and classification definitions of acid sulfate soil materials proposed by Sullivan *et al.* (2010) at the 6th International Acid Sulfate Soil and Acid Rock Drainage Conference in September 2008 in Guangzhou, China. This new classification system for acid sulfate soil materials has also been adopted by the Scientific Reference Panel of the Murray-Darling Basin Acid Sulfate Soil Risk Assessment Project (Murray–Darling Basin Authority, 2010) for use in the detailed assessment of acid sulfate soils in the Murray–Darling Basin.

The criteria to define the soil materials are as follows:

Acid Sulfate Soil Materials

1. **Sulfuric materials** - soil materials currently defined as sulfuric by the Australian Soil Classification (Isbell 1996). Essentially, these are soil materials with a $\text{pH}_w < 4$ as a result of sulfide oxidation.
2. **Sulfidic materials*** – soil materials containing detectable sulfide minerals (defined as containing greater than or equal to 0.01% sulfidic S). The intent is for this term to be

used in a descriptive context (e.g. sulfidic soil material or sulfidic sediment) and to align with general definitions applied by other scientific disciplines such as geology and ecology (e.g. sulfidic sediment). The method with the lowest detection limit is the Cr-reducible sulfide method, which currently has a detection limit of 0.01%; other methods (e.g. X-ray diffraction, visual identification, Raman spectroscopy or infra red spectroscopy) can also be used to identify sulfidic materials.

**This term differs from previously published definitions in various soil classifications (e.g. Isbell, 1996).*

3. **Hypersulfidic material** - Hypersulfidic material is a sulfidic material that has a field pH of 4 or more and is identified by experiencing a drop in pH by at least 0.5 unit to 4 or less (1:1 by weight in water, or in a minimum of water to permit measurement) when a 2-10 mm thick layer is incubated aerobically at field capacity. The duration of the incubation is either:
 - a. until the soil pH changes by at least 0.5 pH unit to below 4, or
 - b. until a stable pH is reached after at least 8 weeks of incubation.
4. **Hyposulfidic material** - Hyposulfidic material is a sulfidic material that has a field pH of 4 or more and is identified by not experiencing a drop in pH by at least 0.5 unit to 4 or less (1:1 by weight in water, or in a minimum of water to permit measurement) when a 2-10 mm thick layer is incubated aerobically at field capacity. The duration of the incubation is until a stable pH is reached after at least eight weeks of incubation.
5. **Monosulfidic materials** - soil materials with an acid volatile sulfur content of 0.01%S or more.

Non-Acid Sulfate Soil materials

In addition the Scientific Reference Panel of the Murray-Darling Basin Acid Sulfate Soil Risk Assessment Project agreed to identify the other acidic soil materials arising from the detailed assessment of wetland soils in the Murray-Darling Basin even though these materials may not be the result of acid sulfate soil processes (e.g. the acidity developed during ageing or incubation may be the result of Fe²⁺ hydrolysis, which may or may not be associated with acid sulfate soil processes). Also the acidity present in field soils may be due to the accumulation of acidic organic matter and/or the leaching of bases. Of course, these acidic soil materials may also pose a risk to the environment and would be identified during the course of the Phase 1 detailed assessment (Murray–Darling Basin Authority 2010). The definition of these *other acidic soil materials* for the detailed assessment of acid sulfate soils in the Murray-Darling Basin is as follows:

1. **Other acidic soil materials** – Either:
 - a. non-sulfidic soil materials that acidify by at least a 0.5 pH_w unit to a pH_w of <5.5 during moist aerobic incubation, or
 - b. soil materials with a pH_w ≥ 4 but < 5.5 in the field.
2. **Other soil materials** – soils that do not have acid sulfate soil characteristics.

2. FIELD SAMPLING AND LABORATORY METHODS

The work was conducted as three integrated components:

1. Acid sulfate soil characterisation.
2. Water quality characterisation.
3. Soil pore water characterisation.

The general approach and description is summarised in Table 2-1. Further details for each component are provided in the following subsections.

Table 2-1. Summary of general approach for conducting the work.

Parameter	Description
Study Area	Includes lower reaches of Finniss River, Currency Creek, and the adjacent Goolwa Channel part of the River Murray.
Sites sampled	25 sites for soil samples, 10 sites for water samples, 4 sites for soil pore water samples.
Field measurements	Site coordinates, site description, water depth or water table depth, vegetation, photographic record. When soil excavated for each soil layer a description of colour, texture, consistence, mottles, odour, and any other important features.
Soil samples collected	Chip trays (two trays, one each for long term storage and morphology, and for pH incubation testing). Jars (one each for EC, pH _{ox} , acid-base accounting parameters, and for storage should further analysis be required). Samples were collected from 80 layers at 25 sites.
Laboratory soil analysis	pH, pH _{incubation} , pH _{ox} , electrical conductivity and acid base accounting parameters (chromium reducible sulfur, total actual acidity, retained acidity, acid neutralising capacity).
Water samples collected	Where surface water occurred, duplicate bottles for laboratory analysis. Samples were collected from 10 sites.
Water measurements in field	pH, EC, SEC, Eh, DO, alkalinity, turbidity.
Laboratory water analysis	Major and trace metals.
Soil pore water samples collected	Peepers located to a depth of 30 cm, kept in place for 4 weeks and retrieved, samples collected from 4 sites
Laboratory soil pore water analysis	Chemical analyses (pH, EC, major and trace metals)
Data compilation	Comprehensive Excel spreadsheet database.
Soil and site data analysis	Characterisation of the acid sulfate soil material type for each soil layer sampled. Characterisation of the site according to the Australian Acid Sulfate Soil Identification Key. Compilation to determine spatial extent.

Parameter	Description
Water quality analysis	Overview of current water conditions after inundation of the acidic soil areas.
Soil pore-water analysis	Status of upper soil water conditions after inundation.
Soil mapping	Polygon map that includes all available information.
Comparison of change over the year	Assessment of previous and collected data sets, both at the site and spatially.
Reporting	All data, assessment, evaluation, monitoring discussion, conclusions on acid sulfate soil conditions, water impacts and predictions for the future.

2.1. Field Sampling of Soil

Field survey work was conducted between 19th and 21st December 2009. During this time 25 sites were visited and 80 soil layers described and sampled. The sites were located to correspond with the same sites sampled during the 2008 acid sulfate soil assessment survey (Fitzpatrick *et al.* 2009a, b) shown in Figure 1-1 and a subset of those sites were selected for sampling as part of this 2009 survey.

The water level had risen since the 2008 survey and all sites sampled were now below the water. Access to the area and sites was by boat and wading. Soil samples were retrieved using a Russian D-auger when the upper sediments were soft and when they were firm a shovel was used. The deeper subsoil layers were retrieved by Russian D-auger or a push tube. Generally 3 or 4 soil layers were sampled, and sample depth range intervals were identified by observing soil morphology change with depth.

Sample site location coordinates were obtained with a global positioning system (GPS), using the WGS 84 Datum: Zone 54 South, and the water depth and surrounding landscape described. Layer depth ranges were recorded and for each layer, the morphology and physical properties described according to standard methodology (e.g. Schoeneberger *et al.* 2002) included: colour (matrix and mottles), texture, structure, consistency, and occasional other identifiable features such as stickiness, plant material, odour and concentrations (NSCT 2009)

Multiple soil samples were taken from each layer and included:

- Soil samples were taken, mixed and placed in three 70 ml screw-top plastic jars, with care taken to exclude air by filling the jars to the maximum level to limit sulfur oxidation during transit and storage. One was used for pH testing and electrical conductivity, the second for chromium reducible sulfur (S_{CR}) suite of analyses for acid base accounting, and the third as a spare for any future analysis.
- Two sub-samples from the layers were placed in two separate chip-trays, one used to display morphologically representative aggregates for each of the sampled layers for later visual reference (e.g. during report writing and placed in the CSIRO Land and Water soil archive), and the second chip-tray was used for acid sulfate soil incubation (pH ageing) in the laboratory (Fitzpatrick *et al.* 2010b).

2.2. Field Sampling of Water

Soil water samples were collected at the same time as the field work for the soils was conducted. All sites were covered with water, the depth of which varied.

Measurements at the site included temperature ($T^{\circ}\text{C}$), specific electrical conductance (SEC or EC), dissolved oxygen (DO), pH, and redox potential (Eh) using a calibrated YSI multi-parameter meter and electrodes. Samples were collected for major and trace chemical analyses in 125 ml polyethylene bottles, 2 bottles for each site. Those for major and trace element analysis were filtered through 0.45 μm membrane filters and the aliquot for cations and trace elements were acidified to ca. 0.2 % v/v HCl to minimise adsorption onto container walls.

2.3. Field Sampling of Soil Pore Water

Soil pore water collection cells were installed on 21st December 2009 and retrieved on 22nd January 2010. The samplers were installed at 4 sites in the Currency Creek and Finniss River region (one each in the upper and lower reaches of both catchments).

The samplers consist of 36 cells and were installed to a fixed depth of 30 cm into the sediment, as shown in Figure 2-1. Location was marked with a floating buoy attached to a concrete block placed adjacent to the sampler.

On retrieval, the exterior of the cells' membrane was cleaned with a jet of deionised water from a spray bottle. A syringe was then used to pierce the membrane and extract the solution which was rapidly placed into pre-labelled vials and placed on ice to be transported to the laboratory for testing.



Figure 2-1. Soil pore water sampler (white plastic with 36 cells) carefully pushed into the sediment to a set depth.

2.4. Laboratory Analysis

A summary of the soil and water analysis conducted and the methods followed are listed in Table 2-2.

Table 2-2. Laboratory analysis conducted on soil and water samples and the method used.

Parameter	Units	Method or Method Code	Method Reference
Soil Analysis			
Soil pH in water (pH_w)	pH unit	pH meter; 1:1 soil:water	Rayment and Higginson 1992
Soil pH after peroxide treatment (pH_{Ox})	pH unit	pH meter; Method 4E1	Rayment and Higginson 1992
Soil $\text{pH}_{\text{incubation}}$	pH unit	See Appendix 4	Sullivan <i>et al</i> (2009) Fitzpatrick <i>et al.</i> (2010b)
Moisture content (of soil sample)	Weight%	80°C drying	Ahern <i>et al.</i> 2004
Chromium reducible sulfur	sulfide %S	Method 22B	Ahern <i>et al.</i> 2004
pH_{KCl}	pH unit	Method 23A	Ahern <i>et al.</i> 2004
Titratable actual acidity	mole H^+ /tonne	Method 23F	Ahern <i>et al.</i> 2004
Retained acidity	mole H^+ /tonne	Method 20J	Ahern <i>et al.</i> 2004
Acid neutralising capacity (where $\text{pH}_{\text{KCl}} > 6.5$)	% CaCO_3	Method 19A2	Ahern <i>et al.</i> 2004
Water extractable sulfate (1:5 soil:water extract)	mg SO_4^- /kg	Method 14F Conducted on surface soil sample	Rayment and Higginson 1992
Water Quality Analysis			
Major cations (Na, K, Ca, Mg) and Si	mg/L	APHA3120 ICPOES	APHA 21 st ed., USEPA SW846 – 6010
Dissolved bromide and chloride (Cl, Br)	mg/L Cl-, Br-	APHA 4500 Cl- APHA 4500 Br-	APHA 21 st ed.
Dissolved nitrate (NO_3^-)	mg/L NO_3^-	APHA 4500 NO_3^-	APHA 21 st ed.
Dissolved ammonia (NH_4^+)	mg/L NH_3	APHA 4500 NH3-H	APHA 21 st ed.
Dissolved phosphate (PO_4^{3-})	mg/L PO_4^{3-}	APHA 4500 P-E	APHA 21 st ed.
Dissolved sulfate (SO_4^{2-})	mg/L SO_4^{2-}	APHA 3120 ICPOES	APHA 21 st ed.
Trace metals or metalloids including Ag, Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Se, Zn			APHA 21 st ed.
Dissolved organic carbon			APHA 21 st ed.
Soil Pore Water Analysis			
Major cations (Na, K, Ca, Mg) and Si	mg/L	APHA 3120 ICPOES	APHA 21 st ed., USEPA SW846 – 6010
Trace metals or metalloids including Ag, Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Se, Zn			APHA 21 st ed.
pH	pH unit	Method 23A	Ahern <i>et al.</i> 2004

2.4.1. Soil analysis methods

There is debate as to the most realistic methodology to estimate if a soil will acidify, and the most effective methodology may vary according to the local environment and associated mineralogy of the soil. In this study, we have combined the three most generally accepted methodologies for acid sulfate soil testing:

- (i) pH testing after peroxide treatment,
- (ii) acid-base accounting, and
- (iii) incubation (ageing) testing using the chip-tray method developed by CSIRO (Fitzpatrick *et al.* 2010b).

These methodologies have different strengths and weaknesses and therefore all have been utilised in the current project. A summary of these methods is presented here.

The current practice in CSIRO Land and Water is to use all of the above techniques and, where possible, to monitor changes in the field during periods of drying to assess the most likely scenarios of acid generation and neutralisation.

pH testing after peroxide treatment

Hydrogen peroxide (H_2O_2) is a strong oxidising agent and is used to encourage the full oxidation of sulfide minerals (principally pyrite: FeS_2), hence the production of acidity. Since peroxide is a very strong oxidising agent, it can be argued that the resultant pH measured is a worst-case scenario, as in nature oxidation is rarely complete. In nature, the presence of carbonate minerals such as calcite ($CaCO_3$) may neutralise acid produced, however, in some cases the carbonate may not fully dissolve due to slow dissolution rates (reaction kinetics) or because of mineral or organic coatings. The dissolution rates of individual minerals may be controlled by a number of factors, hence additional tests based on measuring the carbonate content are recommended.

Acid-base accounting

Acid-base accounting is a technique which balances the potential acid generated (AGP) from sulfide-S (Cr-reducible S or S_{CR}) plus the total actual acidity (TAA) and Retained Acidity (RA) of the soil with the total amount of potential alkalinity (ANC) generated. The ANC is usually only routinely measured when soil pH is greater than 6.5. The net acid generating potential (NAGP) is the acid generating potential (AGP) minus ANC, which gives an indication of expected pH if both react fully.

Arguments against this technique include the fact that the form of carbonate may not be available to soil solutions (e.g. if it is coated and protected with organic material or iron oxides) or if it is in a form which is not particularly reactive (e.g. iron carbonates and dolomite ($CaMgCO_3$) have much slower reaction kinetics than calcite). However, the oxidation of pyrite to insoluble Fe oxides may also cause the pyrite not to react fully if it becomes coated with protective secondary minerals. Thus it may be difficult to assess acidification scenarios effectively.

Acid-base accounting is used to assess both the potential of a soil material to produce acidity from sulfide oxidation and also its ability to neutralise any acid formed. The standard acid based accounting applicable to acid sulfate soils is described in Ahern *et al.* (2004) and summarised here. The two equations below show the calculation of net acid (NA) and net acid generating potential (NAGP).

Net Acidity (NA) = Potential Sulfidic Acidity (AGP) + Existing Acidity (TAA) + Retained Acidity (RA) – measured Acid Neutralising Capacity (ANC) / Fineness Factor (FF)

and

Net Acid Generating Potential (NAGP) = Potential Sulfidic Acidity (AGP) – measured Acid Neutralising Capacity (ANC)

Incubation (ageing) testing

This method, which is often considered to represent a more realistic scenario for acid sulfate soil testing, is based on the “incubation” (or ageing) of soil samples. A number of specific techniques are employed, but all are based on keeping the sample moist for a specified period (usually a number of weeks; recent recommendations have increased the period from 8 to 19 weeks), which allows slow oxidation of sulfide minerals to occur. Although this may mimic nature more closely and does not force reactions to occur (as with the peroxide test) or rely on total ‘potential reaction’, it can be argued that the complex processes occurring in the field are not adequately reproduced during this laboratory ageing, e.g. complex processes including exchange with sub-surface waters (containing ANC) or biogeochemical reactions. These factors should also be taken into consideration wherever possible, although often require a thorough understanding of water movement (e.g. groundwater), and are often site and scenario specific.

2.4.2. Water analysis methods

The water samples were immediately transferred to a refrigerator and kept cool at 4°C until analysed. Major cations and sulfur were analysed on an ARL 3580B Inductively Coupled Plasma Optical Emission Spectrometer (ICP OES). For trace multi-element analysis, water samples are analysed by Inductively Coupled Plasma Mass Spectrometry (ICPMS) [APHA method 3125] on an Agilent 7500ce (Agilent Technologies, Tokyo, Japan). Nitrogen species, Cl and PO₄ were analysed by colorimetric analysis using a segmented flow analyser, Br, F and SO₄ by ion chromatography and NPOC by a TOC Analyser. Alkalinity was determined by titration to a fixed endpoint according to APHA method 2320. Acidity was determined by titration with a standardised alkali to an end-point pH of 8.3 (APHA method 2310).

Moisture content was analysed by gravimetric procedure based on weight loss over a 12-24 h drying period at 110±5°C. Paste pH was determined on a saturated paste by a pH electrode, Electrical conductivity of saturated soil paste was determined using a saturated paste (Rayment and Higginson 1992).

2.4.3. Soil pore water analysis

Soil pore water analysis methods were as used for surface water (Table 2-2).

3. SOIL RESULTS AND ASSESSMENT

This section presents the soil assessment data from the field survey conducted in December 2009 and then compares the results with data from the same site and sample layer obtained in November 2008.

Field survey work was conducted between 19th and 21st December 2009, with some data obtained from preliminary field work at Wally's Landing in November 2009. During this time 25 sites were visited (24 sites sampled for laboratory analysis) and 80 soil layers described and sampled. Laboratory analysis for pH testing and acid-base accounting were conducted during December through to February 2010.

3.1. Site Location

The location of soil sample sites is presented in Figure 3-1, and shows that the sites provide a good distribution throughout the survey area.

The site identification numbers and locations are listed for each of the areas in Table 3-1. A detailed listing of the site information along with the descriptive profile data is provided in Appendix 2. The site identification number corresponds with the site number from the November 2008 survey and is prefixed with M2 to indicate it is the second monitoring event. For this sampling event a unique site label is allocated which identifies the site and the start sample number sequence for that site. The table shows the number of samples collected for each site and the water depth. Note that water and soil pore water samples were collected at selected sites to provide a distribution throughout the study area.

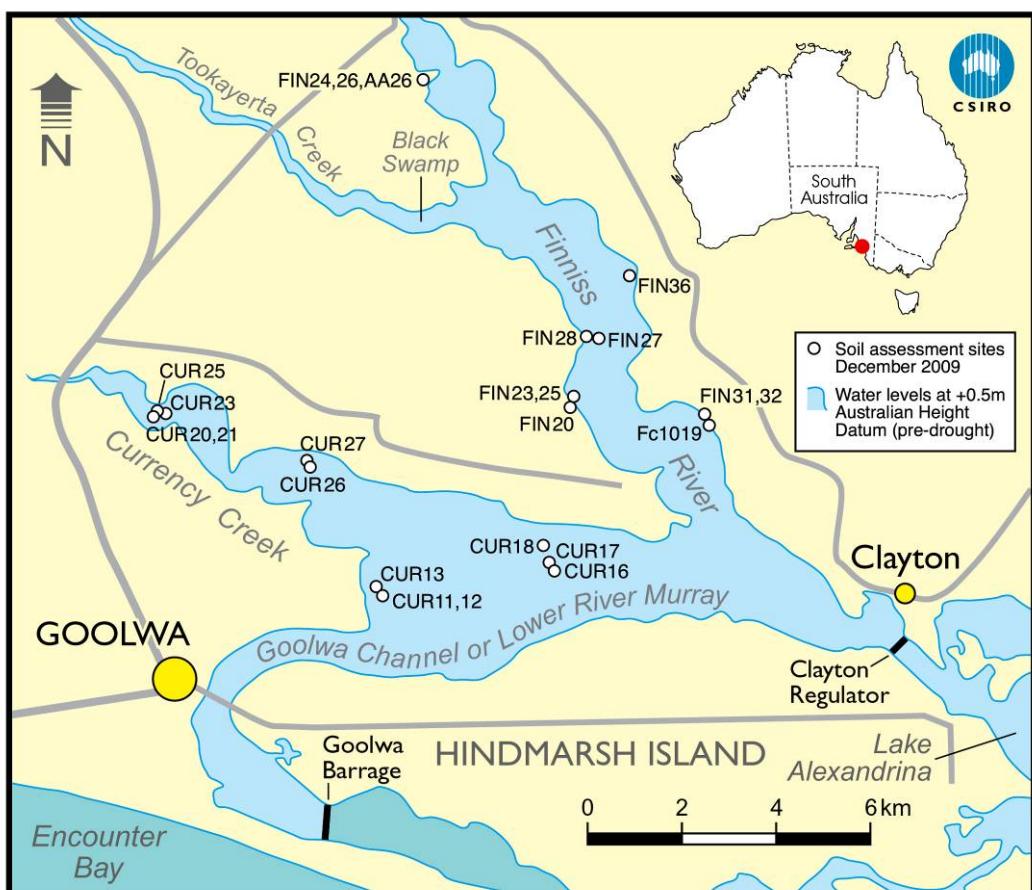


Figure 3-1. Map showing the location of the soil sample sites.

Table 3-1. Site identification number, locality, depth to water table, and number of samples collected.

Site ID	Site Label	Easting (m) Zone 54H	Northing (m) Zone 54H	Soil samples collected	Water samples collected	Soil pore water samples collected	Water Depth (cm)
FIN28-M2	Fc 1001	305967	6075101	3	1	1	120
FIN27-M2	Fc 1004	306199	6075065	3			100
FIN36-M2	Fc 1007	306744	6076221	2	1		100
FIN20-M2	Fc 1009	305780	6073929	4	1		60
FIN23-M2	Fc 1013	305749	6074048	3			80
FIN25-M2	Fc 1016	305810	6074052	3	1		90
Fc 1019	Fc 1019	308084	6073635	crystals			-30
FIN32-M2	Fc 1020	308052	6073690	3			20
FIN31-M2	Fc 1023	308025	6073670	2	1		100
CUR17-M2	Fc 1025	305340	6071128	4	1		70
CUR18-M2	Fc 1029	305203	6071480	4		1	50
CUR16-M2	Fc 1033	305386	6070903	3			100
CUR12-M2	Fc 1037	302328	6070504	3	1		60
CUR11-M2	Fc 1040	302368	6070522	3			50
CUR13-M2	Fc 1043	302274	6070677	4			?
CUR27-M2	Fc 1048	301055	6072892	5	1		80
CUR26-M2	Fc 1053	301102	6072838	3			150
CUR24-M2	Fc 1056	298561	6073753		1		160
CUR23-M2	Fc 1057	298538	6073745	5			95
CUR25-M2	Fc 1062	298426	6073792	4		1	70
CUR21-M2	Fc 1066	298360	6073708	4			50
CUR20-M2	Fc 1070	298354	6073692	3	1		130
Fc 1073	Fc 1073	296819	6074191		1		150
Fc 1074	Fc 1074	303199	6079683			1	130
FIN24M4-5	LFa01-A	303196	6079705	3			110
FIN26M3-4	LFa01-B	303215	6079640	3			80
AA26	LFa01-C	?	?	5			135
FIN26M4-2	LFa01-D	303087	6079610	1			60
Total Count				80	11	4	

3.2. Soil Morphology

A detailed listing of the site information along with the descriptive profile data is provided in Appendix 2. Soil colour, mottles, texture, structure and consistency are valuable field indicators for soil identification and appraisal. Types and Sub-types of Acid Sulfate Soils (Appendix 1) can determine potential impacts on acid sulfate soil formation during desiccation or inundation, and likely products of oxidation based on acid generating and acid neutralising characteristics. Sandy or quartz-rich soils are often more at risk of acidification because they have little capacity to neutralise acidity, whereas clay-rich soils have ability to neutralise acidity through dissolution of clay minerals but have a greater potential to produce higher amounts of retained or stored acidity. Individual soil profiles often show variations in layer textures, contributing to complexity of interpreting likely acid sulfate soil behaviour and hazards at each site.

All soils sampled were below surface water due to the September 2009 water level rises caused by the construction of the Clayton regulator and pumping of water into the Finniess River – Currency Creek and Goolwa Channel catchment area. Most soils that were continuously inundated by water (subaqueous soils) or remained saturated were structureless and soft, but where the surface and upper subsoil layers had previously dried by the lowering water levels, deep desiccation cracks had developed and often persisted

even after reflooding (FIN 20, 23, 25, 27, 28). The soil textures were commonly clayey, and in some areas individual soil profiles show variations in texture between layers (see Appendix 2). The clayey soils tended to be very soft at depths below 40cm and had probably never experienced desiccation below this depth. The soil matrix colour was mainly dark greys, pale grey, olive-greys and bluish greys. The colours are indicative of the reduction-oxidation state of the soil, and the predominance of darker colours particularly in the subsoils indicated reducing or anaerobic conditions.

3.3. Soil Laboratory Data

A summary of all the soil laboratory results for pH testing and acid base accounting chemistry is presented in Table 3-2 and a complete list of all results is presented in Appendix 3.

Table 3-2. Laboratory data summary for pH testing and sulfate chemistry for all samples.

Parameter	Description	Units	Minimum	Median	Maximum	No. of Samples
EC	Electrical conductivity	mS/cm (dS/m)	0.50	2.13	5.98	80
pH _w	pH in water		2.73	5.37	8.37	80
pH _{FOX}	pH after peroxide treatment		1.04	1.79	7.03	80
pH _{incubation}	pH after ageing 9 weeks		1.80	2.85	7.90	80
pH _{KCl}	pH in KCl		3.25	5.34	9.25	80
TAA	Total actual acidity	mole H ⁺ / tonne	0.00	15.48	217.00	80
RA	Retained acidity	mole H ⁺ / tonne	0.00	0.00	180.00	80
ANC	Acid neutralising capacity as %CaCO ₃	mole H ⁺ / tonne	0.00	0.00	2243.75	80
S _{CR}	Chromium reducible sulfur	mole H ⁺ / tonne	0.00	115.39	1103.97	80
NA	Net acidity	mole H ⁺ / tonne	-1271.30	150.85	1117.64	80

Plotted distributions of results are presented in Figure 3-2 for pH testing and in Figure 3-3 for net acidity and chromium reducible sulfur. This tabled summary is for all 80 samples collected in the region. Of more interest are the values on a layer by layer basis in a soil profile and where that profile occurs in the landscape. This is discussed in later sections. However, this general summary in Table 3-2 along with the cumulative distribution figures indicates that the soil samples:

- are generally acidic, with 75% of samples having a pH in soil water less than 7, and about 21% with a pH <4,
- are likely to oxidise to highly acidic levels, with about 79% of samples having a pH peroxide below the critical value of 2.5,
- for pH incubation data, have 68% of samples are below the critical pH value of 4,
- generally contain actual acidity, as shown by the high total actual acidity median and maximum values,
- have retained acidity in 24 of the samples (30% of total samples),

- have acid neutralising capacity in 18 of the samples (22% of total samples), with some samples having very high values as indicated by the maximum value measured,
- mostly have potential acidity, as shown by the high median and maximum values for chromium reducible sulfur, with 77 of the samples having a value greater than 0 (96% of total samples), and
- mostly had acidity with 70 of the samples having a positive net acidity (88% of total samples), and only 10 samples had sufficient neutralising capacity to be net negative. As indicated by the high median and maximum values, samples generally contained net acidity that was high.

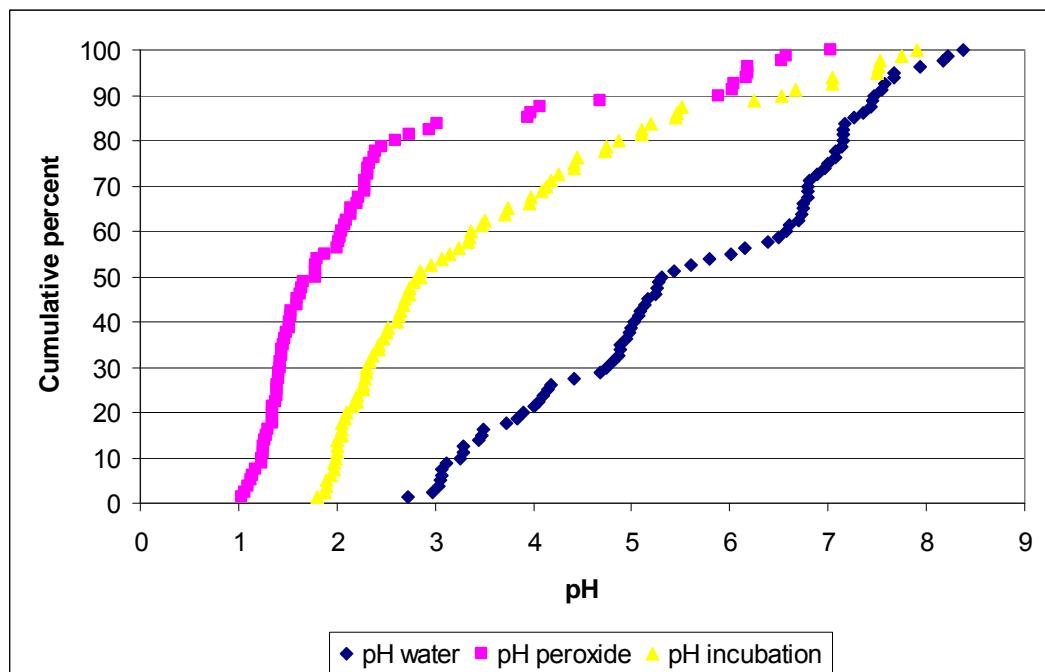


Figure 3-2. pH data results plotted as a cumulative percentage.

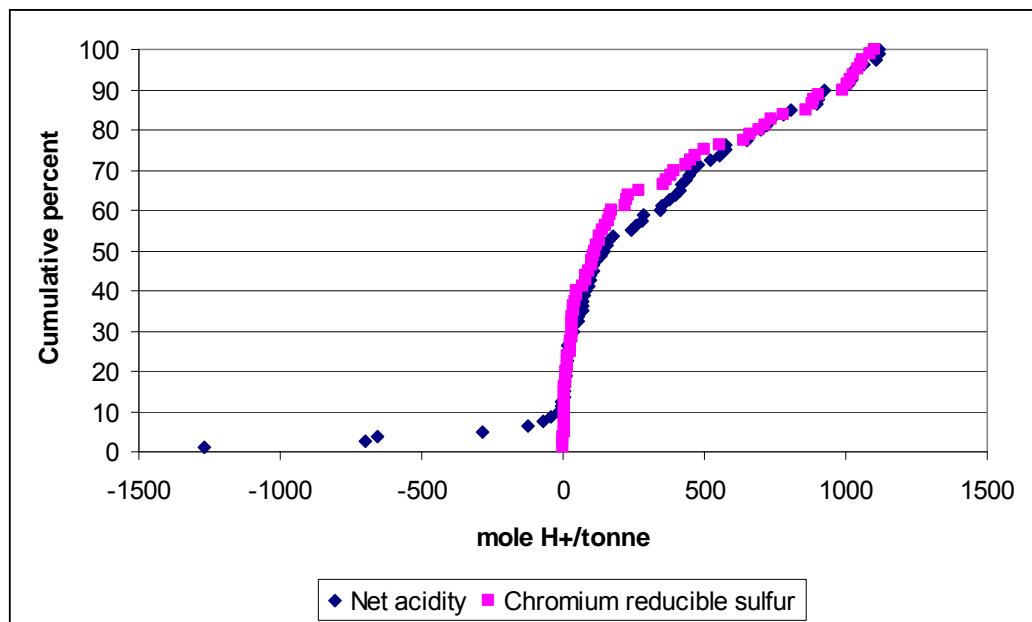


Figure 3-3. All net acidity and chromium reducible sulfur results plotted as a cumulative percentage.

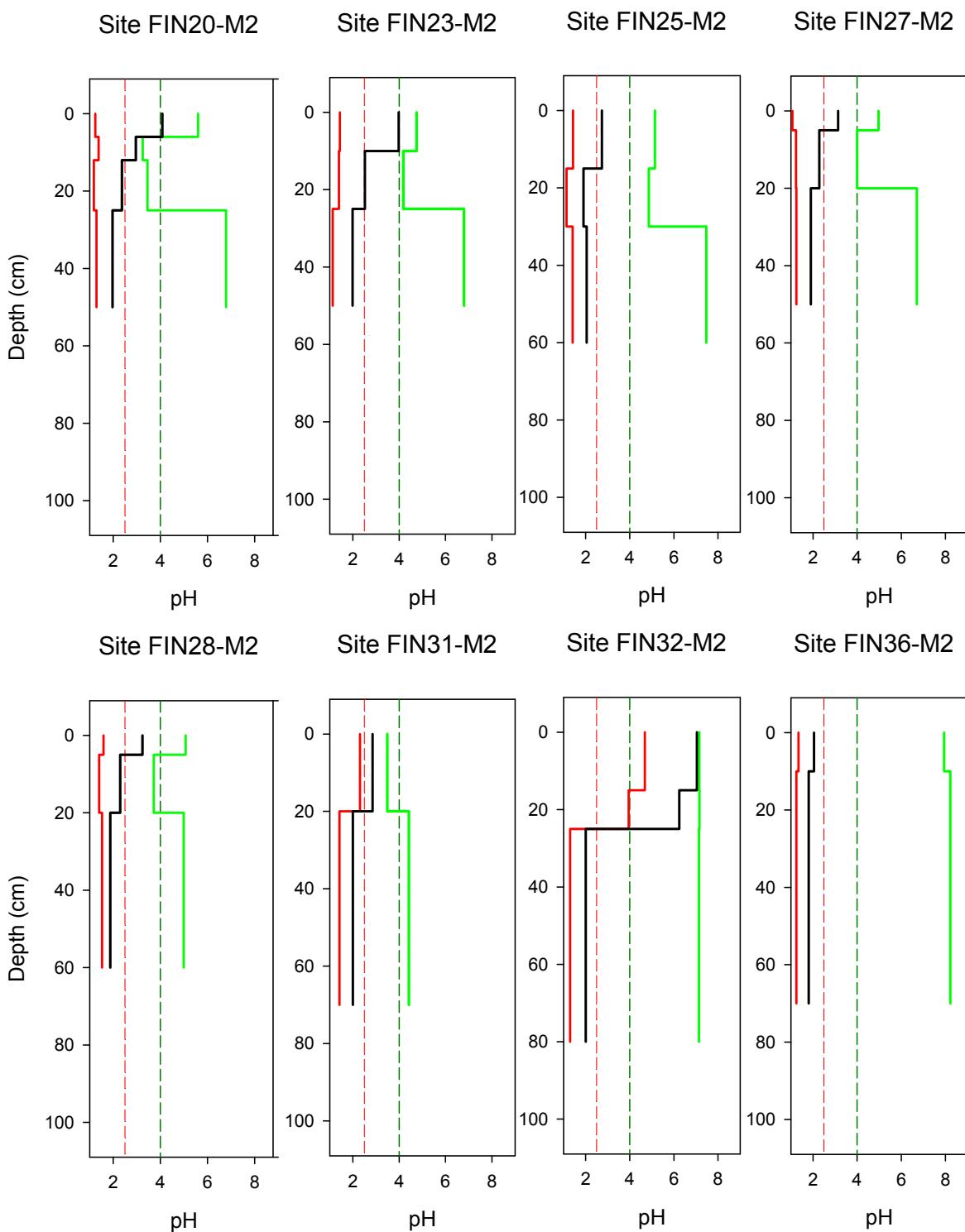
3.4. Soil pH testing results (pH_w , pH_{ox} , $\text{pH}_{\text{incubation}}$)

The pH results are listed in Appendix 3. These values are presented below as pH depth plots and the sites have been grouped according to the sampling areas Finniss River in Figure 3-4, Currency Creek in Figure 3-5, and Wally's Landing in Figure 3-6.

The pH_w values ranged from 2.73 (FIN26M4 5-15 cm) to 8.37 (CUR16 30-60 cm). Seventeen of the 80 samples (21%) from 12 soil profiles had a pH_w below the critical value of 4.0, which characterised them as sulfuric material. Most samples were in the second layer below the soil surface with an upper depth of between 2 and 5cm, not the surface layer, and for some profiles (CUR17, CUR18, CUR27, FIN20) these low values extended into the subsoil layers. The surface layers did not show low values ($\text{pH} < 4$) as was observed in their dry state in November 2008, this was probably due to the immediate interface with the surface water which has acid neutralising capacity.

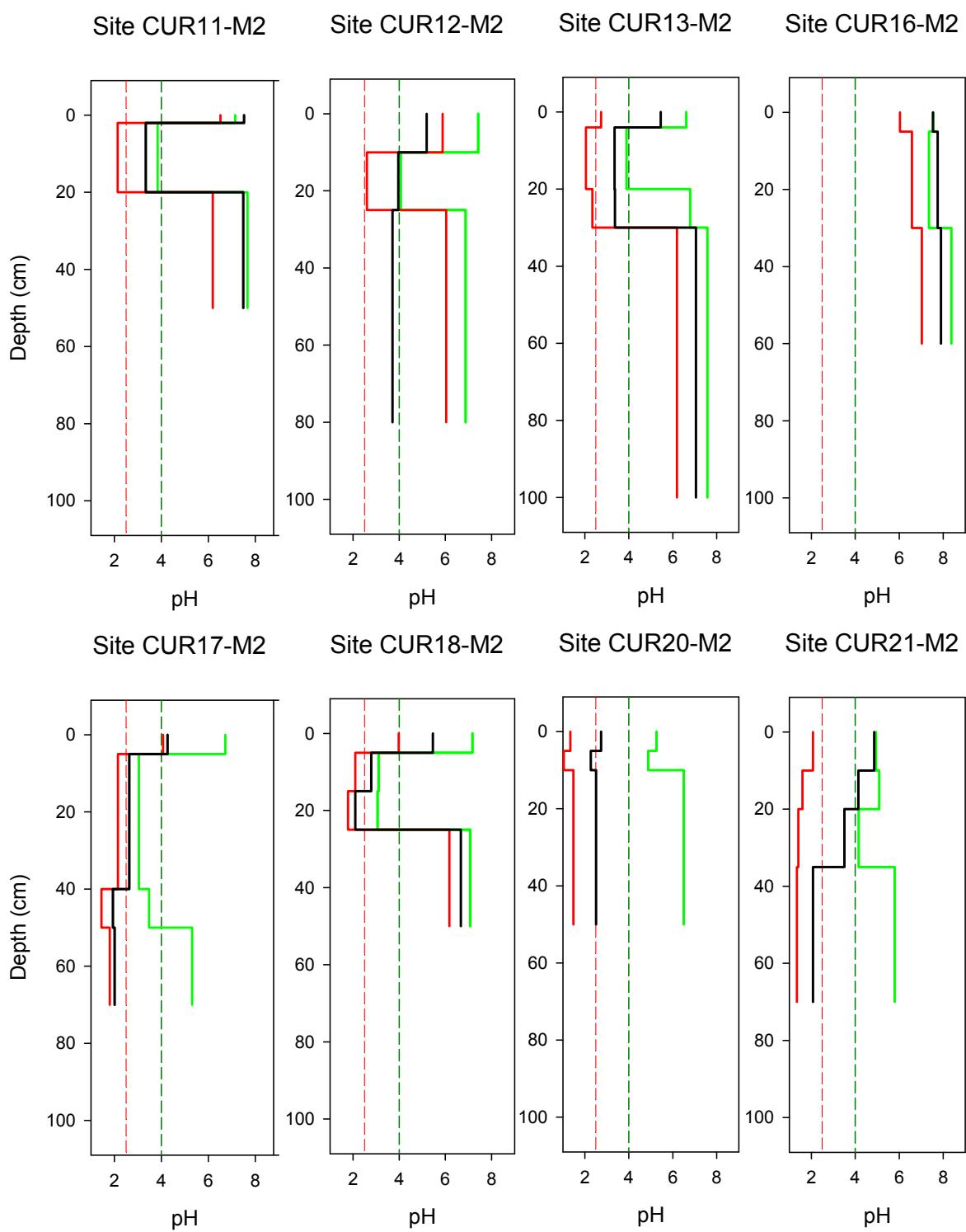
Following treatment with peroxide the soil pH dropped significantly and pH_{ox} values ranged from 1.04 (CUR20 5-10 cm) to 7.03 (CUR16 30-60 cm). Sixty-three of the 80 samples (79%) from 21 soil profiles were below the critical pH_{ox} value of 2.5. This indicates that most of the soil layers have the potential to acidify to less than 4 on exposure to air (oxygen) under moist conditions.

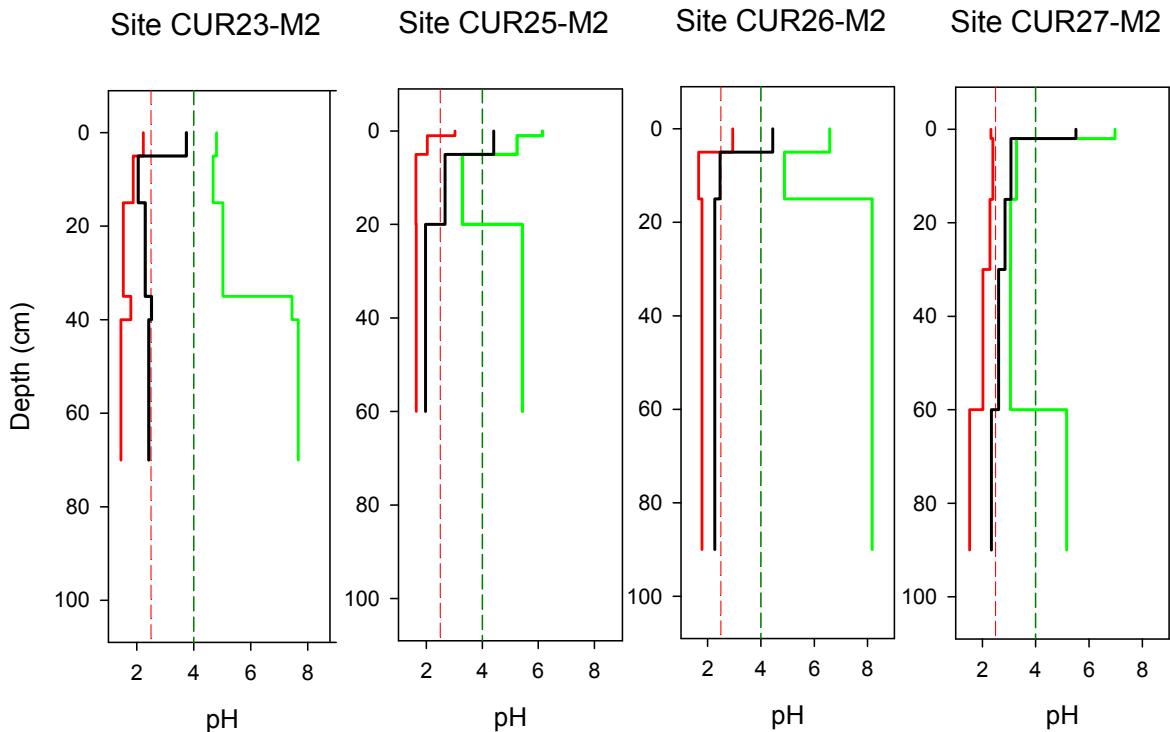
Chip tray soil samples were aged and measured for pH after nine weeks of incubation. The $\text{pH}_{\text{incubation}}$ values ranged from 1.02 (FC1019 surface scrape) to 8.40 (CUR16 60-65 cm). Fifty-six of the 80 samples (70%) from 23 soil profiles, dropped to $\text{pH}_{\text{incubation}}$ below 4.0. Samples occurred throughout the soil profiles.



Showing soil pH (pH_W as green line), peroxide treated pH (pH_{OX} as red line) and ageing pH ($pH_{incubation}$ after 9 weeks as black line). Critical pH_W and $pH_{incubation}$ value of 4 (black dashed line) and critical pH_{OX} value of 2.5 (red dashed line).

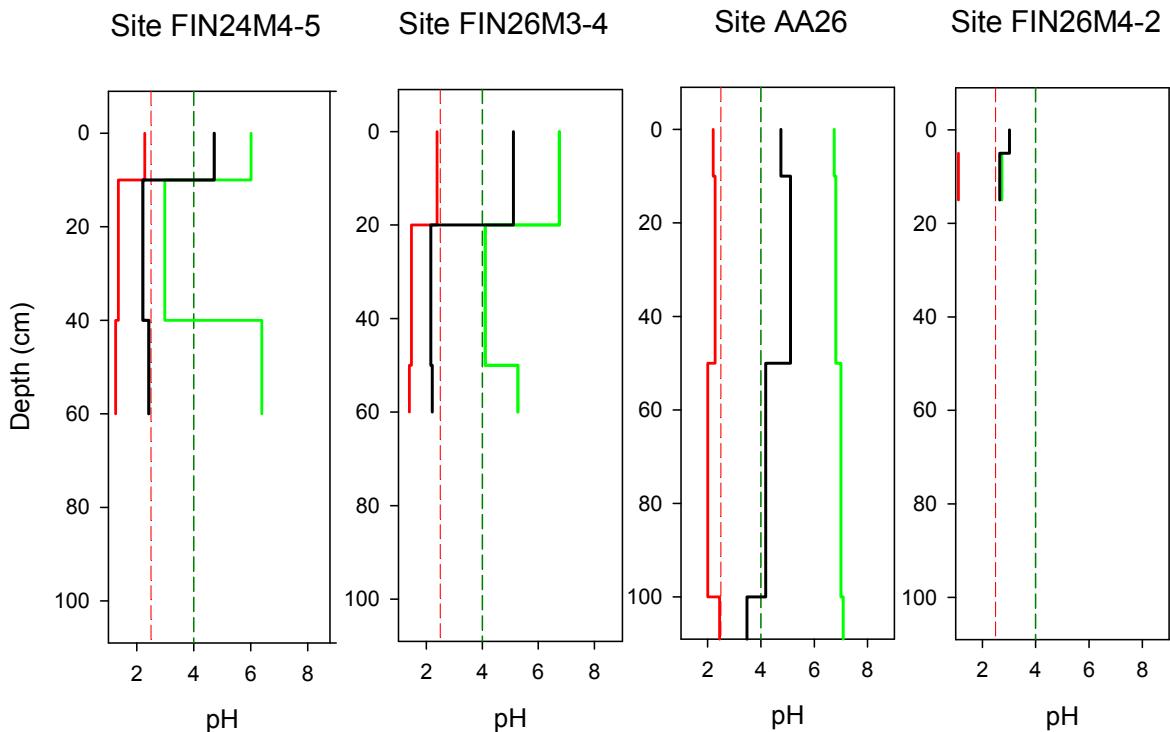
Figure 3-4. Finniss River pH depth profiles.





Showing soil pH (pH_W as green line), peroxide treated pH (pH_{OX} as red line) and ageing pH ($\text{pH}_{\text{incubation}}$ after 9 weeks as black line). Critical pH_W and $\text{pH}_{\text{incubation}}$ value of 4 (black dashed line) and critical pH_{OX} value of 2.5 (red dashed line).

Figure 3-5. Currency Creek pH depth profiles.



Showing soil pH (pH_W as green line), peroxide treated pH (pH_{OX} as red line) and ageing pH ($\text{pH}_{\text{incubation}}$ after 9 weeks as black line). Critical pH_W and $\text{pH}_{\text{incubation}}$ value of 4 (black dashed line) and critical pH_{OX} value of 2.5 (red dashed line).

Figure 3-6. Wally's Landing pH depth profiles.

3.5. Acid Base Accounting Results

The acid base accounting results are listed in Appendix 3. These values are presented below as net acidity and component depth plots, the sites have been grouped according to the sampling areas - Finniss River in Figure 3-7, Currency Creek in Figure 3-8, and Wally's Landing in Figure 3-9.

The net acidity values ranged from -1271 (CUR11 20-50cm) to 1117 (FIN27 20-50cm) moles H⁺/tonne. Seventy of the 80 samples (88%) had a positive net acidity. Ten samples had a negative net acidity indicating where there was excess acid neutralising capacity. All of these samples occurred in the Currency Creek area and at different depth ranges that included surface and deep subsoil layers.

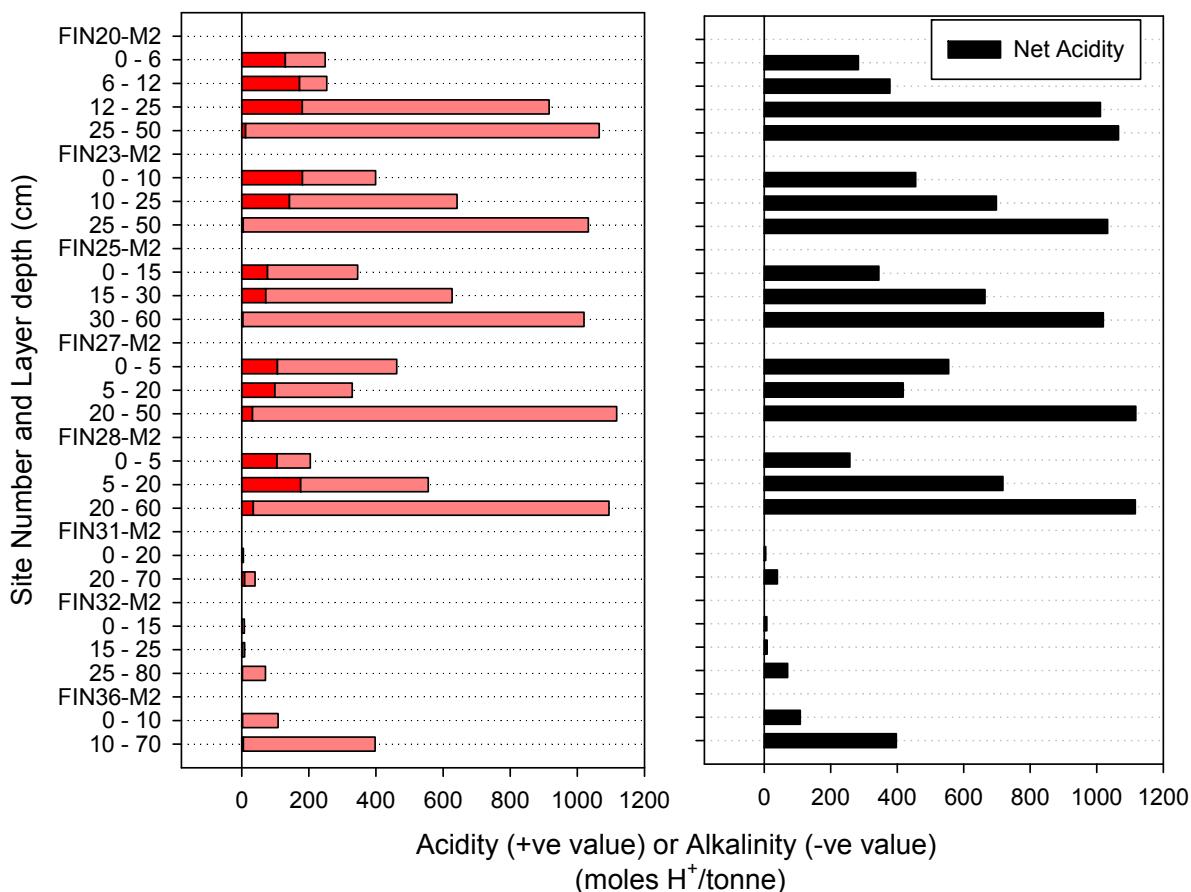


Figure 3-7. Finniss River depth profiles of Net Acidity (NA) shown on the right. The left side shows the components TAA (red bar), AGP as SCR (pink bar).

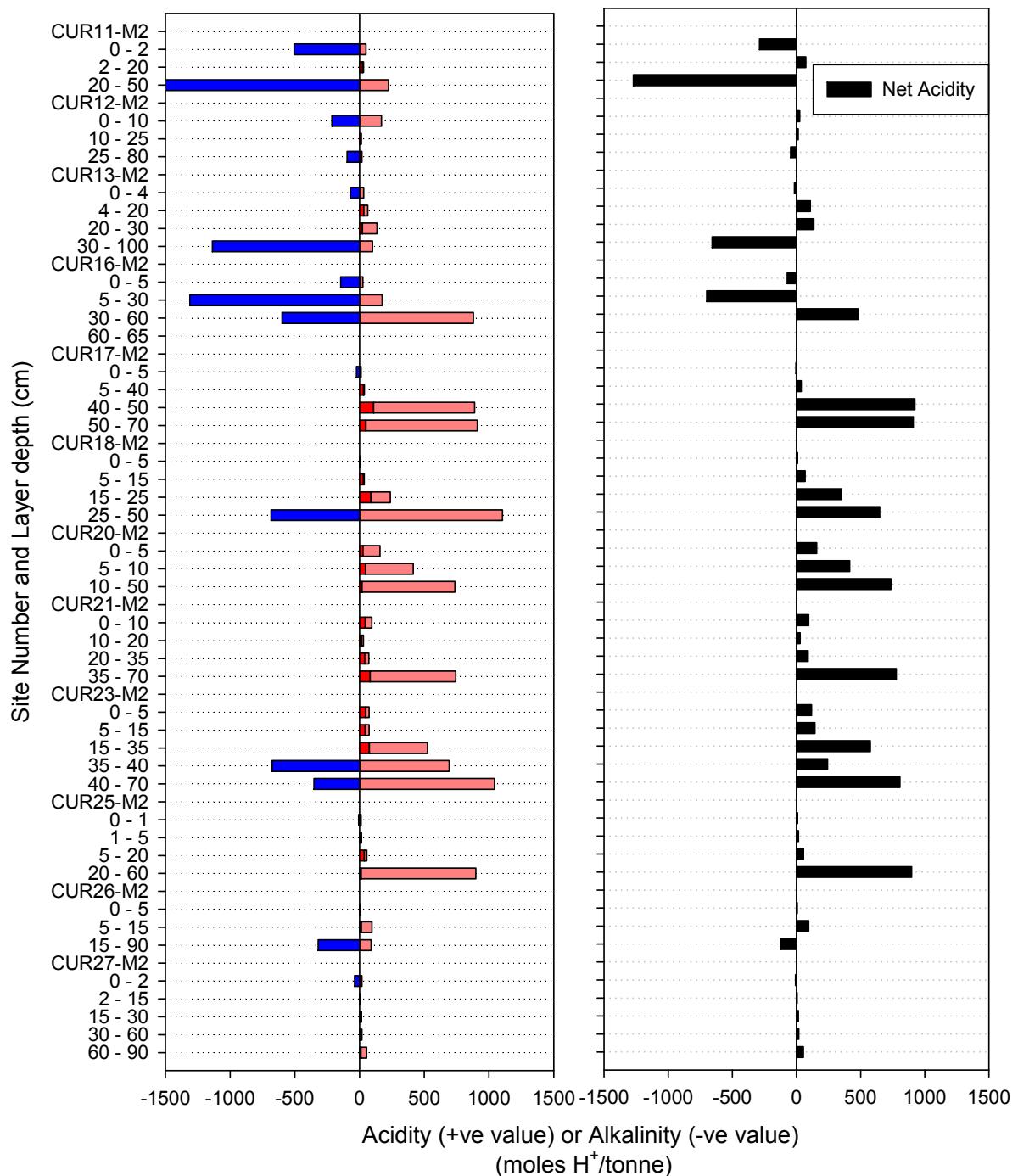


Figure 3-8. Currency Creek depth profiles for Net Acidity (NA) shown on the right. The left side shows the components TAA (red bar), AGP as S_{CR} (pink bar), and ANC (blue bar).

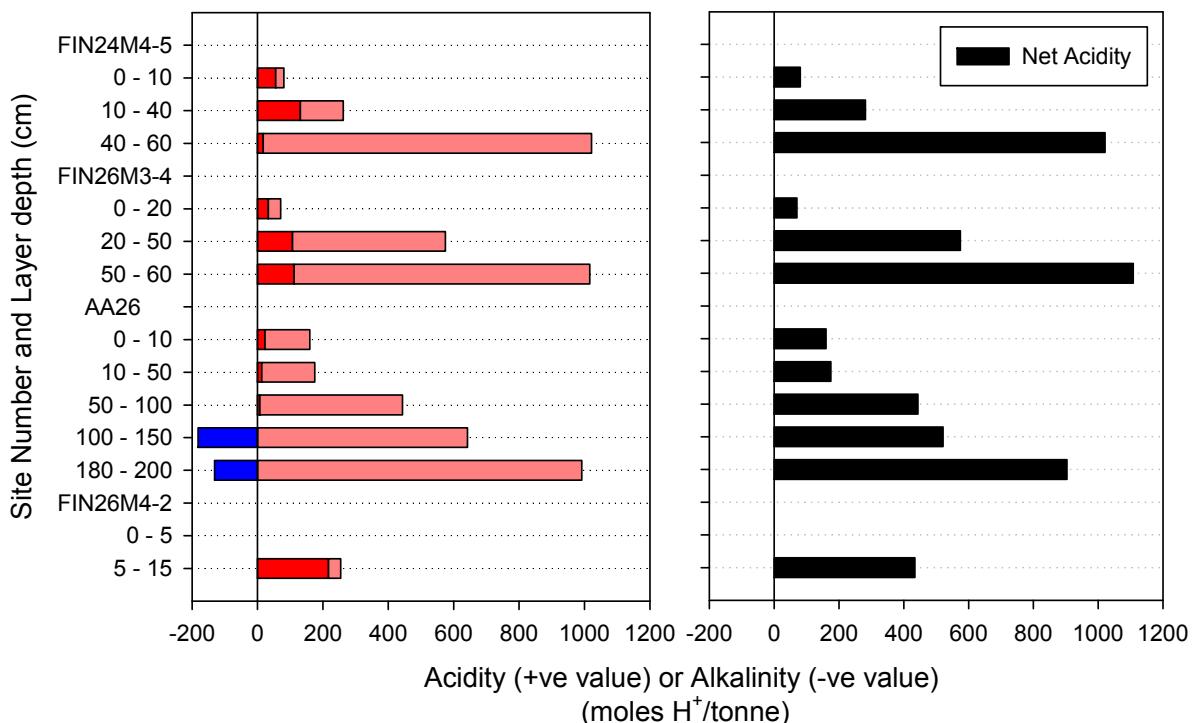


Figure 3-9. Wally's Landing depth profiles for Net Acidity (NA) shown on the right. The left side shows the components TAA (red bar), AGP as S_{CR} (pink bar), and ANC (blue bar).

3.6. Acid Sulfate Soil Material Assessment

3.6.1. Classification of Soil Layers

The acid sulfate soil material class for each layer is listed in Appendix 3. The assessment identified the samples were classified and distributed as follows:

- 16 sulfuric soil material layers (20%) occurred in 11 soil profiles (44% of total profiles)
- 37 hypersulfidic soil material layers (46%) occurred in at least one layer of 22 soil profiles (88% of total profiles)
- 21 hyposulfidic soil material layers (26%)
- 6 other soil material layers (8%)

The sulfuric soil material layers tended to occur at the second layer below the surface with an upper depth of about 5 cm. They were distributed throughout the study area. Hypersulfidic soil materials were distributed throughout the study area occurring in at least one layer of 22 soil profiles and at different depths throughout the soil profiles.

3.6.2. Characterisation of Sites According to the Acid Sulfate Soil Identification Key

Soil materials for each layer were allocated to an acid sulfate soil material class, as described in the previous section. To determine the Acid Sulfate Soil Identification Subtype the sequence of soil layers, texture, surface and water conditions are considered as outlined in the Australian Acid Sulfate Soil Identification Key presented in Appendix 1. All of the sites sampled were below surface water and are identified as subaqueous, and then allocated to the appropriate subtype as presented in Table 3-3.

The table separates the sites into regions for the study area but there was no obvious pattern to the site classifications at this broad scale with each region having a mix of sulfuric and hypersulfidic subaqueous soils.

Table 3-3. Acid sulfate soil characterisation and classification for each site.

Site Number	Label Number	Identification Key Subtype
Currency Creek sites		
CUR11-M2	FC1040	sulfuric subaqueous soil
CUR12-M2	FC1037	hypersulfidic subaqueous clayey soil
CUR13-M2	FC1043	sulfuric subaqueous soil
CUR20-M2	FC1070	hypersulfidic subaqueous clayey soil
CUR21-M2	FC1066	hypersulfidic subaqueous clayey soil
CUR23-M2	FC1057	hypersulfidic subaqueous clayey soil
CUR24-M2	FC1056	hypersulfidic subaqueous clayey soil
CUR25-M2	FC1062	sulfuric subaqueous soil
CUR26-M2	FC1053	hypersulfidic subaqueous clayey soil
CUR27-M2	FC1048	sulfuric subaqueous soil
Goolwa Channel sites		
CUR16-M2	FC1033	subaqueous soil
CUR17-M2	FC1025	sulfuric subaqueous soil
CUR18-M2	FC1029	sulfuric subaqueous soil
Finniss River sites		
FIN20-M2	FC1009	sulfuric subaqueous soil
FIN23-M2	FC1013	hypersulfidic subaqueous clayey soil
FIN25-M2	FC1016	hypersulfidic subaqueous clayey soil
FIN27-M2	FC1004	hypersulfidic subaqueous clayey soil
FIN28-M2	FC1001	sulfuric subaqueous soil
FIN31-M2	FC1023	sulfuric subaqueous soil
FIN32-M2	FC1020	hypersulfidic subaqueous clayey soil
FIN36-M2	FC1007	sulfidic subaqueous soil
Wally's Landing sites		
AA26	LFa01-C1	hypersulfidic subaqueous clayey soil
FIN24M4-5	LFa01-A1	sulfuric subaqueous soil
FIN26M3-4	LFa01-B1	hypersulfidic subaqueous clayey soil
FIN26M4-2	LFa01-D1	sulfuric subaqueous soil

3.7. Comparison of results between the 2008 and 2009 surveys

The sites assessed for this December/November 2009 field survey correspond with sites visited during the November 2008 survey (Fitzpatrick *et al.* 2009a,b), and therefore allows a comparison of results between the two sampling events. These comparisons are described in the following three subsections, firstly as a broad overview of sample counts against key criteria, secondly as a change in soil classification, and thirdly as a direct comparison of laboratory results with like for like soil layer data.

3.7.1. Count of results by measured parameter

To provide a general overview of changes in acid sulfate soil properties for the soils in the region as a whole, a count of sample results that met critical criteria values were compared as a percentage of total samples for each of the soil properties from the November 2008 and December/November 2009 surveys, and presented in Table 3-4.

The results indicate that samples with $\text{pH}_W < 4$ has decreased, and is probably due to the previously dry acidic surface soils being inundated and being neutralised by the water. Generally the acid base accounting properties have decreased except for the sum net acidity values that have shown an increase in the number of samples with a positive result. The key data set comparison that characterises the soils into acid sulfate soil material types shows that sulfuric layers have decreased and the hypersulfidic soil layers have decreased by a small margin.

While Table 3-4 provides a general summary of change over time for the region data set as a whole, of more interest is the comparison of the soil properties for the same soil layer for the two survey periods. This is discussed in the following sections.

Table 3-4. Comparison of data from November 2008 and December 2009 surveys, showing count of result meeting soil property criteria.

Parameter	November 2008			December 2009			Assessment
	Total count	Matching criteria count	Percent of total	Total count	Matching criteria count	Percent of total	
Criteria							Comparison of percentage change
$\text{pH}_W < 4$	119	40	34	80	16	20	decrease
$\text{pH}_{\text{ox}} < 2.5$	119	83	70	80	63	80	increase
$\text{pH}_{\text{incubation}} < 4$	119	77	65	80			
$\text{pH}_{\text{KCl}} < 6.5$	119	75	63	80	62	78	decrease
TAA > 0	119	75	63	80	62	78	decrease
ANC > 0	119	43	36	80	18	22	decrease
RA > 0	119	34*	29	80	24	30	no change
$S_{\text{CR}} > 0$	119	119	100	80	77	96	decrease
NA > 0	119	90**	76	80	70***	88	increase
Sites with a sulfuric layer	33	18	55	25	11	44	decrease
Remaining sites (not sulfuric) with a hypersulfidic layer	15	15	100	14	13	93	decrease

Note:

* - indicates that the count is based on number of samples that should have had retained acidity measured. Retained acidity was not measured on the November 2008 samples.

** - indicates that net acidity data calculated did not include a value for retained acidity, all samples were assumed to be 0.

*** - net acidity for the December 2009 samples did include a value for retained acidity. To allow a better comparison a recalculation was conducted with retained acidity equal to 0, as was done for the November 2008 samples. It was found that the same number of samples returned a NA > 0 which was 70, the difference was that some values had a higher positive value.

3.7.2. Site characterisation

The site classification for the two sampling events in November 2008 and December 2009 surveys is presented in Table 3-5, where data is sorted according to regions and then classified in accordance with 2009 subtype (Appendix 1). The main difference between the two sampling events is that all December/November 2009 sampling sites are classified as

"subaqueous", due to the water level rising and inundating the study area. Consequently, all sites sampled were covered with surface water, whereas in 2008 the sites were mostly all above the water level as shown in ASS maps (Figure 1-3 and Fitzpatrick *et al.*, 2009a; 2010a) of the study area.

Soils that were identified as sulfuric soils or sulfuric cracking clay soils in 2008 are in 2009 identified as sulfuric subaqueous soils (Table 3-5). However, a few of the sulfuric soils transformed to hypersulfidic subaqueous clayey soils indicating the sulfuric horizon has been somewhat neutralised. The various hypersulfidic soil subtypes identified in 2008 are now classified as hypersulfidic subaqueous clayey soils (Table 3-5).

Table 3-5. Site classification for November 2008 and December/*November 2009 surveys, sorted by region and then classified according 2009 subtype (Appendix 1).

Site Number	Label Number	Identification Key Subtype November 2008 sampling (From: Fitzpatrick <i>et al.</i> 2009a,b)	Identification Key Subtype December 2009 sampling (From: this survey / report)
Currency Creek sites			
CUR20-M2	FC1070	hypersulfidic subaqueous clayey soil with MBO	hypersulfidic subaqueous clayey soil
CUR26-M2	FC1053	hypersulfidic subaqueous clayey soil with MBO	hypersulfidic subaqueous clayey soil
CUR23-M2	FC1057	sulfuric cracking clay soil	hypersulfidic subaqueous clayey soil
CUR24-M2	FC1056	sulfuric cracking clay soil	hypersulfidic subaqueous clayey soil
CUR12-M2	FC1037	sulfuric soil	hypersulfidic subaqueous clayey soil
CUR21-M2	FC1066	sulfuric soil	hypersulfidic subaqueous clayey soil
CUR11-M2	FC1040	hypersulfidic subaqueous clayey soil	sulfuric subaqueous soil
CUR13-M2	FC1043	sulfuric cracking clay soil	sulfuric subaqueous soil
CUR25-M2	FC1062	sulfuric soil	sulfuric subaqueous soil
CUR27-M2	FC1048	sulfuric soil	sulfuric subaqueous soil
Goolwa Channel sites			
CUR16-M2	FC1033	subaqueous soil	subaqueous soil
CUR17-M2	FC1025	sulfuric soil	sulfuric subaqueous soil
CUR18-M2	FC1029	sulfuric soil	sulfuric subaqueous soil
Finniss River sites			
FIN25-M2	FC1016	hypersulfidic cracking clay soil	hypersulfidic subaqueous clayey soil
FIN27-M2	FC1004	hypersulfidic cracking clay soil	hypersulfidic subaqueous clayey soil
FIN32-M2	FC1020	hypersulfidic soil	hypersulfidic subaqueous clayey soil
FIN23-M2	FC1013	sulfuric cracking clay soil	hypersulfidic subaqueous clayey soil # <i>sulfuric</i> subaqueous clayey soil
FIN36-M2	FC1007	sulfidic subaqueous soil	sulfidic subaqueous soil
FIN20-M2	FC1009	sulfuric cracking clay soil	sulfuric subaqueous soil
FIN28-M2	FC1001	sulfuric cracking clay soil	sulfuric subaqueous soil
FIN31-M2	FC1023	sulfuric soil	sulfuric subaqueous soil
Wallys Landing sites*			
AA26	LFa01-C1	hypersulfidic subaqueous clayey soil	hypersulfidic subaqueous clayey soil
FIN26M3-4	LFa01-B1	sulfuric cracking clay soil	hypersulfidic subaqueous clayey soil
FIN24M4-5	LFa01-A1	sulfuric cracking clay soil	sulfuric subaqueous soil
FIN26M4-2	LFa01-D1	sulfuric cracking clay soil	sulfuric subaqueous soil

#Where: *sulfuric* listed in italicics font recorded a pH < 4 at time zero incubation but > 4 when measured in 1:1 water (Appendix 3).

*Wally's Landing sites were sampled in November 2009

3.7.3. Laboratory results – pH and acid base accounting parameters

Key laboratory data parameters were compared between the 2008 and 2009 sampling events. Sample layer depths between the two sampling events were not identical but were very similar, sample layers from the same site locations were plotted pairwise for each of the parameters. These are presented for pH testing (pH_w , pH_{ox} , $\text{pH}_{\text{incubation}}$) in Figure 3-10, and for acid base accounting (total actual acidity, chromium reducible sulfur, and net acidity) in Figure 3-11.

Initial observations of the plots showed no significant patterns. The pH_w plot shows a number of samples that had low pH values in 2008 are now near neutral in 2009. These probably correspond with the sulfuric surface soils that have been neutralised by the surface water. The majority of the pH_{ox} data has similar values for both sampling events. $\text{pH}_{\text{incubation}}$

shows values which are generally similar. The total actual acidity plot indicates that the values tend to be higher for the 2009 data set compared with the 2008. The chromium reducible sulfur data are similar at the lower end ($<0.7\%S_{CR}$) and then are widely scattered at higher values. Net acidity values are similar at the lower end (between 0 and 400 mole H^+/t) and widely scattered at values above and below that.

No obvious patterns or trends can be seen in the data set when plotted as a whole and could be due to soil variability. Further exploratory data analysis would be recommended to identify if stratifying the data according to position of the soil layer in the profile or general location identifies trends.

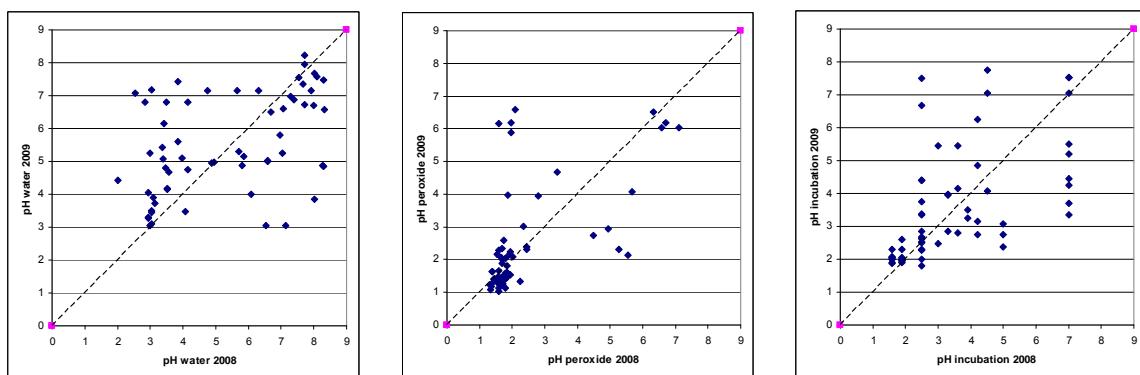


Figure 3-10. pH data comparison between 2008 and 2009 survey data for pH_W , pH_{Ox} , and $pH_{incubation}$ (dashed line shows 1:1).

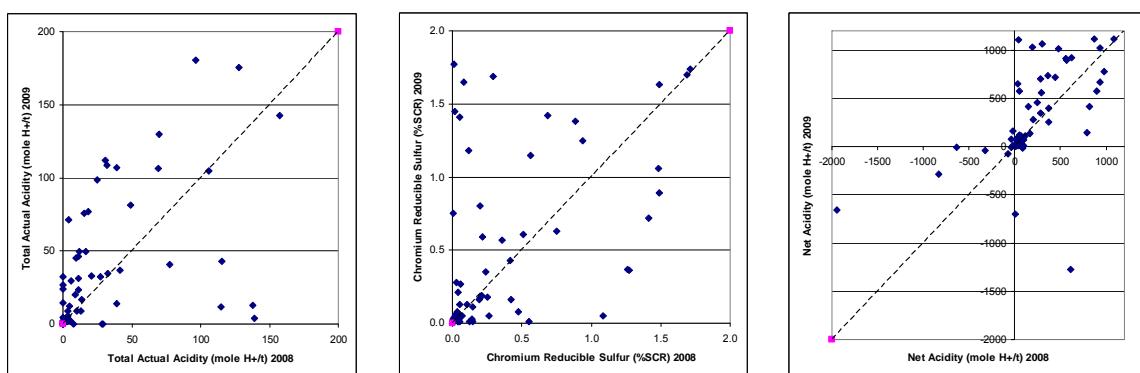


Figure 3-11. Acid base accounting parameter comparison between 2008 and 2009 laboratory data for total actual acidity, chromium reducible sulfur and net acidity (dashed line shows 1:1).

4. SURFACE WATER RESULTS AND ASSESSMENT

A total of 11 surface waters were sampled across the study area at the same time as soil sampling (Figure 4-1). Five samples were collected from Finniss River and 5 from Currency Creek, with one sample from the Goolwa Channel close to the mouth of Currency Creek. A complete listing of all data is presented in Appendix 3.

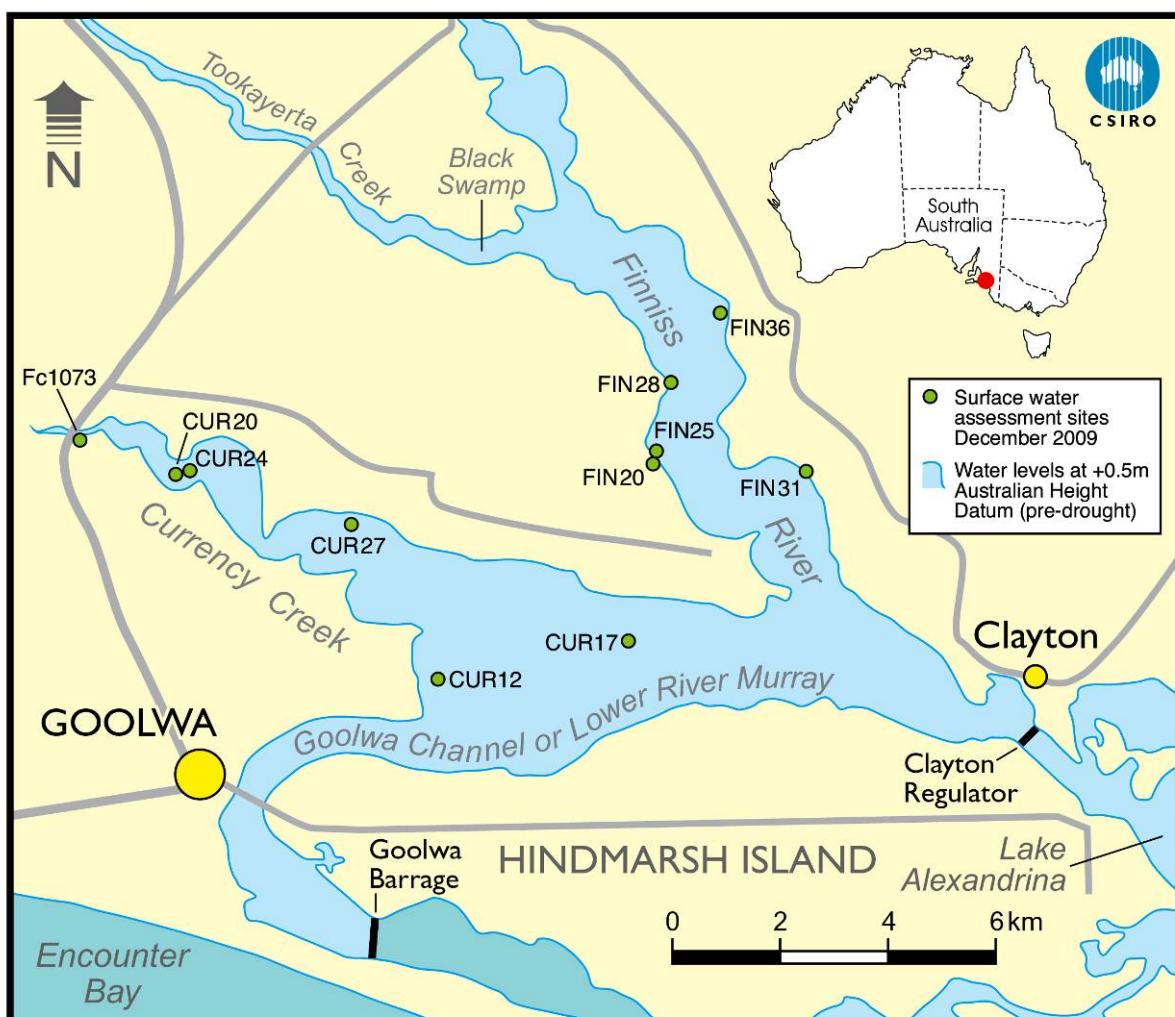


Figure 4-1. Location map showing position of surface water sampling sites.

The salinity of the surface waters varied significantly, from 7150 to 10200 $\mu\text{S cm}^{-1}$ (Table 4-1). The highest salinities were mainly in Currency Creek, although sample FC 1073 in the upper reaches of Currency Creek was relatively fresh. The pH of the waters varied from 6.32 to 8.65, but was typically neutral to slightly alkaline.

At site FIN 20, deep cracks in the re-flooded soils were noted during sampling. A distinct orange-brown colouration of the water indicated the presence of abundant Fe-rich suspended sediments, most likely the ferric oxyhydroxysulfate mineral schwertmannite (Figure 4-2). Measurement of field parameters showed that the water in the cracks (CRACK in Table 4-1) had a much higher SEC ($27000 \mu\text{S cm}^{-1}$) and lower pH (5.23) than the overlying water ($5890 \mu\text{S cm}^{-1}$ and 6.32 respectively). Dissolved oxygen was present in all surface waters, but was low at site FC1009.

Table 4-1. Field parameters measured on surface waters from Finniss River and Currency Creek.

Site ID	Site Label	Collection Date	Temp. (°C)	SEC ($\mu\text{S cm}^{-1}$)	D.O. (mg l^{-1})	pH	Turbidity (NTU)
FIN28-M2	FC1001	19/12/09	19.3	5140	8.58	6.79	73.6
FIN36-M2	FC1007	19/12/09	19.8	5530	10.4	7.85	25
FIN20-M2	FC1009	19/12/09	19.4	5890	2.1	6.32	93
FIN20-M2	CRACK	19/12/09	19.0	27000	3.3	5.23	
FIN25-M2	FC1016	19/12/09	20.3	5620	9.55	7.3	26
FIN31-M2	FC1023	19/12/09	21.5	7150	11.5	8.1	16
CUR17-M2	FC1025	19/12/09	22.1	9220	12.6	8.42	11
CUR12-M2	FC1037	19/12/09	24.8	9530	10.3	8.61	7
CUR27-M2	FC1048	20/12/09	20.0	10200	9.15	8.65	6.5
CUR24-M2	FC1056	20/12/09	20.6	9660	9.74	8.08	12.5
CUR20-M2	FC1070	20/12/09	21.0	9380	9.37	7.29	15
adhoc	FC1073	20/12/09	22.9	6070	7.61	7.57	14



Figure 4-2. Surface water at site FC1009 / FIN20 (see Figure 4-1) showing an “orange” reddish-brown colouration of water most likely due to a mixture of iron rich mineral precipitates (e.g. oxyhydroxysulfate mineral, schwertmannite and ferrihydrite), aluminosilicate clays and possibly orange coloured algae.

The waters were dominated by Na and Cl and of Na-Cl type, displaying a close grouping and plotting close to seawater composition on a Piper plot (Figure 4-3). Sample FC1073 at the upper reaches of Currency Creek sits outside of the main group. Most waters are also displaced toward higher relative proportions of Ca and SO₄ than seawater. The concentrations of most major elements followed the SEC differences between Finniss and Currency Creek (Figure 4-4). Alkalinites were very variable, varying from 35 to 274 mg l⁻¹ as HCO₃, the highest being in the upper reaches of Currency Creek. Nutrient concentrations (N and P) were typically below detection limit, the exception being at site FC1009 in Finniss River, where NH₄ concentrations were high (0.48 mg l⁻¹ NH₄-N). Total N at all sites indicated the dominant form of N is present as organic N (Total N varied from 1.23 to 3.21 mg l⁻¹). Dissolved organic carbon was relatively high in all samples with concentrations close to 20 mg l⁻¹.

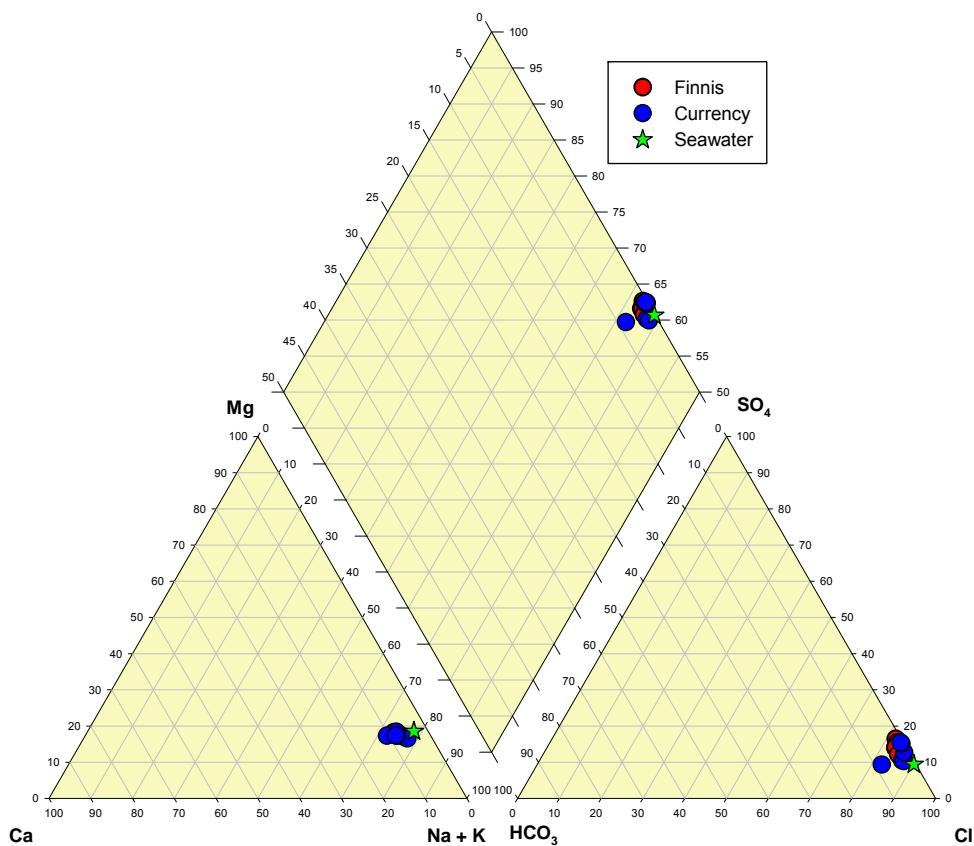


Figure 4-3. Piper plot showing the relative proportions of major solutes in the surface waters of Finniss River and Currency Creek.

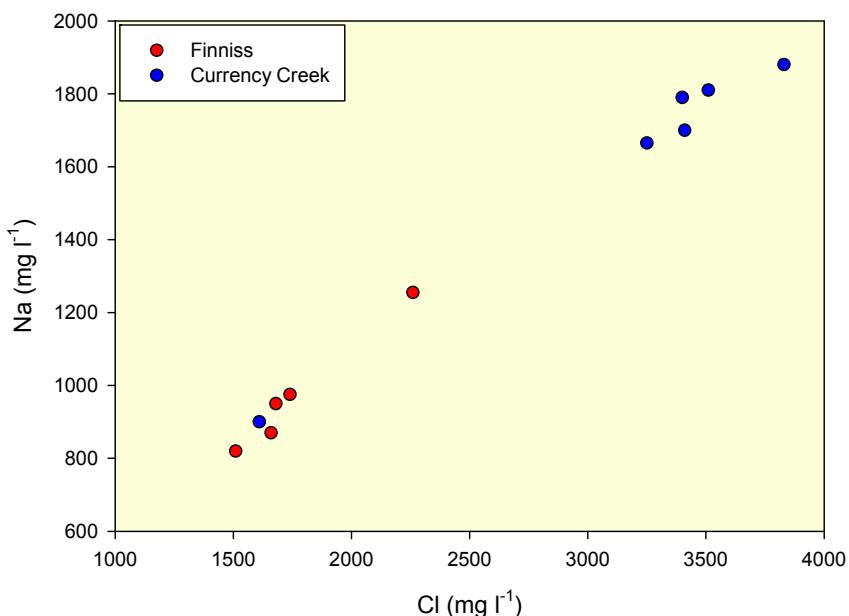


Figure 4-4. Plot of Na vs. Cl for surface waters showing typically higher concentrations in Currency Creek.

Ratio plots are shown on Figure 4-5 for selected major element/chloride ratios, used to assess potential enrichments due to soil-water interactions following re-flooding. For Na/Cl, Mg/Cl and K/Cl, the Finniss samples and upper Currency Creek sample plot close to seawater, with slightly lower ratios in Currency Creek. In contrast, SO₄/Cl ratios are variable and typically high, indicating an additional source to that expected from seawater or rainfall (which generally reflects seawater ratios for most major elements). Comparisons should be made with ongoing monitoring data across the Lower Lakes and input waters during initial re-flooding of this area following construction of the Clayton regulator. The most likely source is the abundant and widespread occurrences of oxyhydroxysulfate minerals noted during previous studies as surface efflorescences or within the soil profiles (Fitzpatrick *et al.* 208b,d). This would suggest transport of acidity, since most oxyhydroxysulfate minerals generate acidity upon dissolution. This appears to be substantiated by a good negative correlation between alkalinity and SO₄/Cl ratio (Figure 4-6).

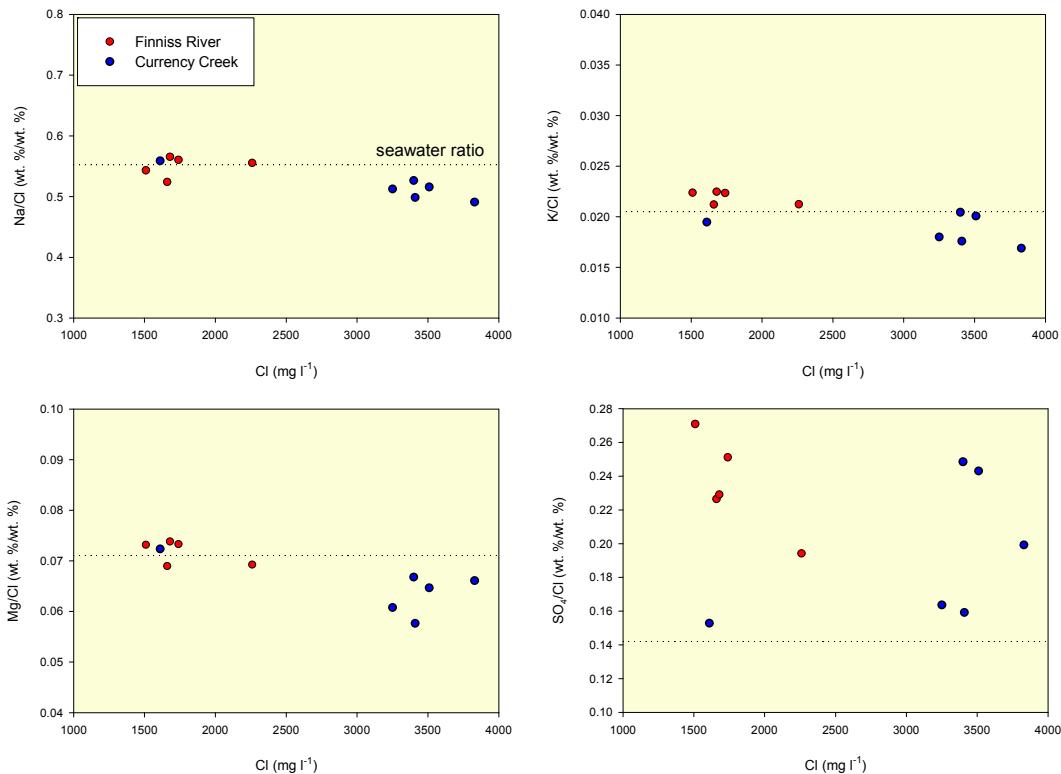


Figure 4-5. Ratio plots for major element/chloride ratios plotted against Cl as an indicator of salinity.

Iron concentrations were high (1.5 mg l^{-1}) at site FC1009, where orange-brown coloured water was noted, and also at site FC1001 (0.71 mg l^{-1}) in the Finniss north of FC1009 (Figure 4-1). Manganese was high at these sites and also at the upper site in Currency Creek (FC1073). It is likely that the Fe is present as colloidal particulate matter, although these sites also had lower pH than the other waters sampled. The concentrations of most metals were low, as expected for the pH range of the surface waters. Of those present, Zn was typically present at the highest concentration (18 to $108 \mu\text{g l}^{-1}$), and Ni, Co and Sn were present at a few $\mu\text{g l}^{-1}$.

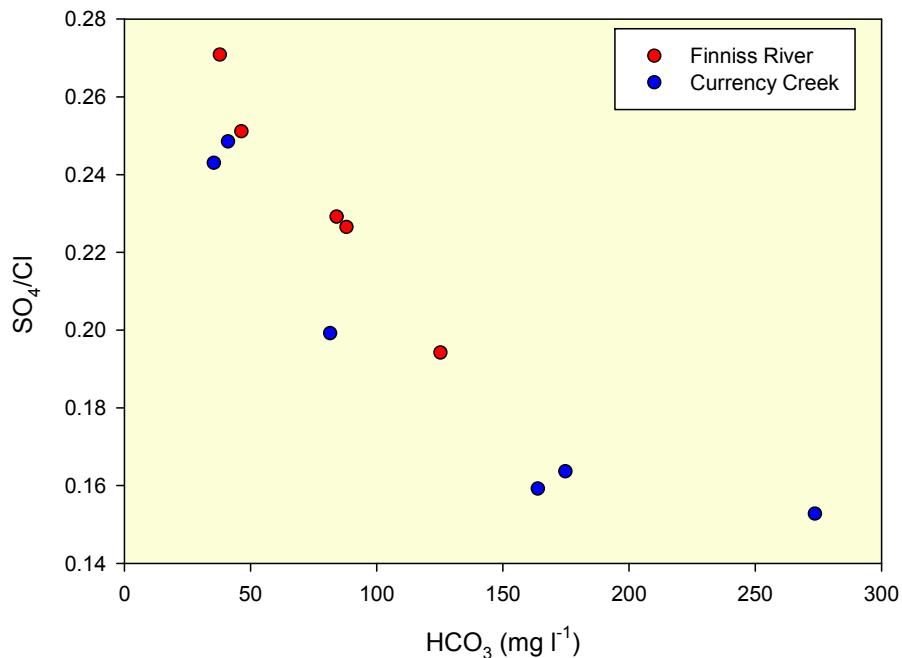


Figure 4-6. Negative correlation between SO_4/Cl ratio (i.e. excess SO_4 from soil-water interaction) and alkalinity. The dissolution of hydroxysulfate minerals, which generate acidity can thus explain the variations in alkalinity across the area.

5. SOIL PORE WATER RESULTS

As part of the investigation on the extent of ASS materials in the lower reaches of Finniss River, Currency Creek, and Goolwa Channel regions, the chemistry of the soil pore water at four sites (two in the Finniss River, and two in Currency Creek) was analysed using *in situ* equilibrium dialysis samplers (see Figure 5-3).

In situ equilibrium dialysis samplers, commonly known as peepers can be used to gather high resolution depth profiles of the pore water chemistry in saturated soils (Hesslein 1976; van Oploo *et al.* 2008a, Johnston *et al.* 2009). These high resolution depth profiles were used to help assess what, if any, effects the recent rewetting and/or flushing by winter rainfall at these locations has had on the soil pore water.

Little or no published information exists on *in situ* processes and rates of geochemical reactions in subaqueous sulfuric soils when anoxic conditions are restored. However, the following relevant published information is available on: (i) tidal salt marsh and mangrove environments (e.g. Portnoy and Giblin 1997; Johnston *et al.* 2009) and (ii) mesocosm rewetting events on acid sulfate soils in the Lower Lakes (Hicks *et al.* 2009). The latter mesocosm experiments are the first published *in situ* and high resolution attempt to assess the changes to sediment and pore water chemistry following the climate induced rewetting of inland ASS soils with sulfuric materials. This knowledge will help develop and address the need for appropriate monitoring strategies for the protection of water and soil quality.

5.1. Methods

Peepers used in this study consist of a thicker centre section and two thin cover plates with matching sampling chamber windows (Figure 5-1). Both are constructed of poly methyl methacrylate (Perspex). The peeper samples over a 35cm length, typically split into 3 - 4cm in the overlying water and the remaining 31 – 32 cm in the sediment. The peeper's 35cm sampling region is divided into 36 discrete horizontal sampling chambers giving the peeper a vertical sampling resolution of 1 cm.

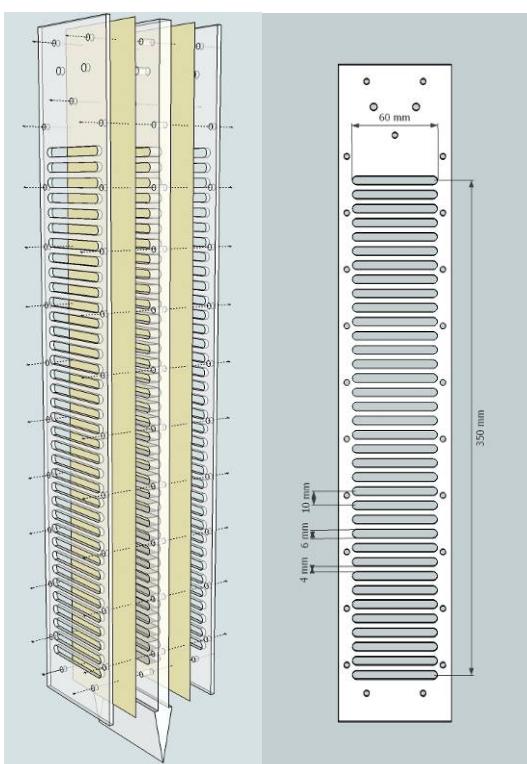


Figure 5-1. 3D to-scale diagram of peepers used in this study. The polysulfone membrane is coloured yellow in diagram for clarity (usual colour is white).

Each sampling chamber (dimensions 6 cm x 0.6 cm x 0.9 cm) has an approximate sample volume of 3.2 ml, which is typically adequate for required analyses to be made. As a way of retaining an appropriate sample volume without increasing time required for equilibration the sample chambers are exposed on both sides. This results in a peeper with a low design factor (F , cm) (Eq. 1) (Treasdale *et al.* 1995). The effective chamber window area of these peepers is 7.2 cm^2 (3.6 cm^2 with 2-sided equilibration design) and given a sample volume of 3.2ml results in a low design factor of 0.44 cm ($F\text{ (cm)} = V\text{ (cm}^3\text{)} / A\text{ (cm}^2\text{)}$) for these peepers.

The peepers were soaked in dilute nitric acid (10% v/v) for 48 hours then thoroughly rinsed with deionised water before assembly. To assemble the peepers, inert polysulfone membranes (pore size $\approx 0.45\text{ }\mu\text{m}$) were placed over the sampling chambers on one side of the centre section and fixed in place by a thin cover plate and nylon screws. Each sampling chamber was then filled with deoxygenated high purity water ensuring all air bubbles were excluded before fixing the second cover in place with nylon screws. This can be done by simply over filling each chamber using a squirt bottle and sliding the polysulfone membrane over the sampling chambers. When the cover plate is fixed in place with the nylon screws excess water is expelled.

Once all peepers were assembled they were submerged in water in a sealable polyvinyl chloride (PVC) cylinder capable of maintaining the deoxygenated status during transport to the field. The water in the PVC transport cylinder was deoxygenated by bubbling nitrogen through it for 72 hours prior to deployment. At the last moment the flow rate of the nitrogen was increased before sealing the transport vessel ready for deployment.

Peepers were deployed using a specialised apparatus (Figure 5-2) and in a manner that minimised sediment disturbance. The specialised apparatus assists with installation in water that is too deep for deployment by hand but not deep enough to warrant a diver. It also ensures that the peeper is installed with a known number of cells in the overlying water when visual observation is not possible.



Figure 5-2. Photo showing lower end of specialised peeper installation apparatus with peeper ready to be deployed.

Four site locations were selected for peeper deployment (Figure 5-3). See section 3 for site descriptions. Two peepers were deployed at each site in order to increase sample volume, in particular for acidity and alkalinity titrations. Peepers were placed approximately 10 cm from one another which was a sufficient enough distance to avoid interference (Harper *et al.* 1999).

The peepers were deployed for 33 days, from 21st of December 2009 to 22 January 2010. Locations were marked with a floating buoy attached to a concrete block placed adjacent to the sampler. Peeper equilibration times can be influenced by sediment characteristics (Harper *et al.* 1997) and peeper design (van Oploo *et al.* 2008b), however, typical equilibration times for Hesslein style peepers, similar to those used in this study, (Hesslein 1976) are around 14 days (Teasdale *et al.* 1995). Due to limited availability of a suitable boat and captain the equilibration time used in this study was longer than required. The 33 day equilibration time had no detrimental effects to the polysulfone membrane such as membrane breakdown.

When removed from the sediment, the peeper was brought onto the boat where any adhering sediment was gently washed off using a jet of deionised water from a washer bottle. Sample was then extracted from the chambers and transferred to 10 ml screw top vials using a micropipette with acid washed 5 ml tips and transferred to a chilled (\approx 1-2 °C) ice box. Extraction was made easier by orientating the peeper lengthways and at a slight angle and piercing the lower edge of the membrane. The above process was completed within 10 minutes and repeated for the second peeper. Extracted sample from the second peeper was combined with the sample from the corresponding chamber of the first peeper from the same site, effectively taking an average of both peepers. The relative distance of each chamber from the soil water interface was known to be equal for both peepers due to the use of the specialised deployment apparatus allowing us to combine the sample with confidence.

Samples were transported back to the laboratory and stored at 4°C overnight before commencing analysis the next day. Firstly, a subsample was removed for immediate analysis of pH, EC and acidity or alkalinity. The remaining sample was preserved with HCl and stored at 4°C until analysed for major and minor cations by ICP-OES and ICP-MS (Table 2-2).

5.2. Results and Discussion.

Four sites in the Currency Creek and Finniss River region (one each in the upper and lower reaches of both catchments) were selected for pore water analysis (Figure 5-3). Sediment morphology descriptions captured during the soil survey taking place concurrently to this study assisted in the selection of these sites. These four sites were chosen because:

- (i) they were known to contain sulfuric material based on morphology information (chemistry data was unavailable at the time of site selection),
- (ii) they were distributed spatially over the study area covering both the upper and lower reaches of the lower catchment area of both Currency Creek and Finniss River,
- (iii) the period of time since the sites were either rewetted or ‘flushed’ by winter rainfall was known, and
- (iv) the sites were easily accessible by boat and reasonably secure from interference.

Detailed descriptions and photographs of each site can be found in Appendix 2.

All results are tabled in Appendix 5 and summarised in the following tables and figures.

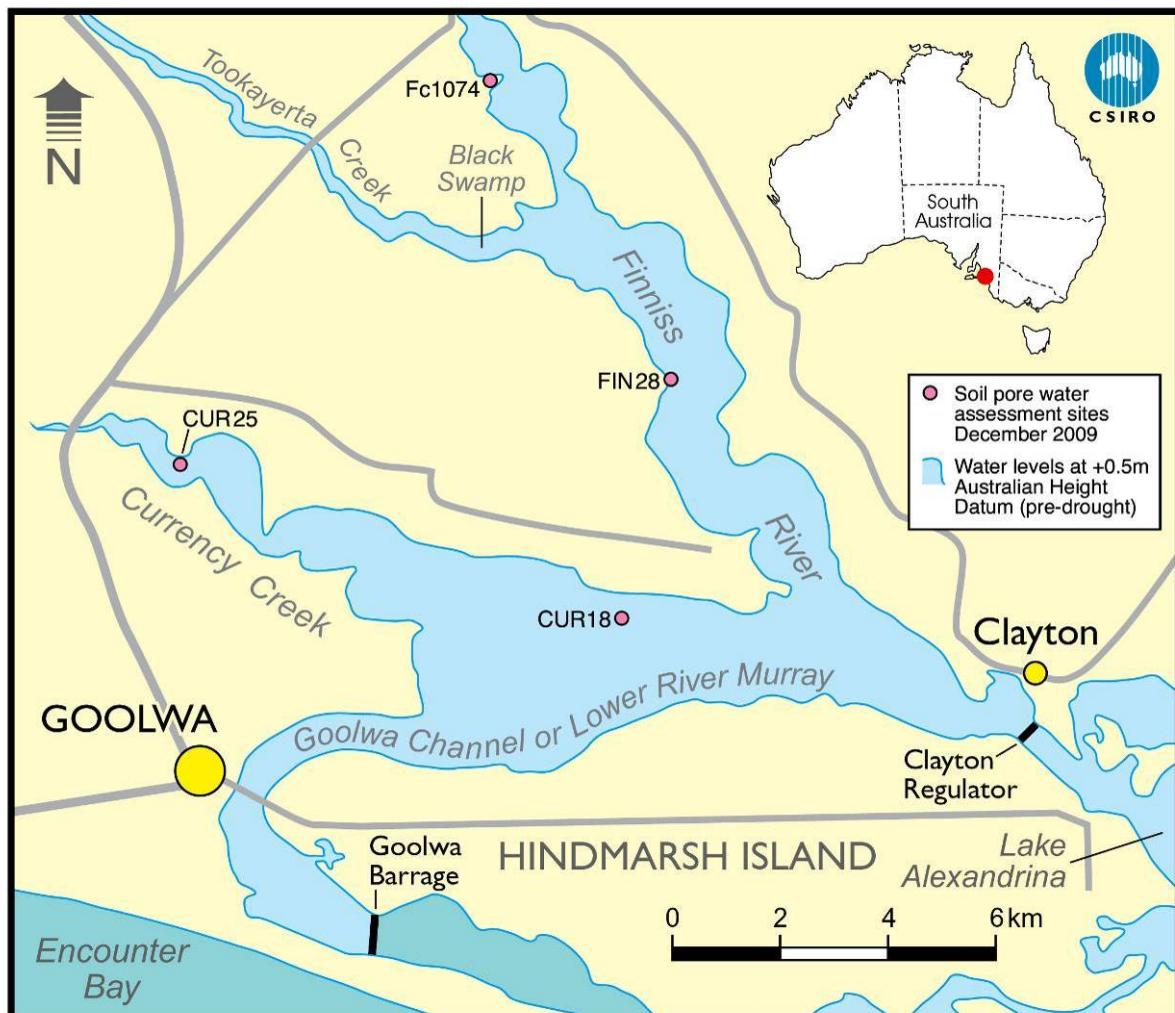


Figure 5-3. Location map showing position of soil-pore water sampling sites.

5.2.1. 1-D spatial variability of pH, EC and Acidity or Alkalinity.

FC1001 (FIN28).

The pH of the surface water (pH 7.0 - 7.2) gradually decreases to a pH of 6.6 at the sediment-water interface (SWI) (Figure 5-4). The pH remains approximately stable from the SWI to 2 cm below the SWI before rapidly decreasing to an approximate pH of 4.4 from 3 cm to 8 cm below the SWI. Below this there was a second rapid decrease in pH to a pH of 3.2 from 8 cm to 31 cm below the SWI, reaching a minimum pH of 3.08 at 22 cm. Since rewetting (\approx 5 months prior to peeper deployment), alkalinity from the surface water has only managed to neutralise or partly neutralise the top 3 cm of sediment, the remainder has remained strongly acidic, with acidity values increasing from 3 meq/L to 40 meq/L with depth. The alkalinity of the surface water to 3 cm below the SWI is low and ranges from 0.05 to 1.21 meq/L. A much larger alkalinity would usually be expected for surface water in this type system. Hence, it is likely that the alkalinity of the surface water has been depleted by the initial mobilisation of acidic cations and subsequent net acid flux from the sediment to the surface water. There is a trend of gradual linear increase in EC from 6cm below the SWI to the deepest sampling chamber, from approximately 5 dS/m to 13 dS/m. EC of the surface water is approximately 5 dS/m.

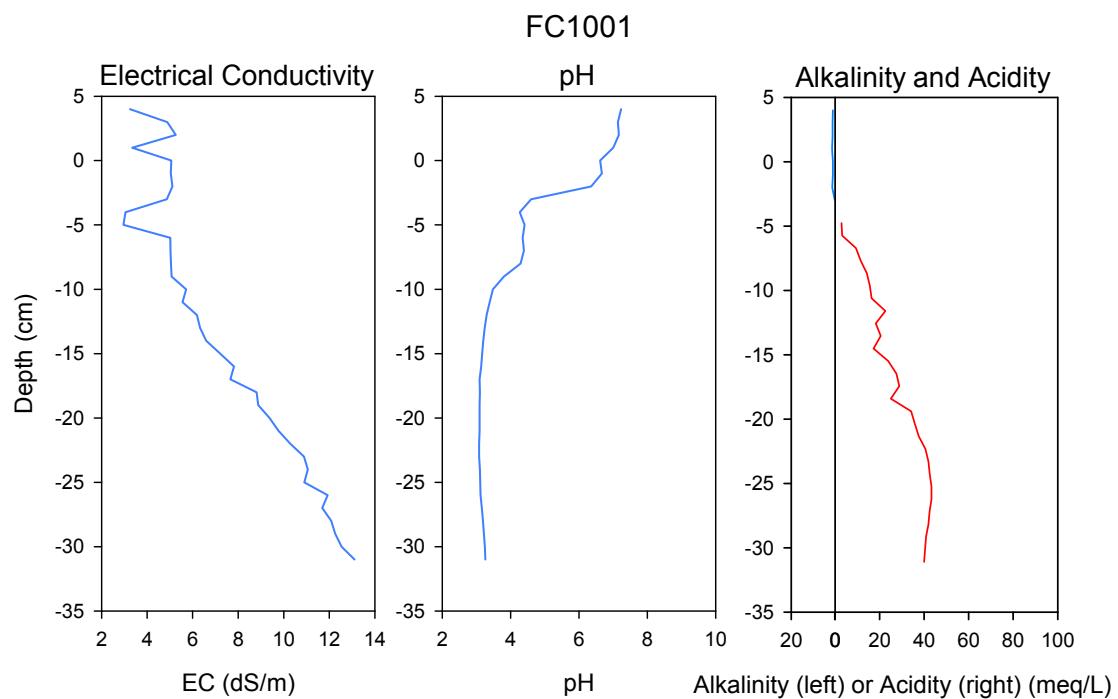


Figure 5-4. Plots of EC, pH, alkalinity, and acidity with depth for site FC1001 (FIN28).

FC1029 (CUR18)

Alkalinity of the surface water (≈ 3 meq/L) is also lower than would be expected for this region (Figure 5-5). Following 5 months of rewetting the pore water pH appears to have been affected by the overlying surface water up to 5cm below the SWI. pH remains relatively constant below this until 29 cm below the SWI where it increases rapidly to above pH 6.0.

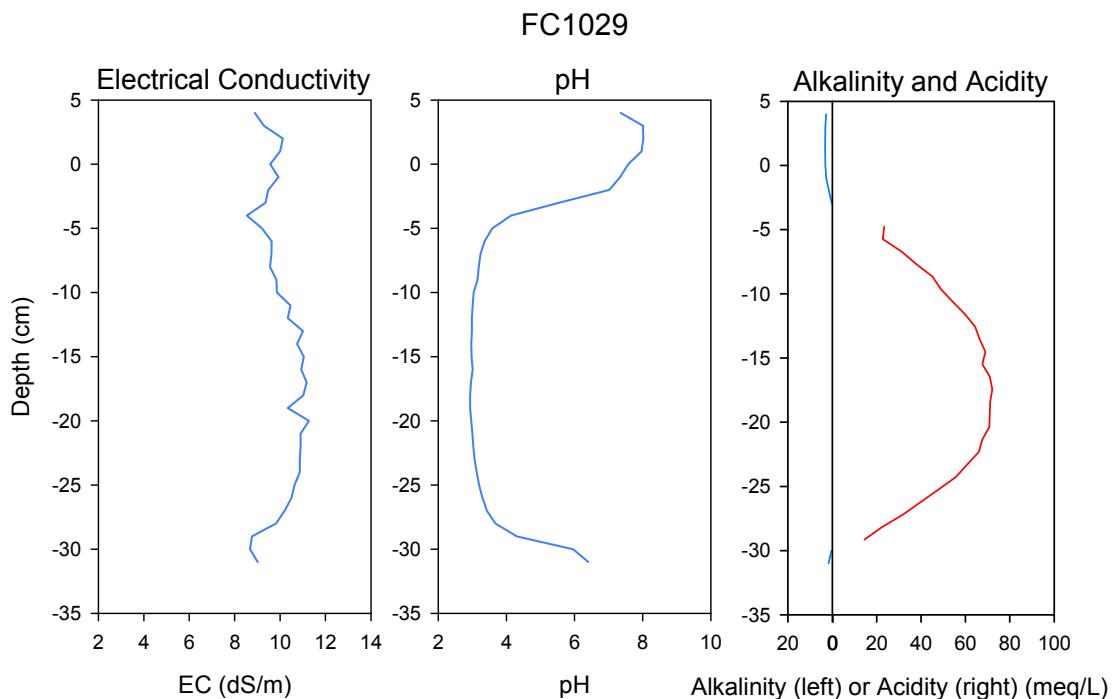


Figure 5-5. Plots of EC, pH, alkalinity, and acidity against depth for site FC1029 (CUR18).

The rapid increase in pH is due to encountering hyposulfidic material (Appendix 3). Acidity is considered extremely high with a maximum acidity of 72.1 meq/L at 17 cm below the SWI. EC remained relatively constant (\approx 10 dS/m) over the analysed depths.

FC1062 (CUR25)

Rewetting (\approx 5 months) has had little to no effect on soil pore water pH (Figure 5-6). Surface water has a pH of 7.2 and alkalinity of 1 meq/L. pH and alkalinity of the sampling chamber straddling the SWI is 6.27 and 0.65 meq/L, respectively. pH of the remaining sampling chambers (spanning 2 cm below SWI to 32 cm below SWI) is reasonably consistent at around 2.8. Conversely, acidity is not static with depth, peaking at 55.4 meq/L at 10 cm below the SWI. Acidity mostly remains $>$ 20 meq/L for sampling chambers 1 cm and greater below the SWI, meaning soil pore water is highly buffered at these low pH values.

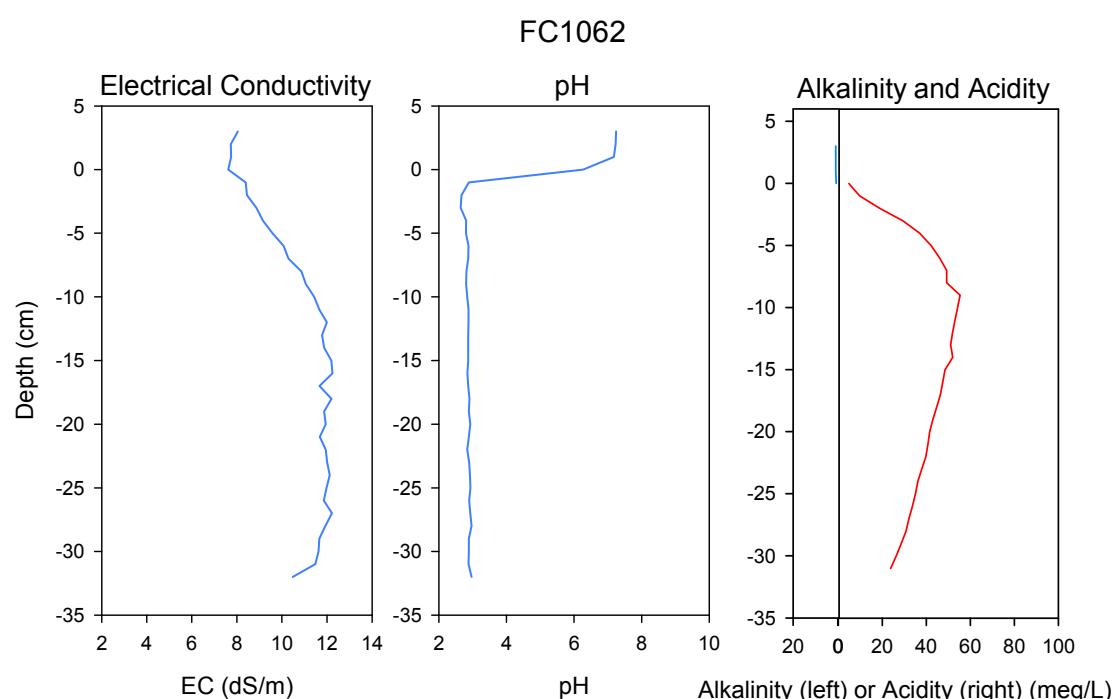


Figure 5-6. Plots of EC, pH, alkalinity, and acidity against depth for site FC1062 (CUR25).

FC1074

Of the four sites, FC1074 has been the most affected by rewetting (Figure 5-7). Effects on pH, EC and alkalinity/acidity can be seen down to 15 cm below the SWI. This may be due to both:

- (i) the longer period of inundation (8 months) compared to the other sampled sites (5 months), and
- (ii) the heavily cracked surface allowing for easier and deeper penetration of the Surface Water (SW) into the previously sulfuric soils.

This is consistent with surface feature observations of polygonal cracking to >15 cm (Appendix 2). The EC of the soil pore water is approximately equal to the EC of the surface water to 12 cm below the SWI, where the EC changes abruptly. This provides the best indicator that the observed trends are most likely related to changes caused by rewetting and not the trends that would have been present prior to rewetting. pH changes less abruptly, gradually decreasing from 7.67 to 4.02 by 15 cm below the SWI. pH of the soil pore water

remains < 4 for the rest of the peeper sampling interval. EC and acidity increase steadily from 15 cm below the SWI to the deepest sampling chamber.

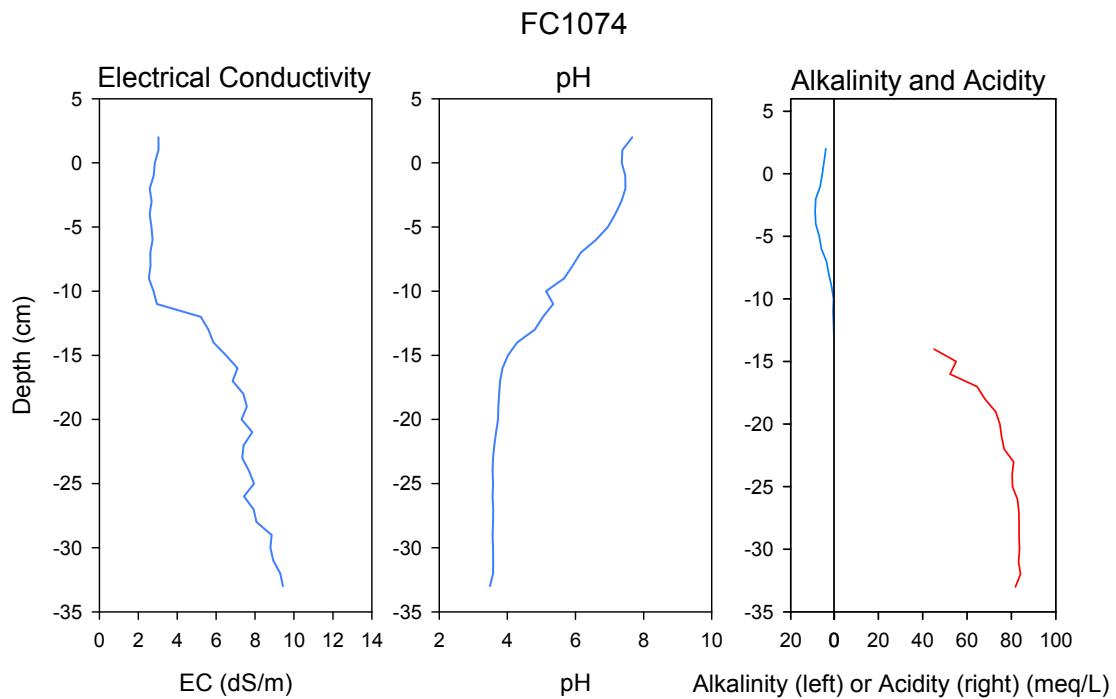


Figure 5-7. Plots of EC, pH, alkalinity, and acidity against depth for site FC1062.

5.2.2. Acidic Cations

The below figures are provided to examine the relative contribution of each of the acidic cations to the overall acidity. At all sites Al^{3+} and Fe^{2+} contributed at least 10 fold that of H^+ and Mn^{2+} to the total acidity and are presented on separate graphs in order to preserve detail.

FC1001

Site FC1001 shows a steady increase in the concentration of all acidic cations species with depth (Figure 5-8). A peak in iron concentration can be observed at 1 cm above the SWI and 3 cm below the SWI, which is consistent with the red brown precipitates (likely iron oxy hydroxides) found on the soil surface at the time of peeper deployment (Appendix 2). The summation of acidic cation concentrations closely mirrors the acidity valued determined by titration with NaOH.

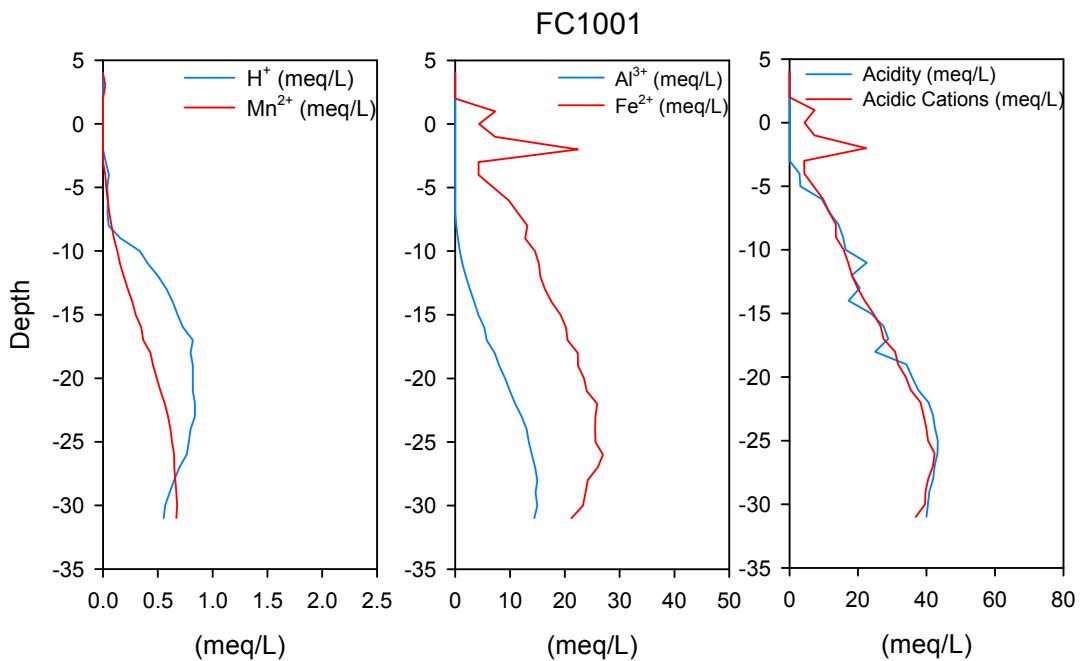


Figure 5-8. Individual acidic cation profiles for H^+ , Mn^{2+} (left), Al^{3+} and Fe^{2+} (middle) and summed concentrations of acidic cations against acidity (right) for site FC1001.

FC1029

Aluminium concentrations are significantly higher at this site than the other three sites (Figure 5-9). Concentrations of all acidic cations increase with depth until reaching a maximum at 15 cm to 20 cm below the SWI, where they begin to decrease, reaching concentrations similar to those of the surface water by the final sampling chamber. Again, acidity measurements show good correlation with ICP-OES and ICP-MS derived values.

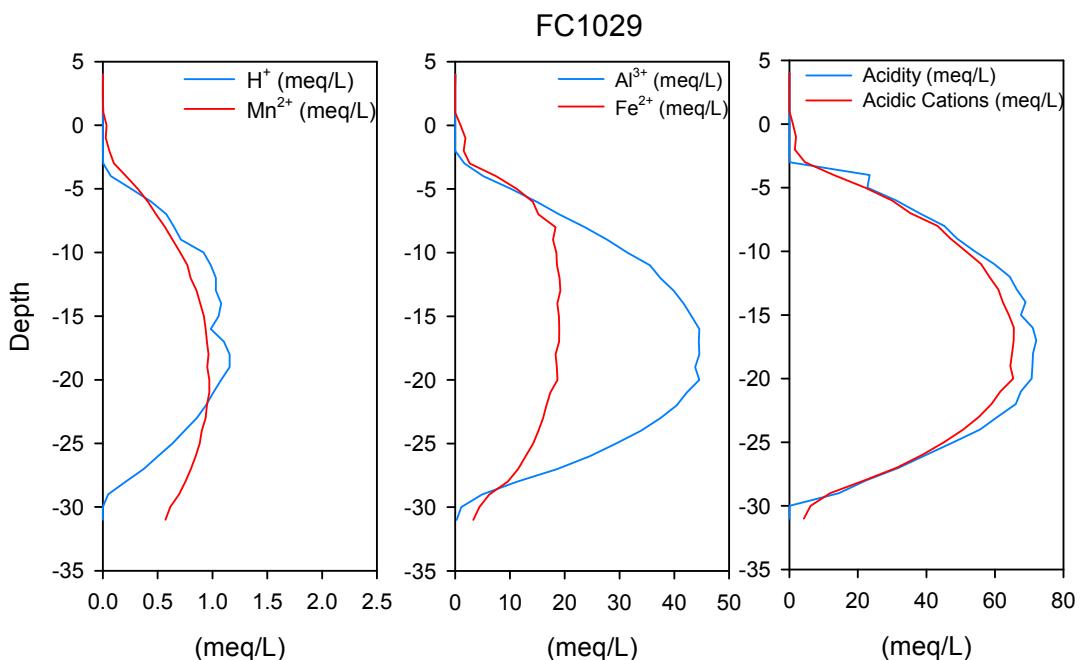


Figure 5-9. Individual acidic cation profiles for H^+ , Mn^{2+} (left) Al^{3+} and Fe^{2+} (middle) and summed concentrations of acidic cations against acidity (right) for site FC1029.

FC1062

The concentration of H^+ ion was relatively constant over the sampling interval (Figure 5-10). The concentrations of Mn^{2+} and Al^{3+} are also relatively constant below 10 cm. Consequently, acidity is mainly driven by the concentration of Fe^{2+} . A spike in Fe^{2+} can be seen at approximately 0 cm (the SWI), again, consistent with the observation of red brown precipitates at the time of peeper deployment.

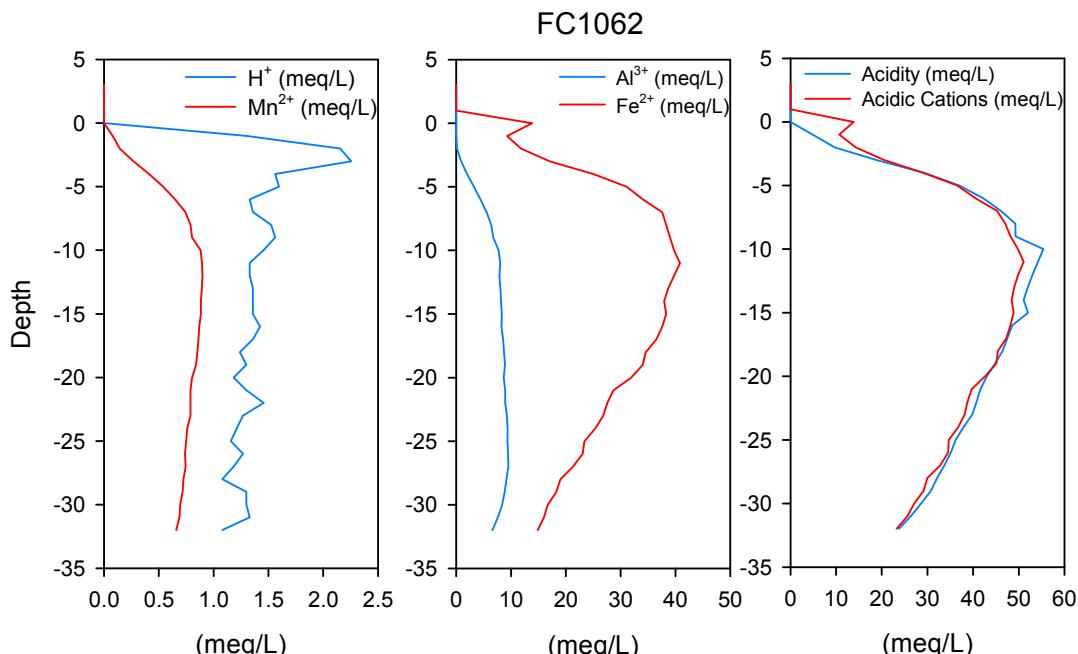


Figure 5-10. Individual acidic cation profiles for H^+ , Mn^{2+} (left) Al^{3+} and Fe^{2+} (middle) and summed concentrations of acidic cations against acidity (right) for site FC1062.

FC1074

The acidity of site FC1074 was controlled largely by the dissolved iron concentration (Figure 5-11). Acidity is thought to be a result of Fe^{2+} , however if oxidising conditions are still present within the profile, the very low pH values observed (≈ 3) may mean Fe^{3+} is also contributing to the acidity.

Iron reaches concentrations in excess of 90 meq/L. Acidity by titration was underestimated when compared to acidic cation concentrations. During acidity titration of samples with $\text{pH} < 4.5$ a dark green precipitate (thought to be FeCl_3 or possibly green rust see Taylor, 1984) formed on the addition of NaOH. It is thought that the underestimation of acidity by titration is due to the formation of these precipitates, or more specifically the subsequent removal of iron from solution caused by the precipitation of FeCl_3 .

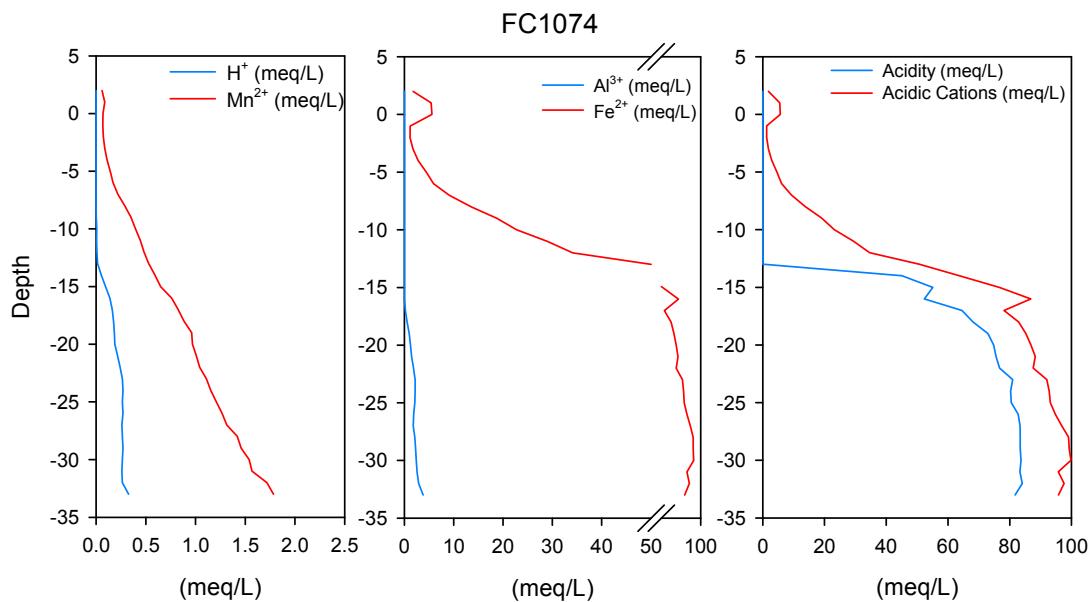


Figure 5-11. Individual acidic cation profiles for H^+ , Mn^{2+} (left) Al^{3+} and Fe^{2+} (middle) and summed concentrations of acidic cations against acidity (right) for site FC1074.

5.2.3. Soil Pore Water Quality

For the purpose of this study the ecosystems of the Currency Creek and Finniss River were considered to be highly disturbed and the ANZECC guideline trigger values (GTV) for protection of 80% of species in fresh water ecosystems were determined as the most appropriate, and are therefore utilised below (ANZECC/ARMCANZ 2000). Only those instances where GTV were exceeded are discussed in any detail. It can be assumed that if no data is presented GTV were not exceeded. Exceedances are summarised in Table 5-1 and GTV used are summarised in Table 5-2.

Table 5-1. Summary table of for toxicants where the guideline trigger values were exceeded for 80% species protection in freshwater ecosystems (exceedance based on non-hardness corrected values for elements Cd, Cu, Ni, Zn, and Pb). (\checkmark = exceedance)

		<i>FC1001</i>	<i>FC1029</i>	<i>FC1062</i>	<i>FC1074</i>
Aluminium (pH>6.5)	Al	\checkmark	\checkmark	\checkmark	\checkmark
Arsenic	As (IV)	--	\checkmark	\checkmark	--
Boron	B	\checkmark	\checkmark	\checkmark	--
Cadmium	Cd	\checkmark	\checkmark	\checkmark	--
Chromium	Cr (VI)	\checkmark	\checkmark	--	--
Copper	Cu	\checkmark	\checkmark	\checkmark	--
Manganese	Mn	\checkmark	\checkmark	\checkmark	\checkmark
Nickel	Ni	\checkmark	\checkmark	\checkmark	\checkmark
Lead	Pb	\checkmark	\checkmark	\checkmark	\checkmark
Zinc	Zn	\checkmark	\checkmark	\checkmark	\checkmark

Table 5-2. Guideline trigger values applied to data. The GTV is shown as a dashed line in Figures 5-12 through 15.

	Guideline trigger value ($\mu\text{g/L}$)
Freshwater - 80% species protection	
Al (pH > 6.5)	150
As (V)	140
B	1 300
Cd	0.8
Cr (VI)	40
Cu	2.5
Mn	3 600
Ni	88
Pb	9.4
Zn	31

Aluminium

All sites greatly exceed the ANZECC GTV for aluminium in waters with a pH above 6.5 (Figure 5-12). Although the pH of all sites was typically < 6.5 the GTV for aluminium in waters with pH > 6.5 was used to check for exceedances. This was done because only a low reliability GTV (0.8 $\mu\text{g/L}$) is provided for waters with pH values < 6.5 (ANZECC/ARMCANZ 2000). Site FC1029 shows a > 250 times exceedance of the GTV, with sites FC1001 and FC1062 showing a 50 to 100 times exceedance. For sites FC1001, FC1029, and FC1062 concentrations exceed the GTV for the majority of the profile. GTV exceedances are associated with the very low pHs observed at > \approx 5 cm below the SWI. It is expected that at these low pH values the majority of aluminium would exist as highly toxic dissolved Al^{3+} .

Arsenic

Only sites FC1029 and FC1062, those deployed in Currency Creek, significantly exceed the GTV for arsenic (Figure 5-12). For site FC1029 concentrations are in exceedance of the GTV from 19 to 25 cm below the SWI, and for site FC1062 from 4 to 21 cm below the SWI.

Boron

All sites except for FC1074 exceed the GTV for boron (Figure 5-12). For site FC1074 the majority of sampling chambers reported concentration of boron below the limit of detection (< 1 mg/L).

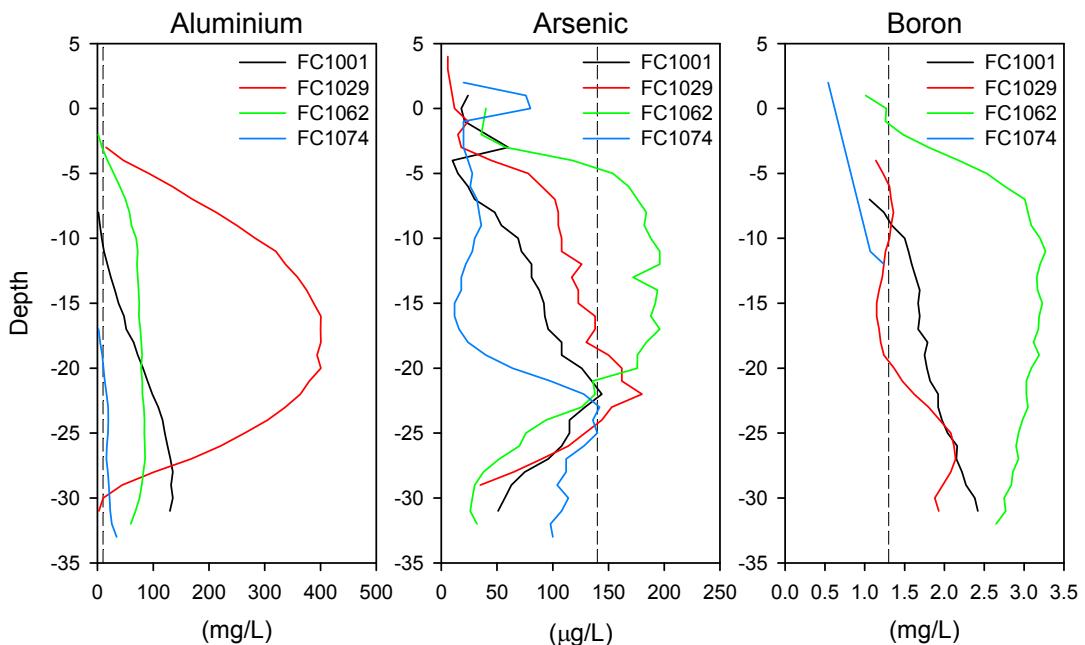


Figure 5-12 Profiles of aluminium (left), arsenic (middle), and boron (right) for each of the four sites. The black, dashed line represents the relevant ANZECC WQ guideline trigger value for 80% species protection.

Cadmium

Only site FC1074 stayed below the GTV over the entire depth range (Figure 5-13). Both Currency Creek peepers (FC 1029 and FC1062) exhibit similar trends, whereby concentrations increase to a maximum at around 15 cm below the SWI before decreasing to values approximating the GTV by the deepest sampling chamber.

Chromium

Only site FC1029 significantly exceeds the GTV over the majority of the depth range, with site FC1001 showing a slight exceedance below 19 cm (Figure 5-13). The maximum concentration recorded for site FC1029 equates to an approximate 5 times exceedance of the GTV.

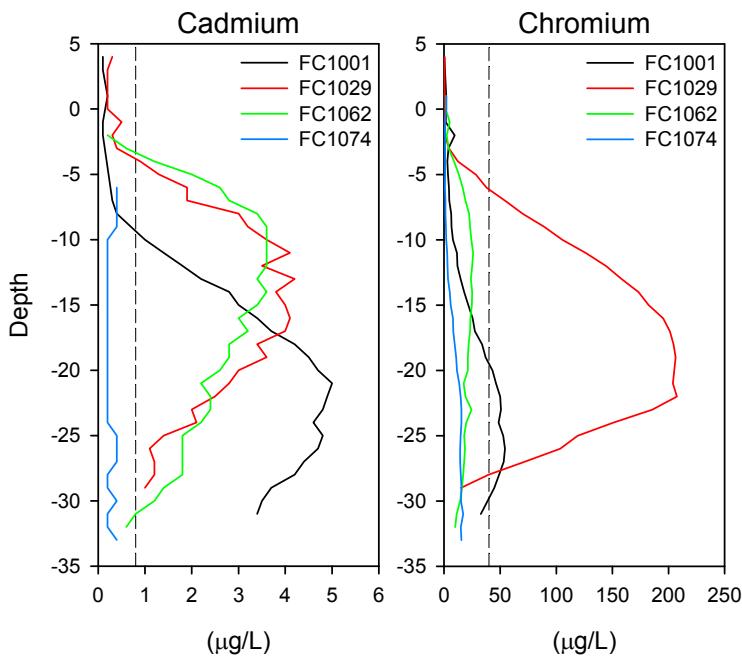


Figure 5-13. Profiles of cadmium (left), and chromium (right) for each of the four sites. The black, dashed line represents the relevant ANZECC WQ guideline trigger value for 80% species protection.

Copper

All sites exceed the GTV besides site FC1074. However, site FC1062 only exceeds the GTV by a maximum of 4.5 $\mu\text{g/L}$ (Figure 5-14). At their maximum concentrations, found around 15 cm below the SWI, sites FC1001 and FC1029 exceed the GTV by a factor of approximately 16 times.

Manganese

All sites have exceeded the GTV at or before 10 cm below the SWI (Figure 5-14). Similar trends are observed between peepers from the same catchment. FC1001 and FC 1074, those deployed in Finniss River, show a similar rate of increase in concentration with depth. Although, the rates of increase are similar the actual concentration values are different with site FC1074 having higher concentrations than FC1001 over the depth range. Sites FC1029 and FC1062, those deployed in Currency Creek, show a bulging trend whereby concentration increases with depth until a maximum reached at approximately 15 cm below the SWI, concentrations then begin to decrease, reaching concentrations of approximately $\frac{2}{3}$ that of the maximum concentrations.

Nickel

All sites exceed the GTV for nickel (Figure 5-14). For sites FC10029 and FC1074 the GTV was exceed by 2 cm below the SWI and remains as such over the remaining depth range. Interestingly, concentrations of Finniss River deployed peepers (FC1001 and FC1074) become approximately identical below 17 cm. The reason for this is unknown considering the significant spatial distance between them. This trend has not been observed for any other element.

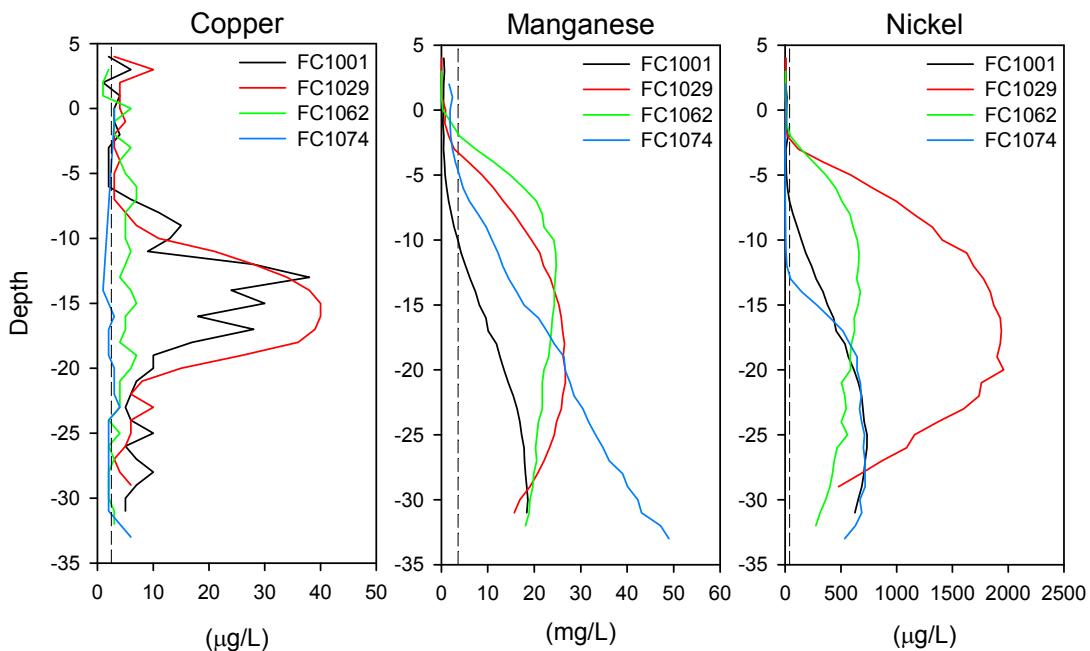


Figure 5-14. Profiles of copper (left), manganese (middle), and nickel (right) for each of the four sites. The black, dashed line represents the relevant ANZECC WQ guideline trigger value for 80% species protection.

Lead

All sites exceed the GTV for lead (Figure 5-15). There is an initial peak (1 cm below the SWI) in exceedance of the GTV for site FC1074 before values drop back below the GTV. GTV are not exceeded again until approximately 15cm below the SWI. All other sites are in exceedance of the GTV at or before 3 cm below the SWI and remain in exceedance for all deeper sampling chambers. The degree of exceedance was highly variable over the depth ranges of all sites.

Zinc

All sites exceed the GTV for zinc (Figure 5-15). Peepers installed at Currency Creek offer some similarities in the trends, but the magnitude of exceedance is always greater for FC1062.

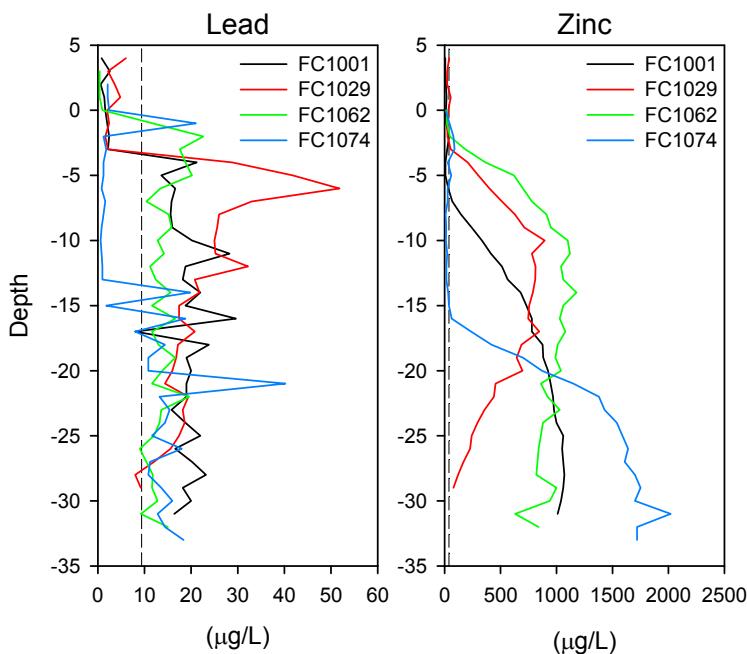


Figure 5-15. Profiles of lead (left), and zinc (right) for each of the four sites. The black, dashed line represents the relevant ANZECC WQ guideline trigger value for 80% species protection.

5.3. Conclusion and knowledge gaps

We found that 5 - 8 months following seasonal winter rainfall events, together with pumping from the regulator at Clayton Bay, the rewetting or ‘flushing’ of these sites had little or no effect on the types of ASS materials found. All sites have remained sulfuric, with pH values <4 being recorded over large depth intervals in the top 35 cm of the subaqueous soil/sediment profile. Some sites have shown a small amount of neutralisation but this has usually been confined to the very uppermost regions of the subaqueous soil/sediment profile. We found that the soil pore water is heavily buffered (high acidity) at these low pH values and that the surface water immediately overlying the subaqueous soil/sediment had very low alkalinity. This is likely to be the reason why the pore water has remained sulfuric.

The impact on water quality has also been assessed against the relevant ANZECC guideline trigger values for a number of cations. Exceedances of the guideline trigger values were common across the assessed cations at all four sites with a number of exceedances being a number of orders of magnitude larger than the guideline trigger value.

These four *in situ* experiments have demonstrated that acidity, and associated hazards, produced when these profiles were previously exposed to the atmosphere due to the lowering water levels cannot be expected to be remediated in a quick manner and certainly not within one winter. Hence, the time interval over which this can be expected to occur remains unknown. Gaining knowledge of the time scales needed to return these profiles to their pre-drought condition (i.e. re-establishment of reducing conditions) is important for the understanding of rewetted ASS.

Further investigation into the recovery of these sulfuric soils when they are rewetted is essential in order to fill a number knowledge gaps that still remain following this study. The climate-induced rewetting of these exposed sulfuric soils provides a unique opportunity to both monitor and assess soil and water quality, and importantly to study the recovery of these sulfuric soils. Repeating these four experiments, initially after approximately 1 year but, ideally until equilibrium is reached (i.e. end member subaqueous soil profile has developed) will capitalise on this unique *in situ* reflooding opportunity. Additionally, we recommend

extending the analyses of the soil and pore-water to include a greater number of parameters (e.g. Eh, dissolved anions, sulfur and iron speciation, organic/inorganic carbon, acid base accounting, and soil physical data), which would be used to:

- Further assess improvement or worsening of water and sediment quality against ANZECC guideline values over time.
- Assess the impact of sulfate and metal reduction on soil and water chemistry. For example, alkalinity generation and sulfate reduction rates to provide a fundamental understanding of iron and sulfur geochemistry in these “recovering” ASS systems. It is these processes that consume acidity and reduce metal availability. Hence, understanding these mechanisms will greatly improve environmental management.
- Assess the time scales involved in re-formation of reduced inorganic species (as part of the “on-going monitoring” proposal mentioned above) using soil core(s), continuous Eh and pH monitoring, and thin film dialysis samplers (e.g. DET/DGT) and peepers.
- Calculate the diffusion fluxes of contaminants and acidity from the soil to the water column and the rate of diffusion of alkalinity from the water column to the soil.
- Apply geochemical modelling tools and information from C, S and Fe speciation and transformation studies to understand the processes and develop improved conceptual models of soil change following rewetting at each site investigated.
- Develop predictive models of soil behaviour following rewetting including differences between soil subtypes and other attributes found to have an influence, for example organic matter and hydro-toposequence position.

6. Summary and Conclusions

This survey conducted in December 2009 is a follow-up on survey work conducted one year previously in November 2008 (Fitzpatrick *et al.* 2009a). It provides a well distributed site and sample data set that provides information on current conditions and monitoring of change since the previous sampling event. Significantly this study area of Finniss River, Currency Creek and the Goolwa Channel has been inundated due to the construction of the Clayton regulator and pumping of water from Lake Alexandrina raising the water level from -0.70 to approximately + 0.5 AHD in November to December 2009.

The most significant change to the area is that soils previously sampled in 2008 that were exposed are now covered with surface water. The soils investigated are now characterised as subaqueous. It was found that the previous sulfuric surface soil layers have been neutralised probably from the surface waters, but it has remained sulfuric below the surface layer from about 5 cm depth where the soil material was sulfuric in 2008. Net acidity results indicated that 70 of the 80 soil layers sampled had a positive value and that there has been little or no neutralisation of the underlying soil layers.

These changes are clearly illustrated in the top photograph and conceptual cross-section diagram of Site CUR 13 taken in November 2008 in the exposed creek-bed of Goolwa Channel/Currency Creek near north Goolwa (Figure 6-1), which shows an acid sulfate soil profile with sulfuric material ($\text{pH} < 4$) to a depth of 30 cm. The sulfuric material comprises:

- (i) prominent "orange" reddish brownish coatings of the mineral schwertmannite on the soil surface, which overlies pale yellow mottles of natrojarosite in a grey clay matrix, and
- (ii) dark grey hypersulfidic material below 30 cm.

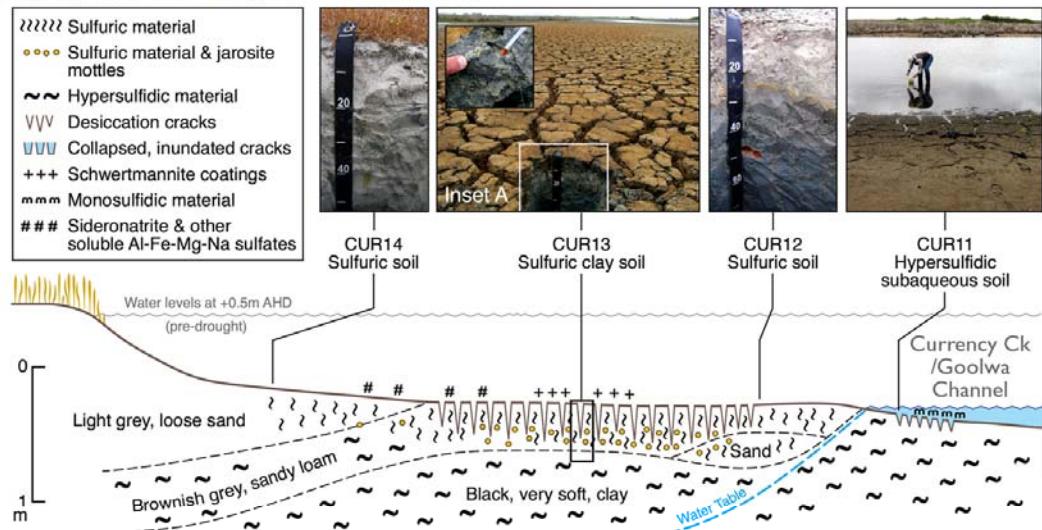
Schwertmannite and natrojarosite are good mineral indicators of the presence of sulfuric material ($\text{pH} < 4$), that has formed in the upper layers and below this is hypersulfidic material ($\text{pH} > 4$). With the receding water levels due to extreme drought conditions between 2006 and 2009 the previously hypersulfidic subaqueous soil, which contains abundant pyrite (FeS_2) has been exposed, dried and reacted with oxygen from the air to form sulfuric clay soils that have large cracks with columnar structure.

The lower, photograph (Figure 6-1) was taken in December 2009 and the conceptual cross-section diagram constructed for the same locality after reflooding due to winter rainfall runoff from adjacent catchments and pumping from Lake Alexandrina following installation of the Clayton regulator. The reflooded Acid Sulfate Soil stayed submerged under 80 cm of water for a period of approximately six months but remained largely acidic (i.e. Sulfuric subaqueous clay) except for a thin 5 cm thick surface layer comprising black monosulfidic material, which overlies sulfuric material with pale yellow mottles of natrojarosite (second layer) and dark grey hypersulfidic material below 30 cm.

The surface water chemistry indicates transport of SO_4 to the surface water, and therefore most likely acidity which explains the decreases in alkalinity. If there is further transportation of acidity into the surface water then buffering capacity in the surface waters will be consumed increasing the risk of acidification of the waters.

The soil pore-water concentration profiles for trace metals and metalloids mirror the pH and acidity profiles with numerous exceedances of GTVs. These results demonstrate that while surface water quality has been improved by the reflooding of ASS with sulfuric materials, the improvement is 'skin deep' with sulfuric materials remaining at very shallow depths, and with poor sediment pore water quality. This poor water and sediment quality has implications for the re-establishment of sediment biota, e.g. mussels are unlikely to tolerate the low sediment pH values.

a) Drying due to drought (November 2008)



b) Reflooding due to rainfall with regulator installed at Clayton (December 2009)

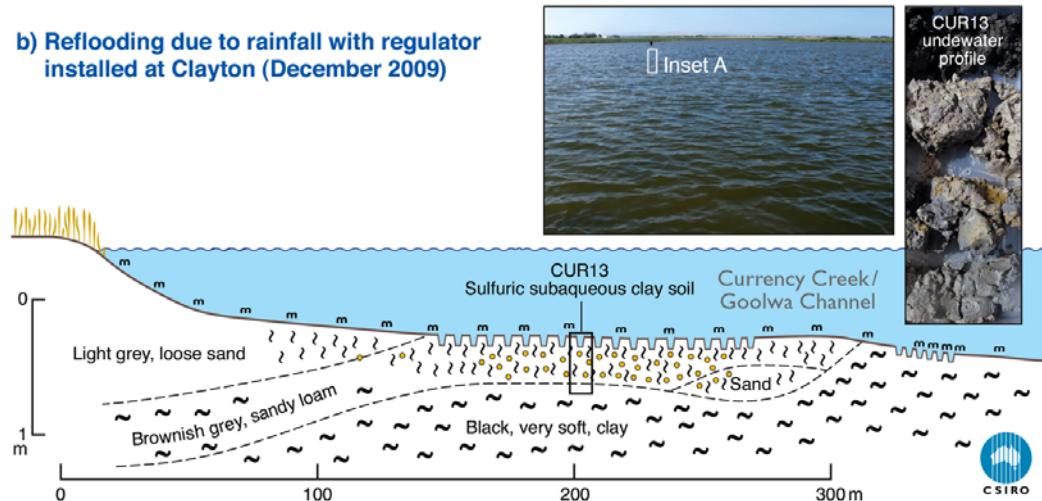


Figure 6-1. Photograph and conceptual cross-section diagram of Acid Sulfate Soil of the subtype "Sulfuric cracking clay soil" in the dry river bed of Currency Creek, near north Goolwa (Site No CUR 13 sampled in November 2008), looking west towards to the Adelaide Hills, South Australia. This shows: (i) trans-horizon polygonal cracks with very coarse columnar ped structures; the result of desiccation and dewatering of a former "Hypersulfidic subaqueous clayey soil" during drying cycles due to recent extreme drought conditions; (ii) surface coating of the reddish-brown mineral, schwertmannite, which has a pH ranging between 3.0 and 3.6 (sulfuric material), (iii) sulfuric material ($\text{pH} < 4$) with pale yellow mottles of natrojarosite in a dark grey clay matrix between 10 cm to 30 cm, and (iv) very dark grey hypersulfidic material (iron sulfides) at depth ($> 30 \text{ cm}$). The lower photograph and conceptual cross-section diagram is taken at same locality in December 2009 after reflooding following winter rainfall runoff from adjacent catchments and construction of Clayton and Currency Creek water regulators.

The findings of this study should be integrated with data from previous monitoring studies (e.g. Baker *et al.* 2010). This will enable a more complete documentation of processes and outcomes incorporating previous baseline data. A consolidated dataset, which can be updated with the results of any future monitoring will provide information to inform long-term strategies for lake management. We recommend that monitoring of at least 4 to 6 representative sites continue during rewetting phases, e.g. during winter rainfall or re-flooding due to increased river flows, when acidity and metal mobilisation are likely to have the most significant impact.

REFERENCES

- Ahern CR, McElnea AE, Sullivan LA (2004). Acid sulfate soils laboratory methods guidelines. In 'Queensland Acid Sulfate Soils Manual 2004'. Department of Natural Resources, Mines and Energy, Indooroopilly, Queensland, Australia.
<http://www.nrw.qld.gov.au/land/ass/pdfs/lmg.pdf>.
- ANZECC and ARMCANZ (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. National Water Quality Management Strategy Paper No. 4, Australian and New Zealand Environment and Conservation Council & Agriculture and Resource Management Council of Australia and New Zealand, Canberra.
- Baker, AKM, Fitzpatrick, RW, Shand, P, Simpson SL, Merry RH, and Thomas M (2010). Temporal variations in representative Acid Sulfate Soil environments around Lakes Alexandrina and Albert, South Australia. Prepared for The Murray Darling Basin Authority and South Australian Murray Darling Basin Natural Resources Management Board. Client Report R-325-8-2, CSIRO: Sustainable Agriculture Research Flagship, 250 pp.
<http://www.clw.csiro.au/publications/science/2010/SAF-Lakes-Alexandrina-Albert-sulfate-soils-temporal.pdf>
- DENR (2010), Acid sulfate soils research program summary report. Prepared by the Lower Lakes Acid Sulfate Soils Research Committee for the SA Department of Environment and Natural Resources, Adelaide. 45 pp.
http://www.environment.sa.gov.au/Conservation/Rivers_Wetlands/Coorong_Lower_Lakes_Murray_Mouth/The_environment/Acid_sulfate_soils/Acid_Sulfate_Soils_Research_Program_reports
- Fanning DS (2002). Acid sulfate soils. pp 11-13. In R Lal (ed.). Encyclopaedia of Soil Science. Marcel Dekker, New York.
- Fitzpatrick RW, Grealish G, Chappell A, Marvanek S, Shand P (2010a). Spatial variability of subaqueous and terrestrial Acid Sulfate Soils and their properties, for the Lower Lakes, South Australia.. Prepared for South Australia Department of Environment and Natural Resources(DENR). Client Report R-689-1-15: CSIRO Sustainable Agriculture National Research Flagship 122 pp. <http://www.clw.csiro.au/publications/science/2010/SAF-Lower-Lakes-SA-sulfate-soils.pdf>
- Fitzpatrick Rob, Gerard Grealish, Paul Shand, Richard Merry, Nathan Creeper, Mark Thomas, Andrew Baker, Brett Thomas, Warren Hicks and Nilmini Jayalath (2010b). Chip-tray incubation – a new field and laboratory method to support Acid Sulfate Soil Hazard Assessment, Classification and Communication. In: RJ Gilkes and N Prakongkep (Editors). Proceedings of the 19th World Congress of Soil Science; Soil Solutions for a Changing World; ISBN 987-0-646-53783-2; Published on DVD; <http://www.iuss.org>; Symposium WG 3.1 Processes in acid sulfate soil materials; 2010 Aug 1–6, Brisbane, Australia; IUSS; 2010, pp 28-31.
- Fitzpatrick RW, Grealish G, Shand P, Thomas BP, Merry RH, Creeper NL, Raven MD, Jayalath N (2009a). Preliminary Risk Assessment of Acid Sulfate Soil Materials in the Currency Creek, Finniss River, Tookayerta Creek and Black Swamp region, South Australia. CSIRO Land and Water Science Report 01/09. CSIRO, Adelaide, 45 pp.
<http://www.clw.csiro.au/publications/science/2009/sr01-09.pdf>
- Fitzpatrick RW, Grealish G, Shand P, Simpson SL Merry R.H, Raven MD (2009b). Acid sulfate soil assessment in Finniss River, Currency Creek, Black Swamp and Goolwa Channel, South Australia. Prepared for the Murray Darling Basin Authority. CSIRO Land and Water Science Report 26/09. CSIRO, Adelaide, 213 pp.
<http://www.clw.csiro.au/publications/science/2009/sr26-09.pdf>

Fitzpatrick RW, Shand P (2008). Inland Acid Sulfate Soils: Overview and conceptual models. In *Inland Acid Sulfate Soil Systems Across Australia* (Eds. R.W. Fitzpatrick and P Shand). pp 6-74. CRC LEME Open File Report No. 249 (Thematic Volume) CRC LEME, Perth, Australia.

<http://crcleme.org.au/> and <http://www.clw.csiro.au/acidsulfatesoils/index.html>

Fitzpatrick RW, Marvanek SP, Shand P, Merry RH, Thomas M, Raven MD (2008a). Acid Sulfate Soil Maps of the River Murray below Blanchetown (Lock 1) and Lakes Alexandrina and Albert when water levels were at pre-drought and current drought conditions. CSIRO Land and Water Science Report 12/08. CSIRO, Adelaide, 10 p There are 2 versions of the report – one without maps as appendix and one with maps:
http://www.clw.csiro.au/publications/science/2008/sr12-08_withmaps.pdf
http://www.clw.csiro.au/publications/science/2008/sr12-08_nomaps.pdf

Fitzpatrick RW, Shand P, Marvanek S, Merry RH, Thomas M, Simpson SL, Raven MD, McClure S (2008b). Acid sulfate soils in subaqueous, waterlogged and drained soil environments in Lake Albert, Lake Alexandrina and River Murray below Blanchetown (Lock 1): properties, distribution, genesis, risks and management. Prepared for Department of Environment and Heritage, SA. CSIRO Land and Water Science Report 46/08. CSIRO, Adelaide, 167. pp.

<http://www.clw.csiro.au/publications/science/2008/sr46-08.pdf>

Fitzpatrick RW, Powell B, Marvanek S (2008c). Atlas of Australian Acid Sulfate Soils. In *Inland Acid Sulfate Soil Systems Across Australia* (Eds Rob Fitzpatrick and Paul Shand). pp 63-77. CRC LEME Open File Report No. 249. (Thematic Volume) CRC LEME, Perth, Australia.

Fitzpatrick RW, Shand P, Merry RH (2009c). Acid Sulfate Soils. In: J.T Jennings (Ed.). 'Natural History of the Riverland and Murraylands'. Royal Society of South Australia (Inc.) Adelaide, South Australia, pp. 65-111

Fitzpatrick RW, Shand P, Thomas B, Marvanek S, Merry RH, Creeper N, Thomas M, Raven MD, Simpson SL, McClure S, Jayalath N (2008d). Acid sulfate soils in the Coorong, Lake Alexandrina and Lake Albert: properties, distribution, genesis, risks and management of subaqueous, waterlogged and drained soil environments. Prepared for Department of the Environment, Water, Heritage and Arts. CSIRO Land and Water Science Report 52/08. CSIRO, Adelaide, 177. pp. <http://www.clw.csiro.au/publications/science/2008/sr52-08.pdf>

Hicks WS, Creeper N, Hutson J, Fitzpatrick RW, Grocke S, Shand P (2009). The potential for contaminant mobilisation following acid sulfate soil rewetting: Field Experiment. Prepared by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) Land and Water for the SA Department of Environment and Natural Resources, Adelaide. 113 pp.
http://www.environment.sa.gov.au/Conservation/Rivers_Wetlands/Coorong_Lower_Lakes_Murray_Mouth/The_environment/Acid_sulfate_soils/Acid_Sulfate_Soils_Research_Program_reports

Harper MP, Davison W, Tych W (1997). Temporal, spatial, and resolution constraints for in situ sampling devices using diffusional equilibration: Dialysis and DET. Environmental Science & Technology 31, 3110-3119.

Harper MP, Davison W, Tych W (1999). Estimation of pore water concentrations from DGT profiles: A modelling approach. Aquatic Geochemistry 5, 337-355.

Hesslein RH (1976) Insitu Sampler for Close Interval Pore Water Studies. Limnology and Oceanography 21, 912-914.

Isbell RF (1996). The Australian Soil Classification. CSIRO Australia.

Johnston SG, Burton ED, Keene AF, Bush RT, Sullivan LA, Isaacson L (2009). Pore Water Sampling in Acid Sulfate Soils: A New Peeker Method. *Journal of Environmental Quality* 38, 2474-2477.

MDBA (2010) Murray–Darling Basin Authority (2010). Detailed Assessment of Acid Sulfate Soils in the Murray–Darling Basin: Protocols for sampling, field characterisation, laboratory analysis and data presentation. MDBA Publication 57/10. ISBN 978-1-921557-67-5. 58 pp.

National Committee on Soil and Terrain (NCST) (2009). ‘Australian soil and land survey field handbook (3rd edn).’ CSIRO Publishing: Melbourne.

Pons LJ (1973). Outline of the genesis, characteristics, classification and improvement of acid sulphate soils. In: Dost, H. (Ed.) ‘Proceedings of the 1972 (Wageningen, Netherlands) International Acid Sulfate Soils Symposium’, Volume 1. International Land Reclamation Institute Publication 18. (Wageningen, Netherlands), pp3-27.

Rayment GE, Higginson FR (1992). ‘Australian laboratory handbook of soil and water chemical methods’. Inkata Press, Melbourne.

Schoeneberger PJ, Wysocki DA, Benham EC, Broderson WD (editors) (2002). Field book for describing and sampling soils, Version 2.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

Shand P, Merry RH, Fitzpatrick RW (2008a). Acid sulfate soil assessment of wetlands associated with Lock 8 and Lock 9 weir pools. CSIRO Land and Water Science Report 40/08.

Shand P, Edmunds WM (2008b). The baseline inorganic chemistry of European groundwaters. In, WM Edmunds & P Shand (eds.), *Natural Groundwater Quality*, 21-58. Blackwell Publishing, Oxford.

Simpson, S, Angel B, Spadaro D, Fitzpatrick, RW, Shand P, Merry RH, Thomas M (2008). Acid and Metal Mobilisation Following Rewetting of Acid Sulfate Soils in the River Murray, South Australia. CSIRO Land and Water Science Report 27/08.

Soil Survey Staff, (2003). ‘Keys to Soil Taxonomy.’ 9th edn. (United States Department of Agriculture, Soil Conservation Service, Blacksburg).
http://soils.usda.gov/technical/classification/tax_keys

Sullivan LA, Fitzpatrick RW, Bush RT, Burton ED, Shand P, Ward NJ (2010). The classification of acid sulfate soil materials: further modifications. Southern Cross GeoScience Technical Report No. 310. Southern Cross University, Lismore, NSW, Australia. 12 pp.

Sullivan LA, Ward NJ, Bush RT, Burton ED (2009) Improved identification of sulfidic soil materials by a modified incubation method. *Geoderma* 149, 33 – 38.

Taylor RM (1984) Influence of chloride on the formation of iron oxides from Fe(II) chloride. I. Effect of [Cl]/[Fe] on the formation of magnetite. *Clays and Clay Minerals* 167–174.

Teasdale PR, Batley GE, Apte SC, Webster IT (1995). Pore-Water Sampling with Sediment Peepers. *Trac-Trends in Analytical Chemistry* 14, 250-256.

van Oploo P, White I, Ford P, Melville MD, Macdonald BCT (2008a). Pore water chemistry of acid sulfate soils: Chemical flux and oxidation rates. *Geoderma* 146, 32-39.

van Oploo P, White I, Macdonald BCT, Ford P, Melville MD (2008b). The use of peepers to sample pore water in acid sulphate soils. *European Journal of Soil Science* 59, 762-770.

APPENDICES

APPENDIX 1: AUSTRALIAN ACID SULFATE SOIL IDENTIFICATION KEY

To assist users to identify types and subtypes of soils a user-friendly soil identification key was developed to more readily define and identify the various types and subtypes of acid sulfate soil and non-acid sulfate soil. The key is designed for people who are not experts in soil classification systems such as the Australian Soil Classification (Isbell 1996). Hence it has the potential to deliver soil-specific land development and soil management packages to advisors, planners and engineers working in the Murray-Darling Basin.

The soil identification key uses non-technical terms to categorise acid sulfate soils and other soils in terms of attributes that can be assessed in the field by people with limited soil classification experience. Attributes include water inundation (subaqueous soils), soil cracks, structure, texture, colour, features indicating water logging and 'acid' status – already acidified, i.e. sulfuric material, or with the potential to acidify, i.e. sulfidic material– and the depths at which they occur or change in the soil profile.

The key consists of a systematic arrangement of soils into 5 broad acid sulfate soil types, each of which can be divided into up to 6 soil subtypes. The key layout is bifurcating, being based on the presence or absence of particular soil profile features (i.e. using a series of questions set out in a key). A soil is allocated to the first type whose diagnostic features it matches, even though it may also match diagnostic features further down the key. The soil types and subtypes in the Soil Identification Key are largely in the same order as occurs in the Australian Soil Classification (Isbell 1996) and Keys to Soil Taxonomy (Soil Survey Staff 2003). A collection of plain language soil type and subtype names was developed. The 5 acid sulfate soil types in the Key are: (i) Subaqueous Soils, (ii) Organic Soils, (iii) Cracking Clay Soils, (iv) Sulfuric Soils and (v) Sulfidic Soils (Table A1-1). These are further subdivided into 17 soil subtypes based on occurrence of sulfuric material, sulfidic material, clayey or sandy layers; monosulfidic material and firmness.

Table A1-1: Summary soil identification key for acid sulfate soils. After finding the soil type, use Table A1-2 to find the soil subtype.

Diagnostic features for Soil Type	Soil Type
Does the soil occur in shallow permanent flooded environments (typically not greater than 2.5 m)?	Subaqueous soil 
No ↓ Yes →	
Does the upper 80cm of soil consist of more than 40 cm of organic material (peat)?	Organic soil 
No ↓ Yes →	
Does the soil develop cracks at the surface OR in a clay layer within 150 cm of the soil surface OR have slickensides (polished and grooved surfaces between soil aggregates), AND is the subsoil uniformly grey coloured (poorly drained or very poorly drained)?	Cracking clay soil 
No ↓ Yes →	
Does a sulfuric layer (pH<4) occur within 150 cm of the soil surface, AND is the subsoil uniformly grey coloured (poorly drained)?	Sulfuric soil 
No ↓ Yes →	
Does sulfidic material (pH>4 which changes on ageing to pH<4) occur within 150 cm of the soil surface, AND is the subsoil uniformly grey coloured (poorly drained)?	Hypersulfidic soil 
No ↓ Yes →	
Does sulfidic material (pH>4 which does not change on ageing to pH<4) occur within 150 cm of the soil surface, AND is the subsoil uniformly grey coloured (poorly drained)?	Hypsosulfidic soil 
No ↓ Yes →	
Other soils	Other soils

Table A1-2: Soil identification key for acid sulfate soil subtypes.

Soil Type	Diagnostic features for Soil Subtype		Soil Subtype	
Subaqueous soil No ↓ Yes →	Does hypersulfidic material (pH>4 which changes on ageing to pH<4) occur within 100 cm of the soil surface? AND Does a clayey layer with slickensides occur within 100 cm of the soil surface? No ↓ Yes →	Does a monosulfidic black ooze (MBO) material layer >10 cm thick occur within 50 cm of the soil surface? No ↓ Yes →	Hypersulfidic subaqueous clayey soil with MBO	1.1
	↓	→	Hypersulfidic subaqueous clayey soil	1.2
	↓	Does a sandy or loamy layer occur within 100 cm of the soil surface? No ↓ Yes →	Sulfidic subaqueous soil	1.3
	Does sulfuric material occur within 100 cm of the soil surface? No ↓ Yes →	→	Sulfuric subaqueous soil	1.4
			Subaqueous soil	1.5
Organic soil No ↓ Yes →	Does hypersulfidic material (pH>4 which changes on ageing to pH<4) occur within 100 cm of the soil surface? AND Does a clayey layer with slickensides occur within 100 cm of the soil surface? No ↓ Yes →	Does a monosulfidic black ooze (MBO) material layer >10 cm thick occur within 50 cm of the soil surface? No ↓ Yes →	Hypersulfidic organic clayey soil with MBO	2.1
			Hypersulfidic organic clayey soil	2.2
		Does a sandy or loamy layer occur within 100 cm of the soil surface? No ↓ Yes →	Hypersulfidic organic soil	2.3
	Does sulfuric material occur within 100 cm of the soil surface? AND Does a clayey layer with slickensides occur within 100 cm of the soil surface? No ↓ Yes →		Sulfuric organic clayey soil	2.4
		Does a sandy or loamy layer occur within 100 cm of the soil surface? No ↓ Yes →	Sulfuric organic soil	2.5
¹ Cracking	Does hypersulfidic	Does a monosulfidic black	Hypersulfidic cracking	3.1

Soil Type	Diagnostic features for Soil Subtype		Soil Subtype	
clay soil No ↓ Yes →	material occur within 100 cm of the soil surface? AND Does a clayey layer with slickensides occur within 100 cm of the soil surface? No ↓ Yes →	ooze (MBO) material layer >10 cm thick occur within 50 cm of the soil surface? No ↓ Yes →	clay soil with MBO	
		→	Hypersulfidic cracking clay soil	3.2
	Does sulfuric material occur within 100 cm of the soil surface? AND Does a clayey layer with slickensides occur within 100 cm of the soil surface? No ↓ Yes →		Sulfuric cracking clay soil	3.3
			Cracking clay soils	3.4
Sulfuric soil No ↓ Yes →	Does sulfuric material occur within 100 cm of the soil surface? No ↓ Yes →		Sulfuric soil	4.1
Hypersulfidic soil No ↓ Yes →	Does hypersulfidic material and a sandy to loamy layer occur within 100 cm of the soil surface?	Does a monosulfidic black ooze (MBO) material layer >10 cm thick occur within 50 cm of the soil surface? No ↓ Yes →	Hypersulfidic soil with MBO	5.1
		No ↓ Yes →	Hypersulfidic soil	5.2
Other soils			Hydrosol - sandy or loamy	6.1

¹"Cracking clay soil" is equivalent to "Vertosol" (Isbell 1996) e.g. Sulfuric cracking clay soil is similar to: "Sulfuric Vertosol". The latter terminology is used in the Legend of the "Atlas for Australian Acid Sulfate Soils" by Fitzpatrick, Powell and Marvanek (2008c)

APPENDIX 2: Site locations, Morphology, Photographs of Sites, Profiles and Samples

Site ID	Site Label	Date Sampled	Zone	Easting (m)	Northing (m)	Soil samples	Water samples	Soil pore water	Water Depth (cm)
adhoc	Fc 1019	19-Dec-09	54H	308084	6073635	crystals			-30
FIN20-M2	Fc 1009	19-Dec-09	54H	305780	6073929	4	1		60
FIN23-M2	Fc 1013	19-Dec-09	54H	305749	6074048	3			80
FIN25-M2	Fc 1016	19-Dec-09	54H	305810	6074052	3	1		90
FIN27-M2	Fc 1004	19-Dec-09	54H	306199	6075065	3			100
FIN28-M2	Fc 1001	19-Dec-09	54H	305967	6075101	3	1	1	120
FIN31-M2	Fc 1023	19-Dec-09	54H	308025	6073670	2	1		100
FIN32-M2	Fc 1020	19-Dec-09	54H	308052	6073690	3			20
FIN36-M2	Fc 1007	19-Dec-09	54H	306744	6076221	2	1		100
adhoc	Fc 1073	20-Dec-09	54H	296819	6074191		1		150
adhoc	Fc1074	21-Dec-09	54H	303199	6079683			1	130
CUR11-M2	Fc 1040	19-Dec-09	54H	302368	6070522	3			50
CUR12-M2	Fc 1037	19-Dec-09	54H	302328	6070504	3	1		60
CUR13-M2	Fc 1043	19-Dec-09	54H	302274	6070677	4			?
CUR16-M2	Fc 1033	19-Dec-09	54H	305386	6070903	3			100
CUR17-M2	Fc 1025	19-Dec-09	54H	305340	6071128	4	1		70
CUR18-M2	Fc 1029	19-Dec-09	54H	305203	6071480	4		1	50
CUR20-M2	Fc 1070	20-Dec-09	54H	298354	6073692	3	1		130
CUR21-M2	Fc 1066	20-Dec-09	54H	298360	6073708	4			50
CUR23-M2	Fc 1057	20-Dec-09	54H	298538	6073745	5			95
CUR24-M2	Fc 1056	20-Dec-09	54H	298561	6073753		1		160
CUR25-M2	Fc 1062	20-Dec-09	54H	298426	6073792	4		1	70
CUR26-M2	Fc 1053	20-Dec-09	54H	301102	6072838	3			150
CUR27-M2	Fc 1048	20-Dec-09	54H	301055	6072892	5	1		80
FIN24M4-5	LFa01-A	4-Nov-09	54H	303196	6079705	3			110
FIN26M3-4	LFa01-B	4-Nov-09	54H	303215	6079640	3			?
AA26	LFa01-C	4-Nov-09	54H	?	?	5			135
FIN26M4-2	LFa01-D	4-Nov-09	54H	303087	6079610	1			60
Total No						80	11	4	

Soil morphology of samples collected 19 and 21st December 2009. Some Wally's Landing samples were collected in November 2009.

Sample ID	Site Label	Locality description	Sampling tool	Upper depth (cm)	Lower depth (cm)	Morphology
LFa01-A.1	FIN24M4-5.1	Finniss River: Wally's Landing and Wetland - Middle of drainage ditch located to the north east of the Finniss River in approximately 110 cm of water. Reeds growing from water near banks. Bed of ditch comprised polygonally cracked soils (cracks > 15 cm). Significant Phragmites growth since first sampling and water level had fallen from 1.1 m. Subaqueous .	Spade/ Gouge Auger	0	10	Dark brown to black light to medium clay gel containing very dark brown silty clay peds with monosulfidic material and sub-rounded quartz gravel (0.5 – 2 cm) (sampled from polygonally crack soil).
LFa01-A.2	FIN24M4-5.2			10	40	Dark brown grey medium clay with vertical cracks commonly infilled with medium sand and coated with jarosite. Jarosite was more diffuse from 10 to 15 cm and more prominent and bright below 15 cm.
LFa01-A.3	FIN24M4-5.3			40	60	Dark green grey medium clay.
LFa01-B.1	FIN26M3-4.1	Finniss River: Wally's Landing and Wetland Middle of drainage ditch located to the north east of the Finniss River in approximately 80 cm of water. Reeds growing from water near banks. Bed of ditch comprised polygonally cracked soils (cracks > 15 cm). Significant Phragmites growth since first sampling and water level had fallen from 1.3 m. Subaqueous .	Spade/ Gouge Auger	0	20	Very dark grey to black light to medium clay gel containing peds of fine sandy clay loam. Layer of sub-rounded quartz gravel from 18 to 20 cm.
LFa01-B.2	FIN26M3-4.2			20	50	Grey light to medium clay with few diffuse yellow mottles along root channels. Vertical cracks to 50 cm infilled with medium sand with many prominent yellow jarosite mottles. Jarosite mottles were more prominent at depth but less than in first sampling.
LFa01-B.3	FIN26M3-4.3			50	60	Dark green grey medium clay.
LFa01-C.1	AA26.1		D-Auger	0	10	Very dark brownish grey sapric light

Sample ID	Site Label	Locality description	Sampling tool	Upper depth (cm)	Lower depth (cm)	Morphology
		Finniss River: Wally's Landing and Wetland. Southern side of Finniss River channel at the end of Wally's Jetty in approximately 135 cm of water. Subaqueous.				medium clay with monosulfidic material. Strong organic smell and many matted roots.
LFa01-C.2	AA26.2			10	50	Olive grey light medium clay with bands (< 1 cm) of black light medium clay.
LFa01-C.3	AA26.3			50	100	Olive grey light medium clay with bands (< 1 cm) of black light medium clay.
LFa01-C.4	AA26.4			100	150	Olive grey light medium clay with bands (< 1 cm) of black light medium clay (100 to 115 cm). Blac*k light medium clay (115 to 150 cm)
LFa01-C.5	AA26.5			180	200	Light olive grey medium to heavy clay. Strong smell of H ₂ S. Layer of rounded to sub-rounded platy quartz gravel from 170 to 173 cm.
LFa01-D.1	FIN26M4-2.1	Finniss River: Wally's Landing and Wetland Southern side of Finniss River channel on western side of Wally's Jetty, approximately one metre from the bank under 60 cm water. Subaqueous.	Spade	0	5	Dark grey to black silty clay with areas of black clay gel with monosulfidic material. Distinct brown and orange brown mottles (20 %). Many roots from 0 to 0.5 cm.
LFa01-D.2	FIN26M4-2.2			5	15	Grey brown and brown sandy clay. Common roots with yellow jarosite mottles and coatings (30 – 35 %) along root channels and on surfaces.
FIN20-M2	FC1009			0	6	Black clay with organic black clayey gel with monosulfidic material. Many dead roots from 0 to 1 cm, soft.
FIN20-M2	FC1010			6	12	Dark greyish brown, heavy clay. Common

Sample ID	Site Label	Locality description	Sampling tool	Upper depth (cm)	Lower depth (cm)	Morphology
						roots with distinct yellow jarosite mottles and coatings (30 – 35 %) along root channels and on surfaces of subangular blocky structures
FIN20-M2	FC1011	Finniss River: Airstrip site –closest site to main bank adjacent to airstrip with very wide cracks still clearly evident under 60 cm water. Subaqueous.	D-Auger	12	25	Grey, heavy clay. Common roots with distinct yellow jarosite mottles and coatings (30 – 35 %) along root channels and on surfaces of subangular blocky structures.
FIN20-M2	FC1012			25	50	Dark grey, heavy clay with subangular blocky structures.
FIN23-M2	FC1013			0	10	Black with surface layer of gel with monosulfidic material , light clay with organic/ peat with many dead roots from 0 to 1 cm, soft.
FIN23-M2	FC1014	Finniss River: Airstrip site –middle site near Phragmites with cracks still clearly evident under 80 cm water. Subaqueous.	Spade/ D-Auger	10	25	Dark grey brown with distinct yellow jarosite mottles and coatings (15 %) along root channels and on surfaces of subangular blocky structures, heavy clay, common roots.
FIN23-M2	FC1015			25	50	Dark grey brown heavy clay, very soft
FIN25-M2	FC1016			0	15	Black, sapric peat and many matted roots with monosulfidic material. Strong organic smell
FIN25-M2	FC1017	Finniss River: Airstrip site –furthest site from main bank; just outside the main entrance waterway / channel of whole wetland with some cracks still clearly evident under 90 cm water. Subaqueous.	Spade/ D-Auger	15	30	Dark grey matrix with blackish brown mottles and distinct yellow jarosite mottles and coatings (10 %) along root channels and on surfaces of subangular blocky structures, heavy clay, common roots.

Sample ID	Site Label	Locality description	Sampling tool	Upper depth (cm)	Lower depth (cm)	Morphology
FIN25-M2	FC1018			30	60	Dark grey brown, heavy clay, very soft
FIN27-M2	FC1004			0	5	Black, sapric peat, clayey and many matted roots with monosulfidic material. Strong organic smell.
FIN27-M2	FC1005	Finniss River: Finniss River Estate (Peter Elmes) site –furthest site from main bank; just outside the main entrance waterway / channel of whole wetland with few cracks evident because of organic mulch on surface under 100 cm water. Subaqueous.	Spade/ Gouge Auger/ D-Auger	5	20	Black, heavy clay with few roots with distinct yellow jarosite mottles and coatings (5 %) along root channels and on surfaces, very soft.
FIN27-M2	FC1006			20	50	Dark greyish olive green, heavy clay, very soft
FIN28-M2	FC1001			0	5	Black, medium clay with monosulfidic material.
FIN28-M2	FC1002	Finniss River: Finniss River Estate (Peter Elmes) site –nearest site from main bank; in main wetland or back swamp with many cracks evident under 120 cm water. Subaqueous.	Spade/ Gouge Auger/ D-Auger	5	20	Dark grey, heavy clay with many roots with distinct yellow jarosite mottles and coatings (30 %) along root channels and on surfaces of subangular blocky structures, very soft.
FIN28-M2	FC1003			20	60	Dark grey and greenish olive, heavy clay with few roots with few diffuse yellow jarosite mottles and coatings (15 %) along root channels and on surfaces of subangular blocky structures, very soft.
FIN31-M2	FC1023	Finniss River: Midway on old shoreline 50m from water edge under 100 cm water. Subaqueous.	Spade/ Gouge Auger	0	20	0-2 cm (not sampled) black, medium sand with monosulfidic material. Grey, sand, few relic roots with distinct yellowish jarosite mottles (20 %), distinct brownish red and brown mottles (5 %), soft

Sample ID	Site Label	Locality description	Sampling tool	Upper depth (cm)	Lower depth (cm)	Morphology
FIN31-M2	FC1024			20	70	Grey, loamy sand, relic roots with distinct yellowish jarosite mottles (10 %), distinct brownish red and brown mottles (5 %), soft
FIN32-M2	FC1020	Finniss River: high, in reeds before step up under 20 cm water. Subaqueous.	Spade/ Gouge Auger	0	15	0-2 cm (not sampled) black, medium sand with monosulfidic material. Grey, sand, very few relic roots, soft
FIN32-M2	FC1021			15	25	Dark grey brownish grey sand, soft.
FIN32-M2	FC1022			25	80	Dark brownish grey sand, friable
FIN36-M2	FC1007			0	10	Black, sandy clay loam, with monosulfidic material, soft.
FIN36-M2	FC1008	Finniss River: low, 10m from shoreline under 100 cm water. Subaqueous.	Spade/ Gouge Auger	10	20	Black, medium clay, with some monosulfidic material in cracks, very soft.
FC1019	FC1019	Sample taken of salts (pH 2.69)	Spade	0	0.5	Greenish and white salts (pH 2.69)
CUR11-M2	FC1040	0	2	Dark greyish medium clay with cracks and monosulfidic material in cracks and on surface.		
CUR11-M2	FC1041	Currency Creek: Goolwa North site 4 metres from shore, cracks in soil surface filled with MBO under 50 cm water. Subaqueous.	Spade/ Gouge Auger	2	20	Dark grey medium clay soft with strong jarosite mottles (15 %) in old pores and cracks.
CUR11-M2	FC1042			20	50	Dark grey light clay becoming more sandy with depth, very soft. Slight sulfidic smell.
CUR12-M2	FC1037			0	10	Dark brown with monosulfidic material, sandy clay loam, friable
CUR12-M2	FC1038	Currency Creek: Goolwa North site 15m from shore under 60 cm water. Subaqueous.	Spade/ Gouge Auger	10	25	Dark grey sandy loam with few distinct yellowish brown mottles (5 %) associated with vertical root channels, soft

Sample ID	Site Label	Locality description	Sampling tool	Upper depth (cm)	Lower depth (cm)	Morphology
CUR12-M2	FC1039			25	80	Dark grey loamy sand with few shell fragments
CUR13-M2	FC1043	Currency Creek: Goolwa North site 80m from shore under 100 cm water. Subaqueous.	Spade/ Gouge Auger	0	4	Very dark greyish brown with monosulfidic material, clay loam, peaty with some organic matter / many fine roots.
CUR13-M2	FC1044			4	20	Dark greyish light clay loam, peaty with some organic matter / many fine roots and with strong jarosite mottles (10 %).
CUR13-M2	FC1045			20	30	Grey sandy loam with common reddish yellowish mottles along root channels.
CUR13-M2	FC1046			30	100	Dark grey sandy loam with > 5% shell fragments, pieces and whole shells at depth.
CUR16-M2	FC1033	Goolwa Channel transect: furthest site from main bank about 80m from shore on edge of main channel no cracks evident under 100 cm water. Subaqueous.	Spade/ Gouge Auger	0	5	Very dark brown with monosulfidic material, medium sand with very few medium brown and red brown mottles, soft.
CUR16-M2	FC1034			5	30	Dark grey medium sandy, firm, layer with black upper 10cm of fibrous organic material with a lower light grey and shell fragments
CUR16-M2	FC1035			30	60	Dark grey to olive grey medium sandy, firm
CUR16-M2	FC1036			60	65	Dark grey to olive grey clayey sand, very soft.
CUR17-M2	FC1025	Goolwa Channel transect: middle site on an old beach shoreline	Spade/ Gouge Auger	0	5	Black peaty with monosulfidic material, soft.
CUR17-M2	FC1026			5	40	Dark brown, sandy with strong jarosite

Sample ID	Site Label	Locality description	Sampling tool	Upper depth (cm)	Lower depth (cm)	Morphology
		with no cracks evident because of sand covering clay under 70 cm water. Subaqueous.				mottles (20 %), firm.
CUR17-M2	FC1027			40	50	Light brownish grey, sandy loam, with strong jarosite mottles (15 %), firm.
CUR17-M2	FC1028			50	70	Light olive brown to greenish olive grey with many prominent reddish yellow mottles, medium clay, very firm.
CUR18-M2	FC1029	Goolwa Channel transect: closest site from main bank - midway to steep up into reeds no cracks evident under 50 cm water. Subaqueous.	Spade/ Gouge Auger	0	5	Black with monosulfidic material, medium sand, loose.
CUR18-M2	FC1030			5	15	Dark grey with strong jarosite mottles (20 %), medium sand, loose.
CUR18-M2	FC1031			15	25	White with strong jarosite mottles (10 %) medium sand , friable
CUR18-M2	FC1032			25	50	Greyish brown, medium sand, firm
CUR20-M2	FC1070			0	5	Dark grey matrix with black monosulfidic material, medium loamy sand, soft.
CUR20-M2	FC1071	Currency Creek: 2m into main water channel under 130 cm water. Subaqueous.	Spade/ Gouge Auger	5	10	Dark grey, medium clay, soft.
CUR20-M2	FC1072			10	50	Dark olive green, medium clay with weak subangular structure, quartz fragments and some shells.
CUR21-M2	Fc 1066			0	10	Black matrix with grey mottles and some black monosulfidic material, peaty medium loamy sand, soft.
CUR21-M2	Fc 1067	Currency Creek: near reeds, 20m from main water channel under 50 cm water. Subaqueous.	Spade/ Gouge Auger	10	20	Dark grey with black mottles, medium sandy loam, friable.
CUR21-M2	Fc 1068			20	35	Dark grey, sandy clay loam, friable.

Sample ID	Site Label	Locality description	Sampling tool	Upper depth (cm)	Lower depth (cm)	Morphology
CUR21-M2	Fc 1069			35	70	Dark olive green to black, medium clay, soft.
CUR23-M2	FC1057	Currency Creek: Near water edge Under 95 cm water. Subaqueous.	Spade/ Gouge Auger	0	5	Dark greyish brown with black with monosulfidic material and reddish brwn mottles (10%), medium sand, soft.
CUR23-M2	FC1058			5	15	Dark grey with strong jarosite mottles (10 %), light clay , strong subangular structure. Sharp boundary to underlying layer.
CUR23-M2	FC1059			15	35	Dark olive green to black, medium clay, soft.
CUR23-M2	FC1060			35	40	Dark olive green to black, medium clay, soft.
CUR23-M2	FC1061			40	70	Dark olive green to black, medium clay, very soft.
CUR25-M2	FC1062	Currency Creek: high, 20m in wetland from step up to reeds along water edge under 50 cm water. Subaqueous.	Spade/ Gouge Auger	0	1	Orange gel with black monosulfidic material, medium sand, very soft.
CUR25-M2	FC1063			1	5	Black with monosulfidic material, medium sand, soft.
CUR25-M2	FC1064			5	20	Grey, with distinct yellow jarosite mottles (10 %) on surfaces of peds and old root channels, diffuse brownish red and brown mottles (5 %) and black mottles (5 %); sandy clay , subangular blocky, soft.
CUR25-M2	FC1065			20	60	Dark olive green to grey, medium clay, soft
CUR26-M2	FC1053	Currency Creek: Jetty + vineyard + homestead view site 80m	Spade/ Gouge	0	5	Black with some monosulfidic material, medium sand, soft.

Sample ID	Site Label	Locality description	Sampling tool	Upper depth (cm)	Lower depth (cm)	Morphology
CUR26-M2	FC1054	plus from jetty / shore under 150 cm water. Subaqueous.	Auger	5	15	Dark brown, loamy sand, soft
CUR26-M2	FC1055			15	90	Dark brownish grey, loamy sand, soft with few shells
CUR27-M2	FC1048	Currency Creek: Jetty + vineyard + homestead view site 10m from reeds under 80 cm water. Subaqueous.	Spade/ Gouge Auger	0	2	Black with some monosulfidic material, medium sand, soft
CUR27-M2	FC1049			2	15	Grey, loamy sand, relic roots with distinct yellowish jarosite mottles (20 %), distinct brownish red and brown mottles (5 %), soft
CUR27-M2	FC1050			15	30	Grey, loamy sand, relic roots with distinct yellowish jarosite mottles (20 %), distinct brownish red and brown mottles (5 %), soft
CUR27-M2	FC1051			30	60	Grey loamy sand with reddish brown mottles (5 %). Common relic roots with common jarosite mottles along root channels, soft
CUR27-M2	FC1052			60	90	Dark grey to olive , loamy sand with common relic roots with few jarosite mottles along root channels, soft

Wetland, profile and chip-tray photographs

Wally's Landing and Wetlands sites

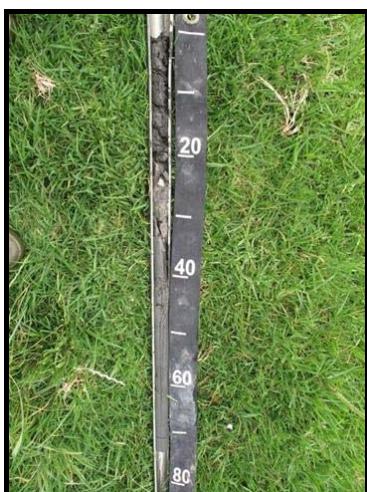
LFa01-A - 2009



LFb01-A – 2010 (from Baker *et al.* 2010)



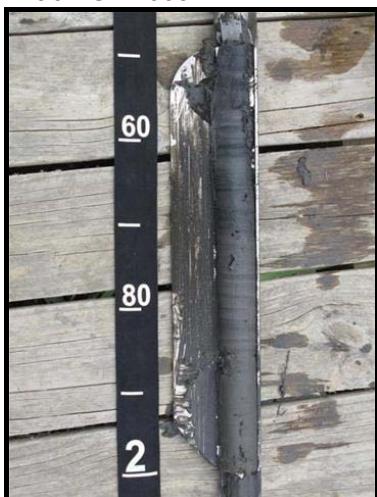
LFa01-B - 2009



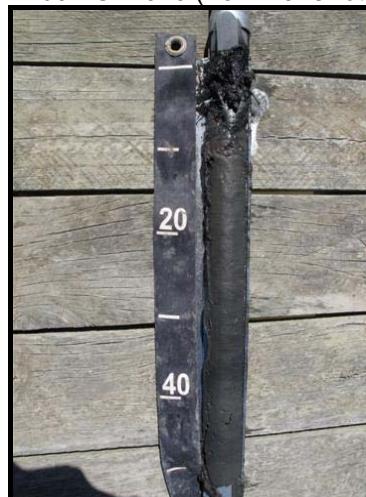
LFb01-B- 2010 (from Baker *et al.* 2010)



LFa01-C - 2009



LFb01-C- 2010 (from Baker *et al.* 2010)



LFa01-D - 2009



LFb01-D - 2010



Finniss River and Wetlands sites

Finniss River: Airstrip site – closest site to main bank adjacent to airstrip with very wide cracks still clearly evident under 60 cm water. **Subaqueous**.

FIN_20 – wetland 2009; see also Figure 4-2



FIN_20 – 2009: core taken using D-auger



FIN_20 – Chip-tray - 2009



Finniss River: Airstrip site –middle site near Phragmites with cracks still clearly evident under 80 cm water.

Subaqueous.

FIN_23 – wetland – 2009; FIN 23 – Core profile using D-auger



FIN_23 – chip-tray - 2009



Finniss River: Airstrip site –furthest site from main bank; just outside the main entrance waterway / channel of whole wetland with some cracks still clearly evident under 90 cm water. **Subaqueous.**

FIN_25 – wetland - 2009



FIN_25 – Chip-tray



FIN 25 – Profile using D-Auger



Finniss River: Finniss River Estate (Peter Elmes) site –furthest site from main bank; just outside the main entrance waterway / channel of whole wetland with few cracks evident because of organic mulch on surface under 100 cm water. **Subaqueous.**

FIN_27 – wetland 2009



FIN_chip-tray



Finniss River: Finniss River Estate (Peter Elmes) site –nearest site from main bank; in main wetland or back swamp with many cracks evident under 120 cm water. **Subaqueous.**

FIN 28 wetland 2009

FIN_28 Chip tray



Finniss River: Midway on old shoreline 50m from water edge under 100 cm water.

Subaqueous.

FIN_31 view of sampling site

FIN 31 – Chip-tray



Finniss River: high, in reeds before step up under 20 cm water. **Subaqueous.**

FIN_32 near site

FIN 32 – Chip-tray



Currency Creek and Wetlands sites

Currency Creek: Goolwa North site 80m from shore under 100 cm water. Subaqueous. No CUR 13



Top photograph “Sulfuric cracking clay soil” subtype in the dry river bed of Goolwa Channel - Currency Creek area, near north Goolwa (No CUR 13 sampled in November 2008), looking west towards to the Adelaide Hills, South Australia. This shows: (i) trans-horizon polygonal cracks with very coarse columnar ped structures; the result of desiccation and dewatering of a former “Hypersulfidic subaqueous clayey soil” during drying cycles due to recent extreme drought conditions; (ii) surface coating of the reddish-brown mineral, schwertmannite, which has a pH ranging between 3.0 and 3.6 (sulfuric material), (iii) sulfuric material ($\text{pH} < 4$) with pale yellow mottles of natrojarosite in a dark grey clay matrix between 10 cm to 30 cm, and (iv) very dark grey hypersulfidic material (iron sulfides) at depth ($> 30 \text{ cm}$).

With the receding water levels due to extreme drought conditions between 2006 and 2009 the previously hypersulfidic subaqueous soil, which contains abundant pyrite (FeS_2) has been exposed, dried and reacted with oxygen from the air to form sulfuric clay soils that have large cracks with columnar structures.

Bottom photograph taken at same locality in December 2009 after reflooding due to winter rainfall runoff from adjacent catchments and pumping from Lake Alexandrina following installation of the temporary flow regulator across the Goolwa Channel at Clayton Bay. The reflooded Acid Sulfate Soil stayed submerged under 80 cm of water for a period of six months and remained largely acidic (i.e. Sulfuric subaqueous clay) except for a thin 5 cm thick surface layer comprising black monosulfidic material, which overlies sulfuric material with pale yellow mottles of natrojarosite (second layer) and dark grey hypersulfidic material below 30 cm.

Goolwa Channel transect: closest site from main bank - midway to steep up into reeds
no cracks evident under 50 cm water. **Subaqueous.**

CUR 18 - site



CUR 18 - profile



CUR 18 – chip-tray



Currency Creek: 2m into main water channel under 130 cm water. **Subaqueous.**
CUR 20 near site



CUR 20 – chip tray



Currency Creek: near reeds, 20m from main water channel under 50 cm water. **Subaqueous.**
CUR 21 near site

CUR 21 chip tray samples



Currency Creek: Near water edge Under 95 cm water. **Subaqueous**
CUR 23 chip tray samples



Currency Creek: high, 20m in wetland from step up to reeds along water edge under 50 cm water. **Subaqueous**
CUR 25 chip tray samples

CUR 25 soil profile



CUR 25 chip tray samples



Currency Creek: Jetty + vineyard + homestead view site 80m plus from jetty / shore under 150 cm water. **Subaqueous.**
CUR 26 wetland site **CUR 26 chip tray samples**



Currency Creek: Jetty + vineyard + homestead view site 10m from reeds under 80 cm water. **Subaqueous.**
CUR 27 chip tray samples



APPENDIX 3: LABORATORY RESULTS – SOIL PH TESTING AND ACID BASE ACCOUNTING PARAMETERS

A complete set of all data is provided in an Excel database that accompanies this report – presented in this Appendix is listed the main data parameters and results.

The methods are described in the methods section.

All analysis is based on dry weight. Results at or below detection limits are replaced with '0' for calculation purposes.

The table columns present the data in the following order:

1. Site ID Number – unique alphanumeric site identification (FIN – sites from Finniss River, CUR – sites from currency creek).
2. Layer ID Number – unique alphanumeric number allocated to each soil sample
3. Depth range – depth range of layer that sample was collected from
4. EC – electrical conductivity
5. pH water – pH unit of the soil water
6. pH_{Ox} – pH unit of the soil after peroxide treatment
7. pH_{incubation} – pH unit of the soil at the start (0 week) and after incubation for 9 weeks (
8. Texture laboratory – texture of the soil as characterised by the laboratory prior to analysis, there are 3 categories; coarse, medium and fine
9. pH_{KCl} – pH unit of the soil after KCl treatment
10. Total Actual Acidity –
11. Chromium reducible sulfur – reduced inorganic sulfur measured as % chromium reducible sulfur
12. Acid neutralising capacity - acid neutralising capacity expressed as equivalent % CaCO₃ and mole H⁺/t
13. Retained Acidity – retained acidity
14. Net Acidity – Potential Sulfidic Acidity (i.e. S_{CR}) + Titratable Actual Acidity + Retained Acidity - measured ANC/FF.
Note FF (fineness factor) set at 1.5
15. Acid sulfate soil material category – soil layer allocated based on criteria presented in Section 1.5

Site ID.	Layer ID.	Depth Range	EC	pH _w	pH _{Ox}	pH incubation		Texture Laboratory	pH _{KCl}	Total Actual Acidity	Chromium Reducible Sulfur		Acid Neutralising Capacity		Retained Acidity	Net Acidity	Acid Sulfate Soil Material
				cm	ms	unit	unit				category	unit	mole H ⁺ /t	%S _{CR}	mole H ⁺ /t	%CaCO ₃	mole H ⁺ /t	mole H^{+}/t	category
FIN20-M2	FC1009	0 - 6	0.73	5.60	1.24	4.91	4.08	Medium	4.31	129.98	0.19	119.51	..	0.00	34.71	283.20	hyposulfidic (S _{CR} ≥ 0.10%)
FIN20-M2	FC1010	6 - 12	3.18	3.25	1.38	3.37	2.96	Medium	3.46	172.51	0.13	81.08	..	0.00	124.90	378.48	sulfuric
FIN20-M2	FC1011	12 - 25	5.98	3.45	1.18	3.26	2.37	Fine	3.65	180.24	1.18	735.98	..	0.00	94.96	1011.18	sulfuric
FIN20-M2	FC1012	25 - 50	5.47	6.79	1.29	7.90	1.97	Fine	6.17	11.60	1.69	1054.08	..	0.00	0.00	1065.67	hypersulfidic
FIN23-M2	FC1013	0 - 10	1.87	4.75	1.44	4.05	3.98	Medium	4.10	180.72	0.35	218.30	..	0.00	56.60	455.62	hypersulfidic
FIN23-M2	FC1014	10 - 25	4.30	4.18	1.40	3.24	2.52	Fine	3.72	142.55	0.80	498.97	..	0.00	56.60	698.12	Hypersulfidic sulfuric
FIN23-M2	FC1015	25 - 50	2.92	6.80	1.13	7.79	1.99	Fine	6.30	3.87	1.65	1029.13	..	0.00	0.00	1032.99	hypersulfidic
FIN25-M2	FC1016	0 - 15	1.10	5.14	1.43	5.16	2.74	Medium	4.65	76.83	0.43	268.20	..	0.00	0.00	345.03	hypersulfidic
FIN25-M2	FC1017	15 - 30	1.60	4.86	1.14	4.38	1.90	Fine	4.36	71.51	0.89	555.11	..	0.00	37.33	663.95	hypersulfidic
FIN25-M2	FC1018	30 - 60	2.18	7.47	1.41	8.22	2.05	Fine	6.31	3.38	1.63	1016.65	..	0.00	0.00	1020.04	hypersulfidic
FIN27-M2	FC1004	0 - 5	0.80	4.97	1.07	4.55	3.14	Medium	3.96	106.31	0.57	355.52	..	0.00	92.90	554.72	hypersulfidic
FIN27-M2	FC1005	5 - 20	2.27	4.00	1.23	3.76	2.29	Fine	3.74	98.57	0.37	230.77	..	0.00	88.97	418.32	hypersulfidic
FIN27-M2	FC1006	20 - 50	3.56	6.70	1.25	6.83	1.90	Fine	5.65	32.37	1.74	1085.26	..	0.00	0.00	1117.64	hypersulfidic
FIN28-M2	FC1001	0 - 5	2.09	5.07	1.59	4.62	3.24	Fine	4.23	104.86	0.16	99.79	..	0.00	52.67	257.32	hypersulfidic
FIN28-M2	FC1002	5 - 20	3.51	3.72	1.40	3.14	2.30	Fine	3.63	175.40	0.61	380.47	..	0.00	162.32	718.19	sulfuric
FIN28-M2	FC1003	20 - 60	5.20	4.99	1.53	3.37	1.88	Fine	5.43	34.31	1.70	1060.31	..	0.00	21.52	1116.14	Hypersulfidic sulfuric
FIN31-M2	FC1023	0 - 20	0.95	3.49	2.31	3.86	2.85	Course	5.76	4.35	<0.01	0.00	..	0.00	0.00	4.35	sulfuric
FIN31-M2	FC1024	20 - 70	0.97	4.42	1.42	4.80	2.00	Course	5.32	8.70	0.05	31.19	..	0.00	0.00	39.88	hypersulfidic
FIN32-M2	FC1020	0 - 15	0.55	7.15	4.68	8.07	7.04	Course	6.31	1.45	0.01	6.24	..	0.00	0.00	7.69	other soil material
FIN32-M2	FC1021	15 - 25	0.67	7.16	3.95	7.85	6.24	Course	6.26	2.42	0.01	6.24	..	0.00	0.00	8.65	other soil material
FIN32-M2	FC1022	25 - 80	0.91	7.14	1.30	7.03	2.01	Course	6.24	1.93	0.11	68.61	..	0.00	0.00	70.54	hypersulfidic
FIN36-M2	FC1007	0 - 10	0.50	7.94	1.34	8.00	2.05	Medium	6.44	2.42	0.17	106.03	..	0.00	0.00	108.45	hypersulfidic
FIN36-M2	FC1008	10 - 70	0.70	8.22	1.25	8.30	1.80	Medium	6.22	4.35	0.63	392.94	..	0.00	0.00	397.29	hypersulfidic sulfuric
FC1019	FC1019	0 - 0.5	..	..	..	2.69	1.02	..	..	..	..	..	..	..	..	..	..
CUR11-M2	FC1040	0 - 2	1.82	7.15	6.52	7.45	7.52	Medium	9.10	0.00	0.08	49.90	2.53	505.49	0.00	-287.10	hyposulfidic (S _{CR} < 0.10%)
CUR11-M2	FC1041	2 - 20	2.27	3.84	2.14	3.51	3.34	Medium	4.45	24.18	0.01	6.24	..	0.00	42.99	73.41	sulfuric
CUR11-M2	FC1042	20 - 50	2.75	7.67	6.19	7.67	7.49	Medium	8.99	0.00	0.36	224.54	11.23	2243.75	0.00	-1271.30	hyposulfidic (S _{CR} ≥ 0.10%)
CUR12-M2	FC1037	0 - 10	1.04	7.43	5.88	8.02	5.19	Medium	8.18	0.00	0.27	168.40	1.07	213.79	0.00	25.88	hyposulfidic (S _{CR} ≥ 0.10%)
CUR12-M2	FC1038	10 - 25	2.10	4.06	2.60	6.20	3.96	Medium	5.04	14.03	<0.01	0.00	..	0.00	0.00	14.03	other acidic
CUR12-M2	FC1039	25 - 80	3.53	6.88	6.04	6.48	3.71	Medium	8.67	0.00	0.03	18.71	0.48	95.90	0.00	-45.22	hypersulfidic
CUR13-M2	FC1043	0 - 4	1.71	6.61	2.74	7.18	5.45	Medium	7.28	0.00	0.05	31.19	0.35	69.93	0.00	-15.43	hyposulfidic

Site ID.	Layer ID.	Depth Range	EC	pH _w	pH _{Ox}	pH incubation		Texture Laboratory	pH _{KCl}	Total Actual Acidity	Chromium Reducible Sulfur		Acid Neutralising Capacity		Retained Acidity	Net Acidity	Acid Sulfate Soil Material
				cm	ms	unit	unit				category	unit	mole H ⁺ /t	%S _{CR}	mole H ⁺ /t	%CaCO ₃	mole H ⁺ /t	mole H^{+}/t	category
CUR13-M2	FC1044	4 - 20	2.39	3.90	2.05	3.86	3.35	Fine	4.19	32.41	0.05	31.19	..	0.00	45.19	108.78	(S _{CR} < 0.10%) sulfuric
CUR13-M2	FC1045	20 - 30	3.56	6.79	2.34	5.63	3.37	Medium	4.71	23.22	0.18	112.27	..	0.00	0.00	135.48	hypersulfidic
CUR13-M2	FC1046	30 - 100	2.18	7.58	6.19	7.79	7.05	Medium	9.13	0.00	0.16	99.79	5.69	1136.86	0.00	-658.11	hypersulfidic (S _{CR} ≥ 0.10%) no sample
CUR13-M2	FC1047	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	hypersulfidic (S _{CR} < 0.10%)
CUR16-M2	FC1033	0 - 5	0.93	7.55	6.03	7.74	7.53	Medium	9.25	0.00	0.04	24.95	0.73	145.85	0.00	-72.29	hypersulfidic (S _{CR} > 0.10%)
CUR16-M2	FC1034	5 - 30	2.66	7.35	6.58	7.54	7.75	Medium	9.02	0.00	0.28	174.64	6.56	1310.69	0.00	-699.15	hypersulfidic (S _{CR} ≥ 0.10%)
CUR16-M2	FC1035	30 - 60	0.92	8.37	7.03	8.60	7.90	Medium	8.74	0.00	1.41	879.44	3.00	599.40	0.00	479.84	hypersulfidic (S _{CR} ≥ 0.10%)
CUR16-M2	FC1036	60 - 65	..	..	..	8.88	8.40	..	..	..	..	..	..	..	..	..	..
CUR17-M2	FC1025	0 - 5	1.36	6.73	4.07	6.52	4.26	Medium	6.75	0.00	0.02	12.47	0.12	23.98	0.00	-3.51	hypersulfidic (S _{CR} < 0.10%)
CUR17-M2	FC1026	5 - 40	3.04	3.04	2.15	4.38	2.63	Medium	4.77	30.93	0.01	6.24	..	0.00	0.00	37.16	sulfuric
CUR17-M2	FC1027	40 - 50	2.92	3.48	1.45	3.39	1.94	Medium	4.08	108.72	1.25	779.64	..	0.00	35.27	923.63	sulfuric
CUR17-M2	FC1028	50 - 70	2.08	5.31	1.80	4.19	2.01	Medium	4.50	49.77	1.38	860.72	..	0.00	0.00	910.50	hypersulfidic
CUR18-M2	FC1029	0 - 5	0.85	7.17	3.98	6.99	5.46	Course	6.49	1.93	0.01	6.24	..	0.00	0.00	8.17	other acidic
CUR18-M2	FC1030	5 - 15	1.60	3.11	2.10	3.12	2.79	Medium	4.11	29.50	0.01	6.24	..	0.00	32.18	67.92	sulfuric
CUR18-M2	FC1031	15 - 25	2.39	3.06	1.78	2.98	2.10	Medium	3.71	88.03	0.24	149.69	..	0.00	113.39	351.11	sulfuric
CUR18-M2	FC1032	25 - 50	1.77	7.08	6.17	7.11	6.67	Medium	8.29	0.00	1.77	1103.97	3.42	683.32	0.00	648.43	Hyposulfidic (S _{CR} ≥ 0.10%)
CUR20-M2	FC1070	0 - 5	1.63	5.26	1.34	5.33	2.74	Medium	5.07	26.60	0.21	130.98	..	0.00	0.00	157.58	hypersulfidic
CUR20-M2	FC1071	5 - 10	1.84	4.88	1.04	5.29	2.27	Fine	4.52	46.40	0.59	367.99	..	0.00	0.00	414.39	hypersulfidic
CUR20-M2	FC1072	10 - 50	3.01	6.50	1.48	8.08	2.51	Fine	5.86	19.80	1.15	717.27	..	0.00	0.00	737.07	hypersulfidic
CUR21-M2	FC1066	0 - 10	1.23	4.94	2.08	5.59	4.86	Medium	4.72	44.98	0.08	49.90	..	0.00	0.00	94.88	Hyposulfidic (S _{CR} < 0.10%)
CUR21-M2	FC1067	10 - 20	1.81	5.09	1.60	5.14	4.14	Medium	4.79	16.44	0.02	12.47	..	0.00	0.00	28.92	Hypersulfidic (S _{CR} < 0.10%)
CUR21-M2	FC1068	20 - 35	2.70	4.15	1.41	3.88	3.50	Medium	4.28	40.63	0.05	31.19	..	0.00	19.93	91.74	hypersulfidic
CUR21-M2	FC1069	35 - 70	3.57	5.79	1.34	6.08	2.08	Fine	4.11	81.30	1.06	661.14	..	0.00	36.02	778.46	hypersulfidic
CUR23-M2	FC1057	0 - 5	1.40	4.80	2.23	4.79	3.74	Fine	4.19	49.33	0.04	24.95	..	0.00	44.16	118.44	hypersulfidic
CUR23-M2	FC1058	5 - 15	1.55	4.68	1.88	3.78	2.05	Fine	4.06	43.05	0.05	31.19	..	0.00	69.89	144.12	Hypersulfidic Sulfuric
CUR23-M2	FC1059	15 - 35	2.86	5.02	1.53	5.68	2.30	Fine	4.15	75.94	0.72	449.07	..	0.00	50.99	576.00	hypersulfidic
CUR23-M2	FC1060	35 - 40	2.61	7.45	1.79	6.97	6.52	Fine	7.42	0.00	1.11	692.32	3.38	675.32	0.00	242.11	Hyposulfidic (S _{CR} ≥ 0.10%)
CUR23-M2	FC1061	40 - 70	2.15	7.67	1.44	8.51	2.42	Fine	7.43	0.00	1.67	1041.60	1.76	351.65	0.00	807.17	hypersulfidic no sample
CUR24-M2	FC1056	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
CUR25-M2	FC1062	0 - 1	1.18	6.15	3.02	6.16	4.41	Medium	7.15	0.00	0.02	12.47	0.03	5.99	0.00	8.48	Hyposulfidic

Site ID.	Layer ID.	Depth Range	EC	pH _w	pH _{Ox}	pH incubation		Texture Laboratory	pH _{KCl}	Total Actual Acidity	Chromium Reducible Sulfur		Acid Neutralising Capacity		Retained Acidity	Net Acidity	Acid Sulfate Soil Material
				cm	ms	unit	unit				category	unit	mole H ⁺ /t	%S _{CR}	mole H ⁺ /t	%CaCO ₃	mole H ⁺ /t	mole H^{+}/t	category
CUR25-M2	FC1063	1 - 5	1.06	5.24	2.03	5.74	4.41	Medium	5.35	9.19	0.01	6.24	..	0.00	0.00	15.43	(S _{CR} < 0.10%) other acidic
CUR25-M2	FC1064	5 - 20	1.38	3.29	1.63	3.23	2.67	Medium	3.98	36.76	0.03	18.71	..	0.00	0.00	55.47	sulfuric
CUR25-M2	FC1065	20 - 60	3.01	5.43	1.64	5.99	1.97	Fine	5.95	13.06	1.42	885.67	..	0.00	0.00	898.73	hypersulfidic
CUR26-M2	FC1053	0 - 5	1.58	6.58	2.94	6.32	4.44	Medium	6.49	0.97	0.01	6.24	..	0.00	0.00	7.20	other acidic
CUR26-M2	FC1054	5 - 15	3.54	4.88	1.66	4.29	2.47	Medium	4.91	14.51	0.13	81.08	..	0.00	0.00	95.59	hypersulfidic
CUR26-M2	FC1055	15 - 90	2.23	8.17	1.79	8.41	2.27	Fine	7.73	0.00	0.14	89.81	1.60	319.68	0.00	-123.31	hypersulfidic
CUR27-M2	FC1048	0 - 2	1.11	6.97	2.32	7.56	5.51	Medium	8.11	0.00	0.03	18.71	0.19	37.96	0.00	-6.60	Hypersulfidic (S _{CR} < 0.10%)
CUR27-M2	FC1049	2 - 15	1.59	3.28	2.39	3.31	3.07	Course	5.72	5.80	<0.01	0.00	..	0.00	0.00	5.80	sulfuric
CUR27-M2	FC1050	15 - 30	1.93	3.06	2.29	3.24	2.85	Course	5.28	8.71	0.01	6.24	..	0.00	0.00	14.94	sulfuric
CUR27-M2	FC1051	30 - 60	2.25	3.05	2.02	3.31	2.61	Course	4.99	12.09	0.01	6.24	..	0.00	0.00	18.33	sulfuric
CUR27-M2	FC1052	60 - 90	1.72	5.16	1.52	4.93	2.34	Course	5.22	10.64	0.07	43.66	..	0.00	0.00	54.30	Hypersulfidic
FC1073	FC1073	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	no sample
FC1074	FC1074	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	no sample
FIN24M4-5	LFA01-A1	0 - 10	2.46	6.01	2.28	4.64	4.72	Fine	4.69	56.00	0.04	24.95	..	0.00	0.00	80.95	Hypersulfidic (S _{CR} < 0.10%)
FIN24M4-5	LFA01-A2	10 - 40	6.62	2.98	1.35	2.59	2.21	Fine	3.53	131.00	0.21	130.98	..	0.00	20.00	281.98	sulfuric
FIN24M4-5	LFA01-A3	40 - 60	5.70	6.39	1.26	6.55	2.42	Fine	5.74	17.00	1.61	1004.18	..	0.00	0.00	1021.18	Hypersulfidic
FIN26M3-4	LFA01-B1	0 - 20	1.51	6.75	2.38	5.64	5.11	Fine	5.45	33.00	0.06	37.42	..	0.00	0.00	70.42	Hypersulfidic (S _{CR} < 0.10%)
FIN26M3-4	LFA01-B2	20 - 50	5.18	4.10	1.47	3.01	2.16	Fine	3.93	107.00	0.75	467.79	..	0.00	0.00	574.79	Hypersulfidic
FIN26M3-4	LFA01-B3	50 - 60	4.13	5.27	1.39	4.51	2.21	Fine	4.12	112.00	1.45	904.38	..	0.00	92.00	1108.38	Hypersulfidic
AA26	LFA01-C1	0 - 10	2.59	6.75	2.21	6.16	4.75	Fine	5.86	23.00	0.22	137.22	..	0.00	0.00	160.22	Hypersulfidic (S _{CR} ≥ 0.10%)
AA26	LFA01-C2	10 - 50	1.96	6.81	2.28	6.74	5.11	Fine	6.12	13.00	0.26	162.17	..	0.00	0.00	175.17	Hypersulfidic (S _{CR} ≥ 0.10%)
AA26	LFA01-C3	50 - 100	2.62	7.00	2.01	6.93	4.18	Fine	6.36	7.00	0.70	436.60	..	0.00	0.00	443.60	Hypersulfidic (S _{CR} ≥ 0.10%)
AA26	LFA01-C4	100 - 150	3.78	7.08	2.45	7.64	3.48	Fine	6.73	0.00	1.03	642.42	0.91	181.82	0.00	521.21	Hypersulfidic
AA26	LFA01-C5	180 - 200	3.61	7.26	1.52	7.96	2.69	Fine	6.73	0.00	1.59	991.70	0.66	131.87	0.00	903.79	Hypersulfidic
FIN26M4-2	LFA01-D1	0 - 5	..	..	..	3.48	3.02	..	..	..	..	..	..	..	..	..	..
FIN26M4-2	LFA01-D2	5 - 15	4.76	2.73	1.10	2.58	2.65	Fine	3.25	217.00	0.06	37.42	..	0.00	180.00	434.42	sulfuric

APPENDIX 4: LABORATORY RESULTS – SURFACE WATER

Hydrogeochemistry

Site ID	Site Label	Collection Date	Temp (C)	SEC (uS/cm)	D.O. (%)	D.O. (mg/l)	pH	ORP	Turb (NTU)	comments
FIN28-M2	FC1001	19-Dec-09	19.28	5137	94	8.58	6.79	68	73.6	
FIN36-M2	FC1007	19-Dec-09	19.79	5533	116	10.41	7.85	129	25	
FIN20-M2	FC1009	19-Dec-09	19.44	5885	23	21	6.32	-39	93	
FIN20-M2	CRACK	19-Dec-09	18.96	27029	0.3	3.3	5.23	15.6		
FIN25-M2	FC1016	19-Dec-09	20.26	5624	107	9.55	7.3	4.1	26	
FIN31-M2	FC1023	19-Dec-09	21.48	7146	134	11.53	8.1	52	16	
CUR17-M2	FC1025	19-Dec-09	22.07	9219	148	12.6	8.42	86	11	
CUR12-M2	FC1037	19-Dec-09	24.8	9527	169	10.3	8.61	97	7	
CUR27-M2	FC1048	20-Dec-09	19.99	10200	103	9.15	8.65	156	6.5	
CUR24-M2	FC1056	20-Dec-09	20.55	9664	110	9.74	8.08	151	12.5	no soil samples collected at site
CUR20-M2	FC1070	20-Dec-09	20.96	9384	108	9.37	7.29	80	15	
Ad hoc	FC1073	20-Dec-09	22.85	6067	90	7.61	7.57	71	14	top of currency near bridge no soil samples collected
CUR20-M3	FC1062	22-Jan-10	23.55	13475	101.1	8.23	7.67	260.3		peeper retrieval Finnis Site. cells 1-3 in water, 4 transistion, 5-36 in sediment, 1=top 36=bottom
CUR17-M3	FC1029	22-Jan-10	23.43	128.23	118.6	9.68	8.16	172		peeper retrieval Goolwa site. Cells 1-4 in water, 5,6,7 transistion, 8-36 in sediment
FIN28-M3	FC1001	22-Jan-10	24.45	7711	107.6	8.73	6.47	100.2		peeper retrieval Currency site, cells 1-4 in water, 5,6 transistion, 7-36 in sediment
FIN26	FC1074	22-Jan-10	25.92	5165	101.8	8.23	7.4	75.8		peeper retrieval Wallys site. Cells 1-2 in water, 3,4 transistion, 5-36 in sediment

Sample	pH	E.C.	Total Alkalinity	NH ₄ -N	NO _x -N	NO ₂ -N	PO ₄ -P	F ⁻	Cl ⁻	Br ⁻	NO ₃ ⁻	SO ₄ ⁼	Ca	K	Mg	Na	S	NPOC	TN
ID	dS/m	meq/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
FC1001	7.1	4.8	0.6	0.030	<0.005	<0.005	0.005	0.4	1510	5	0.1	409	83.5	33.8	110.5	820	132	22.8	1.23
FC1007	7.9	5.1	1.4	<0.005	<0.005	<0.005	0.010	0.5	1660	5.4	<0.25	376	83.5	35.2	114.5	870	119	21.0	1.24
FC1009	6.9	5.3	0.8	0.479	0.006	0.012	<0.005	0.4	1740	5.2	<0.25	437	94	38.9	127.5	975	148.5	28.3	3.21
FC1016	7.7	5.1	1.4	<0.005	<0.005	<0.005	0.006	0.5	1680	5	0.2	385	90	37.75	124	950	130.5	22.8	1.46
FC1023	8.2	6.4	2.1	<0.005	<0.005	<0.005	0.009	0.6	2260	6.5	0.1	439	105.5	48	156.5	1255	151	20.7	1.34
FC1025	8.6	8.8	2.9	<0.005	<0.005	<0.005	0.008	0.6	3250	9.6	0.2	532	123.5	58.5	197.5	1665	175	20.1	1.44
FC1037	8.8	9.0	2.7	<0.005	<0.005	<0.005	0.007	0.6	3410	11.8	0.3	543	116	60	196.5	1700	177	19.0	1.22
FC1048	8.8	8.8	1.3	<0.005	<0.005	<0.005	<0.005	0.6	3830	13.5	0.7	763	174	64.7	253	1880	273	20.1	1.49
FC1073	7.9	4.8	4.5	<0.005	<0.005	<0.005	0.102	0.8	1610	4.6	0.1	246	116.5	31.35	116.5	900	83.5	23.9	1.64
FC1056	7.4	9.8	0.6	<0.005	<0.005	<0.005	<0.005	0.6	3510	10.3	<0.25	853	176.5	70.5	227	1810	291.5	23.7	1.31
FC1070	7.4	9.8	0.7	<0.005	<0.005	<0.005	<0.005	0.6	3400	9.2	<0.25	845	180	69.5	227	1790	291.5	24.3	1.92

Sample	Al	As	B	Cd	Co	Cr	Cu	Fe	Mn	Mo	Ni	P	Pb	Sb	Se	Si	Sr	Zn
ID	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
FC1001	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	<0.25	0.71	0.269	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	2.51	1.14	<0.25
FC1007	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	2.47	1.20	<0.25
FC1009	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	<0.25	1.525	0.341	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	4.23	1.31	<0.25
FC1016	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	2.52	1.31	<0.25
FC1023	<0.25	<0.25	0.505	<0.25	<0.25	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	1.26	1.66	<0.25
FC1025	<0.25	<0.25	0.655	<0.25	<0.25	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	<0.25	2.10	<0.25
FC1037	<0.25	<0.25	0.655	<0.25	<0.25	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	2.05	<0.25	<0.25
FC1048	<0.25	<0.25	0.882	<0.25	<0.25	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	2.46	<0.25	<0.25
FC1073	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	<0.25	<0.5	0.2895	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	1.02	1.29	<0.25
FC1056	<0.25	<0.25	0.72	<0.25	<0.25	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	2.45	<0.25	<0.25
FC1070	<0.25	<0.25	0.74	<0.25	<0.25	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	<0.5	<0.25	<0.25	<0.25	2.46	<0.25	<0.25

Sample ID.	Li $\mu\text{g/L}$	Be $\mu\text{g/L}$	Al $\mu\text{g/L}$	Sc $\mu\text{g/L}$	Ti $\mu\text{g/L}$	V $\mu\text{g/L}$	Cr $\mu\text{g/L}$	Mn $\mu\text{g/L}$	Co $\mu\text{g}/\mu\text{L}$	Ni $\mu\text{g/L}$	Cu $\mu\text{g/L}$	Zn $\mu\text{g/L}$	As $\mu\text{g/L}$	Se $\mu\text{g/L}$	Rb $\mu\text{g/L}$	Y $\mu\text{g/L}$	Zr $\mu\text{g/L}$	Nb $\mu\text{g/L}$	Mo $\mu\text{g/L}$	Ru $\mu\text{g/L}$	Pd $\mu\text{g/L}$	Ag $\mu\text{g/L}$	Cd $\mu\text{g/L}$	Sn $\mu\text{g/L}$
FC1001	<5	<0.1	<10	<3	<30	<1	<0.3	261.6	2.34	6.2	2.0	108	1.5	0.4	<10	0.16	1.5	<0.5	<3	<0.02	<0.1	<0.02	0.12	4.0
FC1007	<5	<0.1	<10	<3	<30	<1	<0.3	42.7	0.70	3.4	1.6	26	1.0	0.4	<10	0.04	1.5	<0.5	<3	<0.02	<0.1	<0.02	0.12	2.6
FC1009	<5	<0.1	<10	<3	<30	<1	<0.3	325.7	2.10	4.4	1.0	88	2.0	0.2	<10	0.20	1.0	<0.5	<3	<0.02	<0.1	<0.02	0.09	2.4
FC1016	<5	<0.1	<10	<3	<30	<1	<0.3	112.5	0.84	3.8	1.4	22	1.0	0.2	<10	0.04	1.0	<0.5	<3	<0.02	<0.1	<0.02	0.09	1.8
FC1023	<10	<0.2	<20	<5	<50	<2	<0.5	28.2	0.64	3.2	1.2	39	1	<0.4	<20	<0.07	1	<1	<6	<0.04	<0.2	<0.04	<0.06	2.1
FC1025	<10	<0.2	<20	<5	<50	<2	<0.5	9.4	0.60	4.0	1.2	18	2	<0.4	<20	<0.07	1	<1	<6	<0.04	<0.2	<0.04	<0.06	2.4
FC1037	<10	<0.2	<20	<5	<50	<2	<0.5	4.6	0.48	3.2	0.8	27	2	<0.4	<20	<0.07	1	<1	<6	<0.04	<0.2	<0.04	<0.06	2.4
FC1048	<10	<0.2	<20	<5	<50	<2	<0.5	4.2	0.52	3.6	1.2	30	<1	<0.4	<20	<0.07	1	<1	<6	<0.04	<0.2	<0.04	<0.06	3.0
FC1073	<10	<0.2	<20	<5	<50	<2	<0.5	277.0	0.72	2.0	<0.4	45	<1	0.8	<20	<0.07	1	<1	<6	<0.04	<0.2	<0.04	<0.06	1.5
FC1056	<10	<0.2	<20	<5	<50	<2	<0.5	39.8	0.56	4.4	0.8	33	<1	<0.4	<20	<0.07	1	<1	<6	<0.04	<0.2	<0.04	<0.06	1.5
FC1070	<10	<0.2	<20	<5	<50	<2	<0.5	140.2	1.04	5.2	0.8	60	<1	<0.4	<20	<0.07	1	<1	<6	<0.04	<0.2	<0.04	<0.06	1.5

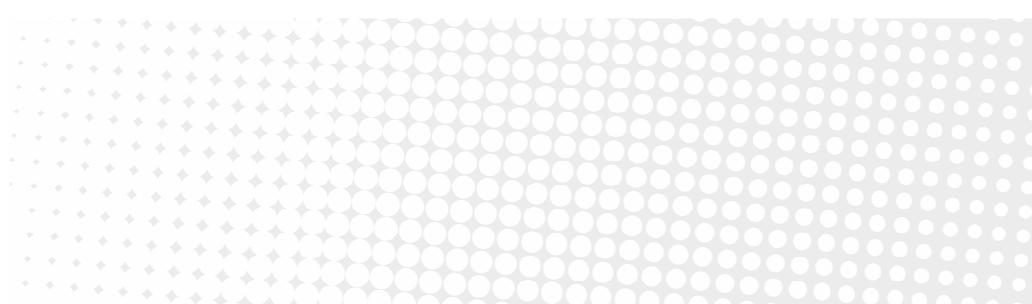
Sample ID.	Sb $\mu\text{g/L}$	Cs $\mu\text{g/L}$	Ba $\mu\text{g/L}$	La $\mu\text{g/L}$	Ce $\mu\text{g/L}$	Pr $\mu\text{g/L}$	Nd $\mu\text{g/L}$	Sm $\mu\text{g/L}$	Eu $\mu\text{g/L}$	Gd $\mu\text{g/L}$	Tb $\mu\text{g/L}$	Dy $\mu\text{g/L}$	Ho $\mu\text{g/L}$	Er $\mu\text{g/L}$	Tm $\mu\text{g/L}$	Yb $\mu\text{g/L}$	Lu $\mu\text{g/L}$	Hf $\mu\text{g/L}$	W $\mu\text{g/L}$	Tl $\mu\text{g/L}$	Pb $\mu\text{g/L}$	Th $\mu\text{g/L}$	U $\mu\text{g/L}$
FC1001	<2	<0.1	258	0.18	0.35	0.05	0.15	<0.05	0.03	0.03	0.01	0.02	0.01	0.02	<0.01	<0.03	<0.01	0.8	2.8	0.30	0.4	1.80	<0.5
FC1007	<2	<0.1	98	0.03	<0.05	<0.01	<0.05	<0.05	<0.01	<0.03	<0.01	<0.02	<0.01	<0.02	<0.01	<0.03	<0.01	1.0	1.4	0.12	<0.2	1.52	0.5
FC1009	<2	<0.1	130	0.18	0.35	0.05	0.20	<0.05	0.01	0.03	<0.01	0.02	<0.01	0.02	<0.01	<0.03	<0.01	0.6	1.0	0.06	0.2	2.48	<0.5
FC1016	<2	<0.1	122	0.03	0.10	<0.01	<0.05	<0.05	<0.01	<0.03	<0.01	<0.02	<0.01	<0.02	<0.01	<0.03	<0.01	0.7	0.7	0.04	0.2	0.88	0.5
FC1023	<3	<0.2	152	<0.05	<0.1	<0.02	<0.1	<0.1	<0.02	<0.05	<0.01	<0.04	<0.01	<0.03	<0.01	<0.05	<0.02	0.6	1.2	0.04	<0.4	0.56	<1
FC1025	<3	<0.2	168	<0.05	<0.1	<0.02	<0.1	<0.1	<0.02	<0.05	<0.01	<0.04	<0.01	<0.03	<0.01	<0.05	<0.02	0.6	1.0	<0.04	<0.4	0.40	<1
FC1037	<3	<0.2	212	<0.05	<0.1	<0.02	<0.1	<0.1	<0.02	<0.05	<0.01	<0.04	<0.01	<0.03	<0.01	<0.05	<0.02	0.4	0.8	<0.04	<0.4	0.40	<1
FC1048	<3	<0.2	160	<0.05	<0.1	<0.02	<0.1	<0.1	<0.02	<0.05	<0.01	<0.04	<0.01	<0.03	<0.01	<0.05	<0.02	0.4	0.8	<0.04	<0.4	0.40	<1
FC1073	<3	<0.2	92	<0.05	<0.1	<0.02	<0.1	<0.1	<0.02	<0.05	<0.01	<0.04	<0.01	<0.03	<0.01	<0.05	<0.02	0.4	0.6	<0.04	<0.4	0.24	1
FC1056	<3	<0.2	72	<0.05	<0.1	<0.02	<0.1	<0.1	<0.02	<0.05	<0.01	<0.04	<0.01	<0.03	<0.01	<0.05	<0.02	0.4	0.6	<0.04	<0.4	0.32	<1
FC1070	<3	<0.2	104	<0.05	<0.1	<0.02	<0.1	<0.1	<0.02	<0.05	<0.01	<0.04	<0.01	<0.03	<0.01	<0.05	<0.02	0.4	0.4	<0.04	<0.4	0.32	<1

APPENDIX 5: LABORATORY RESULTS – SOIL PORE WATER

Sample #	Depth	EC (mS/cm)	pH	Alkalinity	Acidity
FIN28 – Finniss River					
1-FC1001-ASU	4	3.25	7.23	0.91	
2-FC1001-ASU	3	4.89	7.14	1.06	
3-FC1001-ASU	2	5.26	7.17	1.05	
4-FC1001-ASU	1	3.35	7.00	1.21	
5-FC1001-ASU	0	5.06	6.62	0.926	
6-FC1001-ASU	-1	5.04	6.67	0.93	
7-FC1001-ASU	-2	5.11	6.36	1.17	
8-FC1001-ASU	-3	4.87	4.60	0.05	
9-FC1001-ASU	-4	3.05	4.27	acid	2.93
10-FC1001-ASU	-5	2.96	4.41	acid	3.18
11-FC1001-ASU	-6	5.02	4.35	acid	9.40
12-FC1001-ASU	-7	5.03	4.39	acid	11.5
13-FC1001-ASU	-8	5.05	4.29	acid	14.3
14-FC1001-ASU	-9	5.08	3.80	acid	15.6
15-FC1001-ASU	-10	5.72	3.48	acid	16.4
16-FC1001-ASU	-11	5.55	3.39	acid	22.6
17-FC1001-ASU	-12	6.19	3.30	acid	18.2
18-FC1001-ASU	-13	6.33	3.24	acid	20.5
19-FC1001-ASU	-14	6.60	3.20	acid	17.3
20-FC1001-ASU	-15	7.21	3.17	acid	23.8
21-FC1001-ASU	-16	7.82	3.14	acid	27.5
22-FC1001-ASU	-17	7.66	3.09	acid	28.8
23-FC1001-ASU	-18	8.81	3.10	acid	25.0
24-FC1001-ASU	-19	8.88	3.09	acid	34.2
25-FC1001-ASU	-20	9.38	3.09	acid	35.8
26-FC1001-ASU	-21	9.77	3.09	acid	37.6
27-FC1001-ASU	-22	10.3	3.08	acid	40.6
28-FC1001-ASU	-23	10.9	3.08	acid	42.0
29-FC1001-ASU	-24	11.1	3.10	acid	42.5
30-FC1001-ASU	-25	10.9	3.11	acid	43.3
31-FC1001-ASU	-26	11.9	3.12	acid	43.3
32-FC1001-ASU	-27	11.7	3.16	acid	42.4
33-FC1001-ASU	-28	12.1	3.19	acid	42.0
34-FC1001-ASU	-29	12.3	3.22	acid	40.8
35-FC1001-ASU	-30	12.5	3.25	acid	40.4
36-FC1001-ASU	-31	13.1	3.26	acid	40.0
CUR17 – Goolwa Channel					
1-FC1029-ASU	4	8.89	7.36	2.96	
2-FC1029-ASU	3	9.29	8.01	3.27	
3-FC1029-ASU	2	10.1	8.02	3.33	
4-FC1029-ASU	1	10.0	7.97	3.33	
5-FC1029-ASU	0	9.57	7.58	3.29	
6-FC1029-ASU	-1	9.93	7.34	2.84	
7-FC1029-ASU	-2	9.48	7.02	1.63	
8-FC1029-ASU	-3	9.36	5.55	0.346	
9-FC1029-ASU	-4	8.53	4.14	acid	23.4

Sample #	Depth	EC (mS/cm)	pH	Alkalinity	Acidity
10-FC1029-ASU	-5	9.2	3.59	acid	22.8
11-FC1029-ASU	-6	9.63	3.36	acid	31.2
12-FC1029-ASU	-7	9.62	3.24	acid	37.9
13-FC1029-ASU	-8	9.56	3.19	acid	45.2
14-FC1029-ASU	-9	9.84	3.15	acid	48.9
15-FC1029-ASU	-10	9.86	3.04	acid	54.2
16-FC1029-ASU	-11	10.5	3.01	acid	59.8
17-FC1029-ASU	-12	10.3	2.99	acid	64.4
18-FC1029-ASU	-13	11.0	2.99	acid	66.4
19-FC1029-ASU	-14	10.8	2.97	acid	69.0
20-FC1029-ASU	-15	11.0	2.98	acid	67.6
21-FC1029-ASU	-16	10.9	3.01	acid	71.0
22-FC1029-ASU	-17	11.2	2.96	acid	72.1
23-FC1029-ASU	-18	11.0	2.94	acid	71.2
24-FC1029-ASU	-19	10.3	2.94	acid	70.9
25-FC1029-ASU	-20	11.3	2.97	acid	70.7
26-FC1029-ASU	-21	10.9	3.00	acid	67.6
27-FC1029-ASU	-22	10.9	3.03	acid	66.1
28-FC1029-ASU	-23	10.9	3.07	acid	60.8
29-FC1029-ASU	-24	10.9	3.13	acid	55.7
30-FC1029-ASU	-25	10.6	3.20	acid	47.8
31-FC1029-ASU	-26	10.5	3.30	acid	39.9
32-FC1029-ASU	-27	10.2	3.43	acid	31.9
33-FC1029-ASU	-28	9.83	3.68	acid	22.4
34-FC1029-ASU	-29	8.76	4.31	acid	14.4
35-FC1029-ASU	-30	8.68	5.96	0.556	
36-FC1029-ASU	-31	9.02	6.41	1.87	
CUR20 – Currency Creek					
1-FC1062-ASU	1	8.05	7.25	0.926	
2-FC1062-ASU	2	7.73	7.23	0.929	
3-FC1062-ASU	3	7.75	7.18	0.930	
4-FC1062-ASU	0	7.62	6.27	0.647	
5-FC1062-ASU	-1	8.39	2.89	acid	4.85
6-FC1062-ASU	-2	8.45	2.67	acid	9.71
7-FC1062-ASU	-3	8.87	2.65	acid	18.9
8-FC1062-ASU	-4	9.15	2.81	acid	29.3
9-FC1062-ASU	-5	9.58	2.80	acid	37.0
10-FC1062-ASU	-6	10.1	2.88	acid	42.2
11-FC1062-ASU	-7	10.3	2.87	acid	46.1
12-FC1062-ASU	-8	10.9	2.82	acid	49.3
13-FC1062-ASU	-9	11.1	2.81	acid	49.3
14-FC1062-ASU	-10	11.4	2.84	acid	55.4
15-FC1062-ASU	-11	11.7	2.88	acid	68.7
16-FC1062-ASU	-12	12.0	2.88	acid	53.0
17-FC1062-ASU	-13	11.8	2.87	acid	52.0
18-FC1062-ASU	-14	11.9	2.87	acid	51.1
19-FC1062-ASU	-15	12.2	2.87	acid	52.0
20-FC1062-ASU	-16	12.2	2.85	acid	48.5
21-FC1062-ASU	-17	11.7	2.87	acid	68.7
22-FC1062-ASU	-18	12.2	2.91	acid	46.4
23-FC1062-ASU	-19	11.9	2.89	acid	44.8

Sample #	Depth	EC (mS/cm)	pH	Alkalinity	Acidity
24-FC1062-ASU	-20	11.9	2.93	acid	43.0
25-FC1062-ASU	-21	11.7	2.89	acid	41.6
26-FC1062-ASU	-22	12.0	2.84	acid	40.8
27-FC1062-ASU	-23	12.0	2.90	acid	39.8
28-FC1062-ASU	-24	12.1	2.92	acid	37.9
29-FC1062-ASU	-25	12.0	2.94	acid	36.2
30-FC1062-ASU	-26	11.9	2.90	acid	35.1
31-FC1062-ASU	-27	12.2	2.93	acid	33.7
32-FC1062-ASU	-28	11.9	2.97	acid	32.1
33-FC1062-ASU	-29	11.7	2.89	acid	30.8
34-FC1062-ASU	-30	11.6	2.89	acid	28.6
35-FC1062-ASU	-31	11.5	2.88	acid	26.4
36-FC1062-ASU	-32	10.5	2.97	acid	23.8
FIN26 – Wallys Landing					
1-FC1074-ASU	2	3.04	7.67	3.87	
2-FC1074-ASU	1	3.05	7.38	4.71	
3-FC1074-ASU	0	2.85	7.36	5.48	
4-FC1074-ASU	-1	2.80	7.46	6.48	
5-FC1074-ASU	-2	2.59	7.47	8.47	
6-FC1074-ASU	-3	2.68	7.35	8.81	
7-FC1074-ASU	-4	2.59	7.17	8.48	
8-FC1074-ASU	-5	2.68	6.95	6.89	
9-FC1074-ASU	-6	2.73	6.60	5.93	
10-FC1074-ASU	-7	2.62	6.16	3.53	
11-FC1074-ASU	-8	2.62	5.92	2.54	
12-FC1074-ASU	-9	2.55	5.67	1.21	
13-FC1074-ASU	-10	2.78	5.14	0.37	
14-FC1074-ASU	-11	2.96	5.35	0.568	
15-FC1074-ASU	-12	5.21	5.05	0.358	
16-FC1074-ASU	-13	5.60	4.81	0.201	
17-FC1074-ASU	-14	5.86	4.29	acid	45.1
18-FC1074-ASU	-15	6.51	4.02	acid	55.1
19-FC1074-ASU	-16	7.10	3.86	acid	52.4
20-FC1074-ASU	-17	6.85	3.79	acid	64.6
21-FC1074-ASU	-18	7.40	3.76	acid	68.1
22-FC1074-ASU	-19	7.58	3.74	acid	72.9
23-FC1074-ASU	-20	7.31	3.73	acid	74.8
24-FC1074-ASU	-21	7.86	3.67	acid	75.6
25-FC1074-ASU	-22	7.41	3.62	acid	76.7
26-FC1074-ASU	-23	7.34	3.58	acid	80.9
27-FC1074-ASU	-24	7.68	3.57	acid	80.3
28-FC1074-ASU	-25	7.95	3.58	acid	80.5
29-FC1074-ASU	-26	7.43	3.57	acid	82.8
30-FC1074-ASU	-27	7.92	3.59	acid	83.4
31-FC1074-ASU	-28	8.07	3.58	acid	83.4
32-FC1074-ASU	-29	8.85	3.57	acid	83.4
33-FC1074-ASU	-30	8.78	3.58	acid	83.6
34-FC1074-ASU	-31	8.93	3.59	acid	83.3
35-FC1074-ASU	-32	9.30	3.58	acid	84.1
36-FC1074-ASU	-33	9.43	3.49	acid	81.8



Contact Us

Phone: 1300 363 400

+61 3 9545 2176

Email: enquiries@csiro.au

Web: www.csiro.au

Your CSIRO

Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills for building prosperity, growth, health and sustainability. It serves governments, industries, business and communities across the nation.