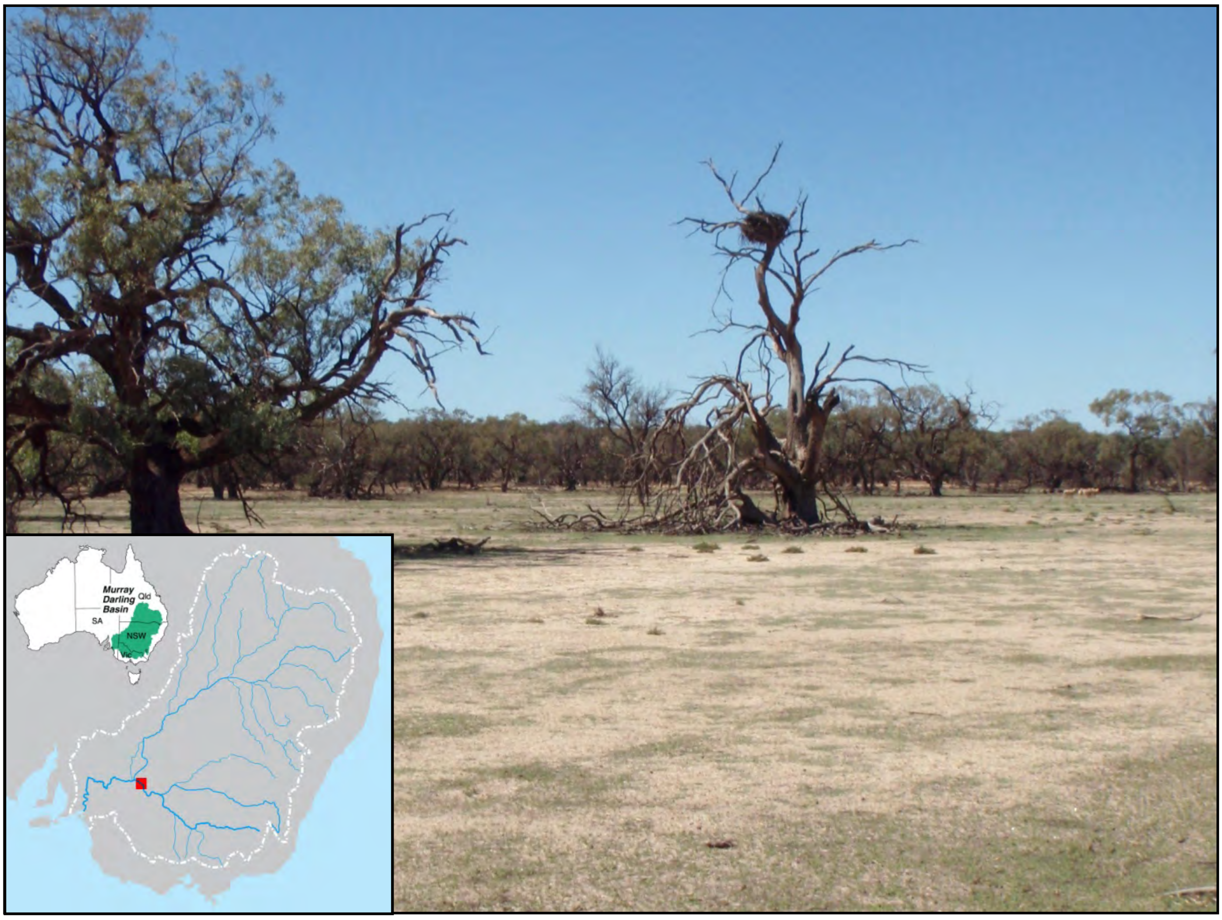
Southern Cross GeoScience

Assessment of Acid Sulfate Soil Materials in the Mildura Region of the Murray-Darling Basin.

N.J. Ward, R.T. Bush, L.A. Sullivan, P. Cheeseman, R. McGrath,
D.M. Fyfe, J. Coughran and V.N.L. Wong

FINAL REPORT



Southern Cross GeoScience Report 210

Prepared for the Murray-Darling Basin Authority

Copyright and Disclaimer

Cover Photograph
Photograph taken at Karadoc Swamp (Wetland 40156).
Photographer: Paul Cheeseman

ACKNOWLEDGEMENTS

The funding for this project was provided by MDBA.

We would like to thanks the following landholders for allowing access to their land and for their cooperation with the field survey team: Greg Johns of Red Cliffs, Victoria; Wes Gregg of Buronga, NSW.

We would like to thank the following individuals/organisation for assistance with the field sampling: Kym Schramm of Parks Victoria for assistance in organising permits; Darren Wilson of the Mallee CMA for assistance in access to sites; Dion Higgins of Mildura Ice Works for assistance in organising transport of soil and water samples; Lower Murray Water for access to Lake Iraak.

EXECUTIVE SUMMARY

The Mildura region is located on the riverine plain of the River Murray on the Victoria and New South Wales border. The wetlands examined in this study were situated to the south-east and north-west of the town of Mildura, Victoria. The Mildura region largely consists of flat alluvial plains created by regular flooding of the River Murray. Water from both the Murray and Darling Rivers is used extensively for irrigation, and supports a diverse horticultural industry that produces a range of fruit and vegetable crops as well as grains, olives, dried fruits and wine. The wetlands assessed in this region include depressions such as lakes, partially in-filled prior channels and billabongs on the River Murray floodplain. Previous studies have found wetlands in the Mildura area, such as Boeill Creek and Bottle Bend Lagoon, to be highly acidic (i.e. pH < 4) (Tulau 2009). Acidification of Bottle Bend Lagoon in 2002, located to the south-east of Mildura, resulted in substantial fish kills following partial drying (McCarthy *et al.* 2006). Evidence of the presence of oxidised acid sulfate soils suggest these soils may have contributed to this fish kill (Lamontagne *et al.* 2006).

The Murray-Darling Basin Authority (MDBA), in partnership with its Partner Governments and scientists, instigated the Murray-Darling Basin Acid Sulfate Soil Risk Assessment Project (MDB ASSRAP), which aims to assess the spatial extent of, and risks posed by acid sulfate soil materials in the Murray-Darling Basin. The MDB ASSRAP project also aims to identify and assess broad management options.

The MDBA Acid Sulfate Soil Risk Assessment Advisory Panel prioritised 96 wetlands throughout the Murray-Darling Basin for detailed acid sulfate soil assessment. This report provides the results of Phase 1 of a two-phased detailed acid sulfate soil assessment procedure for priority wetlands in the Mildura region. This Phase 1 report is aimed solely at determining whether or not acid sulfate soil materials are present in the eight Mildura region priority wetlands.

This study identified the presence of acid sulfate soil materials in 19 of the 52 sites examined in the Mildura region. The type and prevalence of acid sulfate soil materials observed in each wetland is summarised in the table below. The presence of acid sulfate soils was identified in all wetlands except Lake Iraak (40175).

Type and prevalence of acid sulfate soil materials in each wetland.

Type of actual or potential acid sulfate soil material	Wetland ID (No. of sites)							
	40156	40175	40190	40864	40805	40856	21920	21921
Sulfuric	0	0	2	0	2	0	0	0
Hypersulfidic	2	0	0	3	2	1	3	2
Hyposulfidic (S_{CR} ≥ 0.10%)	0	0	0	3	0	3	3	0
Monosulfidic (observed)	2	0	0	3	0	3	4	0
Monosulfidic (potential)	12	7	4	4	8	4	7	4
Hyposulfidic (S_{CR} < 0.10%)	3	0	0	2	0	3	3	0
Other acidic (pH_w &/or $pH_{INCUBATION}$) 4 – 5.5	7	1	2	0	5	0	3	2
Other soil materials	1	8	0	1	0	1	0	0

Sulfuric materials were observed at four sampling sites. The reduced inorganic sulfur content of the samples was high in some areas (i.e. S_{CR} was up to 2.19%). Hypersulfidic soil materials were present in 13 soil profiles (eight of these profiles also contained hyposulfidic materials), and another three soil profiles contained hyposulfidic materials with $S_{CR} \geq 0.10\%$. Monosulfidic soil materials were observed at 23% (i.e. 12) of the sampling sites. An additional three soil profiles contained hyposulfidic materials with $S_{CR} < 0.10\%$. These results indicate that acidity would be produced upon oxidation of sulfides in some of these materials.

A total of 50 surficial soil materials contained soluble sulfate equal to or in excess of the 100 mg/L trigger value for monosulfidic black ooze (MBO) formation potential. The potential formation of MBO was identified in all of the wetlands examined. Other acidic soil materials were also observed at an additional 20 sites.

Based on the priority ranking criteria adopted by the Scientific Reference Panel of the Murray-Darling Basin Acid Sulfate Soil Risk Assessment Project, there were four high priority sites based on the presence of sulfuric material, 13 high priority sites based on hypersulfidic material, nine high priority sites based on hyposulfidic ($S_{CR} \geq 0.10\%$) material and 12 high priority sites based on monosulfidic material. There were 11 moderate priority sites based on the presence of a hyposulfidic material with $S_{CR} < 0.10\%$. In addition, 50 of the 52 sampling sites had a high priority ranking for Phase 2 detailed assessment based on MBO formation hazard. All wetlands in the Mildura region receive a high priority ranking on at least one of the criteria.

The potential hazards at the wetland-scale posed by acid sulfate soil materials in priority wetlands in Mildura region are as below:

- Acidification hazard: The data indicate that with predominantly low to moderate net acidities within the wetlands the overall degree of acidification hazard is moderate. Brickworks Lagoon wetland (40864) is the only exception, with a high acidification hazard due to the presence of hypersulfidic soil materials with high net acidities in 17% of layers.

- Deoxygenation hazard: High monosulfide concentrations ($S_{AV} \leq 0.42\%$ S) in surface soils in three wetlands (i.e. Brickworks Lagoon (40864), Boeill Lagoon (21920) and Outlet Creek (40856)) represent a high deoxygenation hazard. In addition, the soluble sulfate contents of surface soil materials at 50 sites were equal to or greater than the trigger value for MBO formation indicating the possible development of an appreciable deoxygenation hazard at those locations after prolonged wet conditions.

- Metal mobilisation: The moderate to high acidification hazard in some of the wetlands indicates that soil acidification may increase the solubility of metals. The presence of monosulfidic materials in some surface soils at three wetlands and the potential for MBO formation identified in all wetlands may also result in an appreciable metal release hazard. This would depend on factors such as the potential for MBO formation and the metal loading in the wetland.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Region overview

The Mildura region is located on the riverine plain of the River Murray on the Victoria and New South Wales border. The wetlands examined in this study were situated to the south-east and north-west of the town of Mildura, Victoria. The Mildura region largely consists of flat alluvial plains created by regular flooding of the River Murray. Water from both the Murray and Darling Rivers is used extensively for irrigation, and supports a diverse horticultural industry that produces a range of fruit and vegetable crops as well as grains, olives, dried fruits and wine.

The wetlands assessed in this region included depressions such as lakes, partially in-filled prior channels and billabongs on the River Murray floodplain. Wetlands on the edge of the floodplain were typically bounded by undulating, red sandy rise country. Wetlands away from the higher country are under grazing or Parks Victoria land-use. Vegetation communities above the channels often featured box woodland, and river red gum zones in different stages of maturity or mortality. Most sites examined supported a cover of low, succulent shrubs, and patches or zones of reeds such as *Phragmites*, *Typha* and *Juncus* spp. Most of the recently inundated wetlands were bare when this study was undertaken. Salinity was evident at many sites at the time of sampling, in the form of salt crystals on the soil surface and/or crystal plate formations associated with pools.

Previous studies have found wetlands in the Mildura area that were formed on former lake basin sediments, such as Boeill Creek and Bottle Bend Lagoon, to be highly acidic (i.e. pH < 4) (Tulau 2009). Acidification of Bottle Bend Lagoon in 2002, located to the south-east of Mildura, resulted in substantial fish kills following partial drying (McCarthy *et al.* 2006). Evidence of the presence of oxidised acid sulfate soils suggest these soils may have contributed to this fish kill (Lamontagne *et al.* 2006).

Wetlands in this region were identified for acid sulfate soil assessment based on their environmental significance or the risk they may pose to surrounding waters. A series of rapid acid sulfate soil assessments were completed throughout the Mildura region as part of the Murray-Darling Basin Acid Sulfate Soil Risk Assessment Project (MDB ASSRAP). A total of eight wetlands were selected for further detailed assessment based on being identified as having a high priority as a result of both soil and water parameters exceeding screening trigger values (see Appendix 2), and having a risk profile. The parameters found to exceed the ASSRAP trigger values in the Mildura region and their score priority level are shown in Table 1-1. Cowanna Billabong (40803) was originally chosen as a priority wetland, however, this wetland was later replaced by Brickworks Lagoon wetland (40864).

Table 1-1. Summary of parameters exceeding the ASSRAP trigger values and score priority level.

Wetland ID	pH Soil	pH Water	EC Soil	EC Water	Sulfate Soil	Sulfate Water	Priority
40156	Moderate	-	High	-	-	-	High
40175	-	-	High	-	High	-	High
40190	Extreme	-	Moderate	-	High	-	Extreme
40864	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
40805	Extreme	High	High	High	-	High	Extreme
40856	Extreme	-		High	-	High	Extreme
21920	Extreme	-	High	High	-	High	High/Extreme
21921	Moderate	-	High	-	Moderate	-	High

1.2. Acid sulfate soils in the Murray-Darling Basin

Acid sulfate soil is the term commonly given to soil and sediment that contain iron sulfides, or the products of sulfide oxidation. Pyrite (FeS_2) is the dominant sulfide in acid sulfate soil, although other sulfides including the iron disulfide marcasite (Sullivan and Bush 1997; Bush 2000) and iron monosulfides (Bush and Sullivan 1997; Bush *et al.* 2000) can also be found.

Sulfidic sediments accumulate under waterlogged conditions where there is a supply of sulfate, the presence of metabolisable organic matter and iron-containing minerals (Dent 1986). Under reducing conditions sulfate is bacterially reduced to sulfide, which reacts with reduced iron to form iron sulfide minerals. These sulfide minerals are generally stable under reducing conditions, however, on exposure to the atmosphere the acidity produced from sulfide oxidation can impact on water quality, crop production, and corrode concrete and steel structures (Dent 1986). In addition to the acidification of both ground and surface waters, a reduction in water quality may result from low dissolved oxygen levels (Sammut *et al.* 1993; Sullivan *et al.* 2002a; Burton *et al.* 2006), high concentrations of aluminium and iron (Ferguson and Eyre 1999; Ward *et al.* 2002), and the release of other potentially toxic metals (Preda and Cox 2001; Sundström *et al.* 2002; Burton *et al.* 2008a; Sullivan *et al.* 2008a).

Acid sulfate soils form naturally when sulfate in the water is converted to sulfide by bacteria. Changes to the hydrology in regulated sections of the Murray-Darling Basin (MDB) system (due to higher weir pool levels), and the chemistry of rivers and wetlands have caused significant accumulation of sulfidic material in subaqueous and wetland margin soils. If left undisturbed and covered with water, sulfidic material poses little or no threat of acidification. However, when sulfidic material is exposed to the air, the sulfides react with oxygen to form sulfuric acid (i.e. sulfuric materials with $pH < 4$). When these sulfuric materials are subsequently covered with water, significant amounts of sulfuric acid can be released into the water.

Other hazards associated with acid sulfate soil 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.

Record low inflows and river levels in recent years have led to the drying of many wetlands in the MDB, resulting in the exposure of sulfidic material in acid sulfate soil, and soil acidification in many wetlands. The extent and potential threat posed by acid sulfate soil requires urgent assessment.

Despite decades of scientific investigation of the ecological (e.g. Living Murray Icon Site Environmental Management Plan: MDBC 2006a,b,c), hydrological, water quality (salinity) and geological features of wetlands in the MDB, we have only recently advanced far enough to appreciate the wide spectrum of acid sulfate soil subtypes and processes that are operating in these contemporary environmental settings - especially from continued lowering of water levels (e.g. Lamontagne *et al.* 2004; Fitzpatrick *et al.* 2008a,b; Shand *et al.* 2008a,b; Simpson *et al*. 2008; Sullivan *et al*. 2008a). Hence, the MDB Ministerial Council at its meeting in March 2008 directed the then Murray-Darling Basin Commission (MDBC) to undertake an assessment of acid sulfate soil risk at key wetlands in the MDB.

The MDBC (now the Murray-Darling Basin Authority – MDBA), in partnership with its Partner Governments and scientists, designed the MDB ASS Risk Assessment Project, which aims to assess the spatial extent of, and risks posed by acid sulfate soil in the Murray-Darling Basin. The project also aims to identify and assess broad management options.

Wetlands were identified for assessment based on their environmental significance as well as those that may pose a risk to surrounding waters. Through consultation with jurisdictions more than 19,000 wetlands within the MDB were identified. Due to their ecological significance, the decision was made to prioritise Ramsar-listed wetland complexes of the Murray-Darling Basin for immediate detailed acid sulfate soil assessment. In addition, due to the risk profile, wetlands along the Murray River between Blanchetown (Lock 1) and Wellington were also selected for immediate detailed acid sulfate soil assessment. For all other wetlands, a three tiered assessment process was developed, commencing with a desktop assessment, followed by on-ground rapid assessment and then detailed on-ground assessment at sites identified as high priority or having a risk profile. A total of 96 wetlands were identified and selected for further detailed assessment (Figure 1-1). These wetlands were divided for logistical reasons into the following seven regions:

- Murray River, Lock 1 to Lock 3, SA (21 wetlands),
- Murray River, Lock 3 to Lock 5, SA (31 wetlands),
- Mildura region, NSW and Vic (8 wetlands),
- Edward and Wakool Rivers, NSW (12 wetlands),
- Murray River, Hume to Yarrawonga, NSW and Vic (6 wetlands),
- Talwood-Mungindi region, Queensland (1 wetland), and
- Victorian Northern Flowing Rivers (17 wetlands).

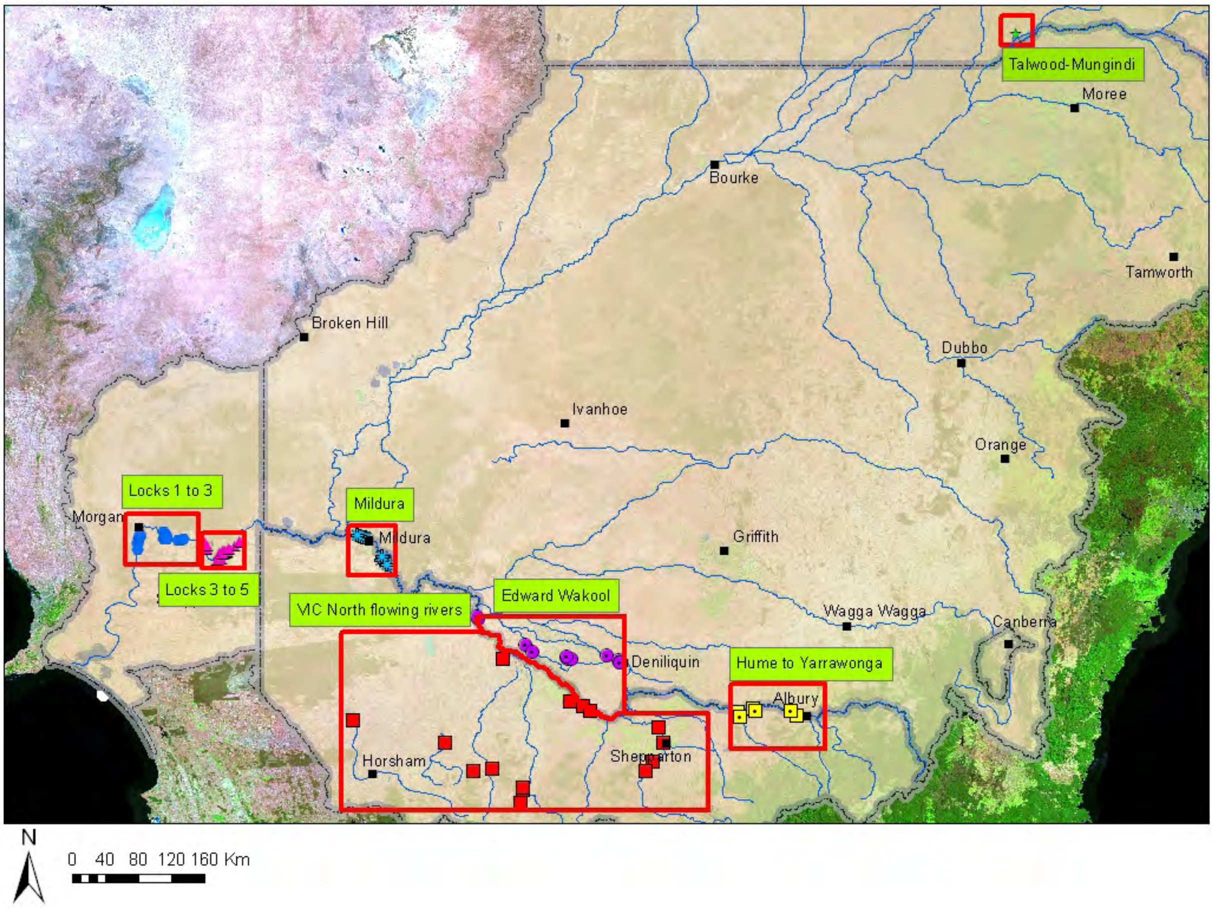


Figure 1-1. Map showing priority wetlands surveyed in the Murray-Darling Basin (source: MDBA).

Southern Cross GeoScience carried out a detailed assessment at 52 representative sites within eight wetlands in the Mildura region in March 2010 to determine whether acid sulfate soils were present, or if there was a potential for acid sulfate soils to form within these wetlands (Figure 1-2). This assessment included the determination of sulfide content within the soil profile at each site. Water-soluble sulfate was used as an indicator of the potential of monosulfide black ooze (MBO) formation in these wetland sites.

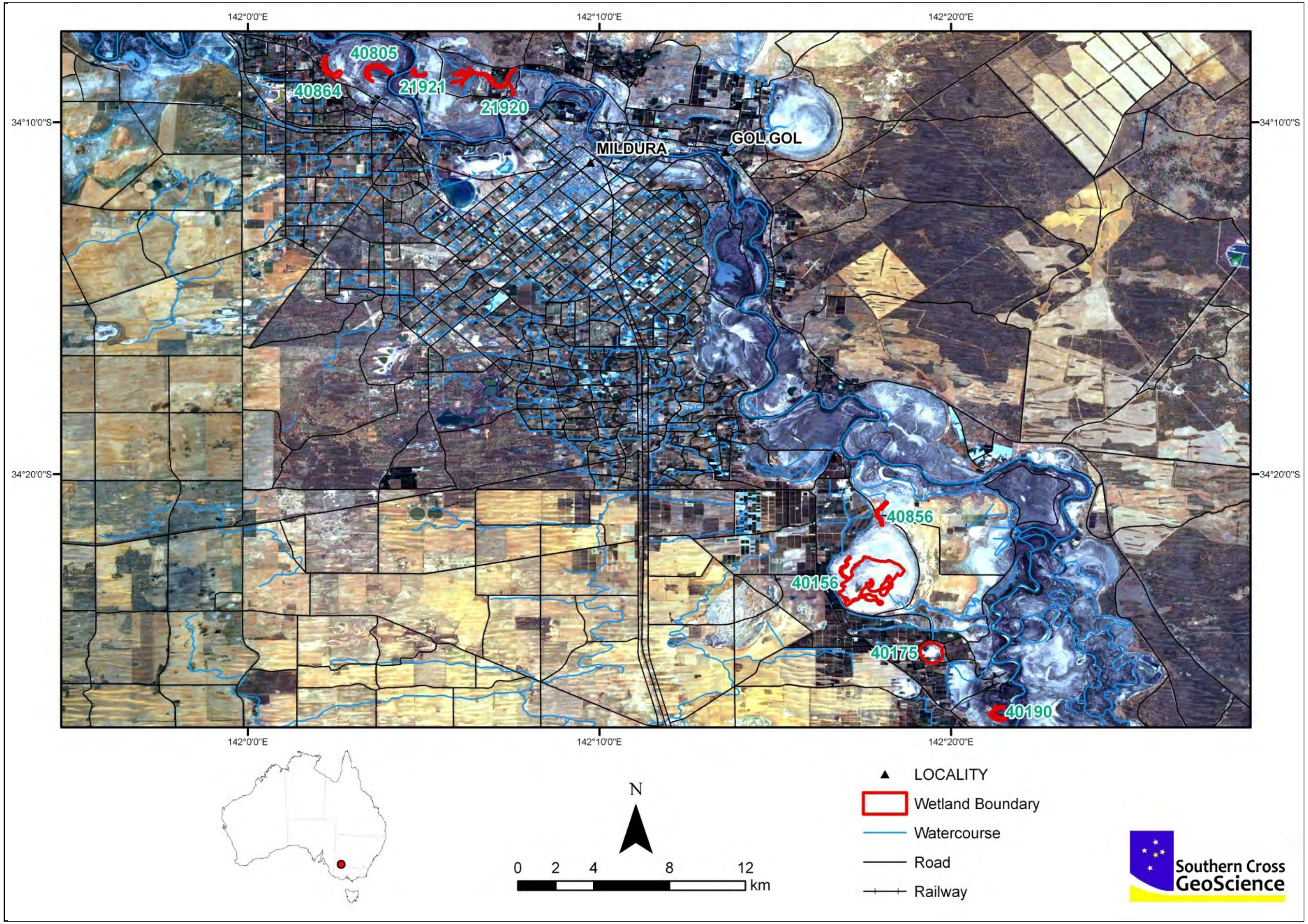


Figure 1-2. Map showing the areas assessed in the Mildura region.

1.3. Detailed Acid Sulfate Soil assessments using two phases

The detailed assessment stage of the MDB ASS Risk Assessment Project involves comprehensive analysis using a set of established and tested field and laboratory methods to determine the presence and extent of acid sulfate soil and associated hazards, including potential for acidification, metal mobilisation and deoxygenation.

In summary the protocol developed by the MDB ASS Risk Assessment Project Scientific Reference Panel requires a two-phase procedure (MDBA 2010).

Phase 1 investigations determine whether or not acid sulfate soil materials are present (or absent) for the study area, and provide characterisation of the properties and types of acid sulfate soil materials.

Phase 1 activities include:

- site selection
- site and profile description
- sample collection and storage
- laboratory analysis (of soil and water)
- identification of acid sulfate soil materials
- prioritisation and selection of Phase 2 samples
- interpretation and reporting

Phase 2 investigations will only be conducted if the acid sulfate soil materials from Phase 1 are determined to be a priority concern for the study area and, based on Phase 1 recommendations, samples will undergo further investigations to determine their nature and severity and the specific risks associated with the acid sulfate soil materials.

Phase 2 activities include:

- laboratory analysis (of soil)
- risk assessment
- interpretation and reporting, including discussion on broad acid sulfate soil management options

The soil samples to be analysed for Phase 2 will have been collected as part of the Phase 1 field assessment and then put into storage. Based on the Phase 1 report recommendations the client will identify samples and the analyses to be conducted on each of the samples for Phase 2.

Following a request from the Murray-Darling Basin Authority (MDBA), Southern Cross GeoScience were engaged to conduct a Phase 1 detailed assessment of acid sulfate soils at the priority wetlands in the Mildura region.

1.4. Methodologies used to assess acid generation potential

As detailed previously, sulfide minerals are generally stable under reducing conditions, however, on exposure to the atmosphere the acidity produced from sulfide oxidation can impact on water quality, crop production, and corrode concrete and steel structures (Dent 1986). In addition to the acidification of both ground and surface waters, a reduction in water quality may result from low dissolved oxygen levels (Sammut *et al.* 1993; Sullivan *et al.* 2002a; Burton *et al.* 2006), high concentrations of aluminium and iron (Ferguson and Eyre 1999; Ward *et al.* 2002), and the release of other potentially toxic metals (Preda and Cox 2001; Sundström *et al.* 2002; Burton *et al.* 2008a; Sullivan *et al.* 2008a).

In nature, a number of oxidation reactions of sulfide minerals (principally pyrite: FeS_2) may occur which produce acidity, including:

$$2FeS_2 + 7O_2 + 2H_2O \text{ ---> } 2Fe^{2+} + 4SO_4^{2-} + 4H^+$$

$$4FeS_2 + 15O_2 + 10H_2O \text{ ---> } 4FeOOH + 8H_2SO_4$$

A range of secondary minerals, such as jarosite, sideronatrite and schwertmannite may also form, which act as stores of acidity i.e. they may produce acidity upon dissolution (re-wetting).

Acid-base accounting (ABA)
Acid-base accounting (ABA) 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 (e.g. Sullivan *et al*. 2001, Sullivan *et al*. 2002b).

The standard acid-based accounting applicable to acid sulfate soils is described in Ahern *et al.* (2004) and summarised here. The equation below shows the calculation of Net Acidity (NA).

Net Acidity (NA) = Potential Sulfidic Acidity (PSA) + Titratable Actual Acidity (TAA) + Retained Acidity (RA) – Acid Neutralising Capacity (ANC)/Fineness Factor (FF)

The components in this ABA are further discussed below and by Ahern *et al*. (2004).

- Potential Sulfidic Acidity (PSA) also known as the 'acid generation potential' (AGP) is most easily and accurately determined by assessing the Chromium reducible sulfur (S_{CR} or CRS) and then converting this to PSA (AGP) as described in Ahern *et al*. (2004).
- Titratable Actual Acidity (TAA) is a measure of the actual acidity in acid sulfate soil materials that have already oxidised. It measures the sum of both soluble and exchangeable acidity.
- Retained Acidity (RA) is the acidity 'stored' in minerals such as jarosite, schwertmannite and other hydroxy sulfate minerals. Although these minerals may be stable under acidic conditions, they can release acidity to the environment when these conditions change.
- Acid Neutralising Capacity (ANC) is measured in soils with pH_{KCl} values > 6.5. These soils may potentially have ANC in the form of (usually) carbonate minerals, principally of calcium, magnesium and sodium. The carbonate minerals present are estimated by titration and alkalinity present expressed in $CaCO_3$ equivalents. By accepted definition (Ahern *et al.* 2004), any acid sulfate soil material with a pH_{KCl} < 6.5 has a zero ANC.

- Fineness Factor (FF) is defined by Ahern *et al.* (2004) as 'A factor applied to the acid neutralising capacity result in the acid-base account to allow for the poor reactivity of coarser carbonate or other acid neutralising material. The minimum factor is 1.5 for finely divided pure agricultural lime, but may be as high as 3.0 for coarser shell material'. Fine grinding of soil materials may lead to an over-estimate of ANC when carbonates are present in the form of hard nodules or shells. In the soil environment, they may provide little effective ANC as exposure to acid may result in the formation of surface crusts (iron oxides or gypsum), preventing or slowing further neutralisation reactions. For reasons including those above, the use of the Fineness Factor also applies to those naturally occurring alkalinity sources in soil materials as measured by the ANC methods.

1.5. Classification of soil materials

Recently, 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 Professor Leigh Sullivan and co-authors in a plenary lecture and Acid Sulfate Soils Working Group meeting at the 6th International Acid Sulfate Soil and Acid Rock Drainage Conference in September 2008 in Guangzhou, China (Sullivan *et al.* 2008b). This new classification system for acid sulfate soil materials (Sullivan *et al.* 2009) has also been recently (October 2008) adopted by the Scientific Reference Panel of the Murray–Darling Basin Acid Sulfate Soil Risk Assessment Project 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:

1. **Sulfuric materials** – soil materials currently defined as sulfuric by the Australian Soil Classification (Isbell 1996). Essentially, these are soil materials with a $pH_W < 4$ 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 (i) has a field pH of 4 or more and (ii) is identified by experiencing a substantial* drop in pH 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.
   **A substantial drop in pH arising from incubation is regarded as an overall decrease of at least 0.5 pH unit.*
   ***A stable pH is assumed to have been reached after at least 8 weeks of incubation when either the decrease in pH is < 0.1 pH unit over at least a 14 day period, or the pH begins to increase.*

4. **Hyposulfidic material** – Hyposulfidic material is a sulfidic material that (i) has a field pH of 4 or more and (ii) does not experience a substantial* drop in pH 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 8 weeks of incubation.
   **A substantial drop in pH arising from incubation is regarded as an overall decrease of at least 0.5 pH unit.*
   ***A stable pH is assumed to have been reached after at least 8 weeks of incubation when either the decrease in pH is < 0.1 pH unit over at least a 14 day period, or the pH begins to increase.*

5. **Monosulfidic materials** – soil materials with an acid volatile sulfide 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 may be the result of Fe^{2+} hydrolysis, which may or may not be associated with acid sulfate soil processes). The acidity present in field soils may also 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 present course of the Phase 1 detailed assessment. 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
   b. soil materials with a $pH_W \geq 4$ but < 5.5 in the field.

2. **Other soil materials** – soils that do not have acid sulfate soil (or other acidic) characteristics.

2. METHODS AND MATERIALS

2.1. Field sampling of soils and waters

Field sampling of the 8 Mildura region priority wetlands was undertaken between 9th and 20th March 2010. A total of 268 soil layers were collected and analysed from 52 representative soil profiles within the Mildura region to assess the current and potential environmental hazard due to the presence of acid sulfate soils (Figure 1-2).

The number of sites sampled within each wetland was dependant on the size of the wetland (Table 2-1). A summary of the number of sites sampled in each of the Mildura priority wetlands is presented in Table 2-2. Sites were selected to ensure that the samples obtained were representative of each wetland for acid sulfate soil assessment. The rationale for site selection within each wetland is presented in Section 2.4.1 and Appendix 1.

Table 2-1. Study area size and suggested number of sites (MDBA 2010).

Study area size (ha)	Number of sample sites
<5	2
5 – 20	4
20 – 100	8
100 – 500	12
>500	20

Table 2-2. Summary of sites sampled in the Mildura priority wetlands.

Wetland ID	State	Main Name	Area (m^2)	Area (ha)	No. of sites
40156	VIC	Karadoc Swamp	3,769,450	377	12
40175	VIC	Lake Iraak	813,810	81	8
40190	VIC	Spencers Bend Billabong	189,798	19	4
40864*	VIC	Brickworks Lagoon	236,650	24	4
40805	VIC	Merbein Common - Catfish	213,268	21	8
40856	VIC	Outlet Creek	134,450	13	4
21920	NSW	Boeill Lagoon	337,608	34	8
21921	NSW	Boeill Lagoon	70,808	7	4

* Wetland was changed from Wetland ID 40803 and thought to be < 20 ha at the time of sampling.

At the majority of wetlands soil profiles were sampled along a toposequence and where possible the profiles were chosen to represent: (i) the lowest point in the landscape, (ii) a moderately elevated site just above the observed or interpreted normal flow level, and (iii) an elevated site above the normal flow level.

Soil samples were collected from at least five sampling depths (to a maximum depth of 90 cm) using a range of implements (i.e. spades, and augers). At dry site locations soil pits were dug using a spade to at least 0.6 m, and then a gouge auger was used to obtain soil samples below the base of the pit down to 90 cm or auger refusal. Soil samples were collected in two separate plastic jars (70 mL) with a screw top lid. Additional soil samples (500 g) were packed into plastic bags in which retained air was minimised for potential future Phase 2 laboratory analysis. Where soils were below the water, soil samples were obtained by using a shovel to grab the upper 20 cm and then a gouge auger was used to approximately 90 cm depth or to auger refusal. Where monosulfides were present the sample was collected into two glass jars (250 mL) with a screw top lid rather than plastic bags. All soil samples were maintained at ≤ 4°C prior to analysis.

Soil samples from each depth at all sites were placed into two separate chip-trays. One tray was used in the determination of the pH following incubation ($pH_{INCUBATION}$) and the other was for long term archive storage.

Site and profile descriptions including global positioning system (GPS) coordinates are presented for each wetland in Appendix 1. Digital photographs were also taken to document each site and soil profile characteristics (see Appendix 1).

Surface water and groundwater quality data was collected from 18 sites in the Mildura region and are presented in Appendix 1. Water pH, specific electrical conductivity (SEC) and redox potential (Eh) were determined in the field using calibrated electrodes linked to a TPS 90-FLMV multi-parameter meter. Water temperature and dissolved oxygen (DO) were measured using calibrated electrodes linked to a Hach HQ40D portable meter. Turbidity was measured using a calibrated TPS WP88 Turbidity meter. Turbidity was not measured for groundwater due to mechanical dispersion of sediment in the groundwater column. Alkalinity was also determined in the field by acid titration (Method 2320B) (APHA 2005).

Where water was present, filtered (0.45 µm) water samples were collected in 250 mL polyethylene bottles. Samples analysed for metals were acidified with 0.1 mL of concentrated hydrochloric acid (HCl). Samples were stored at ≤ 4°C and sent to the Environmental Analysis Laboratory, Southern Cross University for laboratory analysis.

Further details on the procedures followed in collection and storage of soil and water samples are presented in MDBA (2010).

2.2. Laboratory soil analysis methods

All soil samples were oven-dried at 80^{o}C prior to analysis. Any coarse material (> 2 mm) present was removed by sieving, and then samples were ring mill ground.

The moisture content of each soil sample was determined following oven-drying at 80^{o}C (Ahern *et al.* 2004). Several parameters were examined to determine whether acid sulfate soil materials were likely to be present, or if there was a potential for acid sulfate soil materials to form. The parameters measured in this study included pH (pH_W, pH_{FOX}, pH_{KCl} and $pH_{INCUBATION}$), titratable actual acidity (TAA), water soluble sulfate, chromium reducible sulfur (S_{CR}), retained acidity (RA), acid neutralising capacity (ANC), and acid volatile sulfide (S_{AV}).

The existing acidity of each soil layer (pH_W) was assessed by measuring the pH in a saturated paste (1:1 soil:water mixture) (Rayment and Higginson, 1992). The pH_{FOX} was determined following oxidation with 30 % hydrogen peroxide (H_2O_2) (Method 4E1) (Rayment and Higginson, 1992). The KCl extractable pH (pH_{KCl}) was measured in a 1:40 1.0 M KCl extract (Method Code 23A), and the titratable actual acidity (TAA) was determined by titration of the KCl extract to pH 6.5 (Method Code 23F) (Ahern *et al.* 2004). TAA is a measure of the actual acidity in soil materials, and the sum of soluble and exchangeable acidity. The pH following incubation ($pH_{INCUBATION}$) was determined on duplicate moistened soil materials placed in chip trays (Fitzpatrick *et al*. 2008c; Sullivan *et al*. 2009). The duration of the incubation was until a stable pH was reached after at least 8 weeks of incubation.

Water soluble sulfate (1:5 soil:water extract) was conducted on surface soil samples and was prepared following the procedures described in Rayment and Higginson (1992). Water soluble sulfate was analysed by ICP-OES (Inductively Coupled Plasma - Optical Emission Spectrometry). The pyritic sulfur content was quantified using the chromium reduction analysis method of Burton *et al.* (2008b). The acid volatile sulfide fraction was extracted using a cold diffusion procedure (Hsieh *et al.* 2002).

Retained acidity (RA) was determined from the difference between 4M HCl extractable sulfur (S_{HCl}) and 1M KCl extractable sulfur (S_{KCl}) when the sample pH_{KCl} was < 4.5 (Method Code 20J) (Ahern *et al.* 2004). The retained acidity identifies stored soil acidity in the form of jarosite and similar relatively insoluble iron and aluminium hydroxy sulfate compounds (Ahern *et al.* 2004). Acid Neutralising Capacity, measured by the ANC_{BT} method (Method Code 19A2) (Ahern *et al.* 2004), was determined for sulfidic samples with a $pH_{KCl} \geq 6.5$. The Net Acidity was estimated by the Acid-Base Account method of Ahern *et al.* (2004). The objective of each method is discussed further in MDBA (2010).

2.3. Laboratory water analysis methods

The analysis of all water samples in this study was carried out by the Environmental Analysis Laboratory (EAL) at Southern Cross University. The water quality parameters measured on filter samples (0.45 µm) in this study included:

- major cations (Na, K, Ca, Mg) and Si (APHA 3120 ICPOES) (APHA 2005),
- dissolved bromide (APHA 4500 Br^-) and chloride (APHA 4500 Cl^-) (APHA 2005),
- dissolved nitrate (NO_3^-) (APHA 4500 NO_3^-) (APHA 2005),
- dissolved ammonia (NH_4) (APHA 4500 NH_3-H) (APHA 2005),
- dissolved phosphate (PO_4) (APHA 4500 P-E) (APHA 2005),
- dissolved sulfate (SO_4^{2-}) (APHA 3120 ICPOES) (APHA 2005),
- trace metals (Ag, Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn) (APHA 2005), and
- dissolved organic carbon (APHA 2005).

2.4. Quality assurance and quality control

2.4.1. Site selection and sample collection

The Senior Soil Surveyor for all the sampling undertaken in the Mildura priority wetlands was Dr Roger McGrath. Sampling was undertaken by Dr Roger McGrath and Paul Cheeseman between 9th and 20th March 2010. A summary of what was done to select the site locations and layers that were sampled is presented below in Table 2-3.

Table 2-3. Summary of site and layer selection for the Mildura priority wetlands.

Wetland ID	Main Name	Date Sampled	Comments on site/layer selection
40156	Karadoc Swamp	11/03/10 to 14/03/10	This was a large wetland and sites were selected to be spatially and ecologically representative. Two pairs of sites were sampled and one three-site transect otherwise sites were feature-based. Large areas were inaccessible due to a soft moist soil surface.
40175	Lake Iraak	09/03/10, 10/03/10 & 20/03/10	Sites were selected according to the sampling protocol. Six sites were selected on a rough transect across the lake with two sites selected to accommodate point features.
40190	Spencers Bend Billabong	14/3/10 to 15/3/10	Sites were selected longitudinally according to the sampling protocol.
40864	Brickworks Lagoon	17/03/10 to 19/03/10	This wetland was a late inclusion and a boundary map was not available. It was decided to sample longitudinally to be certain that sites were geospatially valid. Sampling according to the protocol was undertaken within this constraint. Only four sites were sampled as the wetland was changed from Wetland ID 40803 and thought to be < 20 ha at the time of sampling. Surface water was not sampled as it was present on a human perturbation (i.e. vehicle tyre tracks).
40805	Merbein Common - Catfish	19/03/10 to 20/03/10	This site was sampled longitudinally according to the protocol. Surface water was not sampled as it was present on a human perturbation (i.e. vehicle tyre tracks).
40856	Outlet Creek	10/03/10 to 11/03/10	This wetland comprised of two distinctive areas. One heavily degraded and one with ongoing remediation. It was decided to divide the sites between each area. In each area a subaqueous site and a bank site were selected.
21920	Boeill Lagoon	16/03/10 & 18/03/10	This wetland was a dendritic channel system. The sampling strategy was to incorporate the thalweg of all main channels with one only toposequence selected in the channel containing the largest body of water.
21921	Boeill Lagoon	16/03/10	Sites were selected longitudinally according to the sampling protocol.

2.4.2. Laboratory analysis

For all tests and analyses, the Quality Assurance and Quality Control procedures were equivalent to those endorsed by NATA (National Association of Testing Authorities). The standard procedures followed included the monitoring of blanks, duplicate analysis of at least 1 in 10 samples, and the inclusion of standards in each batch.

Reagent blanks and method blanks were prepared and analysed for each method. All blanks examined here were either at, or very close to, the limits of detection. On average, the frequencies of quality control samples processed were: 5% blanks, ≥ 10% laboratory duplicates, and 5% laboratory controls. The analytical precision was ±5% for all analyses.

2.5. Criteria for ranking soil materials for inclusion in Phase 2 of the detailed assessment process

The Scientific Reference Panel of the Murray-Darling Basin Acid Sulfate Soil Risk Assessment Project agreed to recommend that soil materials be assigned the following priorities to undertake the Phase 2 detailed assessment:

High Priority

1) All sulfuric materials.
2) All hypersulfidic materials (as recognised by either 1) incubation of sulfidic materials or 2) a positive net acidity result with a Fineness Factor of 1.5 being used).
3) All hyposulfidic materials with S_{CR} contents ≥ 0.10% S.
4) All surface soil materials (i.e. within 0-20 cm) with water soluble sulfate (1:5 soil:water) contents ≥ 100 mg SO_4 L^{-1}.
5) All monosulfidic materials.

Moderate Priority

All hyposulfidic materials with S_{CR} contents < 0.10% S.

No Further Assessment

1) Other acidic soil materials.
2) All other soil materials.

It is important to note, while the criteria identifying samples for Phase 2 analysis is clearly defined, samples only go through to Phase 2 when consideration is given to the wetland as a whole.

3. RESULTS

3.1. Summary of field and laboratory results

3.1.1. Soil pH (pH_W, pH_{FOX}, pH_{KCl} and $pH_{INCUBATION}$)

The pH_W, pH_{FOX}, pH_{KCl} and $pH_{INCUBATION}$ data for the wetland sites examined in the Mildura region are presented in Appendix 1 and summarised in Table 3-1. The pH_W values ranged between 3.04 and 8.69, with the majority of the samples having a pH_W > 4.5. A total of four sites within the Mildura region would be classified as being sulfuric (i.e. pH_W < 4) including two sites in both Spencers Bend Billabong (site 40190_1 (20-90 cm) and site 40190_2 (0-5 cm)) and Merbein Common – Catfish wetland (site 40805_3 (0-20 cm) and site 40805_6 (0-5 cm)). None of the other soils within the Mildura region were classified as sulfuric.

The pH_{FOX} values ranged between 1.91 and 8.74. The soils often showed a pH drop after treatment with peroxide (e.g. Figure 3-1), with a maximum decrease of 2.7 pH units. The pH_{FOX} results also indicate that some of the surface soils in the Mildura region may have the potential to acidify to pH < 4 as a result of sulfide oxidation. This was particularly evident in soils from the Boeill Lagoon (21921), Spencers Bend Billabong (40190) and Merbein Common – Catfish wetland (40805). However, the S_{CR} data shows many of these layers contain no detectable sulfide (i.e. S_{CR} < 0.01% S). While such decreases in pH after treatment with peroxide are often used to indicate the presence of sulfide minerals in coastal acid sulfate soil materials, the S_{CR} data from these studies suggest that pH decreases in inland acid sulfate soil materials after peroxide has been added are often due to non-acid sulfate soil factors such as the oxidation of organic matter. Only one soil material in Merbein Common – Catfish wetland (site 40805_3 (0-5 cm)) had a pH_{FOX} < 2.5, and this soil material also contained no detectable sulfide.

The $pH_{INCUBATION}$ values ranged between 2.68 and 7.96. Only four of the sulfidic soil materials (i.e. S_{CR} ≥ 0.01% S) acidified to pH < 4 after at least 8 weeks of incubation (i.e. sites 21921_4 (0-5 cm), 40864_3 (16.5-20 cm) and 40856_2 (10-20 cm and 20-40 cm)). However, several non-sulfidic soils (i.e. other acidic) particularly at Merbein Common – Catfish wetland (40805) acidified to pH < 4 over the 8 week incubation period (Appendix 1). Several sulfidic soil materials that did not acidify to pH < 4 after at least 8 weeks of incubation were classified as hypersulfidic as they had positive net acidities (see Section 2.5).

Table 3-1. Summary soil data for pH testing and sulfur suite.

Parameter	Units	Minimum	Median	Maximum	n[1]
pH_W[2]		3.04	6.20	8.69	268
pH_{FOX}[3]		1.91	6.25	8.74	268
pH_{KCl}[4]		3.80	6.29	9.24	268
$pH_{INCUBATION}$[5]		2.68	5.67	7.96	268
TAA[6]	mole H^+/t	0.00	2.94	85.01	268
Soluble SO_4[7]	mg SO_4/L	29.3	8093	33300	52
S_{CR}[8]	Wt. %S	<0.01	<0.01	2.19	268
S_{AV}[9]	Wt. %S	<0.01	<0.01	0.42	268
RA[10]	mole H^+/t	0.00	0.00	11.00	268
ANC[11]	$\%CaCO_3$	0.00	0.00	21.55	268
NA[12]	mole H^+/t	-2,871	3.45	1235	268

[1] n: number of samples. [2] pH_W: pH in saturated paste with water. [3] pH_{FOX}: pH after treatment with 30% H_2O_2. [4] pH_{KCl}: pH of 1:40 1 M KCl extract. [5] $pH_{INCUBATION}$: pH after least 8 weeks of incubation. [6] TAA: Titratable Actual Acidity. [7] Soluble sulfate: in 1:5 soil:water extract. [8] S_{CR}: Chromium Reducible Sulfur. [9] S_{AV}: Acid Volatile Sulfide. [10] RA: Retained Acidity. [11] ANC: Acid Neutralising Capacity: by definition, where $pH_{KCl} < 6.5$ ANC = 0. [12] NA: Net Acidity.

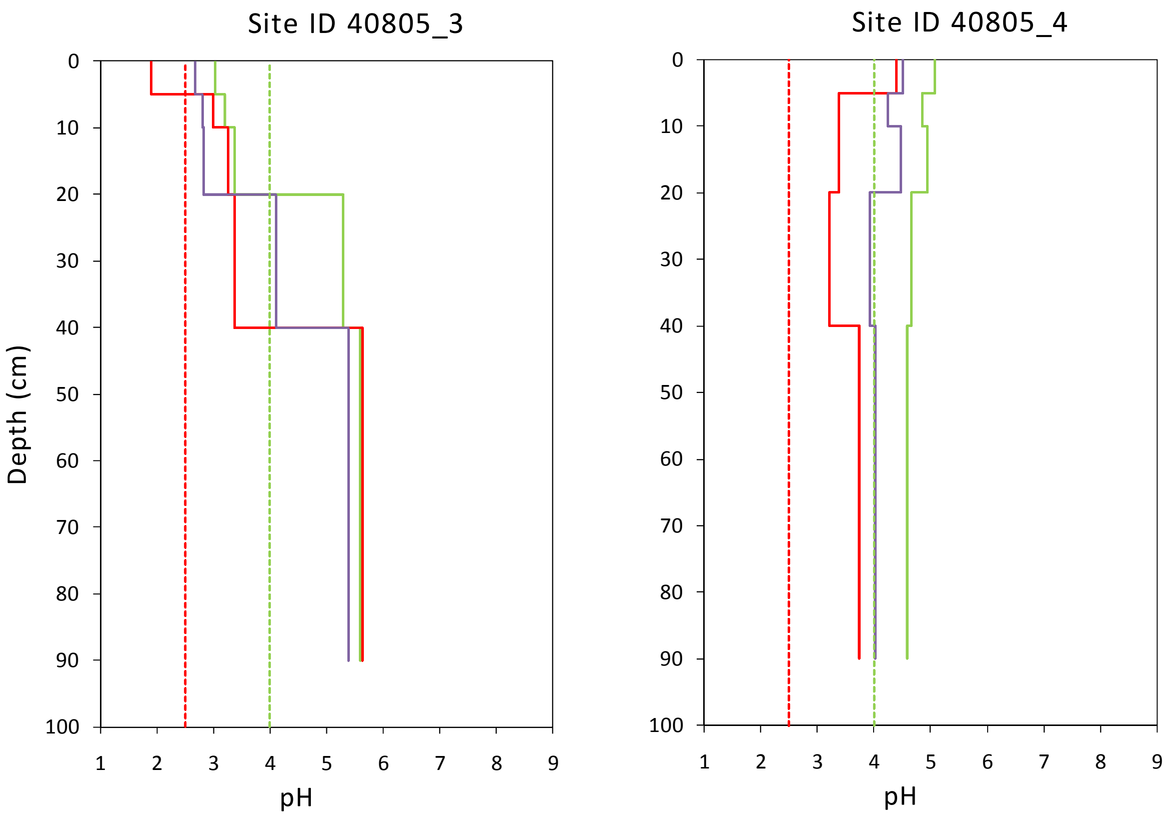


Figure 3-1. Depth profiles of soil pH for (40856_2 – 40856_3), showing soil pH (pH_W as green line), peroxide treated pH (pH_{FOX} as red line) and ageing pH ($pH_{incubation}$ after at least 8 weeks as purple line). Critical pH_W and $pH_{incubation}$ value of 4 (green dashed line) and critical pH_{FOX} value of 2.5 (red dashed line).

3.1.2. Chromium Reducible Sulfur (S_{CR})

The chromium reducible sulfur (S_{CR}) data for wetland sites examined in the Mildura region are presented in Appendix 1 and summarised in Table 3-1. The S_{CR} values ranged between < 0.01 and 2.19% S. Sulfidic soil materials (i.e. $S_{CR} \geq 0.01\%$ S) were only absent from two of the eight wetlands examined (i.e. Lake Iraak (40175) and Spencers Bend Billabong (40190)), with 62 materials of the 268 samples collected equal to or greater than the sulfidic criterion. A total of 19 sites of the 52 sites examined contained sulfidic materials.

A summary of the S_{CR} content and number of sulfidic soil materials observed in each wetland is given in Table 3-2. Brickworks Lagoon (40864) and Outlet Creek (40856) had the highest percentage of sites containing sulfidic soil materials (i.e. 75%). Outlet Creek (40856) wetland also had the highest percentage of layers examined containing sulfidic soil materials (i.e. 60%). Further information on the distribution of sulfidic sediments within each wetland is given in Appendix 1.

Table 3-2. Summary of the S_{CR} content and number of sulfidic soil materials (i.e. $S_{CR} \geq 0.01\%$ S) observed within each wetland in the Mildura priority wetlands.

Wetland ID	Main Name	S_{CR} Range (%S)	No. of sulfidic sites	No. of sulfidic layers	Site No.
40156	Karadoc Swamp	< 0.01 – 0.09	4 (33%)	12 (19%)	9, 10, 11, 12
40175	Lake Iraak	< 0.01	0 (0%)	0 (0%)	n.a.
40190	Spencers Bend Billabong	< 0.01	0 (0%)	0 (0%)	n.a.
40864	Brickworks Lagoon	< 0.01 – 2.19	3 (75%)	14 (58%)	1, 2, 3
40805	Merbein Common - Catfish	< 0.01 – 0.03	2 (25%)	3 (8%)	2, 3
40856	Outlet Creek	< 0.01 – 0.44	3 (75%)	12 (60%)	2, 3, 4
21920	Boeill Lagoon	< 0.01 – 1.38	5 (63%)	18 (45%)	4, 5, 6, 7, 8
21921	Boeill Lagoon	< 0.01 – 0.03	2 (50%)	3 (15%)	3, 4

3.1.3. Acid volatile sulfide (S_{AV})

The acid volatile sulfide (S_{AV}) data for wetland sites examined in the Mildura region are presented in Appendix 1 and summarised in Table 3-1. The S_{AV} values ranged between < 0.01 and 0.42% S. Monosulfidic soil materials (i.e. $S_{AV} \geq 0.01\%$ S) were absent from four of the wetlands examined (i.e. Lake Iraak (40175), Spencers Bend Billabong (40190), Merbein Common - Catfish (40805) and Boeill Lagoon (21921)), with 31 materials of the 268 samples collected equal to or greater than the monosulfidic criterion. A total of 12 sites of the 52 sites examined contained monosulfidic materials. Further information on the distribution of monosulfidic sediments within each wetland is given in Appendix 1

3.1.4. Acid Neutralising Capacity (ANC)

The acid neutralising capacity (ANC) data for wetland sites examined in the Mildura region are presented in Appendix 1 and summarised in Table 3-1. The ANC ranged between zero and 21.6 %$CaCO_3$ (see Table 3-1). Three of the wetlands had no ANC in the soil profile (i.e. Wetland ID 21921, 40190 and 40805).

3.1.5. Net Acidity (NA)

The net acidity data for wetland sites examined in the Mildura region are presented in Appendix 1 and summarised in Table 3-1. Acid-base accounting calculations showed the net acidity ranged between -2,870 and 1,235 mole H^+/tonne, with a median net acidity of 3 mole H^+/tonne. The net acidity thresholds used to characterise the acid sulfate soil materials in this assessment include low net acidity (< 19 mole H^+/tonne), moderate net acidity (19 - 100 mole H^+/tonne) and high net acidity (> 100 mole H^+/tonne). A summary of the net acidity data for each wetland is given in Table 3-3, and shows the presence of soil materials with moderate to high net acidities in all wetlands except Lake Iraak (40175). Only one hypersulfidic soil material in Boeill Lagoon (21920) and four hypersulfidic soil materials in Brickworks Lagoon (40864) had high net acidities.

The acidification hazard from acid sulfate soil disturbance posed by the two wetlands containing sulfuric soil materials (i.e. Spencers Bend Billabong (40190) and Merbein Common – Catfish wetland (40805)) is low to moderate, with net acidities ranging between 3 and 87 mole H^+/tonne. The acidification hazard from acid sulfate soil disturbance posed by the hypersulfidic soil materials ranged from low to high, with net acidities ranging between -182 and 1,234 mole H^+/tonne. As mentioned previously, only five hypersulfidic soil materials had net high acidities.

The positive net acidities in the non-sulfidic samples were due to the presence of some TAA and the lack of any ANC, although a few layers also contained some retained acidity (Appendix 1).

Table 3-3. Summary of the net acidity data for all soil materials in each wetland in the Mildura priority wetlands.

Wetland ID	Main Name	Net Acidity (mole H^+/tonne)		
		Minimum	Median	Maximum
40156	Karadoc Swamp	-344	3	60
40175	Lake Iraak	-2,871	-113	5
40190	Spencers Bend Billabong	12	23	78
40864	Brickworks Lagoon	-886	113	1,235
40805	Merbein Common - Catfish	3	23	87
40856	Outlet Creek	-561	-76	63
21920	Boeill Lagoon	-436	7	290
21921	Boeill Lagoon	3	14	32

3.1.6. Water soluble SO_4

The water soluble SO_4 data for wetland sites examined in the Mildura region are presented in Appendix 1 and summarised in Table 3-1. The water soluble SO_4 in the surface soils (i.e. 0-5 cm) in the Mildura region wetlands ranged between 29 and 33,300 mg/L. The surface soil layer in 50 of the 52 sites examined had a soluble SO_4 content equal to or exceeding the trigger value of 100 mg/L indicating the potential formation of monosulfidic materials.

3.1.7. Titratable actual acidity (TAA)

The titratable actual acidity (TAA) data for wetland sites examined in the Mildura region are presented in Appendix 1 and summarised in Table 3-1. The TAA ranged between zero and 85 mole H^+/tonne, with the majority of soil layers having a TAA < 30 mole H^+/tonne. Sites sampled within Spencers Bend Billabong (40190) and Merbein Common – Catfish wetland (40805) tended to have the highest TAA within the soil profile. There was often an increase in the TAA with depth (Figure 3-2).

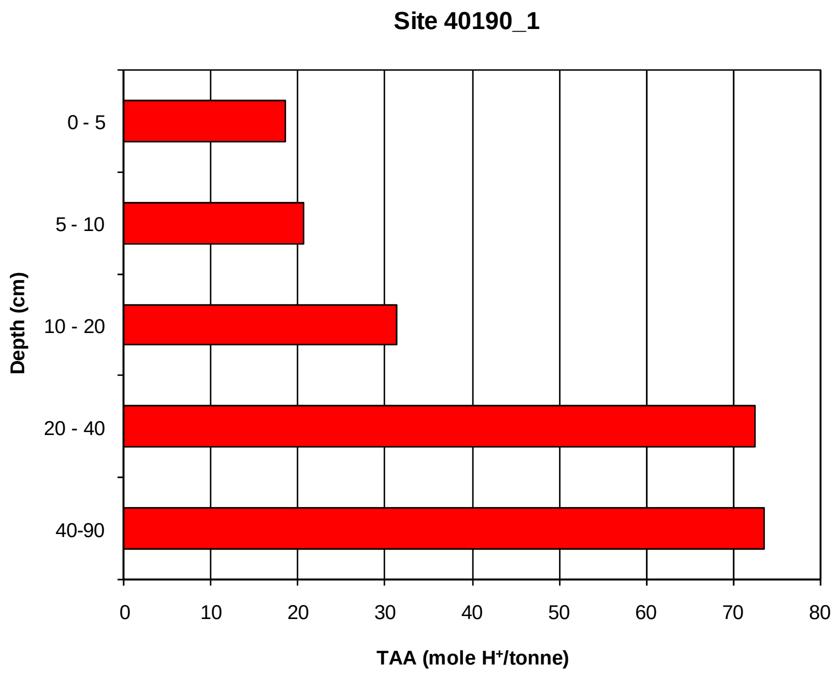


Figure 3-3-2. Variation in TAA (mole H^+/tonne) with depth at site 40190_1.

3.1.8. Retained acidity (RA)

The retained acidity (RA) data for wetland sites examined in the Mildura region are presented in Appendix 1 and summarised in Table 3-1. The RA ranged between zero and 11 mole H^+/tonne, with the majority of soil layers having no RA (i.e. 263 materials of the 268 samples collected). RA was only measured in samples collected from Spencers Bend Billabong (40190) and Merbein Common – Catfish (40805). There was no retained acidity at any of the other sites as all samples had a pH_{KCl} > 4.5.

3.2. Hydrochemistry

The hydrochemical characteristics of the surface water and groundwater in the Mildura region were measured to provide an indication of the baseline water chemistry. Some of the chemical parameters measured may show temporal variations, and therefore the data collected only represents a snapshot of the water quality in the Mildura region.

Surface water quality data was collected from 7 locations in the Mildura region priority wetlands (including sites 21920_7, 21920_8, 40156_4, 40156_9, 40175_4, 40856_2 and 40856_4) (Appendix 1). Groundwater data was collected from 11 locations in the Mildura region priority wetlands (including sites 21920_6, 40156_7, 40156_11, 40156_12, 40175_2, 40864_1, 40864_2, 40864_3, 40805_2, 40805_3, 40805_8 and 40856_3) (Appendix 1). No groundwater data was collected from the remaining sites without standing water as groundwater was not observed during soil pit excavation.

A summary of the surface water and groundwater characteristics measured in the field are presented below in Tables 3-4 and 3-5. The results of the laboratory analyses are presented in Appendix 1. The field pH of the surface waters ranged between 6.5 and 8.9 (Table 3-4) with four sites (sites 40156_4, 40156_9, 40856_2 and 40856_4) exceeding the most relevant ANZECC/ARMCANZ (2000) trigger value for aquatic ecosystems of 8.0. The water data indicates that the surface water has not been affected by acidification. The surface waters were often highly saline with a median SEC of 48,700 µS/cm. The surface water sulfate concentrations ranged between 40 and 10,089 mg/L (Appendix 1). Some nutrient (i.e. NH_4, PO_4), metal (i.e. Al, Ag, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Zn), SEC and turbidity values were found to exceed the most relevant ANZECC/ARMCANZ (2000) guideline value at certain locations (see Appendix 1).

Table 3-4. Summary of surface water hydrochemical characteristics (field).

	pH	**SEC** µS/cm	**DO** mg/L	**Eh** mV	**Turbidity** NTU	**Alkalinity** (mg/L as HCO_3)
Minimum	6.50	28.5	0.24	-286	8	16
Median	8.34	48,700	9.45	209	33	57
Maximum	8.94	406,000	12.32	259	305	1,082
n[1]	7	7	6	7	6	7

[1] n: number of samples

The field pH of the groundwater ranged between 4.6 and 6.7, indicating that the groundwater at some locations may have been affected by acidification (Table 3-5). The highly saline groundwater often had high sulfate concentrations ranging between 286 and 9,456 mg/L.

Table 3-5. Summary of groundwater hydrochemical characteristics (field).

	pH	**SEC** µS/cm	**DO** mg/L	**Eh** mV	**Turbidity** NTU	**Alkalinity** (mg/L as HCO_3)
Minimum	4.57	17,000	0.52	-30	55	11
Median	5.82	56,400	1.21	149	55	104
Maximum	6.69	202,200	4.56	415	55	285
n[1]	11	11	9	11	1	11

[1] n: number of samples

4. DISCUSSION

A detailed assessment was undertaken in the Mildura region in March 2010 to determine whether acid sulfate soils were present, or if there was a potential for acid sulfate soil to form within these wetlands. This study identified the presence of acid sulfate soil materials in 19 of the 52 sites examined in the Mildura region. The soluble sulfate contents of 50 surficial soil materials sampled were equal to or exceeded the trigger value of 100 mg/L indicating the potential formation of monosulfidic materials.

The type and prevalence of acid sulfate soil materials observed in each wetland is summarised below in Table 4-1. The presence of acid sulfate soils was identified in all wetlands except Lake Iraak (40175). Sulfuric materials with low to moderate net acidities were observed at four sites in two of the wetlands (i.e. Spencers Bend Billabong (40190) and Merbein Common – Catfish wetland (40805)). Hypersulfidic soil materials were identified in 13 soil profiles at six wetlands. These materials had net acidities ranging from low to high, although only five hypersulfidic soil materials had high net acidities. Hyposulfidic soil materials were observed in four of the wetlands.

Many of the hyposulfidic soil materials and some hypersulfidic soil materials were classified as hypomonosulfidic and hypermonosulfidic, respectively (Sullivan *et al.* 2010) (see Appendix 1). A total of 12 sites in four of the wetlands examined contained monosulfidic soil materials. High monosulfide concentrations in surface soils (i.e. 0-10 cm) in three of these wetlands (i.e. Brickworks Lagoon (40864), Boeill Lagoon (21920) and Outlet Creek (40856)) represent a high deoxygenation hazard. The potential formation of monosulfidic materials was identified in the surface soils at all of the wetlands examined. Other acidic soil materials were observed at an additional 20 sites, and soil acidity may be sufficient for mobilisation of aluminium at some sites.

Table 4-1 Type and prevalence of acid sulfate soil materials in each wetland.

Type of actual or potential acid sulfate soil material	Wetland ID (No. of sites)							
	40156	**40175**	**40190**	**40864**	**40805**	**40856**	**21920**	**21921**
Sulfuric	0	0	2	0	2	0	0	0
Hypersulfidic	2	0	0	3	2	1	3	2
Hyposulfidic (S_{CR} ≥ 0.10%)	0	0	0	3	0	3	3	0
Monosulfidic (observed)	2	0	0	3	0	3	4	0
Monosulfidic (potential)	12	7	4	4	8	4	7	4
Hyposulfidic (S_{CR} < 0.10%)	3	0	0	2	0	3	3	0
Other acidic (pH_w &/or $pH_{INCUBATION}$) 4 – 5.5	7	0	2	0	5	0	3	2
Other soil materials	1	8	0	1	0	1	0	0

5. HAZARD ASSESSMENT

5.1. Interpretation of soil and water data

Sulfuric soil materials were encountered at four sampling sites (Table 5-1), and only observed in two wetlands (i.e. Spencers Bend Billabong (40190) and Merbein Common – Catfish wetland (40805)). The sulfuric soil materials had low to moderate net acidities ranging between 3 and 87 mole H^+/tonne.

Hypersulfidic materials occurred in the soil profile at 13 of the 52 sampling locations (Table 5-1), and were recorded in all but two of the wetlands examined (i.e. Lake Iraak (40175) and Spencers Bend Billabong (40190)). At Brickworks Lagoon (40864) and Boeill Lagoon (21920) hypersulfidic materials occurred in the lowest elevation drainage depressions where reducing conditions suitable for the formation of sulfides occur. However, this trend was not consistently observed at other wetlands in the Mildura region. The acidification hazard from acid sulfate soil disturbance posed by these materials ranged from low to high (the hypersulfidic soil materials had net acidities ranging between -182 and 1,234 mole H^+/tonne). However, the majority of hypersulfidic soil materials (i.e. 78%) had a low to moderate net acidity and thus a low to moderate acidification hazard.

Hyposulfidic soil materials (S_{CR} ≥ 0.10%) occurred in the soil profile at nine sampling locations (Table 5-1) at three of the wetland sites (i.e. Brickworks Lagoon (40864), Outlet Creek (40856) and Boeill Lagoon (21920)). Eleven hyposulfidic soil materials with S_{CR} < 0.10% were also present in the sampling sites. In addition, 20 sampling sites were classified as other acidic soil materials, and soil acidity may be sufficient for mobilisation of aluminium at some sites.

Monosulfidic soil materials (S_{AV} ≥ 0.01%) occurred in the soil profile at 12 sampling locations (Table 5-1). High monosulfide concentrations (S_{AV} ≤ 0.42% S) in surface soils in three wetlands (i.e. Brickworks Lagoon (40864), Boeill Lagoon (21920) and Outlet Creek (40856)) represent a high deoxygenation hazard. The soluble sulfate contents of 50 surficial soil materials sampled were equal to or exceeded the trigger value of 100 mg/L indicating the potential formation of monosulfidic materials (Table 5-1). The potential formation of MBO was identified in all of the wetlands examined.

The water data indicates that the surface water has not been affected by acidification (Appendix 1).

Table 5-1 Type and prevalence of acid sulfate soil materials.

Type of actual or potential acid sulfate soil material	Number of sampling sites containing sulfuric or sulfidic materials (Total sites = 52)	Proportion of total sampling sites (%)
Sulfuric	4	8
Hypersulfidic	13	25
Hyposulfidic (S_{CR} ≥ 0.10%)	9	17
Monosulfidic (observed)	12	23
Monosulfidic (potential)	50	96
Hyposulfidic (S_{CR} < 0.10%)	11	21
Other acidic (pH_w &/or $pH_{INCUBATION}$) 4 – 5.5	20	38
Other soil materials	11	21

6. CONCLUSIONS AND RECOMMENDATIONS

This report provides the results of Phase 1 of a two-phased detailed assessment procedure to determine the hazards posed by acid sulfate soil materials in priority wetlands in the Mildura region. This Phase 1 report is aimed solely at determining whether or not acid sulfate soil materials are present in the Mildura region priority wetlands.

Sulfuric materials were observed at four sampling sites. The reduced inorganic sulfur content of the samples was high in some areas (i.e. S_{CR} was up to 2.19%). Hypersulfidic soil materials were present in 13 soil profiles (eight of these profiles also contained hyposulfidic materials), and another three soil profiles contained hyposulfidic materials with $S_{CR} \geq 0.10\%$. Monosulfidic soil materials were observed at 23% (i.e. 12) of the sampling sites. An additional three soil profiles contained hyposulfidic materials with $S_{CR} < 0.10\%$. These results indicate that acidity would be produced upon oxidation of sulfides in some of these materials.

A total of 50 surficial soil materials contained soluble sulfate equal to or in excess of the 100 mg/L trigger value for MBO formation potential. The potential formation of MBO was identified in all of the wetlands examined. Other acidic soil materials were also observed at an additional 20 sites.

Based on the priority ranking criteria adopted by the Scientific Reference Panel of the Murray-Darling Basin Acid Sulfate Soil Risk Assessment Project, there were four high priority sites based on the presence of sulfuric material, 13 high priority sites based on hypersulfidic material, nine high priority sites based on hyposulfidic ($S_{CR} \geq 0.10\%$) material and 12 high priority sites based on monosulfidic material. There were 11 moderate priority sites based on the presence of a hyposulfidic material with $S_{CR} < 0.10\%$. In addition, 50 of the 52 sampling sites had a high priority ranking for Phase 2 detailed assessment based on MBO formation hazard. All wetlands in the Mildura region receive a high priority ranking on at least one of the criteria.

The potential hazards at the wetland-scale posed by acid sulfate soil materials in priority wetlands in Mildura region are as below:

- Acidification hazard: The data indicate that with predominantly low to moderate net acidities within the wetlands the overall degree of acidification hazard is moderate. Brickworks Lagoon wetland (40864) is the only exception, with a high acidification hazard due to the presence of hypersulfidic soil materials with high net acidities in 17% of layers.

- Deoxygenation hazard: High monosulfide concentrations ($S_{AV} \leq 0.42\%$ S) in surface soils in three wetlands (i.e. Brickworks Lagoon (40864), Boeill Lagoon (21920) and Outlet Creek (40856)) represent a high deoxygenation hazard. In addition, the soluble sulfate contents of surface soil materials at 50 sites were equal to or greater than the trigger value for MBO formation indicating the possible development of an appreciable deoxygenation hazard at those locations after prolonged wet conditions.

- Metal mobilisation: The moderate to high acidification hazard in some of the wetlands indicates that soil acidification may increase the solubility of metals. The presence of monosulfidic materials in some surface soils at three wetlands and the potential for MBO formation identified in all wetlands may also result in an appreciable metal release hazard. This would depend on factors such as the potential for MBO formation and the metal loading in the wetland.

7. REFERENCES

Ahern CR, Sullivan LA, McElnea AE (2004) Laboratory methods guidelines 2004 - acid sulfate soils. In 'Queensland Acid Sulfate Soil Technical Manual'. (Department of Natural Resources, Mines and Energy: Indooroopilly, Queensland).

ANZECC/ARMCANZ (2000) 'Australian and New Zealand guidelines for fresh and marine water quality.' (Australian and New Zealand Environment and Conservation Council, Agricultural and Resource Management Council of Australia and New Zealand: Canberra). http://hermes.erin.gov.au/pls/crg_public/!CRGPPUBLIC.PSTART?strAction=SearchByChemical

APHA (2005) 'Standard methods for the examination of water and wastewater (21st Ed.).' (American Public Health Association - American Water Works Association: Baltimore, USA).

Burton ED., Bush RT, Sullivan, LA (2006) Acid-volatile sulfide oxidation in coastal floodplain drains: iron-sulfur cycling and effects on water quality. *Environmental Science & Technology* 40, 1217 –1222.

Burton, ED, Bush RT, Sullivan L A, Johnston SG, Hocking, RK (2008a) Mobility of arsenic and selected metals during re-flooding of iron- and organic-rich acid sulfate soil. *Chemical Geology* 253, 64 – 73.

Burton ED, Sullivan LA, Bush RT, Johnston SG, Keene AF (2008b) A simple and inexpensive chromium-reducible sulfur method for acid-sulfate soils. *Applied Geochemistry* 23, 2759-2766.

Bush RT (2000) Iron sulfide micromorphology and mineralogy in acid sulfate soils: Their formation and behaviour. Unpublished Ph.D., University of NSW.

Bush RT, Sullivan LA (1997) Morphology and behaviour of greigite from a Holocene sediment in eastern Australia. *Australian Journal of Soil Research* 35, 853-861.

Bush RT, Sullivan LA, Lin C (2000) Iron monosulfide distribution in three coastal floodplain acid sulfate soils, eastern Australia. *Pedosphere* 10, 237-245.

Dent D (1986) 'Acid sulphate soils: a baseline for research and development.' (International Institute for Land Reclamation and Improvement ILRI, Wageningen, The Netherlands).

Ferguson A, Eyre B (1999) Behaviour of aluminium and iron in acid runoff from acid sulphate soils in the lower Richmond River catchment. *Journal of Australian Geology & Geophysics* 17, 193-201.

Fitzpatrick RW, Marvanek S, Shand P, Merry RH, Thomas, M (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.

Fitzpatrick RW, Merry RH, Raven MD, Shand P (2008b) Acid sulfate soil materials and salt efflorescences in subaqueous and wetland soil environments at Tareena Billabong and Salt Creek, NSW: Properties, risks and management. CSIRO Land and Water Science Report 07/08.

Fitzpatrick RW, Shand P, Thomas M, Merry RH, Raven MD, Simpson SL (2008c) Acid sulfate soils in subaqueous, waterlogged and drained soil environments of nine wetlands below Blanchetown (Lock 1), South Australia: properties, genesis, risks and management. Report prepared for South Australian Murray-Darling Basin Natural Resources Management Board. CSIRO Land and Water Report Number 42/08. CSIRO Land and Water Glen Osmond, SA.

Hsieh YP, Chung SW, Tsau YJ, Sue CT (2002) Analysis of sulfides in the presence of ferric minerals by diffusion methods. *Chemical Geology* 182, 195-201.

Isbell RF (1996) 'The Australian Soil Classification.' (CSIRO Publishing, Melbourne, Vic).

Lamontagne S, Hicks WS, Fitzpatrick RW, Rogers S (2004) Survey and description of sulfidic materials in wetlands of the Lower River Murray floodplains: Implications for floodplain salinity management Technical Report 28/04. CSIRO Land and Water. Adelaide, Australia.

Lamontagne S, Hicks WS, Fitzpatrick RW, Rogers S (2006) Sulfidic materials in dryland river wetlands. *Marine and Freshwater Research* **57**, 775-788.

McCarthy B, Conallin A, D'Santos P, Baldwin D (2006) Acidification, salinization and fish kills at an inland wetland in south-eastern Australia following partial drying. *Ecological Management & Restoration* **7**, 221-223.

MDBA (2010) 'Detailed assessment of acid sulfate soils in the Murray-Darling Basin: Protocols for sampling, field characterisation, laboratory analysis and data presentation.' MDBA Publication No. 57/10, 58 pp

MDBC (2006a) The Barmah-Millewa Forest Icon Site Environmental Management Plan 2006-2007. MDBC Publication No. 30/06.
http://thelivingmurray.mdbc.gov.au/__data/page/195/BM_EMP_2006-07.pdf (last accessed 15/04/2009).

MDBC (2006b) The Hattah Lakes Icon Site Environmental Management Plan 2006–2007. MDBC Publication No. 31/06.
http://thelivingmurray.mdbc.gov.au/__data/page/1327/HL_EMP_2006-07.pdf (last accessed 15/04/2009).

MDBC (2006c) The Gunbower-Koondrook-Perricoota Forest Icon Site Environmental Management Plan 2006–2007. MDBC Publication No. 32/06.
http://thelivingmurray.mdbc.gov.au/__data/page/195/GKP_EMP_2006-07.pdf (last accessed 15/04/2009).

Preda M, Cox ME (2001) Trace metals in acid sediments and waters, Pimpama catchment, southeast Queensland, Australia. *Environmental Geology* 40, 755-768.

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

Sammut J, Callinan RB, Fraser GC (1993) The impact of acidified water on freshwater and estuarine fish populations in acid sulphate soil environments. In 'Proceedings National Conference on Acid Sulphate Soils'. Coolangatta, NSW. 24-25 June 1993. (Ed. RT Bush) pp. 26-40. (CSIRO, NSW Agriculture, Tweed Shire Council).

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

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

Simpson S, Angel B, Spadarol 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.

Sullivan LA, Burton ED, Bush RT, Watling K, Bush M (2008a) Acid, metal and nutrient mobilisation dynamics in response to suspension of MBOs in freshwater and to freshwater inundation of dried MBO and sulfuric soil materials. Southern Cross GeoScience, Report Number 108.

Sullivan LA, Bush RT (1997) Quantitative elemental microanalysis of rough-surfaced soil specimens in the scanning electron microscope using a peak-to-background method. *Soil Science* 162, 749-757.

Sullivan LA, Bush RT, Ward NJ (2002a) Sulfidic sediments and salinisation in the Murray-Darling basin. In 'Proceedings of the 5th International Acid Sulfate Soils Conference. Sustainable Management of Acid Sulfate Soils. Conference Abstracts, Poster Papers'. Tweed Heads, NSW. 25-30 August 2002. (Eds BCT Macdonald, AF Keene, G Carlin, LA Sullivan) pp. 196-197. (Tweed Shire Council: Murwillumbah, NSW).

Sullivan LA, Fitzpatrick RW, Burton ED, Bush RT, Shand P (2008b) Assessing environmental hazards posed by acid sulfate soil materials and other inorganic sulfide-containing soil materials: classification issues. Plenary Paper, Joint Conference of the 6th International Symposium in Acid Sulfate Soils and the Acid Rock Drainage Symposium. Guangzhou, China, 16-20 September 2008.

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. April 2010. Lismore, NSW.

Sullivan LA, Ward NJ, Bush RT (2001) Chemical analysis for acid sulfate soil management. *In* ‘Proceedings of the 2nd Australia and New Zealand Conference on Environmental Geotechnics - Geoenvironment 2001. Newcastle, November 28-30 2001) (Australian Geomechanics Society Inc. Newcastle) pp. 109-120. (Australian Geomechanics Society Inc. Newcastle).

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

Sullivan LA, Ward NJ, Bush RT, Lin, C (2002b) Evaluation of approaches to the chemical analysis of acid sulfate soil. *In* 'Acid sulfate soils in Australia and China.' (Eds C. Lin, M. Melville and L.A Sullivan) pp. 72-82. (Science Press, Beijing).

Sundström R, Aström M, Österholm P (2002) Comparison of metal content in acid sulfate soil runoff and industrial effluents in Finland. *Environmental Science & Technology* 36, 4269-4272.

Tulau M (2009) NSW inland wetlands assessed for ASS. In 'ASSAY - a newsletter about acid sulfate soils'. (Ed. S Walsh) pp. 8-9. (Industry & Investment NSW: Wollongbar, NSW, Australia).

Ward NJ, Sullivan LA, Bush RT (2002) Sulfide oxidation and acidification of acid sulfate soil materials treated with $CaCO_3$ and seawater-neutralised bauxite refinery residue. *Australian Journal of Soil Research* 40, 1057-1067.

8. APPENDICES

APPENDIX 1. Wetland reports

8.1. Karadoc Swamp (Wetland ID 40156)

8.1.1. Location and setting description

Karadoc Swamp wetland is situated on the south side of the River Murray on the floodplain, roughly 25 km south-southeast of Mildura. The designated wetland consists primarily of a large, internal basin, and conjoined reaches of the inlet and outlet channels. The designated wetland is irregular in shape and is situated within a larger, ovoid swamp surrounded by orchards and vineyards to the west and pastoral properties to the east. The wetland extends to 4.9 km in length and 3.0 km at its widest point, with an overall area of 377 hectares. The wetland is bounded by sand dunes. At the time when the soil survey was conducted in 2010, the wetland had surface water in the centre, which was probably more related to recent rainfall than inflow from the river. Apart from the actual lake bed and channels, which contained no vegetation, most of the wetland supported low, succulent shrub vegetation. Two distinctive reed bed areas were associated with artificial drainage systems from surrounding agricultural land. Only a small area of remnant woodland was present within the survey area, and this was sampled. Twelve sites were sampled as shown in Figure 8-1.

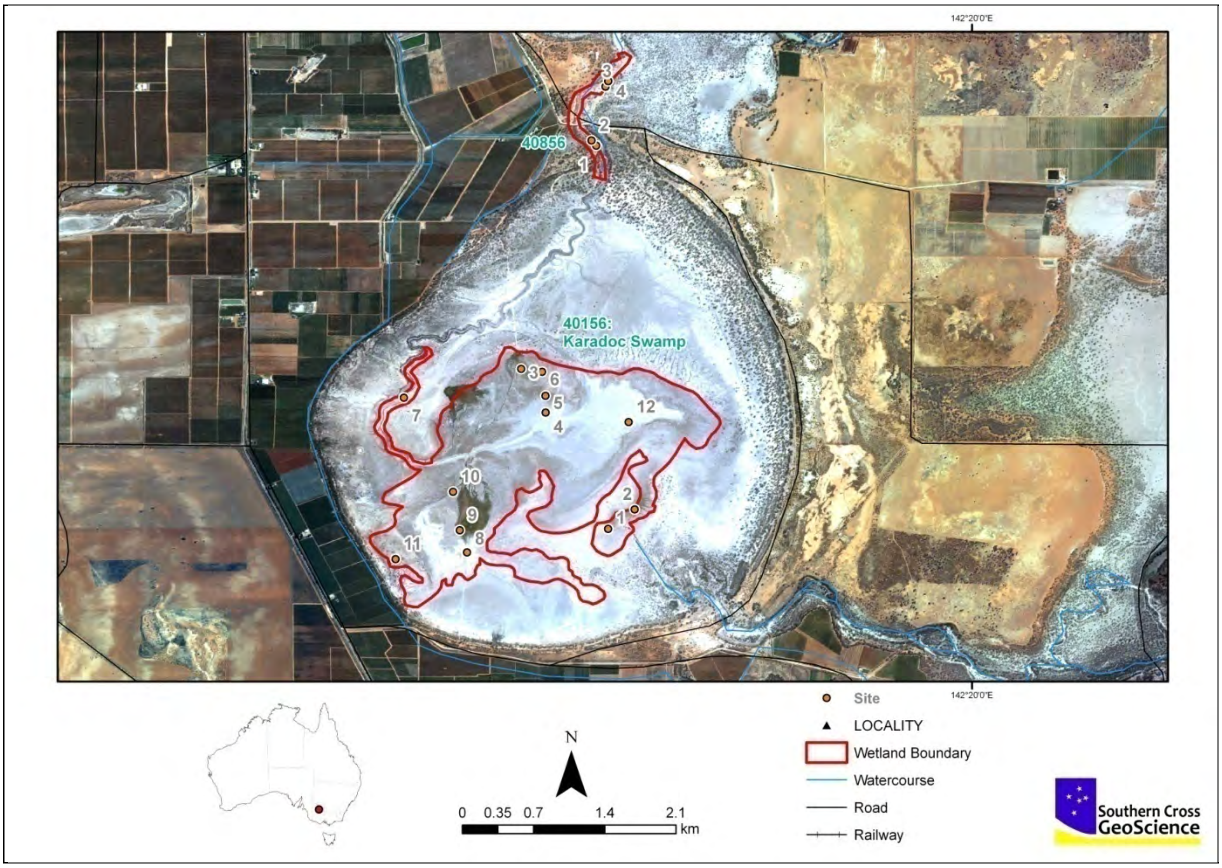


Figure 8-1. Karadoc Swamp Wetland and sample site locations.

8.1.2. Soil profile description and distribution

Twelve sites were described and sampled. The soil subtype and general location description of each site are presented in Table 8-1. Sites were distributed throughout the wetland based on different surface features and locations in the wetland, and a transect approach was used in part.

The profile 40156_1 (Figure 8-3) was situated adjacent to the inlet channel, without surface water. The soil consisted of brown, cracking clay. The profile 40156_2 (Figure 8-4) was situated in the drainage line near the inlet creek, and was moist with surface pools and denser vegetation than 40156_1. The profile 40156_3 (Figure 8-5) was situated proximal to an artificial drainage outlet (but unaffected by it). The surface was dry and well vegetated with sparse succulents amongst a matrix of grasses and forbs, most of which were dead. The profiles 40156_4 to 40156_6 (Figure 8-6 to Figure 8-8) form a transect in the middle of the wetland, including a sub-aqueous, a moist, and a dry site. The profile 40156_7 (Figure 8-9) was situated in the middle of the outlet channel, with a bare, moist surface. The profile 40156_8 (Figure 8-10) was situated in a low, bare area to the south of the main reed bed, and the profile 40156_9 (Figure 8-11) was located on the edge of the reed bed. The profile 40156_10 (Figure 8-12) occurred in a low drainage line to the north of the main reed bed, in an area with moderate cover of low succulent shrubs. The profile 40156_11 (Figure 8-13) was situated near the edge of the wetland, in a zone of dead mature trees The profile 40156_12 (Figure 8-14) was located on the moist, western side of the lake bed, and surface water was not present. Additional site and profile description data are presented in Tables 8-5 and 8-6, respectively.

Table 8-1. Soil identification, subtype and general location description for Karadoc Swamp Wetland.

Site ID	Easting UTM zone 54H	Northing UTM Zone 54H	Acid sulfate soil subtype class	General location description
40156_1	619616	6194012	Cracking Clay Soil	Dryland area at terminus of one Southern inlet channel.
40156_2	619834	6194200	Cracking Clay Soil	Wetland area SW of terminus of one Southern inlet channel.
40156_3	618930	6195587	Cracking Clay Soil	Proximal to northern reed bed. Dryland area to south of reed bed.
40156_4	619124	6195158	Subaqueous Soil	Western end of lake basin proximal to outlet. Lake bed with surface water.
40156_5	619124	6195321	Hydrosol	Western end of lake basin. Moist area to north of surface water
40156_6	619100	6195556	Hydrosol	Western end of lake basin. Dryland area to north of surface water
40156_7	617974	6195318	Cracking Clay Soil	Northern section of outlet channel. Centre of channel.
40156_8	618468	6193797	Cracking Clay Soil	SW section of wetland. Bare moist surface.
40156_9	618411	6194014	Hypomonosulfidic Subaqueous Soil	SW reed bed. In aquatic vegetation with surface water
40156_10	618362	6194391	Hypermonosulfidic Cracking Clay Soil	Drainage line from SW lake section. Centre of drainage line
40156_11	617887	6193738	Hyposulfidic Soil	Zone of dead mature trees near SW margin of wetland.
40156_12	619796	6195056	Hypersulfidic Soil	Eastern end of lake basin. Leeward edge of basin.

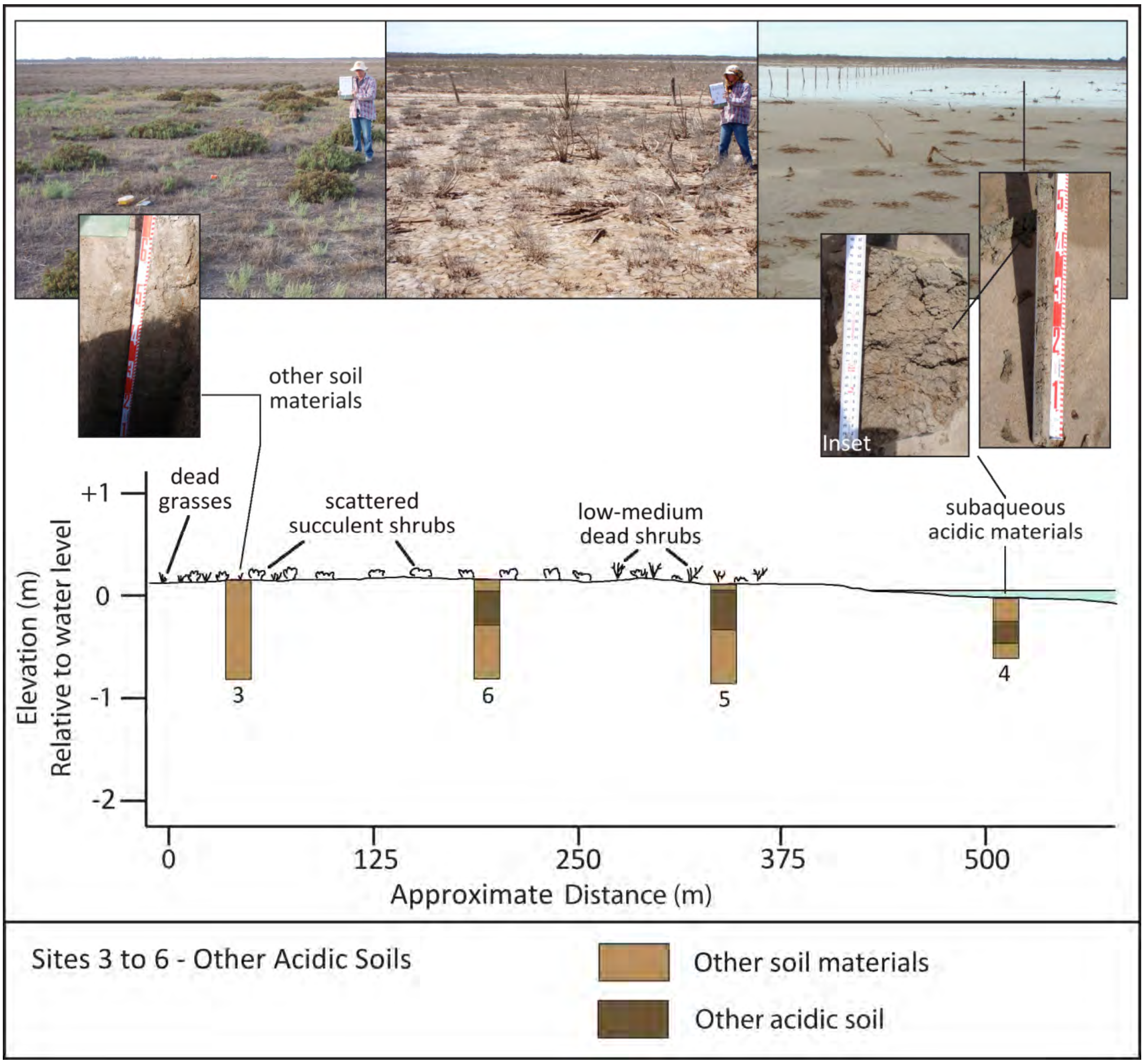


Figure 8-2. Conceptual cross section diagram showing the toposequence relationship of the Karadoc Swamp Wetland sediments/soil materials throughout the wetland.

Figure 8-3. Photographs of site 40156_1, showing the bare cracking clay surface with salt visible, low succulent shrubs to 20 cm, and the soil profile.

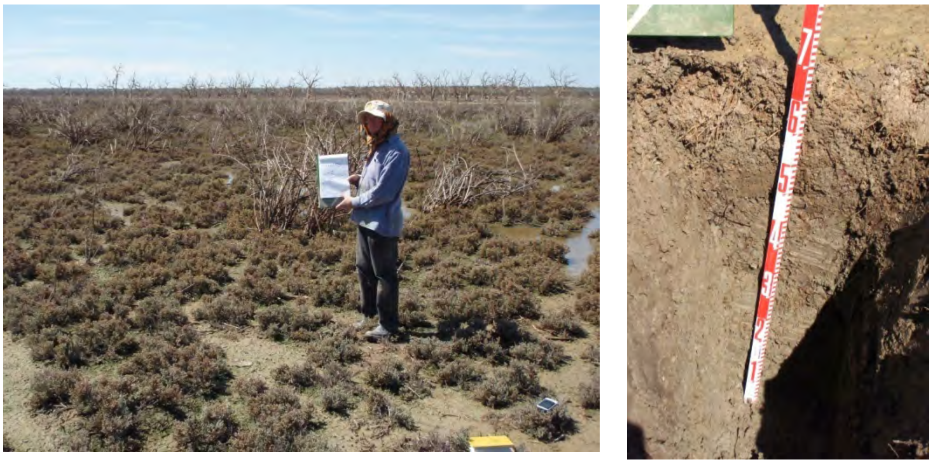


Figure 8-4. Photographs of site 40156_2, showing the denser succulent vegetation and surface pooling, and the soil profile.

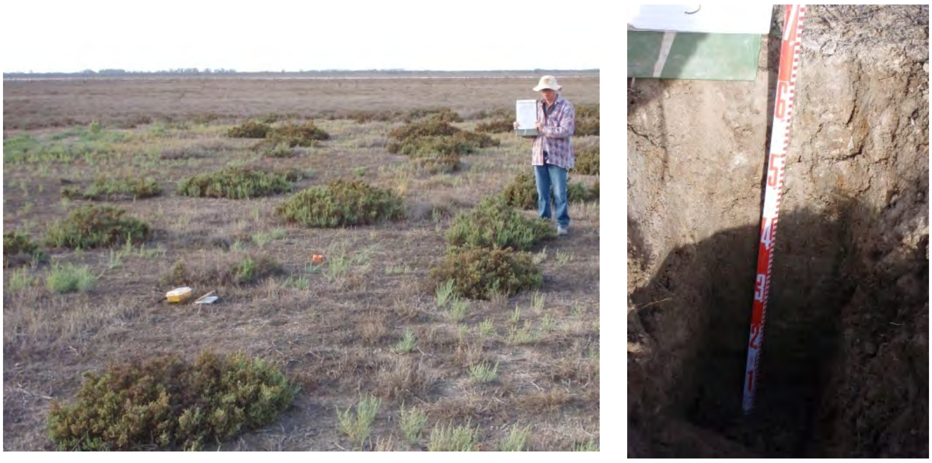


Figure 8-5. Photographs of site 40156_3, showing the dry, cracking surface and sparse succulent vegetation amongst a matrix of dry grasses and forbs, and the soil profile.

Figure 8-6. Photographs of site 40156_4, showing the water body from which the sample was taken, and the soil core.

Figure 8-7. Photographs of site 40156_5, showing the moist but cracking brown clay and the dead low shrub vegetation, and the soil profile.

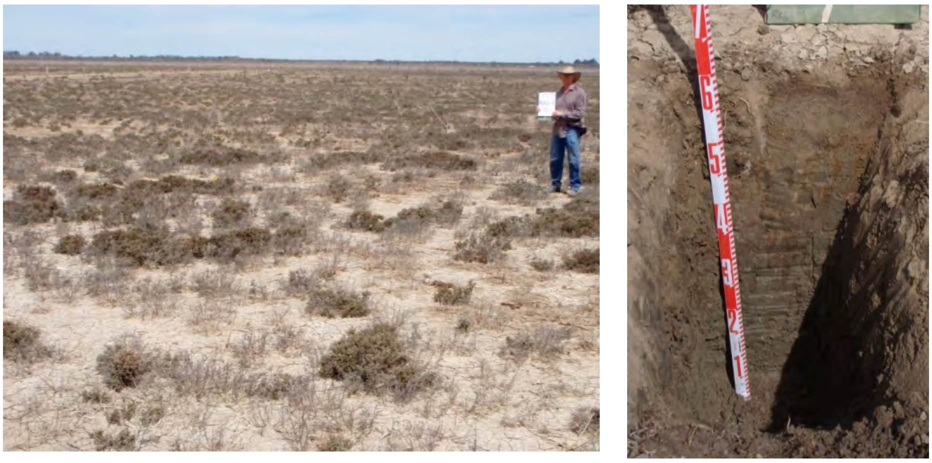


Figure 8-8. Photographs of site 40156_6, showing the low shrubby vegetation, predominantly on mounds, and the soil profile.

Figure 8-9. Photographs of site 40156_7, showing the bare, moist surface of the outlet channel, and the soil profile.

Figure 8-10. Photographs of site 40156_8, showing bare, cracking clay surface, and the soil profile.

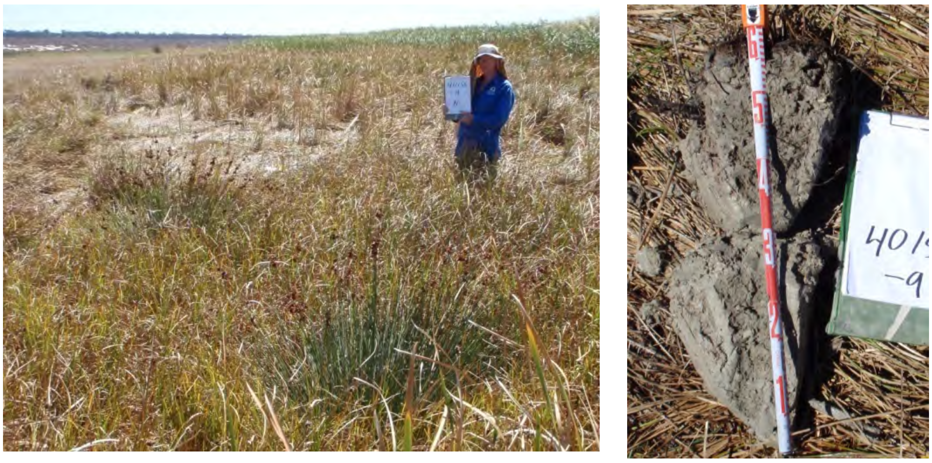


Figure 8-11. Photographs of site 40156_9, showing the location of the site along the edge of the main reed bed, and the soil profile.

Figure 8-12. Photograph of site 40156_10, showing the situation of the site within a drainage line, and the low succulent shrub cover.

Figure 8-13. Photographs of site 40156_11, showing the situation of the site in the zone of mature, dead trees at the edge of the lake, and the soil profile.

Figure 8-14. Photographs of site 40156_12, showing the moist lake bed surface with waterbird tracks, and the soil profile.

8.1.3. Laboratory data assessment

Soil pH testing (pH_W, pH_{FOX}, pH_{KCl}, $pH_{INCUBATION}$)

The pH data is provided in Table 8-2 and profiles for all the sites sampled are presented in Figures 8-15 and 8-16. The pH_W values ranged between 4.41 and 8.24. Sulfuric materials (i.e. $pH_W < 4$) were not present. The pH_{FOX} values ranged between 4.10 and 8.29. The pH_{FOX} results indicate that none of the surface soils may have the potential to acidify to pH < 4 as a result of sulfide oxidation. None of the soil materials acidified to pH < 4 after at least 8 weeks of incubation. Other acidic soil materials were identified at 9 sites, indicating acidity in the soil profile at levels where aluminium may mobilise.

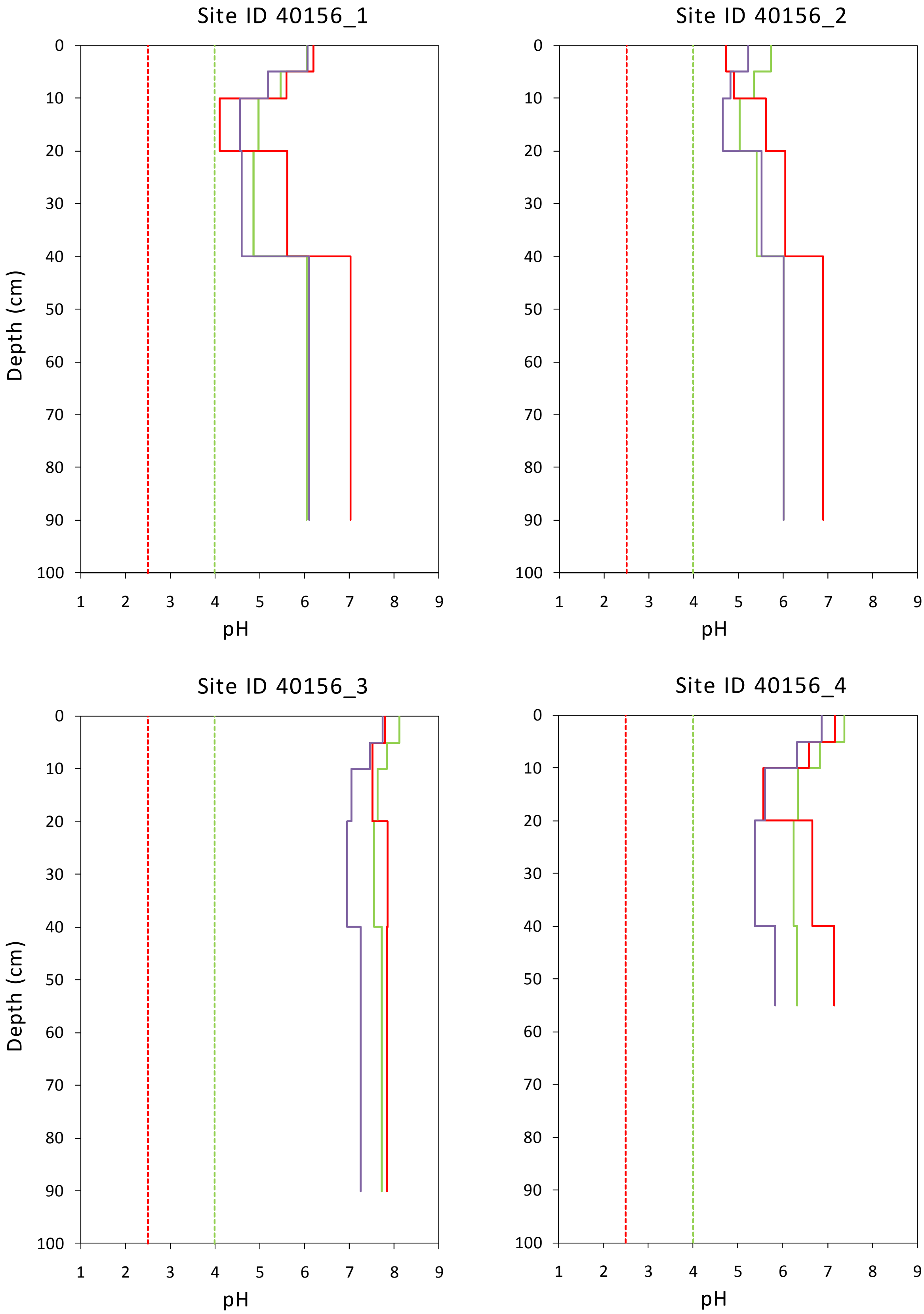


Figure 8-15. Depth profiles of soil pH for Karadoc Swamp Wetland (40156_1 – 40156_4), showing soil pH (pH_W as green line), peroxide treated pH (pH_{FOX} as red line) and ageing pH ($pH_{incubation}$ after at least eight weeks as purple line). Critical pH_W and $pH_{incubation}$ value of 4 (green dashed line) and critical pH_{FOX} value of 2.5 (red dashed line).

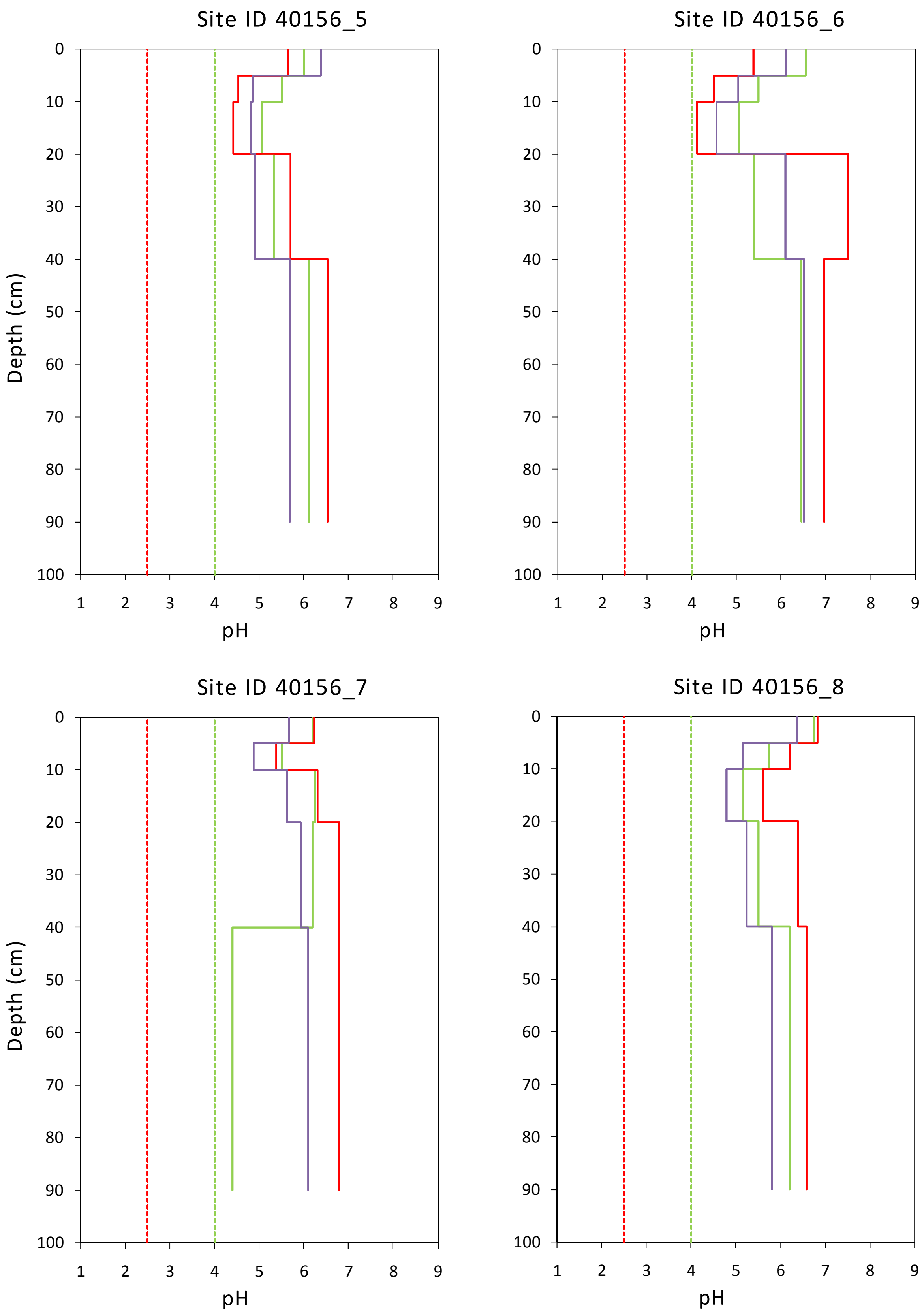


Figure 8-16. Depth profiles of soil pH for Karadoc Swamp Wetland (40156_5 – 40156_8), showing soil pH (pH_W as green line), peroxide treated pH (pH_{FOX} as red line) and ageing pH ($pH_{incubation}$ after at least eight weeks as purple line). Critical pH_W and $pH_{incubation}$ value of 4 (green dashed line) and critical pH_{FOX} value of 2.5 (red dashed line).

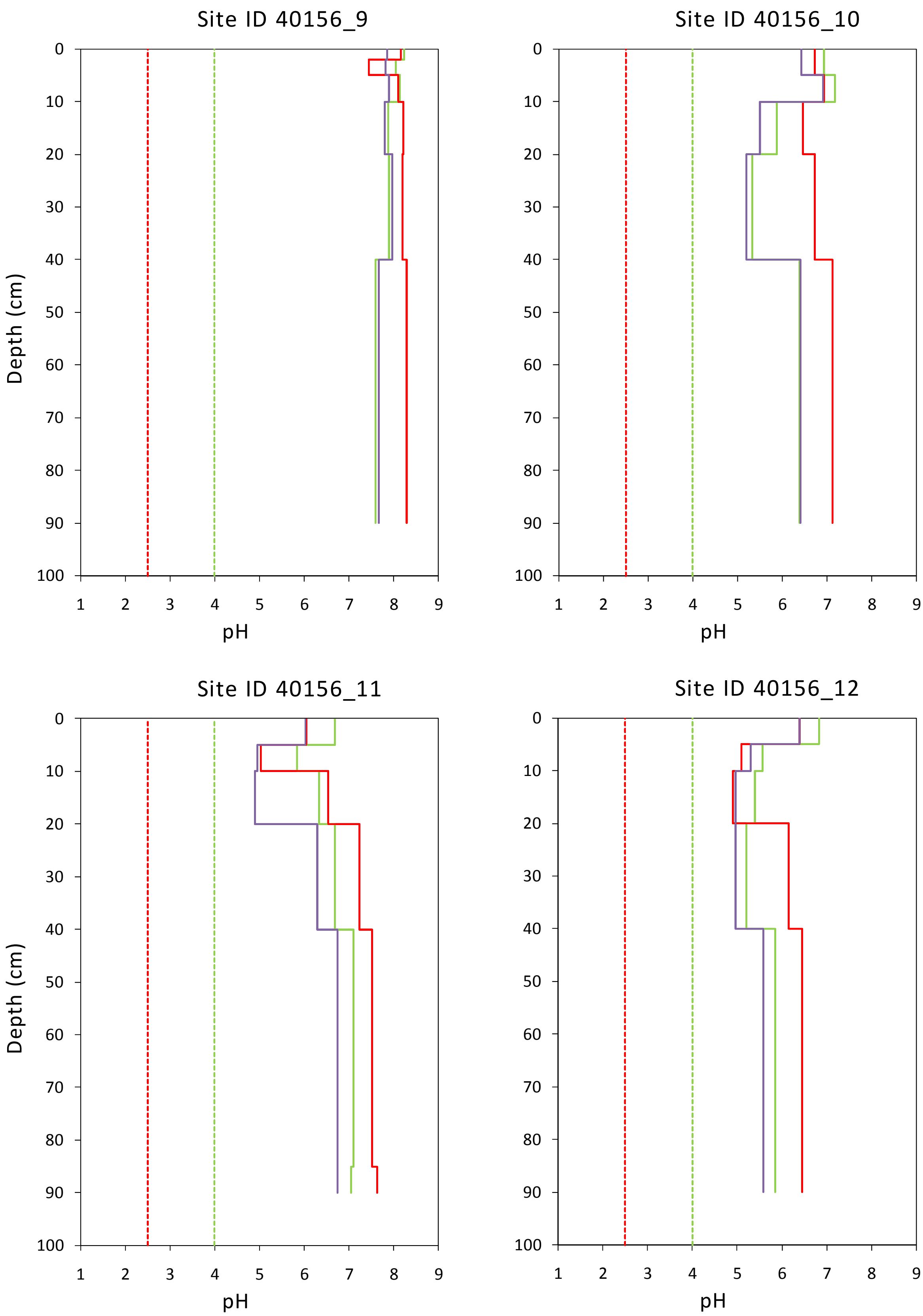


Figure 8-17. Depth profiles of soil pH for Karadoc Swamp Wetland (40156_9 – 40156_12), showing soil pH (pH_W as green line), peroxide treated pH (pH_{FOX} as red line) and ageing pH ($pH_{incubation}$ after at least eight weeks as purple line). Critical pH_W and $pH_{incubation}$ value of 4 (green dashed line) and critical pH_{FOX} value of 2.5 (red dashed line).

Acid-base accounting

The acid-base accounting data is provided in Table 8-2 and summarised in Figures 8-18 to 8-20.

Chromium reducible sulfur

Chromium reducible sulfur (S_{CR}) values ranged between < 0.01 and 0.09% S. Sulfidic soil materials (i.e. S_{CR} ≥ 0.01% S) were identified at four sampling sites (sites 40159_9 - 40159_12), with 12 materials of the 62 samples collected equal to or greater than the sulfidic criterion.

Acid volatile sulfide

The acid volatile sulfide (S_{AV}) values ranged between < 0.01 and 0.01% S. Monosulfidic soil materials (i.e. S_{AV} ≥ 0.01% S) were found at two sites (sites 40159_9 and 40159_10), with only three materials of the 62 samples collected equal to the monosulfidic criterion.

Acid neutralising capacity

The acid neutralising capacity (ANC) ranged between zero and 2.63% $CaCO_3$.

Titratable actual acidity

The titratable actual acidity (TAA) ranged between zero and 17 mole H^+/tonne, with the majority of soil layers having a TAA < 15 mole H^+/tonne. At the sites where a positive TAA was measured throughout the profile, an increase in the TAA with depth was often observed.

Retained acidity

There was no retained acidity at any of the sites as all samples had a pH_{KCl} > 4.5.

Net acidity

The net acidity ranged between -343 and 60 mole H^+/tonne. The four hypersulfidic soil materials had low to moderate net acidities ranging between 7 and 60 mole H^+/tonne.

Water Soluble Sulfate

The water soluble sulfate in the surface soils (i.e. 0-5 cm) ranged between 99.6 and 16,350 mg/L. All 12 surface soil layers examined had a soluble sulfate content equal to or exceeding the 100 mg/L trigger value for MBO formation potential.

Water Data

The surface water and groundwater data measured in the field and laboratory are presented in Tables 8-3 and 8-4, respectively. The field pH of the two surface waters collected was 8.4 and 8.9, with both sites exceeding the most relevant ANZECC/ARMCANZ (2000) trigger value for aquatic ecosystems of 8.0. The water data indicates that the surface water has not been affected by acidification. The surface water sulfate concentrations were 284 and 3,893 mg/L. Some nutrient (i.e. NH_4, PO_4), metal (i.e. Ag, Co, Cr, Cu, Ni, Zn) and SEC values were found to exceed the most relevant ANZECC/ARMCANZ (2000) trigger value. The field pH of the groundwater ranged between 6.1 and 6.4 indicating that the groundwater has not been affected by acidification. The groundwater had high sulfate concentrations of between 5,577 and 9,456 mg/L.

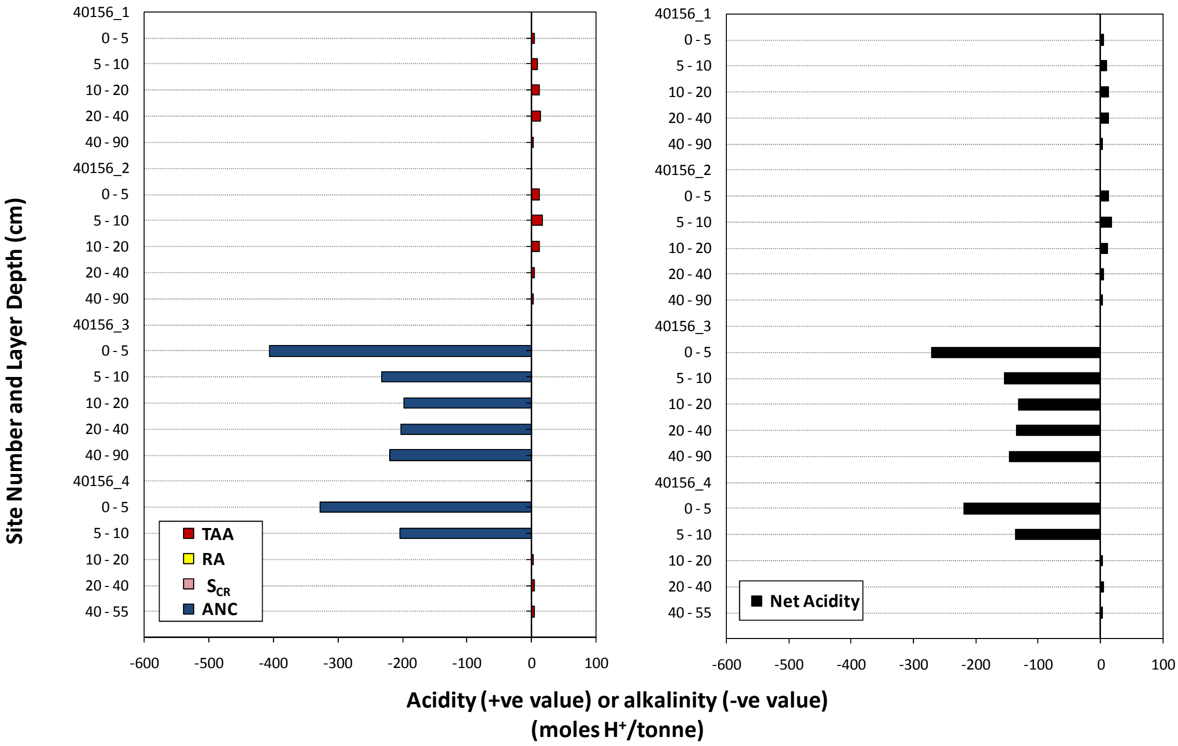


Figure 8-18. Acid-base accounting depth profiles for Karadoc Swamp Wetland (40156_1 – 40156_4). Left side shows the components: titratable actual acidity (TAA - red bar), acid generating potential (AGP as S_{CR} -pink bar), acid neutralising capacity (ANC - blue bar), retained acidity (RA - yellow bar), and right side shows net acidity.

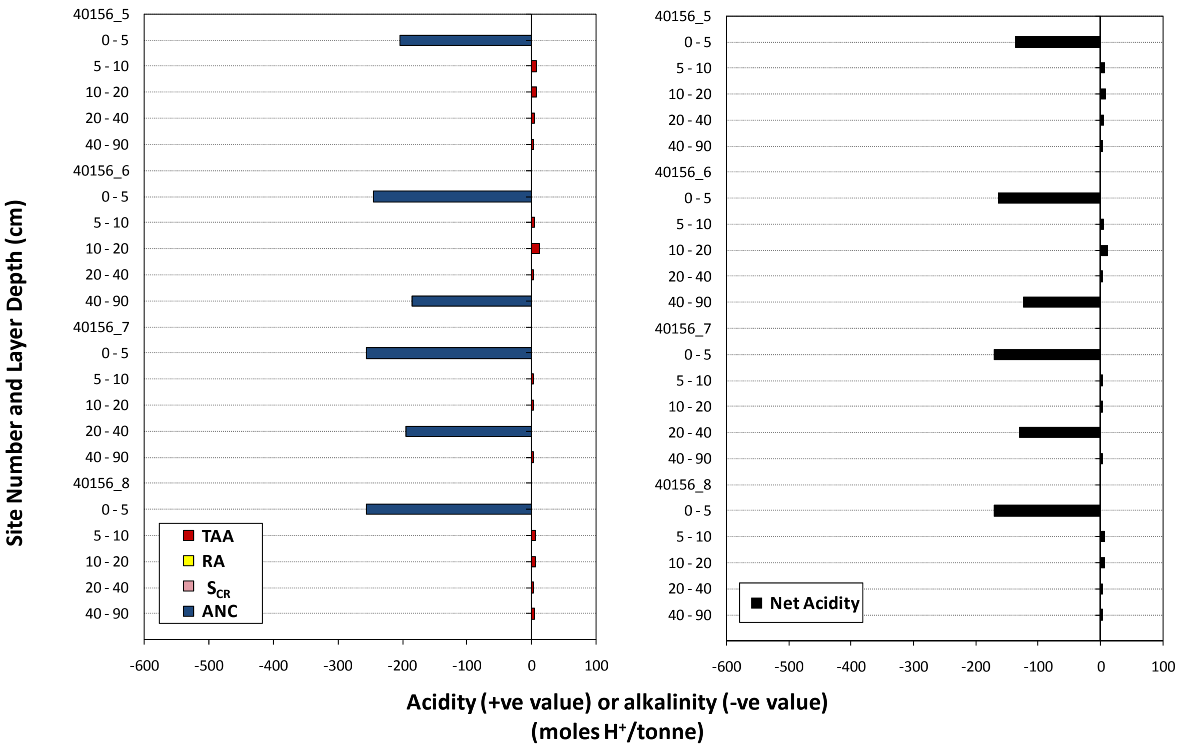


Figure 8-19. Acid-base accounting depth profiles for Karadoc Swamp Wetland (40156_5 – 40156_8). Left side shows the components: titratable actual acidity (TAA - red bar), acid generating potential (AGP as S_{CR} -pink bar), acid neutralising capacity (ANC - blue bar), retained acidity (RA - yellow bar), and right side shows net acidity.

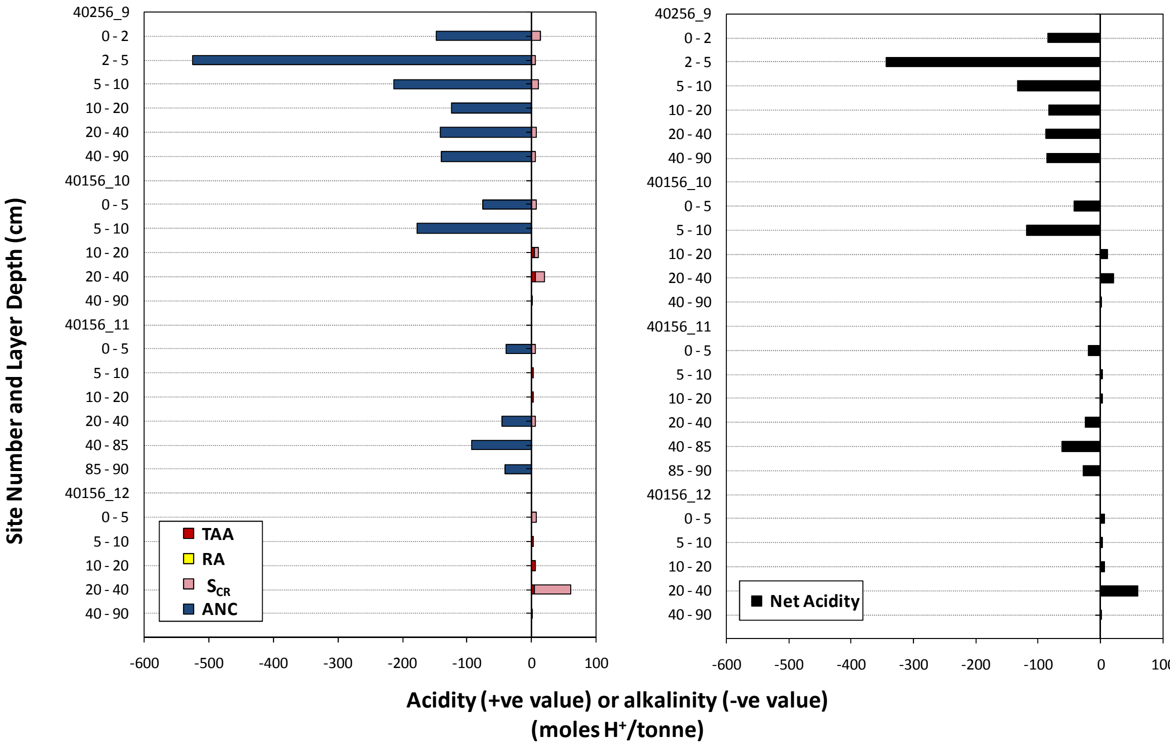


Figure 8-20. Acid-base accounting depth profiles for Karadoc Swamp Wetland (40156_9 – 40156_12). Left side shows the components: titratable actual acidity (TAA - red bar), acid generating potential (AGP as S_{CR} -pink bar), acid neutralising capacity (ANC - blue bar), retained acidity (RA - yellow bar), and right side shows net acidity.

8.1.4. Discussion

Acid sulfate soils only occurred at three sites in the south-western area of the Karadoc Swamp wetland (i.e. sites 40156_9 – 40156_11) and one site in the eastern part of the wetland (i.e. site 40156_12). Sulfuric materials were not observed. The reduced inorganic sulfur content of the samples was low (i.e. S_{CR}. ≤ 0.09% S), with only one soil material exceeding a S_{CR} of 0.02% S. Hypersulfidic soil materials with low to moderate net acidities were present in two soil profiles (one profile also contained a hyposulfidic material), and another two soil profiles contained hyposulfidic materials with S_{CR} < 0.10%. Monosulfidic soil materials with a S_{AV} of 0.01% S were observed at two of the sampling sites. Only one of these monosulfidic materials was observed in a surface soil (i.e. site 40146_9, 0-2 cm). These results indicate that minimal acidity would be produced upon oxidation of sulfides in these materials.

The surficial soil materials at all 12 sites contained soluble sulfate equal to or in excess of the 100 mg/L trigger value for MBO formation potential. Other acidic soil materials were also observed at an additional seven sites.

Based on the priority ranking criteria adopted by the Scientific Reference Panel of the Murray-Darling Basin Acid Sulfate Soil Risk Assessment Project, there were two high priority sites based on hypersulfidic material, and two high priority sites based on monosulfidic material. There were two moderate priority sites based on the presence of a hyposulfidic material with S_{CR} < 0.10%. In addition, 11 sampling sites had a high priority ranking for Phase 2 detailed assessment based on MBO formation hazard.

The potential hazards at the wetland-scale posed by acid sulfate soil materials at the Karadoc Swamp wetland are:

- Acidification hazard: The data indicate that with predominantly low net acidities, and sulfidic materials where the highest S_{CR} was only 0.09% S, that the overall degree of acidification hazard is low. Only two sulfidic soil materials had moderate net acidities.

- Deoxygenation hazard: The soluble sulfate contents of surface soil materials at all 12 sites were equal to or over the trigger value for MBO formation indicating the possible development of an appreciable deoxygenation hazard at those locations after prolonged wet conditions.

- Metal mobilisation: The low acidification hazard indicates that soil acidification is not likely to increase the solubility of metals. However, the potential for MBO formation identified in this wetland may result in an appreciable metal release hazard depending on factors such as the potential for MBO formation and the metal loading in this wetland. Soil acidity may be sufficient for mobilisation of aluminium at some sites.

Summary of key findings for the Karadoc Swamp Wetland:

Soil materials:	Sulfuric materials were not observed. Sulfidic soil materials identified included: hypersulfidic (2 sites), monosulfidic (2 sites) and hyposulfidic < 0.10% S (2 sites). Other acidic soil materials observed at an additional 7 sites. Low net acidities dominant within wetland.
Acid sulfate soil identification:	• Hypersulfidic, hyposulfidic, hypermonosulfidic cracking clay and hypomonosulfidic subaqueous soils identified. • Cracking clay soils, hydrosols and subaqueous soil also identified.
Hazard assessment	• Acidification hazard - low level of concern • Deoxygenation hazard - high level of concern • Metal mobilisation hazard – low to moderate level of concern

Table 8-2. Laboratory analytical data for acid sulfate soil assessment of Karadoc Swamp (Wetland ID 40156).
(red printed values indicates data results of potential concern)

Site and Layer ID.	Depth Range (cm)	Soil Texture	pH water	pH peroxide	pH incubation	Sulfate (mg SO_4 / kg)	pH KCl	Titratable Actual Acidity (mole H^+/t)	Chromium Reducible Sulfur (%S_{CR})	Retained Acidity (mole H^+/t)	Acid Neutralising Capacity (%$CaCO_3$)	Net Acidity (mole H^+/t)	Acid Volatile Sulfide (%S_{AV})	Acid Sulfate Soil Material Classification
1.1	0-5	fine	6.05	6.20	6.06	4260	6.30	4.83	<0.01	0.00	0.00	4.83	<0.01	other soil materials
1.2	5-10	fine	5.46	5.59	5.18		5.63	9.29	<0.01	0.00	0.00	9.29	<0.01	other acidic
1.3	10-20	fine	4.97	4.10	4.56		5.25	12.56	<0.01	0.00	0.00	12.56	<0.01	other acidic
1.4	20-40	fine	4.86	5.61	4.60		5.27	13.28	<0.01	0.00	0.00	13.28	<0.01	other acidic
1.5	40-90	fine	6.05	7.03	6.11		6.17	2.90	<0.01	0.00	0.00	2.90	<0.01	other soil materials
2.1	0-5		5.72	4.72	5.21	5355	5.21	12.58	<0.01	0.00	0.00	12.58	<0.01	other acidic
2.2	5-10	fine	5.35	4.90	4.83		4.97	16.96	<0.01	0.00	0.00	16.96	<0.01	other acidic
2.3	10-20	fine	5.03	5.61	4.66		5.20	11.85	<0.01	0.00	0.00	11.85	<0.01	other acidic
2.4	20-40	fine	5.41	6.05	5.52		5.98	4.31	<0.01	0.00	0.00	4.31	<0.01	other acidic
2.5	40-90	fine	6.01	6.90	6.01		6.36	3.26	<0.01	0.00	0.00	3.26	<0.01	other soil materials
3.1	0-5	fine	8.12	7.79	7.75	100	8.66	0.00	<0.01	0.00	2.04	-271.21	<0.01	other soil materials
3.2	5-10	fine	7.84	7.51	7.46		7.39	0.00	<0.01	0.00	1.16	-154.46	<0.01	other soil materials
3.3	10-20	fine	7.63	7.51	7.05		7.04	0.00	<0.01	0.00	0.99	-132.16	<0.01	other soil materials
3.4	20-40	fine	7.55	7.85	6.95		6.85	0.00	<0.01	0.00	1.01	-135.17	<0.01	other soil materials
3.5	40-90	fine	7.73	7.83	7.25		7.44	0.00	<0.01	0.00	1.10	-146.84	<0.01	other soil materials
4.1	0-5	`	7.38	7.17	6.87	16350	7.69	0.00	<0.01	0.00	1.64	-218.38	<0.01	other soil materials
4.2	5-10	fine	6.83	6.59	6.32		6.82	0.00	<0.01	0.00	1.02	-136.17	<0.01	other soil materials
4.3	10-20	fine	6.34	5.57	5.61		6.32	2.99	<0.01	0.00	0.00	2.99	<0.01	other soil materials
4.4	20-40	fine	6.25	6.66	5.37		6.09	4.07	<0.01	0.00	0.00	4.07	<0.01	other acidic
4.5	40-55	fine	6.32	7.15	5.84		6.25	3.56	<0.01	0.00	0.00	3.56	<0.01	other soil materials
5.1	0-5	fine	6.01	5.64	6.38	15600	7.19	0.00	<0.01	0.00	1.02	-135.97	<0.01	other soil materials
5.2	5-10	fine	5.51	4.54	4.85		5.72	6.81	<0.01	0.00	0.00	6.81	<0.01	other acidic
5.3	10-20	fine	5.06	4.43	4.82		5.45	7.52	<0.01	0.00	0.00	7.52	<0.01	other acidic
5.4	20-40	fine	5.33	5.71	4.92		5.72	5.06	<0.01	0.00	0.00	5.06	<0.01	other acidic
5.5	40-90	fine	6.11	6.53	5.69		6.31	2.60	<0.01	0.00	0.00	2.60	<0.01	other soil materials
6.1	0-5	fine	6.55	5.39	6.12	7200	6.72	0.00	<0.01	0.00	1.22	-163.15	<0.01	other soil materials
6.2	5-10	fine	5.50	4.50	5.05		5.99	4.61	<0.01	0.00	0.00	4.61	<0.01	other soil materials
6.3	10-20	fine	5.07	4.12	4.56		5.24	11.70	<0.01	0.00	0.00	11.70	<0.01	other acidic
6.4	20-40	fine	5.40	7.49	6.09		6.28	3.06	<0.01	0.00	0.00	3.06	<0.01	other acidic
6.5	40-90	fine	6.46	6.96	6.52		6.90	0.00	<0.01	0.00	0.93	-123.30	<0.01	other soil materials

Table 8-2 (continued). Laboratory analytical data for acid sulfate soil assessment of Karadoc Swamp (Wetland ID 40156).
(red printed values indicates data results of potential concern)

Site and Layer ID.	Depth Range (cm)	Soil Texture	pH water	pH peroxide	pH incubation	Sulfate (mg SO_4 / kg)	pH KCl	Titratable Actual Acidity (mole H^+/t)	Chromium Reducible Sulfur (%S_{CR})	Retained Acidity (mole H^+/t)	Acid Neutralising Capacity (%$CaCO_3$)	Net Acidity (mole H^+/t)	Acid Volatile Sulfide (%S_{AV})	Acid Sulfate Soil Material Classification
7.1	0-5	fine	6.19	6.23	5.66	16200	6.90	0.00	<0.01	0.00	1.28	-170.11	<0.01	other soil materials
7.2	5-10	fine	5.51	5.38	4.87		6.15	3.38	<0.01	0.00	0.00	3.38	<0.01	other acidic
7.3	10-20	fine	6.24	6.30	5.63		6.29	2.81	<0.01	0.00	0.00	2.81	<0.01	other soil materials
7.4	20-40	fine	6.20	6.80	5.92		6.50	0.00	<0.01	0.00	0.97	-129.62	<0.01	other soil materials
7.5	40-90	fine	4.41	6.79	6.09		6.40	2.98	<0.01	0.00	0.00	2.98	<0.01	other acidic
8.1	0-5	fine	6.75	6.82	6.37	7905	7.43	0.00	<0.01	0.00	1.28	-170.90	<0.01	other soil materials
8.2	5-10	fine	5.74	6.20	5.16		5.85	6.64	<0.01	0.00	0.00	6.64	<0.01	other acidic
8.3	10-20	fine	5.17	5.60	4.79		5.56	6.53	<0.01	0.00	0.00	6.53	<0.01	other acidic
8.4	20-40	fine	5.51	6.40	5.24		5.92	2.90	<0.01	0.00	0.00	2.90	<0.01	other soil materials
8.5	40-90	fine	6.20	6.59	5.81		6.39	3.63	<0.01	0.00	0.00	3.63	<0.01	other soil materials
9.1	0-2	medium	8.24	8.15	7.85	419	9.03	0.00	0.02	0.00	0.74	-83.74	0.01	hypomonosulfidic (< 0.10)
9.2	2-5	fine	8.05	7.44	7.81		8.50	0.00	0.01	0.00	2.63	-343.93	<0.01	hyposulfidic (< 0.10)
9.3	5-10	fine	8.14	8.10	7.89		7.56	0.00	0.02	0.00	1.07	-132.41	<0.01	hyposulfidic (< 0.10)
9.4	10-20	fine	7.87	8.22	7.79		7.77	0.00	<0.01	0.00	0.62	-82.37	<0.01	other soil materials
9.5	20-40	fine	7.89	8.20	7.96		7.78	0.00	0.01	0.00	0.71	-87.68	0.01	hypomonosulfidic (< 0.10)
9.6	40-90	fine	7.59	8.29	7.66		8.11	0.00	0.01	0.00	0.70	-86.82	<0.01	hyposulfidic (< 0.10)
10.1	0-5	fine	6.93	6.73	6.42	2925	7.29	0.00	0.01	0.00	0.38	-42.91	<0.01	hyposulfidic (< 0.10)
10.2	5-10	fine	7.17	6.94	6.92		8.20	0.00	<0.01	0.00	0.89	-118.43	<0.01	other soil materials
10.3	10-20	fine	5.88	6.47	5.51		5.98	4.43	0.01	0.00	0.00	10.99	<0.01	hypersulfidic[#]
10.4	20-40	fine	5.33	6.73	5.20		5.83	5.67	0.02	0.00	0.00	20.80	0.01	hypermonosulfidic[#]
10.5	40-90	fine	6.39	7.12	6.41		6.48	1.15	<0.01	0.00	0.00	1.15	<0.01	other soil materials
11.1	0-5	fine	6.69	6.05	6.02	10695	7.00	0.00	0.01	0.00	0.20	-20.02	<0.01	hyposulfidic (< 0.10)
11.2	5-10	fine	5.84	5.03	4.96		5.97	2.90	<0.01	0.00	0.00	2.90	<0.01	other acidic
11.3	10-20	fine	6.32	6.53	4.89		6.20	3.03	<0.01	0.00	0.00	3.03	<0.01	other acidic
11.4	20-40	fine	6.68	7.24	6.30		6.94	0.00	0.01	0.00	0.23	-24.68	<0.01	hyposulfidic (< 0.10)
11.5	40-85	fine	7.11	7.51	6.75		7.50	0.00	<0.01	0.00	0.46	-61.43	<0.01	other soil materials
11.6	85-90	fine	7.04	7.63	6.75		6.81	0.00	<0.01	0.00	0.20	-27.14	<0.01	other soil materials
12.1	0-5		6.82	6.39	6.39	16050	6.97	0.00	0.01	0.00	0.00	6.88	<0.01	hypersulfidic[#]
12.2	5-10	fine	5.56	5.09	5.31		6.09	2.42	<0.01	0.00	0.00	2.42	<0.01	other soil materials
12.3	10-20	fine	5.40	4.91	4.97		5.75	5.93	<0.01	0.00	0.00	5.93	<0.01	other acidic
12.4	20-40	fine	5.21	6.15	4.96		5.86	4.94	0.09	0.00	0.00	60.22	<0.01	hypersulfidic[#]
12.5	40-90	fine	5.84	6.46	5.58		6.37	0.94	<0.01	0.00	0.00	0.94	<0.01	other soil materials

[#] Classified as hypersulfidic/hypermonosulfidic based on positive net acidity.

Table 8-3. Field hydrochemistry data for acid sulfate soil assessment of Karadoc Swamp (Wetland ID 40156).

Site and Layer ID.	Temperature (Deg C)	Specific Electrical Conductivity (µS/cm)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	pH	ORP	Redox potential (mV))	Turbidity (NTU)	HCO_3 (mg/L)	Comment
*Lowland River**		*125-2200*	*85-110*		*6.5-8.0*			*6-50*		
*Freshwater Lakes**		*20-30*	*90-110*		*6.5-8.0*			*1-20*		
40156_4 (SW)	18.9	28.5		12.15	8.94		268	13.4	40	
40156_7 (PW)	n.a.	202200		n.a.	6.25		424	n.a.	90	
40156_9 (SW)	25.5	2455		3.57	8.38		251	n.a.	1082	Too shallow to measure turbidity
40156_11 (PW)	25.2	56400		1.10	6.07		239	n.a.	104	Turbidity not measured
40156_12 (PW)	n.a.	56400		n.a.	6.44		325	n.a.	91	Turbidity not measured

* ANZECC water quality guidelines for lowland rivers and freshwater lakes/reservoirs in South-east Australia are provided for relevant parameters (there are currently no trigger values defined for 'Wetlands') (ANZECC/ARMCANZ, 2000). Surface water values outside the ranges defined in the ANZECC guidelines are indicated with red text. (SW) and (PW) indicate whether the sample was taken from surface water or pore-water, respectively.

Table 8-4. Laboratory hydrochemistry data for acid sulfate soil assessment of Karadoc Swamp (Wetland ID 40156).

Parameter	units	ANZECC Guidelines	Site 4 (SW)	Site 7 (PW)	Site 9 (SW)	Site 11 (PW)	Site 12 (PW)
depth	cm						
Na	mg l^{-1}		6,450	33,485	778	13,044	27,220
K	mg l^{-1}		64	172	28	99	170
Ca	mg l^{-1}		1,465	1,805	27	863	1,613
Mg	mg l^{-1}		883	5,988	81	2,061	4,681
Si	mg l^{-1}		0.6	12.5	12.4	10.6	12.3
Br	mg l^{-1}		43.86	196.5	2.38	72.18	147.06
Cl	mg l^{-1}		15,810	68,333	480	22,300	48,201
NO_3	mg l^{-1}	0.7	0.019	7.35	0.046	0.104	21.811
NH_4-N	mg l^{-1}	0.01	0.082	1.382	0.279	0.582	0.739
PO_4-P[E]	mg l^{-1}	0.005	0.086	0.222	0.427	0.016	0.083
SO_4	mg l^{-1}		3,893	5,577	284	6,093	9,456
Ag	µg l^{-1}	0.05	1	11	<1	<1	5
Al[A]	µg l^{-1}	55	10	36	<1	<1	<1
As[B]	µg l^{-1}	13	<10	34	<10	8	<10
Cd	µg l^{-1}	0.2	<1	21	<1	<1	5
Co	µg l^{-1}	2.8	3	22	1	55	6
Cr[C]	µg l^{-1}	1	<5	<5	12	<5	<5
Cu[H]	µg l^{-1}	1.4	28	23	10	13	11
Fe	µg l^{-1}	300	<5	<5	<5	204	<5
Mn	µg l^{-1}	1700	17	7,445	36	13,742	2,899
Ni[H]	µg l^{-1}	11	40	84	<5	74	35
Pb[H]	µg l^{-1}	3.4	<1	12	<1	1	1
Se	µg l^{-1}	11	n/a	n/a	n/a	n/a	n/a
Zn[H]	µg l^{-1}	8	22	27	6	29	18
DOC	mg l^{-1}		n/a	n/a	n/a	n/a	n/a

Notes.

The ANZECC guideline values for toxicants refer to the Ecosystem Protection – Freshwater Guideline for protection of 95% of biota in 'slightly-moderately disturbed' systems, as outlined in the Australian Water Quality Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000). For the nutrients NH_4 and PO_4, guideline values are provided for Freshwater Lakes and Reservoirs. Surface water values outside the ranges defined in the ANZECC guidelines are indicated with red text. (SW) and (PW) indicate whether the sample was taken from surface water or pit-water (groundwater that entered an excavated pit), respectively.

A *Guideline is for Aluminium in freshwater where pH > 6.5.*
B *Guideline assumes As in solution as Arsenic (AsV).*
C *Guideline is for Chromium is applicable to Chromium (CrVI) only.*
E *Guideline is for filterable reactive phosphorous (FRP).*
H *Hardness affected (refer to Guidelines).*

Table 8-5. Site description data for acid sulfate soil assessment of Karadoc Swamp (Wetland ID 40156).

Site No.	Depth to Water Table (cm)	Surface Condition	Earth Cover (Vegetation)	Location Notes	Rationale for site selection	ASS Soil Classification	Comments
1	Beyond sampling depth	Dry	Sparse low succulent shrubs	Dryland area at terminus of one Southern inlet channel.	Situated at inlet, dry site	Other acidic	
2	Beyond sampling depth	Wet	Moderate low succulent shrubs	Wetland area SW of terminus of one Southern inlet channel.	Situated at inlet, wet site	Other acidic	Some living lignum
3	Beyond sampling depth	Dry	sparse succulent shrubs, moderate dead grasses and forbs	Proximal to northern reed bed. Dryland area to south of reed bed.	Vegetation change	Other	Dead reed bases, dead aquatic snail shells.
4	-5	Sub-aqueous	Sub-aqueous	Western end of lake basin proximal to outlet. Lake bed with surface water.	Shallow, un-vegetated sub-aqueous site	Other acidic	Yellow-brown crust on lake bed
5	Beyond sampling depth	Moist	Sparse dead low shrubs	Western end of lake basin. Moist area to north of surface water	Moist area adjacent to surface water	Other acidic	
6	Beyond sampling depth	Dry	Sparse low succulent shrubs	Western end of lake basin. Dryland area to north of surface water	Dry area adjacent to previous site	Other acidic	
7	35	Moist	Bare	Northern section of outlet channel. Centre of channel.	Situated at outlet, moist site	Other acidic	
8	Beyond sampling depth	Moist	Bare	SW section of wetland. Bare moist surface.	Bare, moist site	Other acidic	
9	-2	Sub-aqueous	Sub-aqueous	SW reed bed. In aquatic vegetation with surface water	Shallow, densely vegetated sub-aqueous site	Hypomonosulfidic	
10	Beyond sampling depth	Moist	Moderate low succulent shrubs	Drainage line from SW lake basin. Centre of drainage line	Connecting channel between lake and outlet	Hypermonosulfidic	
11	43	Dry	Bare	Zone of dead mature trees near SW margin of wetland.	Only area incorporating trees (dead)	Hyposulfidic	Dead shrubs and timber
12	Beyond sampling depth	Moist	Bare	Eastern end of lake basin. Leeward edge of basin.	Moist section of lakebed, strong evidence of waterbird activity	Hypersulfidic	Dense waterbird tracks

Table 8-6. Profile description data for acid sulfate soil assessment of Karadoc Swamp (Wetland ID 40156).

Site and Sample No.	Horizon Depth Range (cm)	Soil Colour - moist	Texture Class	Moisture State	Redoximorphic Features Abundance	Redoximorphic Features – Kind	Redoximorphic Features - Colour	Structure - Type	Structure - Grade	pH (field measurement)	Comments (odour, fragments, minerals, plant material, inclusions, other)
1.1	0-5	10YR 4/2	LMC	T	1	M	2.5YR 3/4	PO	W	5.82	
1.2	5-10	10YR 4/3	MHC	T	2	M	2.5YR 4/6	PO	W	5.12	
1.3	10-20	5Y 5/2	MHC	T	2	M	2.5YR 4/6	PO	M	4.65	
1.4	20-40	5Y 5/2	MHC	T	2	M	2.5Y 3/1	PO	M	5.04	
1.5	40-90	5Y 5/1	HC	T	2	M	2.5Y 4/1	PO	M	6.70	
2.1	0-5	5Y 5/2	n/a	W					W	7.03	Too wet to field texture. Roots present.
2.2	5-10	5Y 5/2	MC	M	2	M	5YR 5/6	PO	W	4.55	Organic matter, dense roots.
2.3	10-20	5Y 5/2	MHC	M	1	M	5YR 3/3	PO	M	4.68	Organic matter, dense roots.
2.4	20-40	5Y 5/2	HC	M	1	M	5YR 3/3	PO	M	5.64	Organic matter, dense roots.
2.5	40-90	5Y 5/2	HC	M	2	M	5YR 4/4	PO	M	6.14	
3.1	0-5	5Y 5/1	KMC	D				PO	S	8.31	
3.2	5-10	5Y 4/1	KMC	D	1	M	7.5YR 5/6	PO	S	7.96	
3.3	10-20	5Y 4/1	KMC	D	3	M	7.5YR 5/6	SB	S	7.81	Salt visible on ped surfaces.
3.4	20-40	5Y 4/1	KMHC	T	3	M	7.5YR 5/6	PO	S	7.62	Salt visible on ped surfaces.
3.5	40-90	5Y 4/1	MHC	T	2	M	7.5YR 5/6	PO	M	7.44	Secondary mottle 10 YR 3/2.
4.1	0-5	5Y 6/1	n/a	W					W	7.50	Too wet to field texture.
4.2	5-10	5Y 6/2	MC	W					W	6.82	Too wet to field texture.
4.3	10-20	5Y 5/2	MC	M	1	M	7.5YR 5/6	PO	M	6.49	
4.4	20-40	5Y 5/1	MC	T	2	M	7.5YR 5/6	PO	M	5.97	
4.5	40-55	5Y 5/1	MC	M	1	M	7.5YR 5/6	PO	M	6.15	

Table 8-6 (continued). Profile description data for acid sulfate soil assessment of Karadoc Swamp (Wetland ID 40156).

Site and Sample No.	Horizon Depth Range (cm)	Soil Colour - moist	Texture Class	Moisture State	Redoximorphic Features Abundance	Redoximorphic Features – Kind	Redoximorphic Features - Colour	Structure - Type	Structure - Grade	pH (field measurement)	Comments (odour, fragments, minerals, plant material, inclusions, other)
5.1	0-5	2.5Y 4/2	KMC	M				PO	W	6.05	1% gravel in sample.
5.2	5-10	2.5Y 5/2	KMC	M	1	M	10YR 5/4	PO	M	5.19	
5.3	10-20	2.5Y 5/2	KHC	M	3	M	10YR 5/4	PO	M	5.06	
5.4	20-40	2.5Y 5/1	KHC	M	1	M	10YR 5/4	PO	M	5.88	
5.5	40-90	5Y 4/1	KHC	M	1	M	10YR 5/4	PO	M	5.10	White crystals present.
6.1	0-5	2.5Y 4/2	LMC	T				PO	W	6.09	Roots present.
6.2	5-10	2.5Y 4/2	KMHC	T	1	M	7.5YR 5/4	PO	M	5.39	Roots present.
6.3	10-20	2.5Y 5/2	KHC	T	3	M	7.5YR 5/4	PO	M	4.70	Roots present.
6.4	20-40	5Y 5/2	SHC	T	3	M	10R 3/2	PO	M	5.98	Salt fissures.
6.5	40-90	10YR 4/3	SHC	M	2	M	7.5R 4/2	PO	M	6.88	Salt fissures.
7.1	0-5	5Y 4/1	MC	M	1	M	10YR 6/2	PO	M	5.76	
7.2	5-10	5Y 5/2	MC	M	1	M	10YR 6/2	PO	M	5.35	
7.3	10-20	5Y 5/2	MHC	M	1	M	10YR 6/2	PO	M	6.01	
7.4	20-40	5Y 5/2	MHC	M	2	M	10YR 4/3	PO	M	6.10	
7.5	40-90	5Y 5/1	KHC	W	1	M	10YR 6/2	PO	M	6.08	
8.1	0-5	5Y 4/2	HC	M	1	M	10YR 4/2	PO	M	6.68	
8.2	5-10	5Y 5/2	HC	M	1	M	10YR 4/2	PO	M	5.38	
8.3	10-20	5Y 5/2	HC	M	1	M	10YR 4/2	PO	M	4.97	Nodules present.
8.4	20-40	5Y 6/2	HC	M	2	M	10YR 6/6	PO	M	5.21	Nodules present. Secondary mottle 10 YR 4/2.
8.5	40-90	5Y 6/2	HC	M	1	M	10YR 4/2	PO	M	6.13	Nodules present.

Table 8-6 (continued). Profile description data for acid sulfate soil assessment of Karadoc Swamp (Wetland ID 40156).

Site and Sample No.	Horizon Depth Range (cm)	Soil Colour - moist	Texture Class	Moisture State	Redoximorphic Features Abundance	Redoximorphic Features – Kind	Redoximorphic Features - Colour	Structure - Type	Structure - Grade	pH (field measurement)	Comments (odour, fragments, minerals, plant material, inclusions, other)
9.1	0-2	10 YR 3/4	FSCL	W				PO	W	8.84	Layer is organic. Roots present.
9.2	2-5	5Y 6/2	HC	M				PO	M	8.40	
9.3	5-10	5Y 6/2	HC	M				PO	M	8.17	
9.4	10-20	5Y 6/2	HC	M				PO	M	7.97	
9.5	20-40	5Y 6/2	HC	M				PO	M	7.89	
9.6	40-90	5Y 6/2	HC	M	1	M	10YR 4/2	PO	M	8.09	Mottles between 40-50cm.
10.1	0-5	5Y 6/2	MC	M	3	M	5Y 8/1	PO	M	7.11	
10.2	5-10	5Y 6/2	MC	M	3	M	10YR 5/6	PO	M	6.51	Salt in root channels.
10.3	10-20	5Y 6/2	MHC	M	3	M	10YR 5/6	PO	M	5.89	Salt.
10.4	20-40	5Y 5/2	HC	M	4	M	10YR 4/4	PO	M	5.32	
10.5	40-90	5Y 5/2	HC	M	2	M	10YR 4/4	PO	M	6.41	Secondary mottle GLEY 1 5/10GY.
11.1	0-5	2.5Y 5/2	FSLMC	T	2	M	7.5YR 4/4	PO	W	6.64	
11.2	5-10	2.5Y 5/2	FSMHC	T	2	M	7.5YR 4/4	PO	W	5.31	
11.3	10-20	2.5Y 5/2	SMHC	T	2	M	7.5YR 3/2	PO	M	6.01	Salt fissures.
11.4	20-40	5Y 5/2	SMHC	T	2	M	2.5Y 3/1	PO	M	6.97	Salt fissures.
11.5	40-85	5Y 5/2	KSMC	M	1	M	5Y 6/4	PO	M	7.01	Salt fissures.
11.6	85-90	5Y 6/2	KSMC	M	1	M	5Y 6/4	PO	M	7.11	Nodules present.
12.1	0-5	5Y 5/2	n/a	W				PO	M	7.12	Too wet to field texture.
12.2	5-10	5Y 5/2	MC	M	4	M	2.5Y 5/6	PO	M	6.23	
12.3	10-20	5Y 5/2	MHC	M	4	M	2.5Y 3/3	PO	M	5.25	
12.4	20-40	5Y 5/2	MHC	M	4	M	2.5Y 3/3	PO	M	5.37	
12.5	40-90	5Y 5/1	MHC	M	4	M	5Y 5/4	PO	M	5.74	Secondary mottle 5Y 2.5/1.

8.2. Lake Iraak (Wetland ID 40175)

8.2.1. Location and setting description

The Lake Iraak wetland is situated approximately 30 km south-southeast of Mildura, on the south side of the River Murray, on the floodplain. The wetland can be described as a roughly circular terminal lake approximately 1 km in diameter, and 81 hectares in area. The wetland is surrounded by orchards and vineyards, on red sand hill country. A modified water-holding channel is situated along the southern margin of the wetland. Vegetation features of the wetland include areas characterised by bare clay, low succulent shrubs, sedges, and *Phragmites* sp. reed beds. At the time of sampling, the surface was moist but lacked surface water.

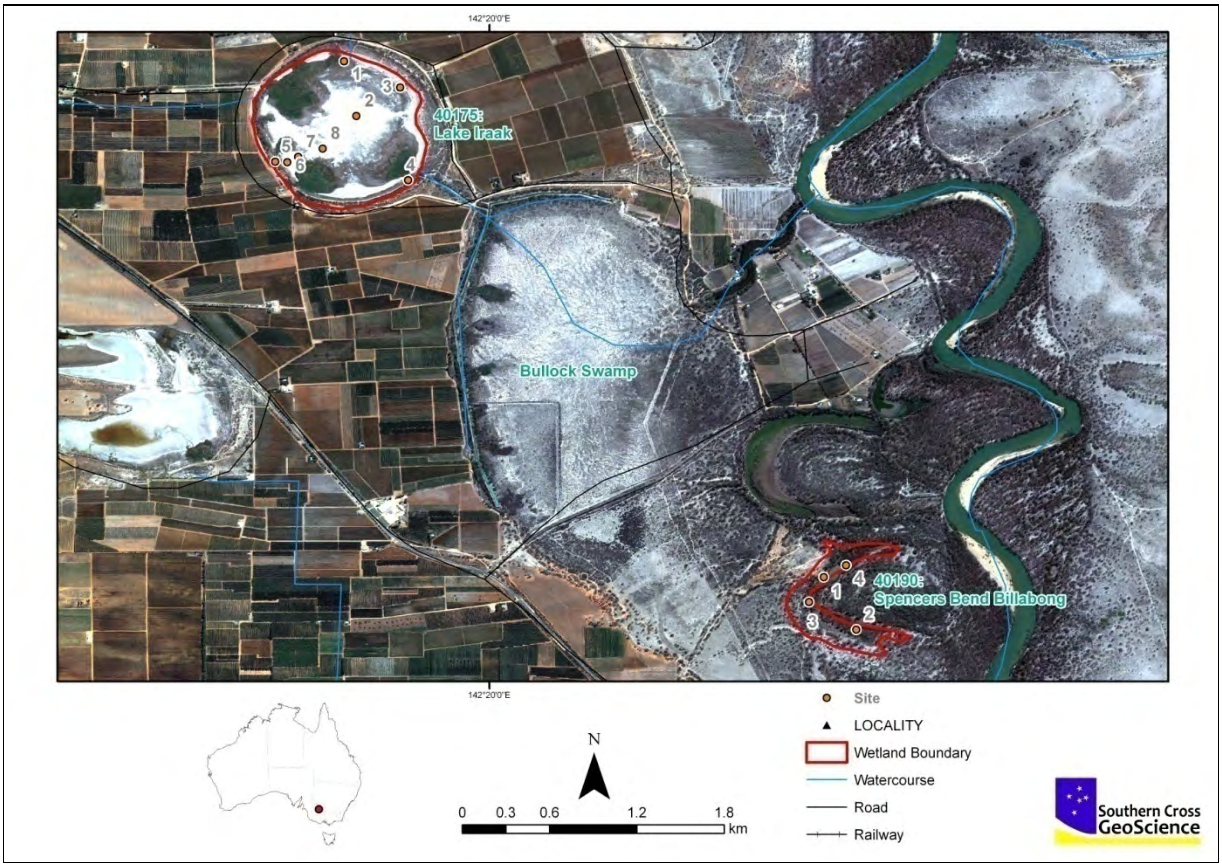


Figure 8-21. Lake Iraak and sample site locations.

8.2.2. Soil profile description and distribution

Eight sites were described and sampled. The soil subtype and general location description of each site are presented in Table 8-7. Sites were distributed throughout the wetland based on different surface features and locations in the wetland, and a transect approach was used in part.

The profile 40175_1 (Figure 8-23) is situated in an area near the margin of the wetland in a zone of low, succulent shrubs. The profiles 40175_5 (Figure 8-27), 40175_6 (Figure 8-28), 40175_7 (Figure 8-29), 40175_8 (Figure 8-30) and 40175_2 (Figure 8-24) formed a transect from a low, red sand dune at the outer margin of the wetland (40175_5) towards the centre of the lake (40175_2), where a zone of lower succulent shrubs and moist soil occurred, with visible salt efflorescences. The profile 40175_3 (Figure 8-25) was situated in the middle of a small reed bed, and profile 40175_4 (Figure 8-26) was situated in the middle of the channel. Additional site and profile description data are presented in Tables 8-11 and 8-12, respectively.

Table 8-7. Soil identification, subtype and general location description for Lake Iraak.

Site ID	Easting UTM Zone 54H	Northing UTM Zone 54H	Acid sulfate soil subtype class	General location description
40175_1	621709	6191202	Hydrosol	Northern edge of wetland. Margin of basin.
40175_2	621774	6190826	Hydrosol	Centre of basin. Bare moist area.
40175_3	622025	6191019	Hydrosol	Reed bed on NE edge of wetland.
40175_4	622062	6190383	Subaqueous Soil	Modified channel on SE edge of wetland. Centre of channel.
40175_5	621309	6190519	Hydrosol	SW margin of wetland. Low red sand mound.
40175_6	621378	6190515	Hydrosol	SW margin of wetland. Edge of basin.
40175_7	621440	6190551	Hydrosol	SW margin of wetland. Between edge and centre of basin.
40175_8	621580	6190606	Hydrosol	Centre of basin. Bare dry area.

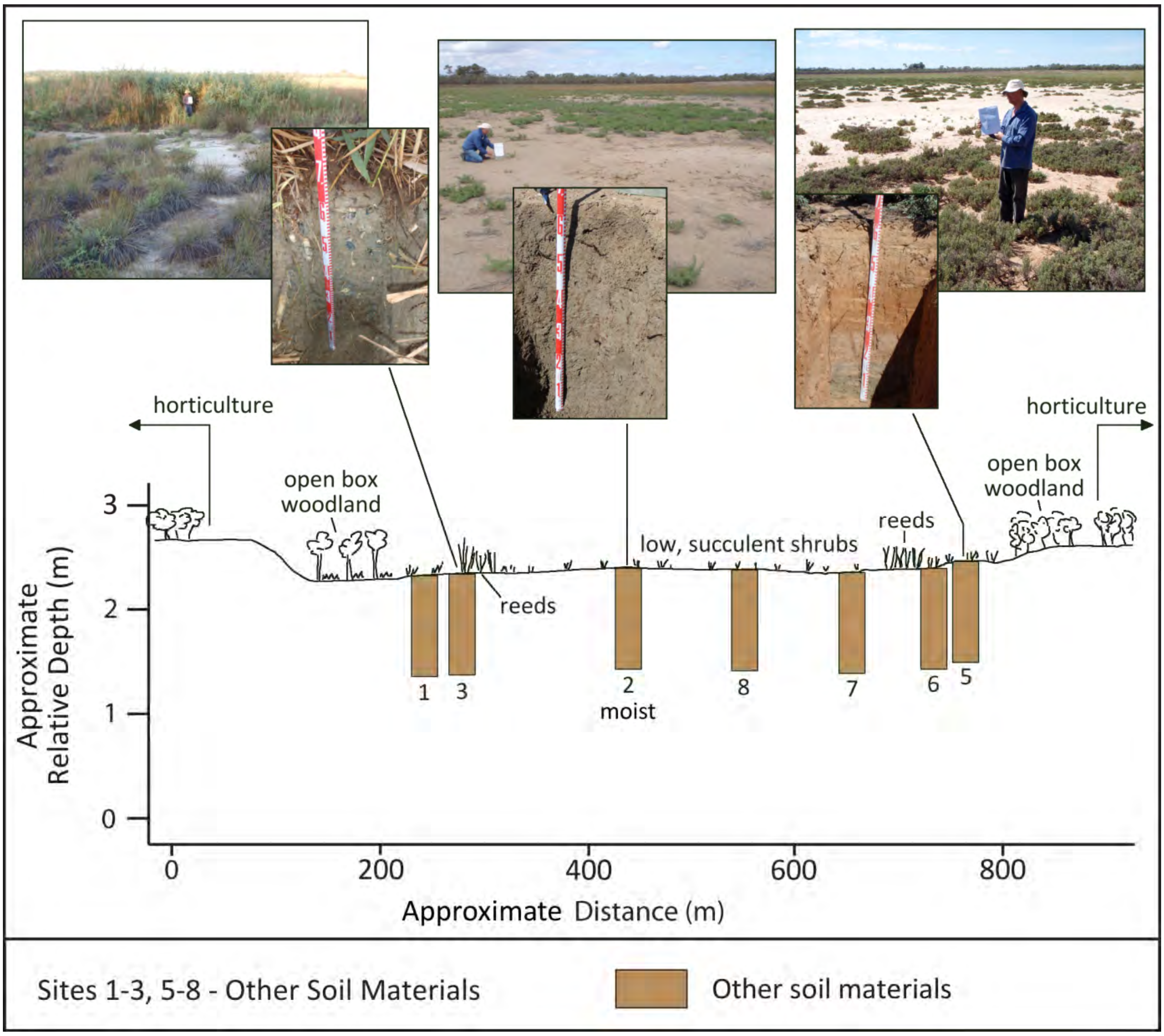


Figure 8-22. Conceptual cross section diagram showing the toposequence relationship of the Lake Iraak sediments/soil materials throughout the wetland.

Figure 8-23. Photographs of site 40175_1, showing location of the site between a zone of living and dead trees and low, succulent shrubs, and the soil profile.

Figure 8-24. Photographs of site 40175_2, showing the low, bare, moist area amongst succulent shrubs in the centre of the wetland, and the soil profile.

Figure 8-25. Photographs of site 40175_3, showing the reed bed from which the sample was taken, and the soil profile.

Figure 8-26. Photographs of site 40175_4, showing the modified channel from which samples were taken, and the soil core.

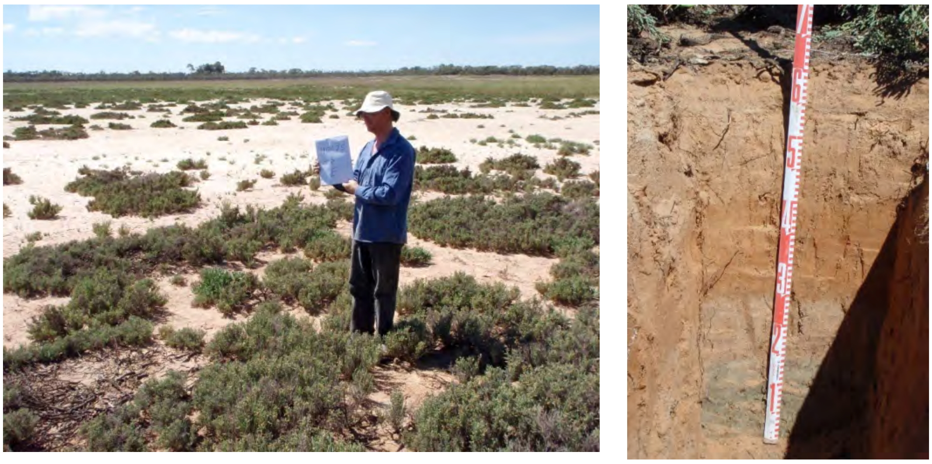


Figure 8-27. Photographs of site 40175_5, showing the low, red sand dune from which the sample was taken among low, succulent vegetation, and the soil profile.

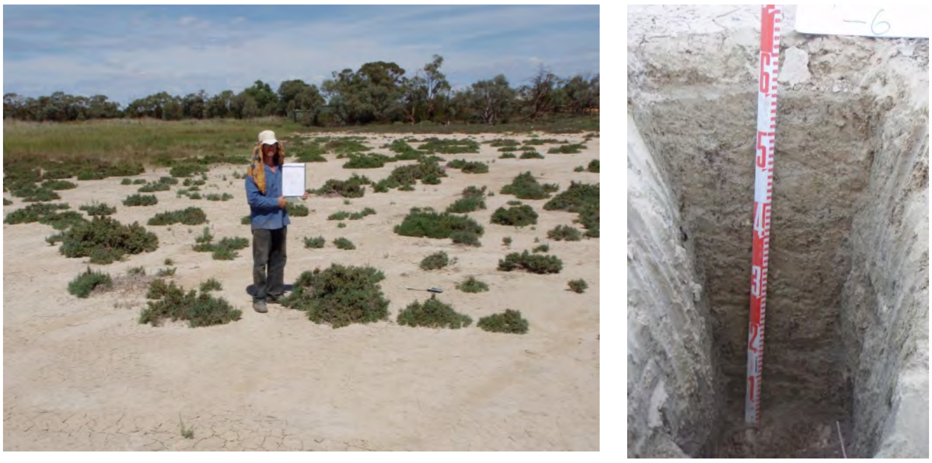


Figure 8-28. Photographs of site 40175_6, showing the bare, grey, cracking clay surface and light succulent vegetation cover, and the soil profile.

Figure 8-29. Photographs of site 40175_7, showing a biological crust over a grey, cracking clay surface with low succulent vegetation, and the soil profile.

Figure 8-30. Photographs of site 40175_8, showing the bare, grey, cracking clay surface, and the soil profile.

8.2.3. Laboratory data assessment

Soil pH testing (pH_W, pH_{FOX}, pH_{KCl}, $pH_{INCUBATION}$)

The pH data is provided in Table 8-8 and profiles for all the sites sampled are presented in Figures 8-31 and 8-32. The pH_W values ranged between 6.25 and 8.69. Sulfuric materials (i.e. $pH_W < 4$) were not present. The pH_{FOX} values ranged between 3.89 and 8.74. The pH_{FOX} results indicate that one of 40 of the surface soils examined may have the potential to acidify to pH < 4 as a result of sulfide oxidation. However, the S_{CR} data shows this layer contained no detectable sulfide (i.e. S_{CR} < 0.01% S). None of the soil materials acidified to pH < 4 after at least 8 weeks of incubation. Other acidic soil materials were not identified at any sites.

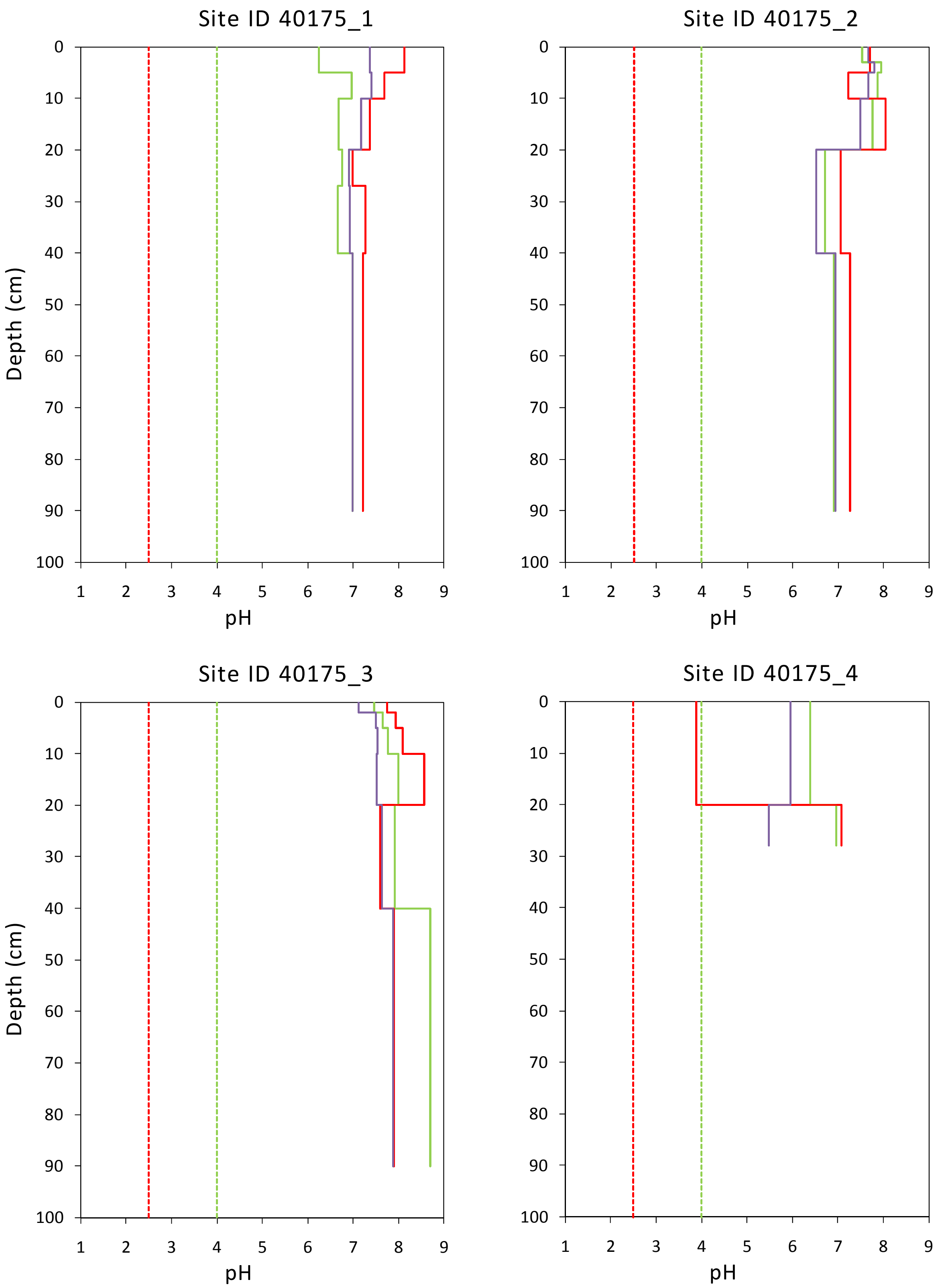


Figure 8-31. Depth profiles of soil pH for Lake Iraak (40175_1 – 40175_4), showing soil pH (pH_W as green line), peroxide treated pH (pH_{FOX} as red line) and ageing pH ($pH_{incubation}$ after at least eight weeks as purple line). Critical pH_W and $pH_{incubation}$ value of 4 (green dashed line) and critical pH_{FOX} value of 2.5 (red dashed line).

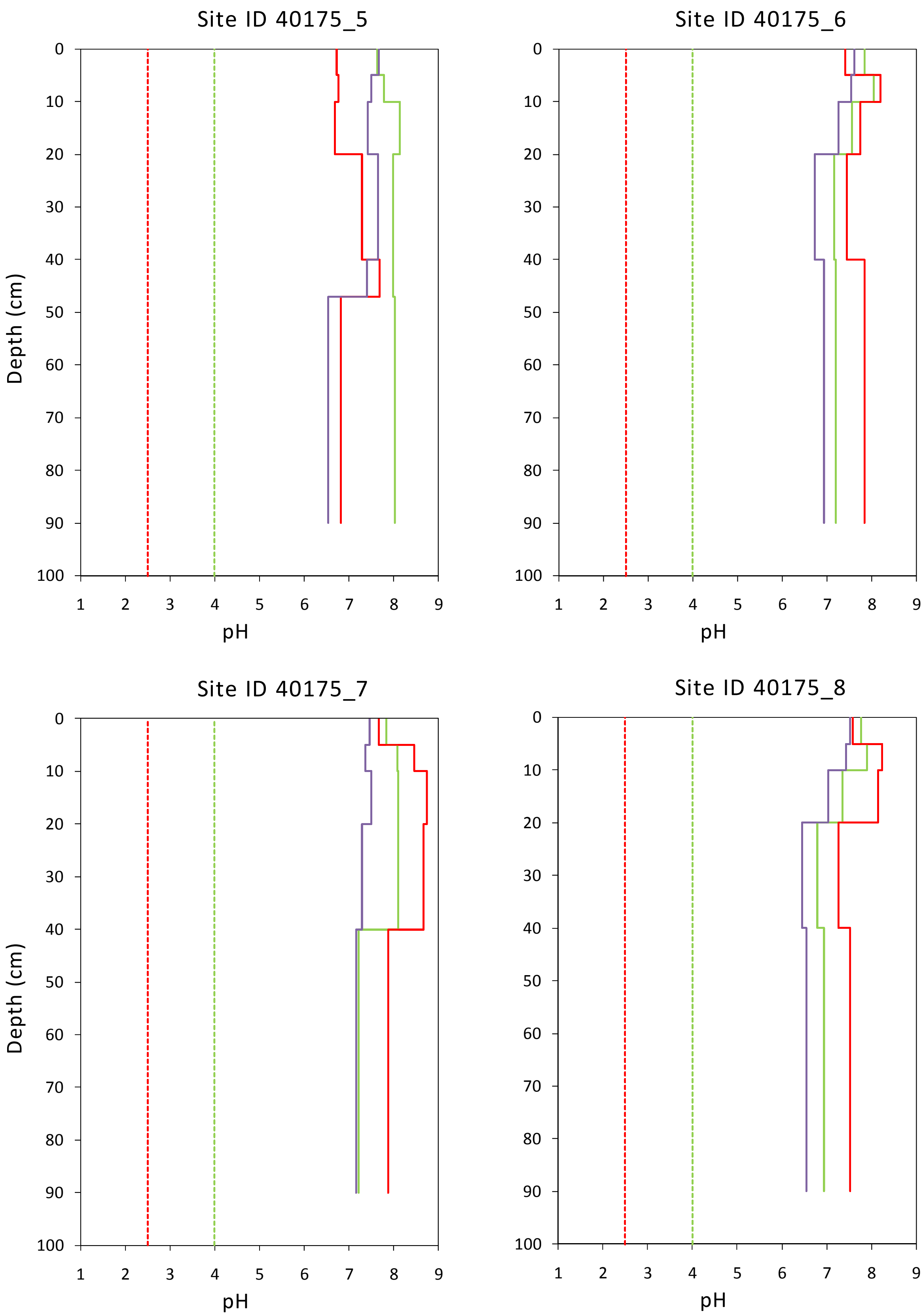


Figure 8-32. Depth profiles of soil pH for Lake Iraak (40175_5 – 40175_8), showing soil pH (pH_W as green line), peroxide treated pH (pH_{FOX} as red line) and ageing pH ($pH_{incubation}$ after at least eight weeks as purple line). Critical pH_W and $pH_{incubation}$ value of 4 (green dashed line) and critical pH_{FOX} value of 2.5 (red dashed line).

Acid-base accounting

The acid-base accounting data is provided in Table 8-8 and summarised in Figures 8-33 and 8-34.

Chromium reducible sulfur

Sulfidic soil materials (i.e. $S_{CR} \geq 0.01\%$ S) were not found within this wetland.

Acid volatile sulfide

Monosulfidic soil materials (i.e. $S_{AV} \geq 0.01\%$ S) were not found within this wetland.

Acid neutralising capacity

The acid neutralising capacity (ANC) ranged between zero and 21.6% $CaCO_3$.

Titratable actual acidity

The titratable actual acidity (TAA) ranged between zero and 4.7 mole H^+/tonne, with the majority of soil layers having no TAA.

Retained acidity

There was no retained acidity at any of the sites as all samples had a $pH_{KCl} > 4.5$.

Net acidity

The net acidity ranged between -2,871 and 5 mole H^+/tonne, with the majority of samples having negative net acidities.

Water Soluble Sulfate

The water soluble sulfate in the surface soils (i.e. 0-5 cm) ranged between 29.3 and 11,760 mg/L. Seven of the eight surface soil layers examined had a soluble sulfate content exceeding the 100 mg/L trigger value for MBO formation potential.

Water Data

The surface water and groundwater data measured in the field and laboratory are presented in Tables 8-9 and 8-10, respectively. The field pH of the surface water collected was 6.5, indicating that the surface water has not been affected by acidification. The surface water sulfate concentration was 40 mg/L. Some nutrient (i.e. NH_4, PO_4), metal (i.e. Al, Cu, Zn) and turbidity values were found to exceed the most relevant ANZECC/ARMCANZ (2000) guideline value. The groundwater at the site sampled had a high sulfate concentration of 7,302 mg/L.

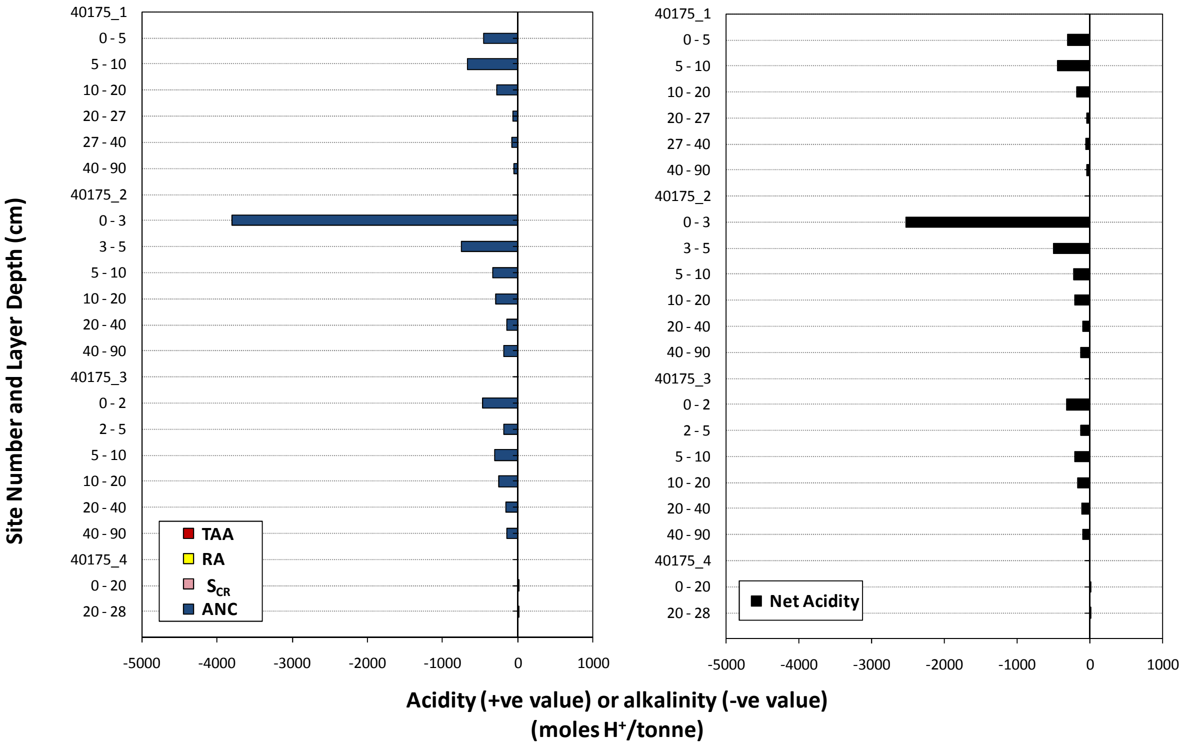


Figure 8-33. Acid-base accounting depth profiles for Lake Iraak (40175_1 – 40175_4). Left side shows the components: titratable actual acidity (TAA - red bar), acid generating potential (AGP as S_{CR} -pink bar), acid neutralising capacity (ANC - blue bar), retained acidity (RA - yellow bar), and right side shows net acidity.

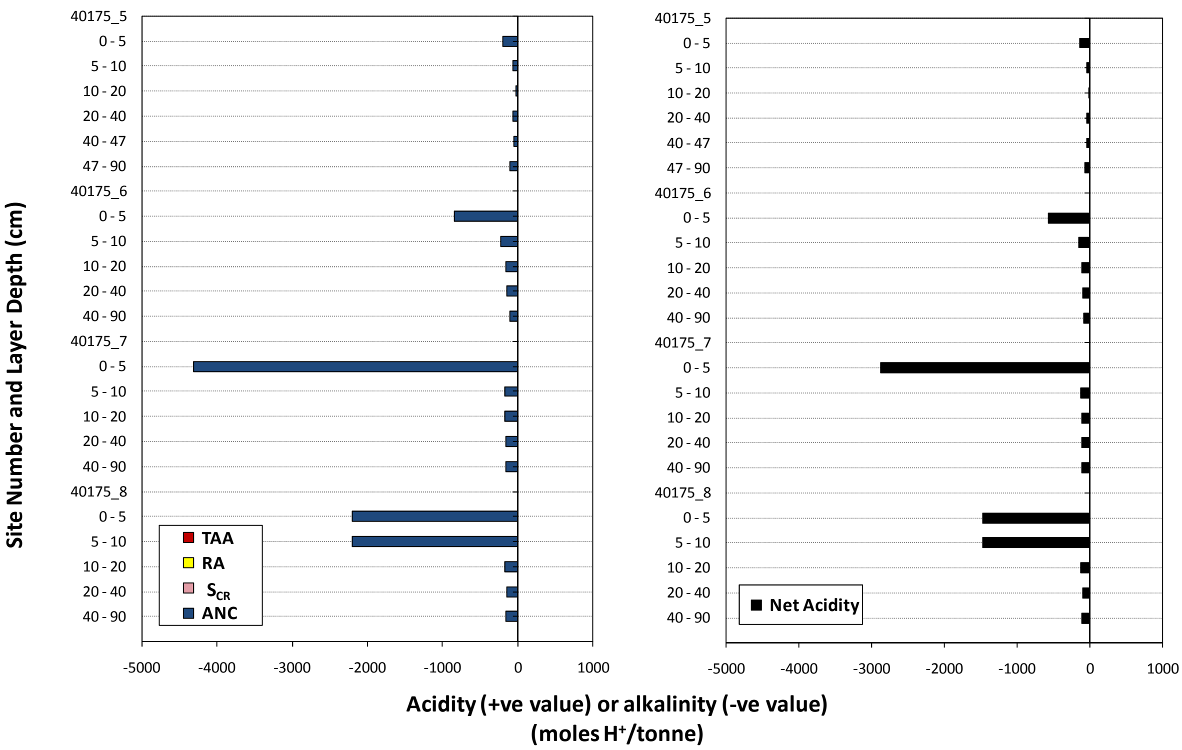


Figure 8-34. Acid-base accounting depth profiles for Lake Iraak (40175_5 – 40175_8). Left side shows the components: titratable actual acidity (TAA - red bar), acid generating potential (AGP as S_{CR} -pink bar), acid neutralising capacity (ANC - blue bar), retained acidity (RA - yellow bar), and right side shows net acidity.

8.2.4. Discussion

Acid sulfate soil materials were not found at Lake Iraak. Other acidic soils were recorded at one site (40175_4). The remaining sites were classified as other soil materials.

Seven surficial soil materials contained soluble sulfate in excess of the 100 mg/L trigger value for MBO formation potential. Based on the priority ranking criteria adopted by the Scientific Reference Panel of the Murray-Darling Basin Acid Sulfate Soil Risk Assessment Project, these seven sampling sites had a high priority ranking for Phase 2 detailed assessment based on MBO formation hazard.

The potential hazards at the wetland-scale posed by the soil materials at Lake Iraak are:

- Acidification hazard: The data indicate that with low net acidities and no sulfidic materials that the degree of acidification hazard is low.

- Deoxygenation hazard: The soluble sulfate contents of surface soil materials at seven sites were over the trigger value for MBO formation indicating the possible development of an appreciable deoxygenation hazard at those locations after prolonged wet conditions.

- Metal mobilisation: The low acidification hazard indicates that soil acidification is not likely to increase the solubility of metals. However, the potential for MBO formation identified in this wetland may result in an appreciable metal release hazard depending on factors such as the potential for MBO formation and the metal loading in this wetland.

Summary of key findings for the Lake Iraak:

Soil materials:	Sulfuric and sulfidic soil materials were not observed. Other acidic soils were observed at 1 site. All soil materials classified as other soil materials. Low net acidities dominant within wetland.
Acid sulfate soil identification:	• No acid sulfate soils identified. • Soils predominantly hydrosols. Subaqueous soil also identified.
Hazard assessment	• Acidification hazard - low level of concern • Deoxygenation hazard - high level of concern • Metal mobilisation hazard – low to moderate level of concern

Table 8-8. Laboratory analytical data for acid sulfate soil assessment of Lake Iraak (Wetland ID 40175).
(red printed values indicates data results of potential concern)

Site and Layer ID.	Depth Range (cm)	Soil Texture	pH water	pH peroxide	pH incubation	Sulfate (mg SO_4 / kg)	pH KCl	Titratable Actual Acidity (mole H^+/t)	Chromium Reducible Sulfur (%S_{CR})	Retained Acidity (mole H^+/t)	Acid Neutralising Capacity (%$CaCO_3$)	Net Acidity (mole H^+/t)	Acid Volatile Sulfide (%S_{AV})	Acid Sulfate Soil Material Classification
1.1	0-5	medium	6.25	8.12	7.37	11760	8.92	0.00	<0.01	0.00	2.31	-307.71	<0.01	other soil materials
1.2	5-10	fine	6.97	7.68	7.40		8.90	0.00	<0.01	0.00	3.35	-446.05	<0.01	other soil materials
1.3	10-20	medium	6.69	7.37	7.18		9.02	0.00	<0.01	0.00	1.38	-184.15	<0.01	other soil materials
1.4	20-27	fine	6.76	6.99	6.91		7.32	0.00	<0.01	0.00	0.32	-42.83	<0.01	other soil materials
1.5	27-40	fine	6.67	7.28	6.93		6.94	0.00	<0.01	0.00	0.40	-52.74	<0.01	other soil materials
1.6	40-90	fine	6.98	7.22	6.99		7.04	0.00	<0.01	0.00	0.28	-37.52	<0.01	other soil materials
2.1	0-3	medium	7.52	7.70	7.67	10395	8.91	0.00	<0.01	0.00	18.998	-2530.51	<0.01	other soil materials
2.2	3-5	fine	7.94	7.70	7.80		8.40	0.00	<0.01	0.00	3.74	-497.65	<0.01	other soil materials
2.3	5-10	fine	7.88	7.23	7.67		8.56	0.00	<0.01	0.00	1.65	-219.36	<0.01	other soil materials
2.4	10-20	fine	7.75	8.05	7.49		7.63	0.00	<0.01	0.00	1.50	-199.49	<0.01	other soil materials
2.5	20-40	fine	6.72	7.05	6.52		6.57	0.00	<0.01	0.00	0.73	-96.81	<0.01	other soil materials
2.6	40-90	fine	6.91	7.26	6.94		7.03	0.00	<0.01	0.00	0.94	-124.79	<0.01	other soil materials
3.1	0-2	medium	7.47	7.75	7.11	393	8.05	0.00	<0.01	0.00	2.38	-316.67	<0.01	other soil materials
3.2	2-5	medium	7.65	7.94	7.50		8.32	0.00	<0.01	0.00	0.92	-122.32	<0.01	other soil materials
3.3	5-10	fine	7.76	8.08	7.53		8.68	0.00	<0.01	0.00	1.52	-203.10	<0.01	other soil materials
3.4	10-20	fine	8.00	8.57	7.52		8.39	0.00	<0.01	0.00	1.27	-169.01	<0.01	other soil materials
3.5	20-40	fine	7.91	7.60	7.64		7.37	0.00	<0.01	0.00	0.80	-106.27	<0.01	other soil materials
3.6	40-90	fine	8.69	7.89	7.87		8.00	0.00	<0.01	0.00	0.71	-94.40	<0.01	other soil materials
4.1	0-20		6.40	3.89	5.95	29.3	5.41	2.43	<0.01	0.00	0.00	2.43	<0.01	other soil materials
4.2	20-28		6.97	7.08	5.49		6.47	1.33	<0.01	0.00	0.00	1.33	<0.01	other acidic
5.1	0-5	coarse	7.63	6.72	7.66	4050	9.19	0.00	<0.01	0.00	0.99	-132.15	<0.01	other soil materials
5.2	5-10	medium	7.77	6.77	7.50		8.52	0.00	<0.01	0.00	0.34	-44.75	<0.01	other soil materials
5.3	10-20	medium	8.14	6.69	7.43		8.08	0.00	<0.01	0.00	0.10	-13.49	<0.01	other soil materials
5.4	20-40	coarse	7.98	7.29	7.65		7.93	0.00	<0.01	0.00	0.30	-39.79	<0.01	other soil materials
5.5	40-47	coarse	7.98	7.69	7.40		7.93	0.00	<0.01	0.00	0.27	-36.35	<0.01	other soil materials
5.6	47-90	fine	8.03	6.81	6.54		6.80	0.00	<0.01	0.00	0.53	-70.12	<0.01	other soil materials

Table 8-8 (continued). Laboratory analytical data for acid sulfate soil assessment of Lake Iraak (Wetland ID 40175).
(red printed values indicates data results of potential concern)

Site and Layer ID.	Depth Range (cm)	Soil Texture	pH water	pH peroxide	pH incubation	Sulfate (mg SO_4 / kg)	pH KCl	Titratable Actual Acidity (mole H^+/t)	Chromium Reducible Sulfur (%S_{CR})	Retained Acidity (mole H^+/t)	Acid Neutralising Capacity (%$CaCO_3$)	Net Acidity (mole H^+/t)	Acid Volatile Sulfide (%S_{AV})	Acid Sulfate Soil Material Classification
6.1	0-5	medium	7.84	7.40	7.61	9915	8.79	0.00	<0.01	0.00	4.21	-560.25	<0.01	other soil materials
6.2	5-10	medium	8.05	8.19	7.54		8.37	0.00	<0.01	0.00	1.14	-152.08	<0.01	other soil materials
6.3	10-20	fine	7.56	7.74	7.25		7.38	0.00	<0.01	0.00	0.82	-109.58	<0.01	other soil materials
6.4	20-40	fine	7.16	7.44	6.72		6.98	0.00	<0.01	0.00	0.73	-96.99	<0.01	other soil materials
6.5	40-90	fine	7.19	7.84	6.94		7.11	0.00	<0.01	0.00	0.56	-73.93	<0.01	other soil materials
7.1	0-5	medium	7.84	7.66	7.45	9090	8.66	0.00	<0.01	0.00	21.55	-2870.67	<0.01	other soil materials
7.2	5-10	fine	8.08	8.46	7.37		7.60	0.00	<0.01	0.00	0.87	-115.34	<0.01	other soil materials
7.3	10-20	fine	8.10	8.74	7.50		7.19	0.00	<0.01	0.00	0.85	-112.81	<0.01	other soil materials
7.4	20-40	fine	8.09	8.67	7.28		6.94	0.00	<0.01	0.00	0.78	-103.82	<0.01	other soil materials
7.5	40-90	fine	7.22	7.87	7.15		7.16	0.00	<0.01	0.00	0.80	-107.18	<0.01	other soil materials
8.1	0-5	medium	7.77	7.58	7.52	11685	8.58	0.00	<0.01	0.00	11.02	-1468.50	<0.01	other soil materials
8.2	5-10	fine	7.91	8.24	7.43		7.58	0.00	<0.01	0.00	11.02	-1468.50	<0.01	other soil materials
8.3	10-20	fine	7.36	8.14	7.03		7.02	0.00	<0.01	0.00	0.88	-117.60	<0.01	other soil materials
8.4	20-40	fine	6.79	7.27	6.45		6.63	0.00	<0.01	0.00	0.75	-99.29	<0.01	other soil materials
8.5	40-90	fine	6.94	7.53	6.55		6.85	0.00	<0.01	0.00	0.81	-108.09	<0.01	other soil materials

Table 8-9. Field hydrochemistry data for acid sulfate soil assessment of Lake Iraak (Wetland ID 40175).

Site and Layer ID.	Temperature (Deg C)	Specific Electrical Conductivity (µS/cm)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	pH	ORP	Redox potential (mV))	Turbidity (NTU)	HCO_3 (mg/L)	Comment
*Lowland River**		*125-2200*	*85-110*		*6.5-8.0*			*6-50*		
*Freshwater Lakes**		*20-30*	*90-110*		*6.5-8.0*			*1-20*		
40175_2 (PW)		n.a.							226	Insufficient depth for instrument probes
40175_4 (SW)	20.6	98.6		7.35	6.50		217	51.6	57	

* ANZECC water quality guidelines for lowland rivers and freshwater lakes/reservoirs in South-east Australia are provided for relevant parameters (there are currently no trigger values defined for 'Wetlands') (ANZECC/ARMCANZ, 2000). Surface water values outside the ranges defined in the ANZECC guidelines are indicated with red text. (SW) and (PW) indicate whether the sample was taken from surface water or pore-water, respectively.

Table 8-10. Laboratory hydrochemistry data for acid sulfate soil assessment of Lake Iraak (Wetland ID 40175).

Parameter	units	ANZECC Guidelines	Site 2 (PW)	Site 4 (SW)
depth	cm			
Na	mg l^{-1}		27,140	12
K	mg l^{-1}		273	2
Ca	mg l^{-1}		1,648	6
Mg	mg l^{-1}		4,337	4
Si	mg l^{-1}		8.9	0.3
Br	mg l^{-1}		154.4	2.2
Cl	mg l^{-1}		48,249	645
NO_3	mg l^{-1}	0.7	8.973	0.146
NH_4-N	mg l^{-1}	0.01	0.207	0.037
PO_4-P^E	mg l^{-1}	0.005	0.137	0.16
SO_4	mg l^{-1}		7,302	40
Ag	µg l^{-1}	0.05	29	<1
Al^A	µg l^{-1}	55	<1	75
As^B	µg l^{-1}	13	<10	<10
Cd	µg l^{-1}	0.2	8	<1
Co	µg l^{-1}	2.8	5	<1
Cr^C	µg l^{-1}	1	<5	<5
Cu^H	µg l^{-1}	1.4	47	5
Fe	µg l^{-1}	300	<5	57
Mn	µg l^{-1}	1700	76	6
Ni^H	µg l^{-1}	11	22	<5
Pb^H	µg l^{-1}	3.4	1	<01
Se	µg l^{-1}	11	n/a	n/a
Zn^H	µg l^{-1}	8	26	20
DOC	mg l^{-1}		n/a	n/a

Notes.

The ANZECC guideline values for toxicants refer to the Ecosystem Protection – Freshwater Guideline for protection of 95% of biota in 'slightly-moderately disturbed' systems, as outlined in the Australian Water Quality Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000). For the nutrients NH_4 and PO_4, guideline values are provided for Freshwater Lakes and Reservoirs. Surface water values outside the ranges defined in the ANZECC guidelines are indicated with red text. (SW) and (PW) indicate whether the sample was taken from surface water or pit-water (groundwater that entered an excavated pit), respectively.

A *Guideline is for Aluminium in freshwater where pH > 6.5.*

B *Guideline assumes As in solution as Arsenic (AsV).*

C *Guideline is for Chromium is applicable to Chromium (CrVI) only.*

E *Guideline is for filterable reactive phosphorous (FRP).*

H *Hardness affected (refer to Guidelines).*

Table 8-11. Site description data for acid sulfate soil assessment of Lake Iraak (Wetland ID 40175).

Site No.	Depth to Water Table (cm)	Surface Condition	Earth Cover (Vegetation)	Location Notes	Rationale for site selection	ASS Soil Classification	Comments
1	Beyond sampling depth	Dry	Sparse low succulent shrubs	Northern edge of wetland. Margin of basin.	Edge of wetland.	Other	
2	>90cm	Moist	Sparse low succulent shrubs	Centre of basin. Bare moist area.	Unvegetated area.	Other	Soil moist enough to bog vehicle
3	Beyond sampling depth	Moist	Dense reed bed	Reed bed on NE edge of wetland.	Reed vegetation.	Other	Swampy smell, but not H_2S
4	-90cm	Sub-aqueous	Sub-aqueous	Modified channel on SE edge of wetland. Centre of channel.	Sub-aqueous site.	Other acidic	Artificial channel
5	Beyond sampling depth	Dry	Moderate leaf litter and low succulent shrubs.	SW margin of wetland. Low red sand mound.	Most elevated point in wetland.	Other	
6	Beyond sampling depth	Dry	Sparse low succulent shrubs.	SW margin of wetland. Edge of basin.	Shrub vegetation.	Other	
7	Beyond sampling depth	Dry	Dense microbiotic crust.	SW margin of wetland. Between edge and centre of basin.	Microbiotic crust.	Other	Zone of low sand dunes, approximately 30cm high and 5m diameter
8	Beyond sampling depth	Dry	Bare.	Centre of basin. Bare dry area.	Unvegetated area.	Other	

Table 8-12. Profile description data for acid sulfate soil assessment of Lake Iraak (Wetland ID 40175).

Site and Sample No.	Horizon Depth Range (cm)	Soil Colour - moist	Texture Class	Moisture State	Redoximorphic Features Abundance	Redoximorphic Features – Kind	Redoximorphic Features - Colour	Structure - Type	Structure - Grade	pH (field measurement)	Comments (odour, fragments, minerals, plant material, inclusions, other)
1.1	0-5	5Y 5/2	FSLC	T	2	M	2.5YR 5/6	n.a.	V	8.06	
1.2	5-10	5Y 5/2	FSMC	T	2	M	2.5YR 4/6	n.a.	V	8.28	
1.3	10-20	5Y 6/2	FSLC	T	2	M	2.5YR 5/6	n.a.	V	7.59	
1.4	20-27	5Y 6/2	FSMC	T	2	M	2.5YR 4/6	n.a.	V	7.40	
1.5	27-40	5Y 6/2	FSMC	T	2	M	5YR 5/8	n.a.	V	7.49	
1.6	40-90	5Y 6/2	FSMC	T	2	M	5YR 5/8	n.a.	V	7.06	
2.1	0-3	5Y 7/2	FSLC	M				n.a.	V	8.22	
2.2	3-5	5Y 5/1	LMC	M				n.a.	V	8.56	
2.3	5-10	5Y 5/1	MC	M				PO	W	8.31	
2.4	10-20	5Y 5/1	MC	M	3	M	5YR 3/3	PO	W	7.62	
2.5	20-40	5Y 5/1	MHC	M	3	M	5YR 3/3	PO	W	7.02	
2.6	40-90	5Y 5/1	LMC	M	3	M	5YR 3/3	PO	W	7.10	Mottles end at 48cm.
3.1	0-2	7.5YR 2.5/3	LC	M				PO	W	8.61	Dense roots.
3.2	2-5	5Y 6/1	LC	M				PO	W	8.07	Dense roots.
3.3	5-10	5Y 6/2	LMC	M	2	M	5YR 6/6	PO	W	7.85	Dense roots.
3.4	10-20	5Y 6/2	MC	M	2	M	5YR 4/6	PO	W	7.60	Fine sand is heard. Roots present.
3.5	20-40	5Y 6/2	MC	M	2	M	5YR 4/6	PO	W	8.06	
3.6	40-90	5Y 7/2	MC	M	2	M	7.5YR 5/6	PO	W	8.52	Roots observed to ~70cm.
4.1	0-20	GLEY 2 5/5B	~FS	W	2	M	5YR 5/4		G	6.59	All measurements made in lab. Too wet to hold texture.
4.2	20-28										Sample missing.

Table 8-12 (continued). Profile description data for acid sulfate soil assessment of Lake Iraak (Wetland ID 40175).

Site and Sample No.	Horizon Depth Range (cm)	Soil Colour - moist	Texture Class	Moisture State	Redoximorphic Features Abundance	Redoximorphic Features – Kind	Redoximorphic Features - Colour	Structure - Type	Structure - Grade	pH (field measurement)	Comments (odour, fragments, minerals, plant material, inclusions, other)
5.1	0-5	10YR 5/4	CS	D				n.a.	G	7.34	Small white aggregates.
5.2	5-10	10YR 5/4	SL	D				n.a.	G	8.07	Small white aggregates.
5.3	10-20	7.5YR 4/6	SL	D	1	M	10YR 5/8	n.a.	G	7.66	Small white aggregates.
5.4	20-40	5YR 5/6	CS	T				n.a.	G	8.03	
5.5	40-47	7.5YR 6/3	CS	T	1	M	10YR 5/8	n.a.	G	7.81	
5.6	47-90	5Y 5/2	FSMHC	T	2	M	2.5Y 4/3	SB	S	6.82	
6.1	0-5	5Y 6/2	CLS	D	1	M	5Y 3/2	PL	W	7.93	
6.2	5-10	5Y 6/3	FSLC	T	1	M	5Y 3/2	SB	S	7.75	
6.3	10-20	5Y 6/3	FSLMC	T	1	M	5Y 3/2	SB	S	7.42	
6.4	20-40	5Y 6/3	FSMHC	T	1	M	5Y 3/2	SB	S	6.85	
6.5	40-90	5Y 6/3	FSMC	T	1	M	5Y 3/2	SB	S	6.95	
7.1	0-5	5Y 6/2	FSLC	D				SB	W	7.93	Salt.
7.2	5-10	5Y 6/3	MC	T				SB	S	7.89	
7.3	10-20	5Y 6/3	MHC	T	1	M	5Y 3/2	SB	S	8.00	
7.4	20-40	5Y 6/3	FSMC	T				SB	S	8.19	
7.5	40-90	5Y 6/3	FSLMC	T				SB	S	7.18	
8.1	0-5	5Y 6/2	FSLC	D				SB	W	7.95	
8.2	5-10	5Y 6/3	FSLMC	T				SB	S	7.89	
8.3	10-20	5Y 6/3	FSLMC	T	1	M	5Y 3/2	SB	S	7.29	Main mottle zone is 15-28cm
8.4	20-40	5Y 6/3	FSLMC	T	1	M	5Y 3/2	SB	S	6.59	Main mottle zone is 15-28cm
8.5	40-90	5Y 6/3	FSLMC	T	1	M	5Y 3/2	SB	S	6.36	Small white aggregates.

8.3. Spencers Bend Billabong (Wetland ID 40190)

8.3.1. Location and setting description

Spencers Bend Billabong is an in-filled oxbow lake situated approximately 33.5 km south-southeast of Mildura. The billabong is on the south side of the River Murray, on the floodplain, and extends for around 1.4 km in length and 230 m in width. The wetland area is 19 hectares. The wetland was dry at the time of sampling. Zones of immature river red gums of varying heights surrounded the channel bed. Vegetation coverage of forbs and grasses reflected recent inundation events, in that the most recently inundated section at the lowest point of the billabong was mostly bare.

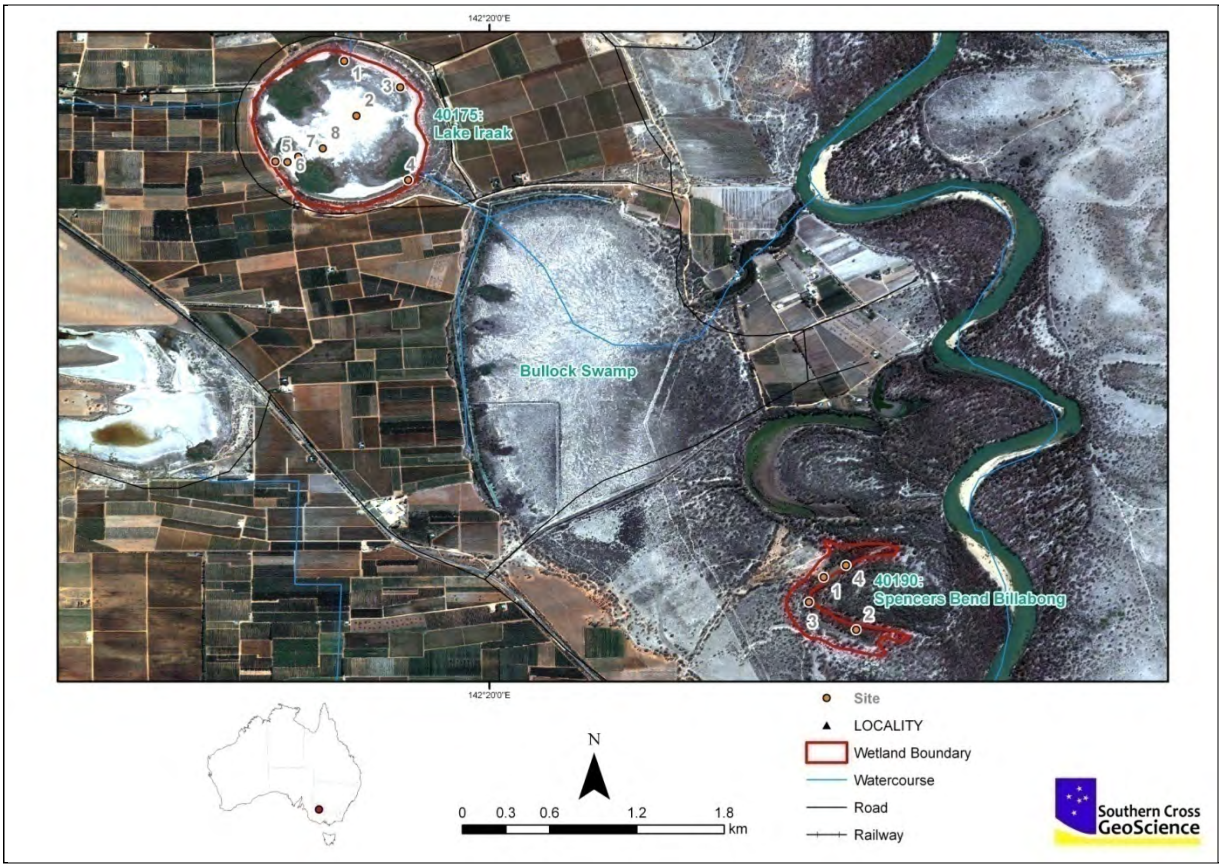


Figure 8-35. Spencers Bend Billabong and sample site locations.

8.3.2. Soil profile description and distribution

Four sites were described and sampled. The soil subtype and general location description of each site are presented in Table 8-13. Sites were distributed throughout the wetland based on different surface features and locations in the wetland, and a transect approach was not used.

The profile 40190_1 (Figure 8-37) was situated in the lowest point of the billabong, in a distinctive, circular depression. The profile 40190_2 (Figure 8-38) was situated at the southern end of the billabong, amongst perennial grasses and forb ground cover in the centre of the channel. The profile 40190_3 (Figure 8-39) was situated in the centre of the billabong (near the ox-bow bend), amongst low forbs and sparse, immature red gums. The profile 40190_4 (Figure 8-40) was situated in a young, open Red Gum forest at the northern end of the billabong. Additional site and profile description data are presented in Tables 8-16 and 8-17, respectively.

Table 8-13. Soil identification, subtype and general location description for Spencers Bend Billabong.

Site ID	Easting UTM Zone 54H	Northing UTM Zone 54H	Acid sulfate soil subtype class	General location description
40190_1	624387	6187630	Sulfuric Cracking Clay	Central section of billabong. Deepest hole in most recently inundated and dried pond.
40190_2	624566	6187268	Sulfuric Soil	Southern section of billabong. Centre of channel.
40190_3	624300	6187461	Hydrosol	Central section of billabong. Edge of most recently inundated and dried pond.
40190_4	624514	6187710	Hydrosol	Northern section of billabong. Forested section of channel.

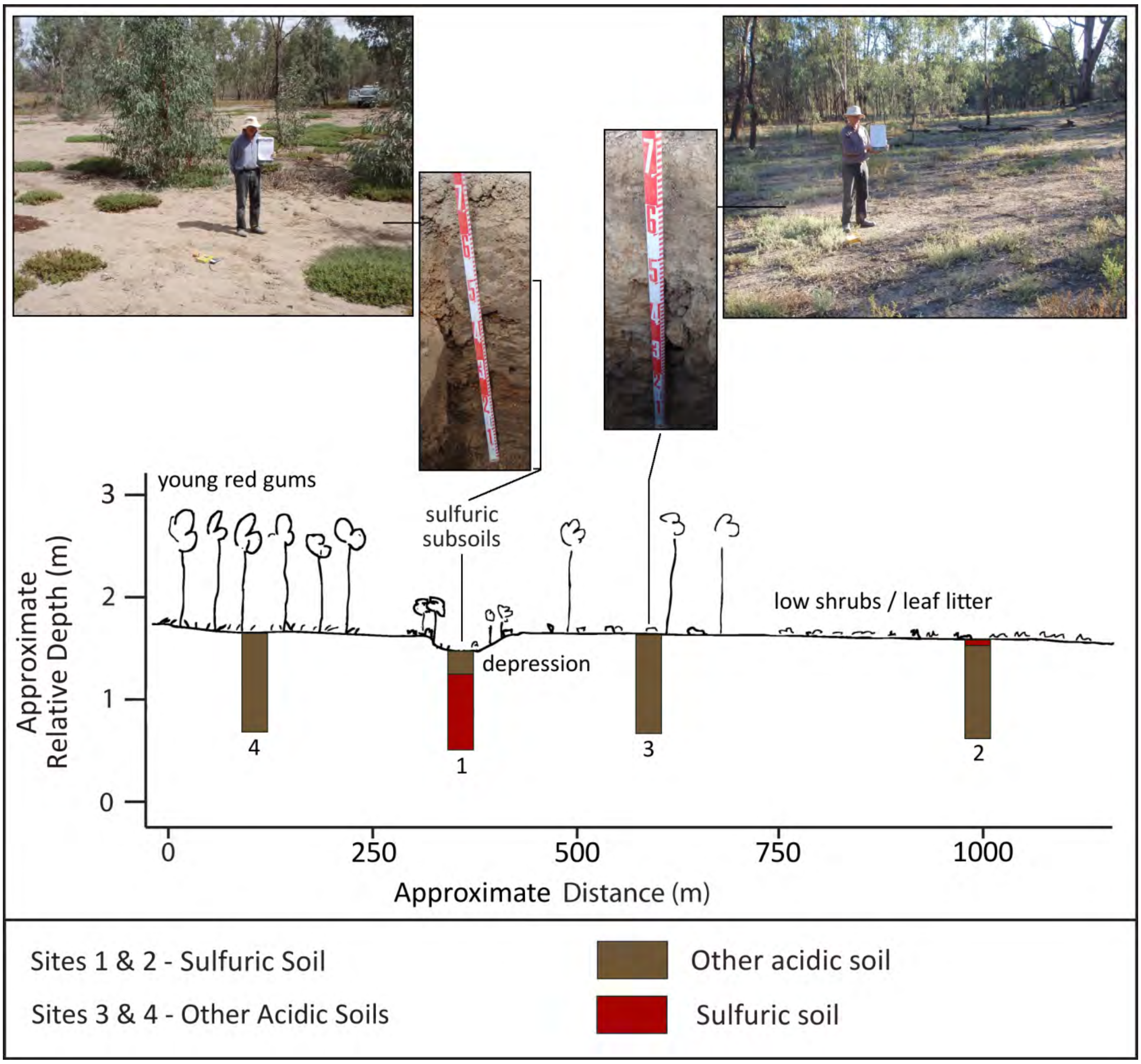


Figure 8-36. Conceptual cross section diagram showing the toposequence relationship of the Spencers Bend Billabong sediments/soil materials throughout the wetland.

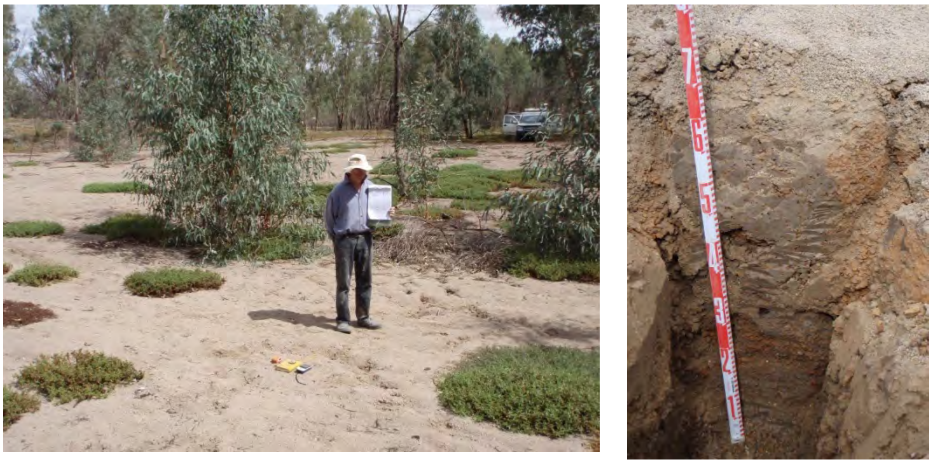


Figure 8-37. Photographs of site 40190_1, showing the depression at the lowest point of the billabong, and the soil profile.

Figure 8-38. Photographs of site 40190_2, showing the billabong channel with low ground forbs and grasses, and the soil profile.

Figure 8-39. Photographs of site 40190_3, showing the low forbs and scattered immature red gums, and the soil profile.

Figure 8-40. Photographs of site 40190_4, showing the open, young Red Gum forest with 90% ground cover (mostly litter), from which the sample was taken, and the soil profile.

8.3.3. Laboratory data assessment

Soil pH testing (pH_W, pH_{FOX}, pH_{KCl}, $pH_{INCUBATION}$)

The pH data is provided in Table 8-14 and profiles for all the sites sampled are presented in Figure 8-41. The pH_W values ranged between 3.82 and 5.72. Sulfuric materials (i.e. $pH_W < 4$) were present at two of the four sites examined (sites 40190_1 and 40190_2). The pH_{FOX} values ranged between 2.82 and 4.71. The pH_{FOX} results indicate that 15 of 21 surface soils examined may have the potential to acidify to pH < 4 as a result of sulfide oxidation. However, the S_{CR} data shows this wetland contained no detectable sulfide (i.e. S_{CR} < 0.01% S). One of the soil materials at site 40190_1 (10-20 cm) acidified to pH < 4 after at least 8 weeks of incubation. Other acidic soil materials were identified at all 4 sites, indicating acidity in the soil profile at levels where aluminium may mobilise.

Acid-base accounting

The acid-base accounting data is provided in Table 8-14 and summarised in Figure 8-42.

Chromium reducible sulfur

Sulfidic soil materials (i.e. S_{CR} ≥ 0.01% S) were not found within this wetland.

Acid volatile sulfide

Monosulfidic soil materials (i.e. S_{AV} ≥ 0.01% S) were not found within this wetland.

Acid neutralising capacity

The acid neutralising capacity (ANC) was zero for all soil materials.

Titratable actual acidity

The titratable actual acidity (TAA) ranged between 12 and 74 mole H^+/tonne, with the majority of soil layers having a TAA < 40 mole H^+/tonne. An increase in the TAA with depth was often observed.

Retained acidity

Retained acidity was only analysed at sites 40190_1 (20-90 cm) and 40190_2 (5-40 cm), as all other samples had a pH_{KCl} > 4.5 and therefore no retained acidity. A positive retained acidity of 5 mole H^+/tonne was only measured in one of the sulfuric soil materials at site 40190 (i.e. 20-40 cm).

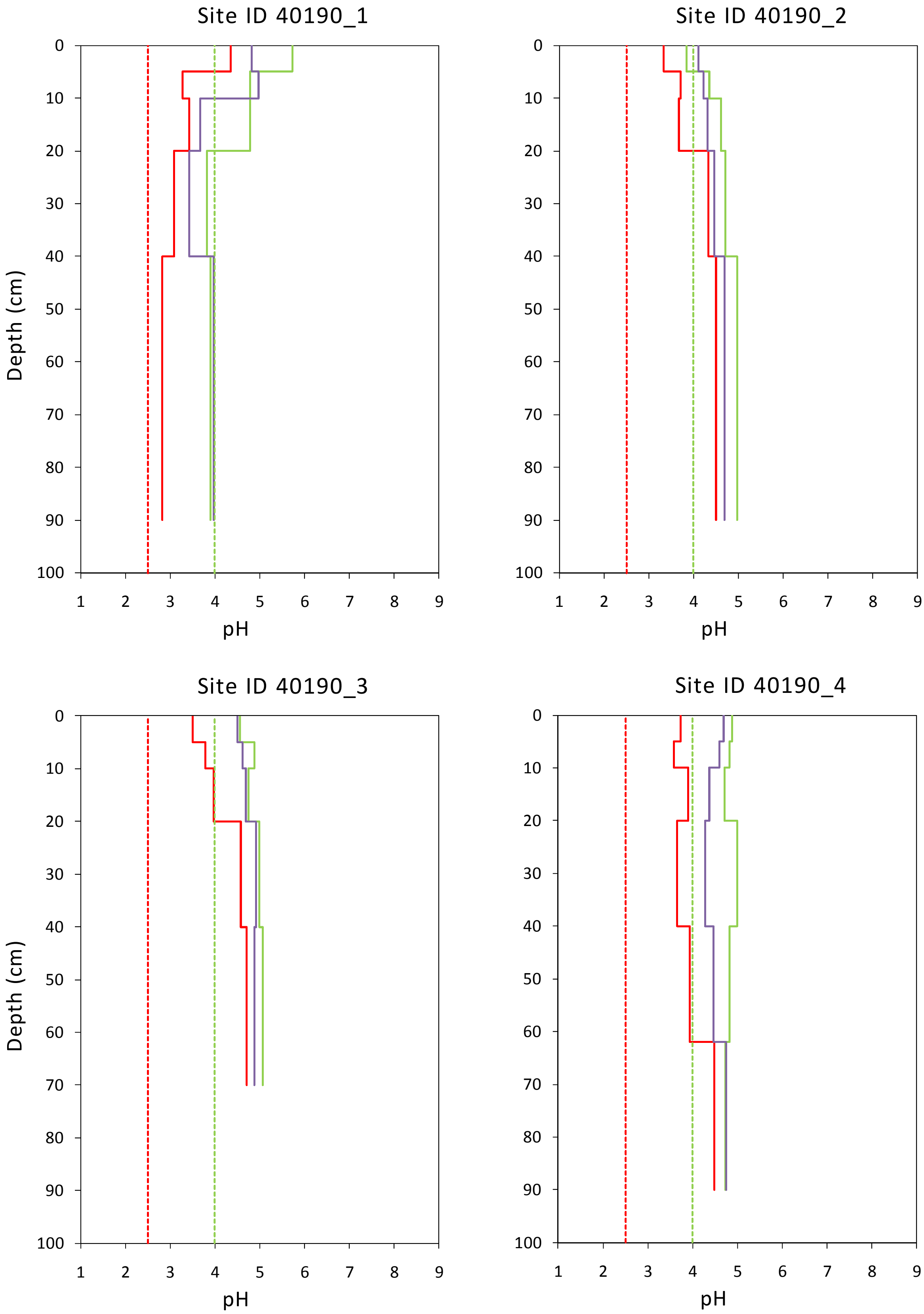


Figure 8-41. Depth profiles of soil pH for Spencers Bend Billabong (40190_1 – 40190_4), showing soil pH (pH_W as green line), peroxide treated pH (pH_{FOX} as red line) and ageing pH ($pH_{incubation}$ after at least eight weeks as purple line). Critical pH_W and $pH_{incubation}$ value of 4 (green dashed line) and critical pH_{FOX} value of 2.5 (red dashed line).

Net acidity

The net acidity for all layers was positive, ranging between 12 and 78 mole H^+/tonne. Three sulfuric soil materials had moderate net acidities ranging between 40 and 78 mole H^+/tonne.

Water Soluble Sulfate

The water soluble sulfate in the surface soils (i.e. 0-5 cm) ranged between 114 and 2,220 mg/L. All of the surface soil layers examined had a soluble sulfate content exceeding the 100 mg/L trigger value for MBO formation potential.

Water Data

No water samples were collected for analysis.

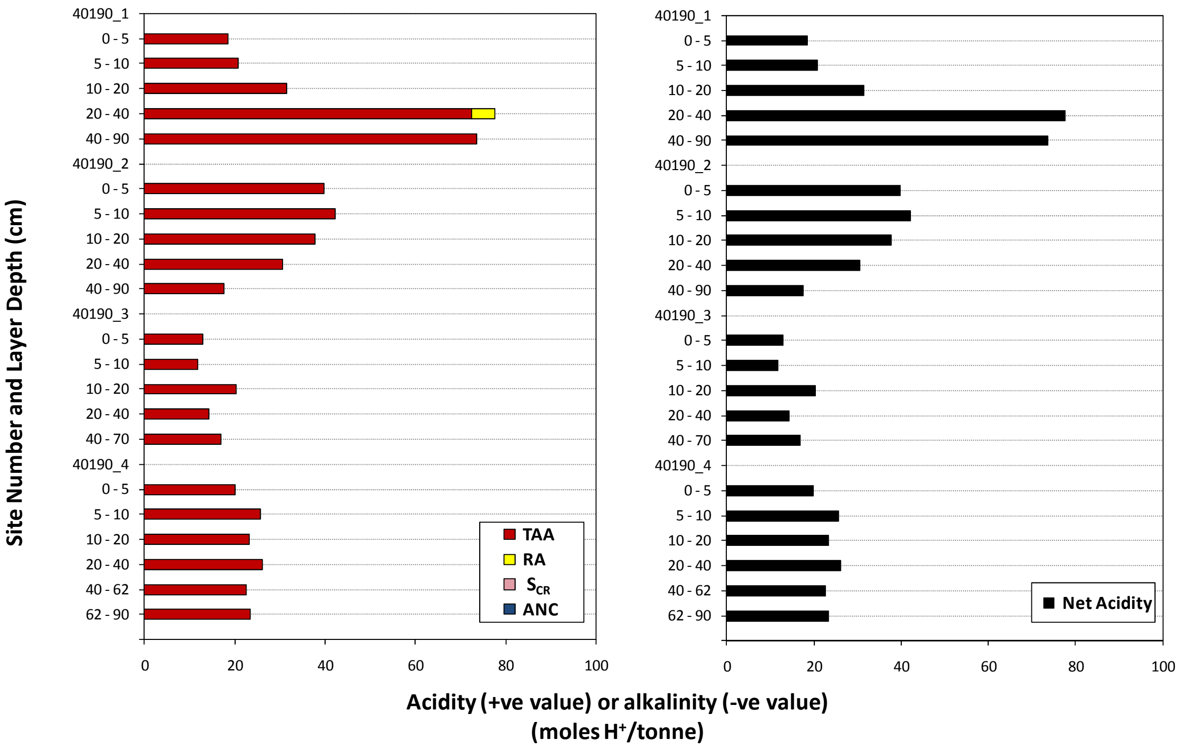


Figure 8-42. Acid-base accounting depth profiles for Spencers Bend Billabong (40190_1 – 40190_4). Left side shows the components: titratable actual acidity (TAA - red bar), acid generating potential (AGP as S_{CR} -pink bar), acid neutralising capacity (ANC - blue bar), retained acidity (RA - yellow bar), and right side shows net acidity.

8.3.4. Discussion

Acid sulfate soils occurred at two sites within Spencers Bend Billabong (i.e. sites 40190_1 (20-90cm) and 40190_2 (0-5 cm)). These two sites contained sulfuric soil materials, and the remaining two sites contained other acidic soils. The three sulfuric materials had moderate net acidities ranging between 40 and 78 mole H^+/tonne.

No sulfidic materials were identified within this wetland. All four surficial soil materials examined contained soluble sulfate in excess of the 100 mg/L trigger value for MBO formation potential.

Based on the priority ranking criteria adopted by the Scientific Reference Panel of the Murray-Darling Basin Acid Sulfate Soil Risk Assessment Project, there were two high priority sites based on the presence of sulfuric material, and four high priority ranking sites for Phase 2 detailed assessment based on MBO formation hazard.

The potential hazards at the wetland-scale posed by the acid sulfate soil materials at Spencers Bend Billabong are:

- Acidification hazard: The data indicate that with the presence of some sulfuric soil materials with moderate net acidities the degree of acidification hazard is moderate.

- Deoxygenation hazard: The soluble sulfate contents of surface soil materials at all four sites were over the trigger value for MBO formation indicating the possible development of an appreciable deoxygenation hazard at those locations after prolonged wet conditions.

- Metal mobilisation: The moderate acidification hazard indicates that soil acidification may increase the solubility of metals. The potential for MBO formation identified in this wetland may also result in an appreciable metal release hazard depending on factors such as the potential for MBO formation and the metal loading in this wetland. Soil acidity may be sufficient for mobilisation of aluminium at all sites.

Summary of key findings for the Spencers Bend Billabong:

Soil materials:	Sulfuric materials observed at 2 sites. No sulfidic materials identified. Other acidic soil materials observed at the other 2 sites. Low to moderate net acidities dominant within wetland.
Acid sulfate soil identification:	• Sulfuric cracking clay and sulfuric soils were identified. • Hydrosols were observed at the remaining sites.
Hazard assessment	• Acidification hazard - moderate level of concern • Deoxygenation hazard - high level of concern • Metal mobilisation hazard – high level of concern

Table 8-14. Laboratory analytical data for acid sulfate soil assessment of Spencers Bend Billabong (Wetland ID 40190).
(red printed values indicates data results of potential concern)

Site and Layer ID.	Depth Range (cm)	Soil Texture	pH water	pH peroxide	pH incubation	Sulfate (mg SO_4 / kg)	pH KCl	Titratable Actual Acidity (mole H^+/t)	Chromium Reducible Sulfur (%S_{CR})	Retained Acidity (mole H^+/t)	Acid Neutralising Capacity (%$CaCO_3$)	Net Acidity (mole H^+/t)	Acid Volatile Sulfide (%S_{AV})	Acid Sulfate Soil Material Classification
1.1	0-5	medium	5.72	4.36	4.82	2220	5.41	18.54	<0.01	0.00	0.00	18.54	<0.01	other acidic
1.2	5-10	fine	4.78	3.28	4.98		5.00	20.74	<0.01	0.00	0.00	20.74	<0.01	other acidic
1.3	10-20	fine	4.79	3.42	3.67		4.76	31.40	<0.01	0.00	0.00	31.40	<0.01	other acidic
1.4	20-40	fine	3.82	3.08	3.43		4.24	72.54	<0.01	5.00	0.00	77.54	<0.01	sulfuric
1.5	40-90	fine	3.90	2.82	3.98		4.17	73.57	<0.01	0.00	0.00	73.57	<0.01	sulfuric
2.1	0-5	fine	3.85	3.34	4.11	242	4.61	39.72	<0.01	0.00	0.00	39.72	<0.01	sulfuric
2.2	5-10	fine	4.36	3.72	4.22		4.33	42.12	<0.01	0.00	0.00	42.12	<0.01	other acidic
2.3	10-20	fine	4.61	3.67	4.31		4.36	37.69	<0.01	0.00	0.00	37.69	<0.01	other acidic
2.4	20-40	fine	4.71	4.34	4.46		4.43	30.47	<0.01	0.00	0.00	30.47	<0.01	other acidic
2.5	40-90	fine	4.97	4.50	4.70		4.67	17.64	<0.01	0.00	0.00	17.64	<0.01	other acidic
3.1	0-5	fine	4.55	3.50	4.50	114	4.97	12.84	<0.01	0.00	0.00	12.84	<0.01	other acidic
3.2	5-10	fine	4.87	3.78	4.62		4.74	11.80	<0.01	0.00	0.00	11.80	<0.01	other acidic
3.3	10-20	fine	4.75	3.97	4.69		4.66	20.36	<0.01	0.00	0.00	20.36	<0.01	other acidic
3.4	20-40	fine	4.99	4.57	4.92		4.81	14.25	<0.01	0.00	0.00	14.25	<0.01	other acidic
3.5	40-70	fine	5.06	4.71	4.88		4.82	16.80	<0.01	0.00	0.00	16.80	<0.01	other acidic
4.1	0-5	fine	4.89	3.73	4.69	189	4.93	19.96	<0.01	0.00	0.00	19.96	<0.01	other acidic
4.2	5-10	fine	4.83	3.58	4.59		4.62	25.58	<0.01	0.00	0.00	25.58	<0.01	other acidic
4.3	10-20	fine	4.72	3.90	4.37		4.66	23.28	<0.01	0.00	0.00	23.28	<0.01	other acidic
4.4	20-40	fine	4.99	3.65	4.28		4.60	26.20	<0.01	0.00	0.00	26.20	<0.01	other acidic
4.5	40-62	fine	4.82	3.93	4.47		4.64	22.55	<0.01	0.00	0.00	22.55	<0.01	other acidic
4.6	62-90	fine	4.73	4.48	4.75		4.68	23.32	<0.01	0.00	0.00	23.32	<0.01	other acidic

Table 8-15. Site description data for acid sulfate soil assessment of Spencers Bend Billabong (Wetland ID 40190).

Site No.	Depth to Water Table (cm)	Surface Condition	Earth Cover (Vegetation)	Location Notes	Rationale for site selection	ASS Soil Classification	Comments
1	Beyond sampling depth	Dry	Bare	Central section of billabong. Deepest hole in most recently inundated but now dry pond.	Lowest point in the wetland.	Sulfuric	
2	Beyond sampling depth	Dry	Moderate Forbs & Leaf Litter	Southern section of billabong. Centre of channel.	Elevated site.	Sulfuric	
3	Beyond sampling depth	Dry	Moderate Forbs & Leaf Litter	Central section of billabong. Edge of most recently inundated but now dry pond.	Moderately elevated site.	Other acidic	
4	Beyond sampling depth	Dry	Dense Leaf litter	Northern section of billabong. Forested section of channel.	Elevated and vegetated site.	Other acidic	

Table 8-16. Profile description data for acid sulfate soil assessment of Spencers Bend Billabong (Wetland ID 40190).

Site and Sample No.	Horizon Depth Range (cm)	Soil Colour - moist	Texture Class	Moisture State	Redoximorphic Features Abundance	Redoximorphic Features - Kind	Redoximorphic Features - Colour	Structure - Type	Structure - Grade	pH (field measurement)	Comments (odour, fragments, minerals, plant material, inclusions, other)
1.1	0-5	2.5Y 4/1	ZLC	D	0	n/a	n/a	PO	S	4.91	
1.2	5-10	2.5Y 4/1	ZMC	D	4	M	10YR 5/8	PO	S	4.49	Vesicles.
1.3	10-20	2.5Y 4/1	MC	T	4	M	10YR 5/8	AB	S	4.11	Vesicles.
1.4	20-40	2.5Y 4/1	MC	T	4	M	10YR 5/8	AB	S	3.80	Vesicles.
1.5	40-90	2.5Y 4/1	ZLMC	T	4	M	7.5Y 5/8	GR	S	3.68	
2.1	0-5	5Y 5/2	ZLMC	D	2	M	2.5Y 6/6	SB	S	4.70	
2.2	5-10	2.5Y 5/2	ZMC	D	2	M	2.5Y 6/6	SB	S	4.66	
2.3	10-20	2.5Y 5/3	ZMHC	T	3	M	10YR 5/8	SB	S	4.74	
2.4	20-40	2.5Y 5/1	ZHC	T	3	M	10YR 5/8	SB	S	4.82	
2.5	40-90	2.5Y 4/1	ZHC	T	1	M	10YR 5/8	SB	S	5.09	
3.1	0-5	2.5Y 4/2	ZLMC	M	1	M	10YR 5/6	SB	S	4.96	
3.2	5-10	2.5Y 4/2	LMC	M	2	M	10YR 5/6	SB	S	4.89	
3.3	10-20	2.5YR 5/1	MC	D	3	M	10YR 4/4	SB	S	4.92	
3.4	20-40	2.5YR 5/1	MHC	D	3	M	10YR 4/4	SB	S	4.84	
3.5	40-70	2.5YR 5/2	MHC	T	3	M	10YR 4/4	SB	S	5.03	Auger refusal at 70cm. Secondary mottle 10YR 2.5/1.
4.1	0-5	2.5Y 4/1	LMC	T	0	n/a	n/a	SB	S	4.86	
4.2	5-10	2.5Y 4/1	LMC	T	1	M	7.5YR 5/6	SB	S	4.74	
4.3	10-20	2.5Y 4/1	MHC	T	4	M	7.5YR 5/6	SB	S	4.96	
4.4	20-40	2.5Y 5/2	MHC	T	3	M	5YR 4/6	SB	S	4.85	Inclusions of sandy clay, light coloured peds.
4.5	40-62	2.5Y 6/1	MHC	T	2	M	5YR 4/6	SB	S	4.54	Inclusions of sandy clay, light coloured peds.
4.6	62-90	5Y 4/2	MHC	T	4	M	10Y 4/6	SB	S	4.97	Secondary mottle 10Y 6/6.

8.4. Brickworks Lagoon (Wetland ID 40864)

8.4.1. Location and setting description

Brickworks Lagoon is situated approximately 12.5 km west-northwest of Mildura. The wetland is a 24 hectare ox-bow lake measuring approximately 1.7 km in length and 180 m at its widest point. The wetland is situated south of the River Murray, on the floodplain. A prominent, well vegetated red sand hill forms a boundary on the southern and western margins of the wetland, beyond which lay agricultural land. A zone of woodland immediately borders the inside margin of the wetland, and further agricultural land is contained within the ox-bow of the wetland. Apart from a small pool apparently created by a bogged vehicle, there was no surface water in the wetland at the time of sampling. Salt efflorescences were visible on the surface of the wetland.

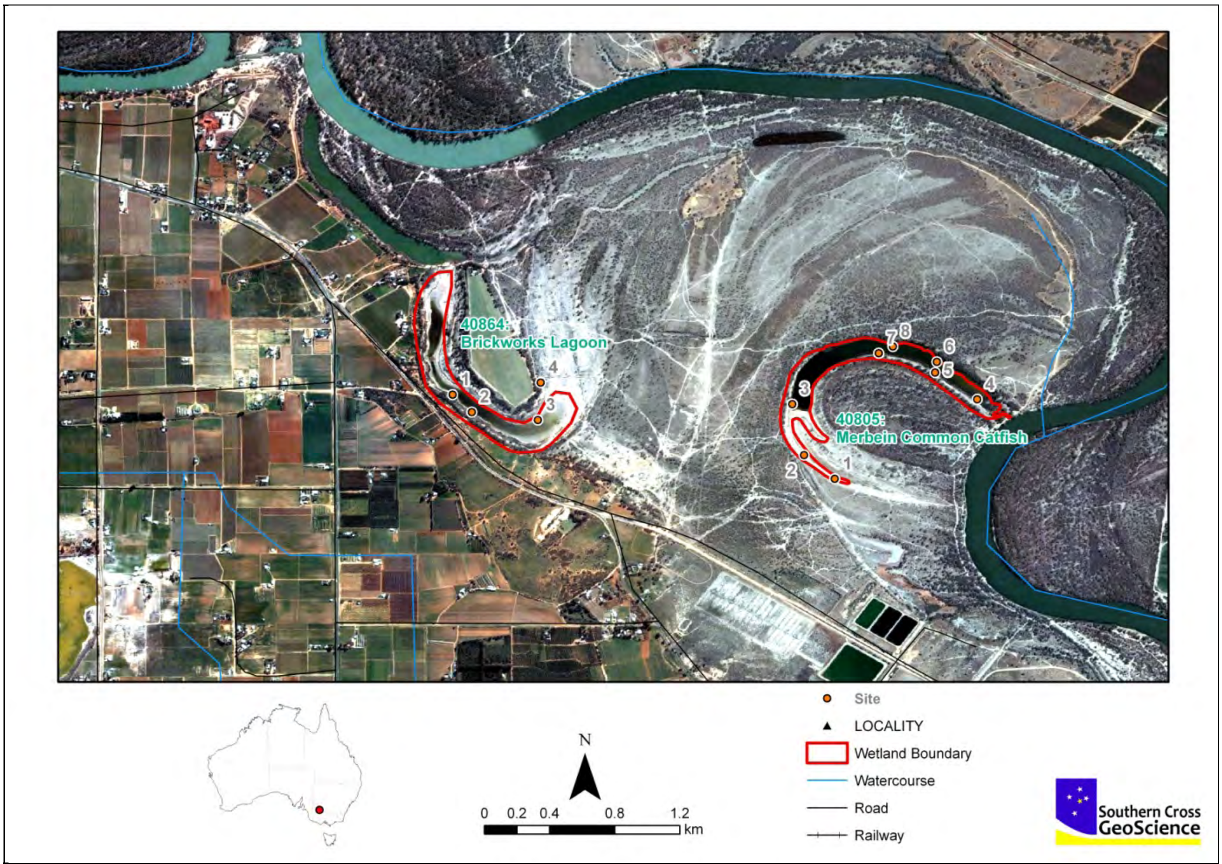


Figure 8-43. Brickworks Lagoon and sample site locations.

8.4.2. Soil profile description and distribution

Four sites were described and sampled. The soil subtype and general location description of each site are presented in Table 8-17. Sites were distributed throughout the wetland based on different surface features and locations in the wetland, and a transect approach was not used.

The four sampled sites were chosen to represent different moisture characteristics of the wetland, and were situated in deep to shallow sections of the channel. The profiles 40864_1 (Figure 8-45), 40864_2 (Figure 8-46) and 40864_3 (Figure 8-47) were situated in bare, salt-encrusted clay. The profile 40864_4 (Figure 8-48) was situated in a zone vegetated by low, succulent shrubs on raised mounds. Additional site and profile description data are presented in Tables 8-21 and 8-22, respectively.

Table 8-17. Soil identification, subtype and general location description for Brickworks Lagoon.

Site ID	Easting UTM Zone 54H	Northing UTM Zone 54H	Acid sulfate soil subtype class	General location description
40864_1	595646	6221587	Hypersulfidic Soil	Central section, middle of channel.
40864_2	595742	6221480	Hypersulfidic Cracking Clay Soil	Central section, middle of channel.
40864_3	596078	6221428	Hypersulfidic Soil	Southern section, middle of channel.
40864_4	596094	6221657	Cracking Clay Soil	Eastern end of billabong. Dryland tip of channel. Site slightly outside the wetland boundary, but representative of this region of the wetland.

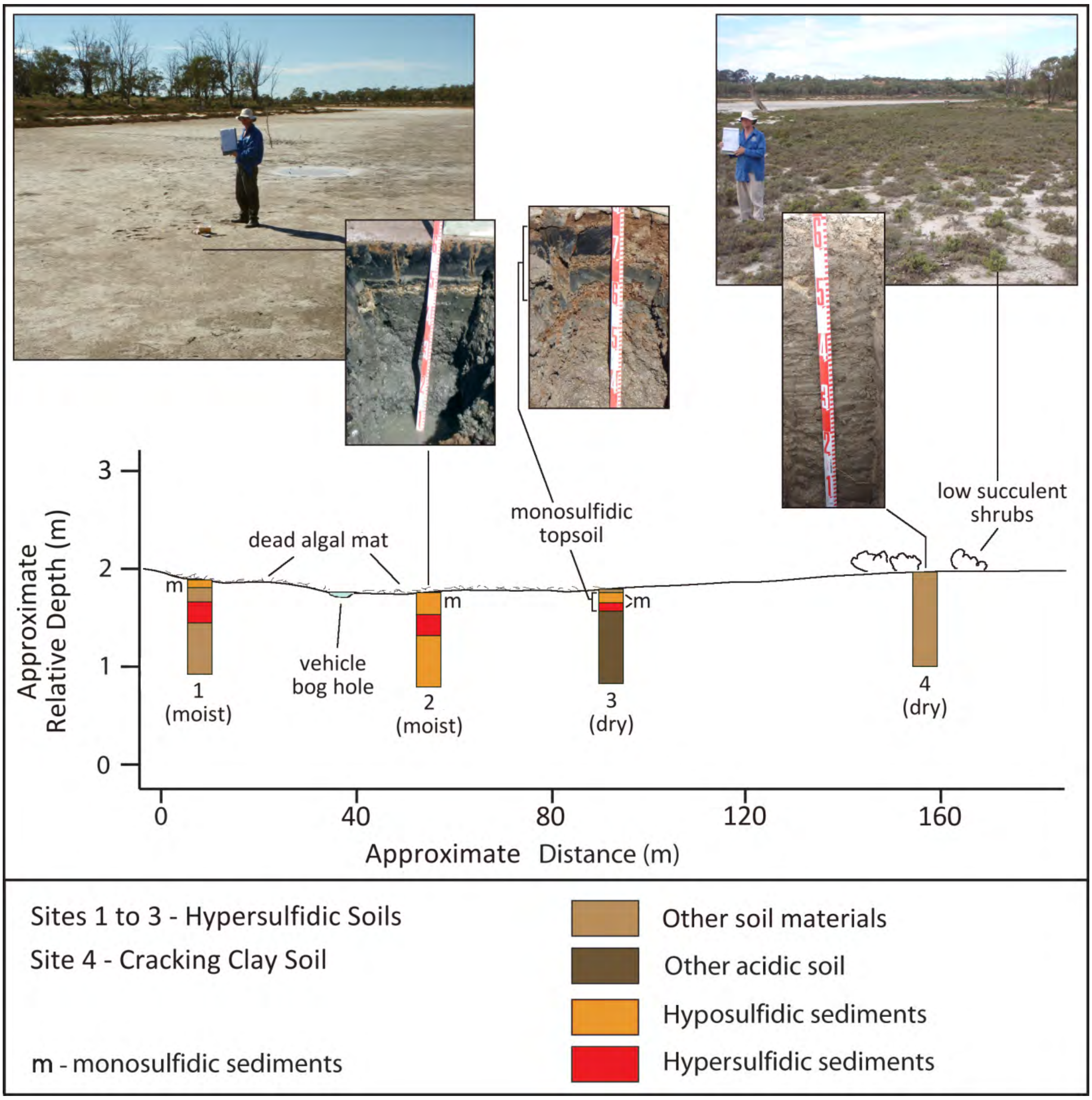


Figure 8-44. Conceptual cross section diagram showing the toposequence relationship of the Brickworks Lagoon sediments/soil materials throughout the wetland.

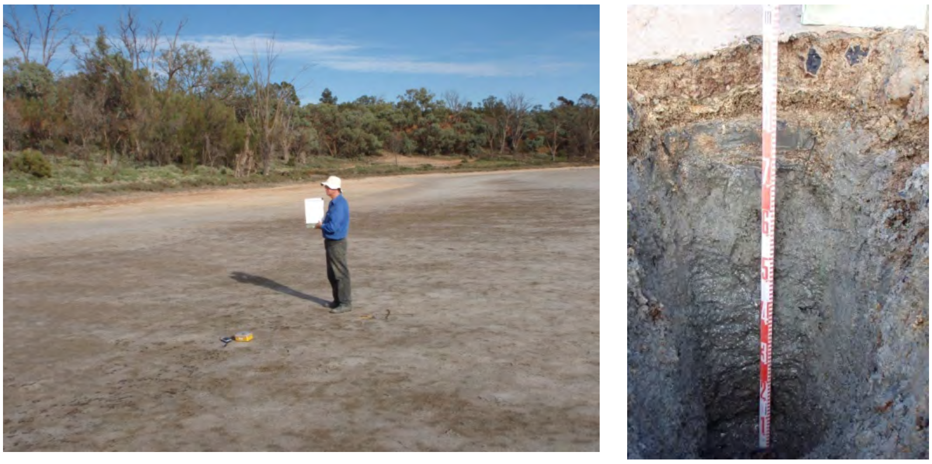


Figure 8-45. Photographs of site 40864_1, showing the bare clay from which the sample was taken, and the soil profile.

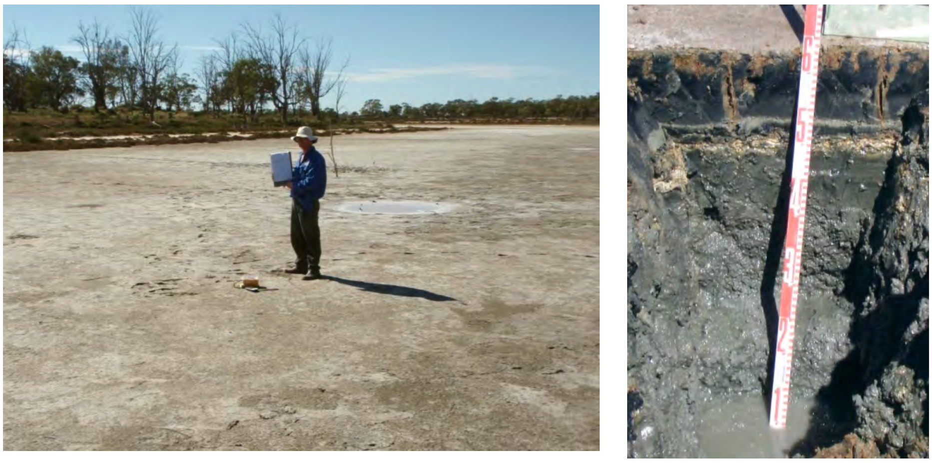


Figure 8-46. Photographs of site 40864_2, showing the bare, cracking clay surface, and the soil profile.

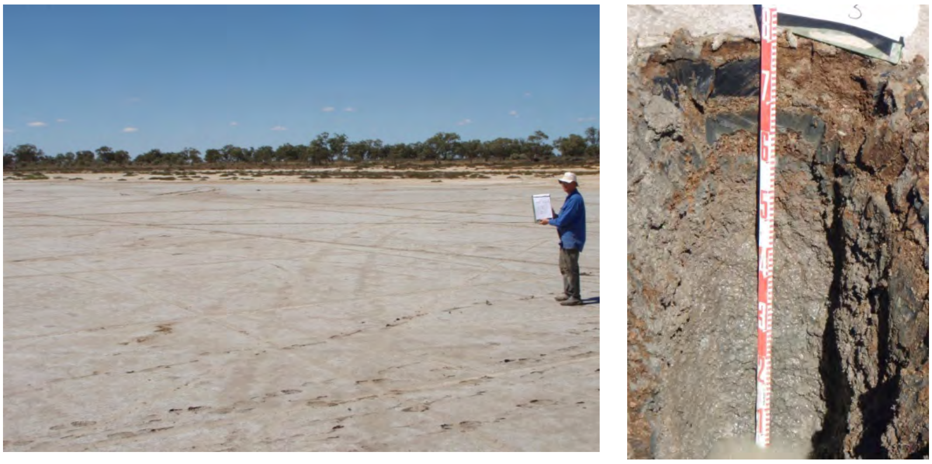


Figure 8-47. Photographs of site 40864_3, showing the bare, cracking clay surface, and the soil profile.

Figure 8-48. Photographs of site 40864_4, showing the cracking clay surface with low succulent shrubs, and the soil profile.

8.4.3. Laboratory data assessment

Soil pH testing (pH_W, pH_{FOX}, pH_{KCl}, $pH_{INCUBATION}$)

The pH data is provided in Table 8-18 and profiles for all the sites sampled are presented in Figure 8-49. The pH_W values ranged between 5.48 and 7.33. Sulfuric materials (i.e. $pH_W < 4$) were not present. The pH_{FOX} values ranged between 4.95 and 7.77. The pH_{FOX} results indicate that none of the surface soils may have the potential to acidify to pH < 4 as a result of sulfide oxidation. Only one of the sulfidic soil materials (i.e. $S_{CR} \geq 0.01\%$ S) acidified to pH < 4 after at least 8 weeks of incubation (site 40864_3 (16.5-20 cm)) despite five sulfidic soils having positive net acidities. Other acidic soil materials were identified at one of the four sites examined, indicating acidity in the soil profile at levels where aluminium may mobilise.

Acid-base accounting

The acid-base accounting data is provided in Table 8-18 and summarised in Figure 8-50.

Chromium reducible sulfur

Chromium reducible sulfur (S_{CR}) values ranged between < 0.01 and 2.19% S. Sulfidic soil materials (i.e. $S_{CR} \geq 0.01\%$ S) were identified at three sites (sites 40864_1 – 40864_3), with 14 materials of the 24 samples collected equal to or greater than the sulfidic criterion.

Acid volatile sulfide

The acid volatile sulfide (S_{AV}) values ranged between < 0.01 and 0.40% S. Monosulfidic soil materials (i.e. $S_{AV} \geq 0.01\%$ S) were found at three sites (sites 40864_1 - 40864_3), with eight materials of the 24 samples collected equal to or greater than the monosulfidic criterion.

Acid neutralising capacity

The acid neutralising capacity (ANC) ranged between zero and 7.7% $CaCO_3$.

Titratable actual acidity

The titratable actual acidity (TAA) ranged between zero and 5.5 mole H^+/tonne, with the majority of soil layers having a no TAA.

Retained acidity

There was no retained acidity at any of the sites in this wetland.

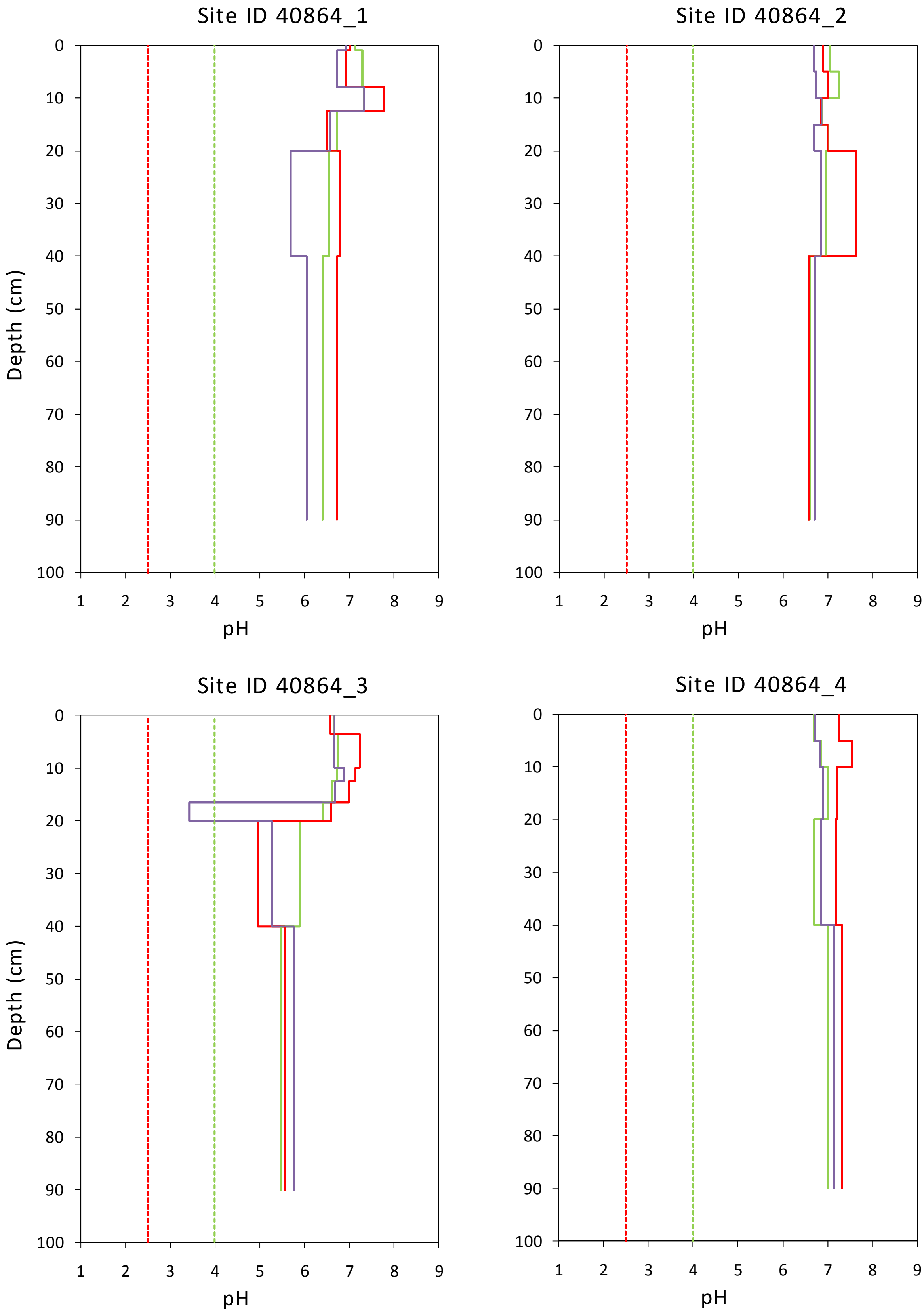


Figure 8-49. Depth profiles of soil pH for Brickworks Lagoon (40864_1 – 40864_4), showing soil pH (pH_W as green line), peroxide treated pH (pH_{FOX} as red line) and ageing pH ($pH_{incubation}$ after at least eight weeks as purple line). Critical pH_W and $pH_{incubation}$ value of 4 (green dashed line) and critical pH_{FOX} value of 2.5 (red dashed line).

Net acidity

Net acidity ranged between -886 and 1,235 mole H^+/tonne. The five hypersulfidic soil materials had moderate to high net acidities ranging between 22 and 1,235 mole H^+/tonne.

Water Soluble Sulfate

The water soluble sulfate in the surface soils (i.e. 0-5 cm) ranged between 5,715 and 33,300 mg/L. All of the surface soil layers examined had a soluble sulfate content exceeding the 100 mg/L trigger value for MBO formation potential.

Water Data

No surface water samples were collected for analysis. The groundwater data measured in the field and in the laboratory are presented in Tables 8-19 and 8-20, respectively. The field pH of the groundwater ranged between 5.1 and 6.4, indicating that the groundwater may have been affected by acidification. The groundwater had high sulfate concentrations of between 6,627 and 8,436 mg/L.

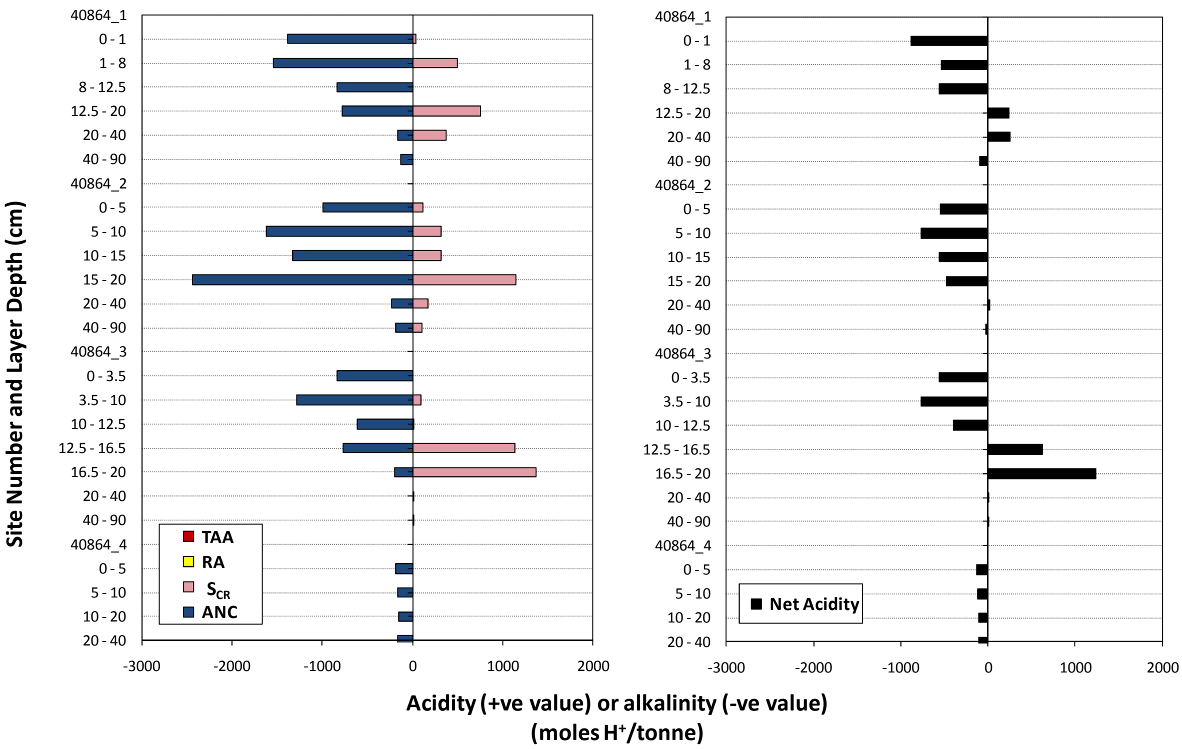


Figure 8-50. Acid-base accounting depth profiles for Brickworks Lagoon (40864_1 – 40864_4). Left side shows the components: titratable actual acidity (TAA - red bar), acid generating potential (AGP as S_{CR} -pink bar), acid neutralising capacity (ANC - blue bar), retained acidity (RA - yellow bar), and right side shows net acidity.

8.4.4. Discussion

Acid sulfate soils occurred at three of four sites examined in the Brickworks Lagoon wetland (i.e. sites 40864_1 – 40864_3). Site 40864_4 was observed to contain other soil materials. Sulfuric materials were not observed. The reduced inorganic sulfur content was often high at the three sites where sulfides were observed (i.e. S_{CR}. was up to 2.19% S). Hypersulfidic soil materials (with moderate to high net acidities) were present in the three sulfidic soil profiles (each profile also contained hyposulfidic materials). Monosulfidic soil materials were observed in the surface layers at three of the sampling sites (i.e. sites 40864_1 - 40864_3), with S_{AV} contents of up to 0.40% S. These results indicate that acidity would be produced upon oxidation of sulfides in some of these materials. The surficial soil materials at all four sites contained soluble sulfate in excess of the 100 mg/L trigger value for MBO formation potential.

Based on the priority ranking criteria adopted by the Scientific Reference Panel of the Murray-Darling Basin Acid Sulfate Soil Risk Assessment Project, there were three high priority sites based on hypersulfidic material, and two high priority sites based on monosulfidic material. In addition, all four sampling sites had a high priority ranking for Phase 2 detailed assessment based on MBO formation hazard.

The potential hazards at the wetland-scale posed by acid sulfate soil materials at the Brickworks Lagoon wetland are:

- Acidification hazard: While low net acidities were dominant in this wetland, four hypersulfidic materials had high net acidities (i.e. 17% of layers), indicating that the overall degree of acidification hazard is high.

- Deoxygenation hazard: High monosulfide concentrations (S_{AV} ≤ 0.40% S) in surface soils at three sites represent a high deoxygenation hazard. In addition, the soluble sulfate content of surface soil materials at all four sites were over the trigger value for MBO formation indicating the possible development of an appreciable deoxygenation hazard at those locations after prolonged wet conditions.

- Metal mobilisation: The high acidification hazard indicates that soil acidification may increase the solubility of metals. The presence of monosulfidic materials in some surface soils and the potential for MBO formation identified in this wetland may also result in an appreciable metal release hazard. This would depend on factors such as the potential for MBO formation and the metal loading in this wetland. Soil acidity may be sufficient for mobilisation of aluminium.

Summary of key findings for the Brickworks Lagoon:

Soil materials:	Sulfuric materials were not observed. Sulfidic soil materials identified included: hypersulfidic (3 sites), monosulfidic (2 sites), hyposulfidic ≥ 0.10% S (2 sites) and hyposulfidic < 0.10% S (2 sites). Other soil materials observed at 1 site. Low net acidities dominant within wetland. High net acidities in 4 hypersulfidic materials.
Acid sulfate soil identification:	• Hypersulfidic and hypersulfidic cracking clay soils identified. • Cracking clay soil identified at 1 site.
Hazard assessment	• Acidification hazard - high level of concern • Deoxygenation hazard - high level of concern • Metal mobilisation hazard – high level of concern

Table 8-18. Laboratory analytical data for acid sulfate soil assessment of Brickworks Lagoon (Wetland ID 40864).
(red printed values indicates data results of potential concern)

Site and Layer ID.	Depth Range (cm)	Soil Texture	pH water	pH peroxide	pH incubation	Sulfate (mg SO_4 / kg)	pH KCl	Titratable Actual Acidity (mole H^+/t)	Chromium Reducible Sulfur (%S_{CR})	Retained Acidity (mole H^+/t)	Acid Neutralising Capacity (%$CaCO_3$)	Net Acidity (mole H^+/t)	Acid Volatile Sulfide (%S_{AV})	Acid Sulfate Soil Material Classification
1.1	0-1		7.14	7.00	6.94	23850	9.04	0.00	0.06	0.00	6.93	-886.30	0.02	hypomonosulfidic (< 0.10)
1.2	1-8		7.29	6.93	6.73		8.68	0.00	0.79	0.00	7.70	-532.17	0.40	hypomonosulfidic (≥ 0.10)
1.3	8-12.5		7.33	7.77	7.32		9.24	0.00	<0.01	0.00	4.20	-559.42	<0.01	other soil materials
1.4	12.5-20		6.72	6.49	6.58		8.23	0.00	1.21	0.00	3.88	239.52	<0.01	hypersulfidic[#]
1.5	20-40	fine	6.54	6.78	5.69		7.46	0.00	0.59	0.00	0.83	258.77	<0.01	hypersulfidic[#]
1.6	40-90	fine	6.40	6.72	6.05		7.04	0.00	<0.01	0.00	0.68	-90.03	<0.01	other soil materials
2.1	0-5		7.04	6.90	6.69	33300	8.45	0.00	0.19	0.00	4.97	-540.55	0.09	hypomonosulfidic (≥ 0.10)
2.2	5-10		7.25	7.00	6.74		8.59	0.00	0.51	0.00	8.09	-761.01	0.25	hypomonosulfidic (≥ 0.10)
2.3	10-15		6.87	6.84	6.85		7.02	0.00	0.52	0.00	6.63	-561.19	0.06	hypomonosulfidic (≥ 0.10)
2.4	15-20		6.99	6.98	6.69		8.50	0.00	1.83	0.00	12.20	-481.34	0.02	hypomonosulfidic (≥ 0.10)
2.5	20-40		6.96	7.63	6.84		7.78	0.00	0.28	0.00	1.15	22.12	<0.01	hypersulfidic[#]
2.6	40-90	fine	6.59	6.57	6.71		7.76	0.00	0.17	0.00	0.96	-24.27	<0.01	hyposulfidic (≥ 0.10)
3.1	0-3.5	fine	6.66	6.58	6.67	22350	8.63	0.00	<0.01	0.00	4.20	-559.51	<0.01	other soil materials
3.2	3.5-10		6.75	7.24	6.67		8.42	0.00	0.46	0.00	6.45	-771.15	0.31	hypomonosulfidic (≥ 0.10)
3.3	10-12.5		6.73	7.14	6.88		8.49	0.00	0.03	0.00	3.07	-390.77	<0.01	hyposulfidic (< 0.10)
3.4	12-5-16.5		6.62	6.99	6.68		8.38	0.00	1.85	0.00	3.83	621.98	0.04	hypermonosulfidic[#]
3.5	16.5-20		6.41	5.55	3.42		7.59	0.00	2.19	0.00	0.98	1234.63	<0.01	hypersulfidic
3.6	20-40	fine	5.90	4.95	5.27		6.24	3.34	<0.01	0.00	0.00	3.34	<0.01	other acidic
3.7	40-90	fine	5.48	5.55	5.76		6.00	5.48	<0.01	0.00	0.00	5.48	<0.01	other acidic
4.1	0-5	fine	6.69	7.26	6.72	5715	7.37	0.00	<0.01	0.00	0.94	-125.65	<0.01	other soil materials
4.2	5-10	fine	6.85	7.54	6.82		7.20	0.00	<0.01	0.00	0.84	-111.99	<0.01	other soil materials
4.3	10-20	fine	7.00	7.20	6.91		7.10	0.00	<0.01	0.00	0.78	-104.55	<0.01	other soil materials
4.4	20-40	fine	6.69	7.19	6.85		7.00	0.00	<0.01	0.00	0.81	-108.00	<0.01	other soil materials
4.5	40-90	fine	7.00	7.32	7.14		7.21	0.00	<0.01	0.00	0.86	-114.75	<0.01	other soil materials

[#] Classified as hypersulfidic/hypermonosulfidic based on positive net acidity.

Table 8-19. Field hydrochemistry data for acid sulfate soil assessment of Brickworks Lagoon (Wetland ID 40864).

Site and Layer ID.	Temperature (Deg C)	Specific Electrical Conductivity (µS/cm)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	pH	ORP	Redox potential (mV))	Turbidity (NTU)	HCO_3 (mg/L)	Comment
*Lowland River**		*125-2200*	*85-110*		*6.5-8.0*			*6-50*		
*Freshwater Lakes**		*20-30*	*90-110*		*6.5-8.0*			*1-20*		
40864_1 (PW)	25.7	22200		4.56	5.05		157	n.a.	110	Turbidity not measured
40864_2 (PW)	29.6	170900		1.57	6.39		4	n.a.	285	Turbidity not measured
40864_3 (PW)	29.6	200000		3.73	5.17		221	n.a.	70	Turbidity not measured

* ANZECC water quality guidelines for lowland rivers and freshwater lakes/reservoirs in South-east Australia are provided for relevant parameters (there are currently no trigger values defined for 'Wetlands') (ANZECC/ARMCANZ, 2000). Surface water values outside the ranges defined in the ANZECC guidelines are indicated with red text. (SW) and (PW) indicate whether the sample was taken from surface water or pore-water, respectively.

Table 8-20. Laboratory hydrochemistry data for acid sulfate soil assessment of Brickworks Lagoon (Wetland ID 40864).

Parameter	units	ANZECC Guidelines	Site 1 (PW)	Site 2 (PW)	Site 3 (PW)
depth	cm				
Na	mg l^{-1}		49,811	42,441	38,126
K	mg l^{-1}		270	278	274
Ca	mg l^{-1}		2,404	1,488	2,030
Mg	mg l^{-1}		8,952	6,272	6,302
Si	mg l^{-1}		12.3	12.0	11.9
Br	mg l^{-1}		281.63	249.21	263.72
Cl	mg l^{-1}		82,110	73,803	79,838
NO_3	mg l^{-1}	0.7	0.134	0.144	0.037
NH_4-N	mg l^{-1}	0.01	17.704	8.568	7.558
PO_4-P[E]	mg l^{-1}	0.005	<0.005	0.028	0.036
SO_4	mg l^{-1}		8,436	8,421	6,627
Ag	µg l^{-1}	0.05	<1	<1	1
Al[A]	µg l^{-1}	55	9	<1	23
As[B]	µg l^{-1}	13	<10	<10	107
Cd	µg l^{-1}	0.2	2	1	5
Co	µg l^{-1}	2.8	203	11	350
Cr[C]	µg l^{-1}	1	<5	<5	<5
Cu[H]	µg l^{-1}	1.4	<5	<5	49
Fe	µg l^{-1}	300	32,376	4,034	2,428
Mn	µg l^{-1}	1700	53,365	13,878	44,781
Ni[H]	µg l^{-1}	11	176	<5	294
Pb[H]	µg l^{-1}	3.4	28	2	445
Se	µg l^{-1}	11	n/a	n/a	n/a
Zn[H]	µg l^{-1}	8	192	7	220
DOC	mg l^{-1}		n/a	n/a	n/a

Notes.

The ANZECC guideline values for toxicants refer to the Ecosystem Protection – Freshwater Guideline for protection of 95% of biota in 'slightly-moderately disturbed' systems, as outlined in the Australian Water Quality Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000). For the nutrients NH_4 and PO_4, guideline values are provided for Freshwater Lakes and Reservoirs. Surface water values outside the ranges defined in the ANZECC guidelines are indicated with red text. (SW) and (PW) indicate whether the sample was taken from surface water or pit-water (groundwater that entered an excavated pit), respectively.

A *Guideline is for Aluminium in freshwater where pH > 6.5.*
B *Guideline assumes As in solution as Arsenic (AsV).*
C *Guideline is for Chromium is applicable to Chromium (CrVI) only.*
E *Guideline is for filterable reactive phosphorous (FRP).*
H *Hardness affected (refer to Guidelines).*

Table 8-21. Site description data for acid sulfate soil assessment of Brickworks Lagoon (Wetland ID 40864).

Site No.	Depth to Water Table (cm)	Surface Condition	Earth Cover (Vegetation)	Location Notes	Rationale for site selection	ASS Soil Classification	Comments
1	40	Moist	Bare, light salt, dense cover of dead algal mats	Central section of lagoon. Centre of channel.	Moderately elevated site.	Hypersulfidic	
2	20	Moist	Bare, salt, dense cover of dead algal mats	Central section of lagoon. Centre of channel.	Lowest point in wetland, adjacent to only surface water present at time of sampling.	Hypersulfidic	
3	35	Moist	Bare, salt	Southern section of lagoon. Centre of channel.	Moderately elevated site.	Hypersulfidic	Tyre tracks around site.
4	Beyond sampling depth	Dry	Sparse succulent shrubs	Eastern end of lagoon. Dryland terrace adjacent to channel.	Most elevated site.	Other	

Table 8-22. Profile description data for acid sulfate soil assessment of Brickworks Lagoon (Wetland ID 40864).

Site and Sample No.	Horizon Depth Range (cm)	Soil Colour - moist	Texture Class	Moisture State	Redoximorphic Features Abundance	Redoximorphic Features - Kind	Redoximorphic Features - Colour	Structure - Type	Structure - Grade	pH (field measurement)	Comments (odour, fragments, minerals, plant material, inclusions, other)
1.1	0-1	2.5Y 5/1	n/a	M				PL	W	6.84	Coarse salt crystals.
1.2	1-8	2.5Y 4/2	n/a	M	4	M	2.5Y 2.5/1	SB	S	6.87	Too wet to texture. Secondary mottle 2.5Y 5/6.
1.3	8-12.5	2.5Y 4/4	n/a	W				SB	W	7.39	Coarse salt crystals.
1.4	12.5-20	2.5Y 2.5/1	n/a	W				n/a	V	6.46	Too wet to texture. Salt bands.
1.5	20-40	2.5Y 4/1	HC	W				SB	S	6.00	Vesicles present.
1.6	40-90	2.5Y 4/1	HC	W				SB	S	5.17	
2.1	0-5	GLEY 1 2.5/N	n/a	W	3	M		n/a	V	7.01	Too wet to texture. Black gel.
2.2	5-10	5Y 2.5/1	n/a	W				n/a	V	7.00	Too wet to texture.
2.3	10-15		n/a	W	2	M		n/a	W	6.84	Too wet to texture. Banded layer comprising 0.5cm of grey, fine sand. 1.2 cm of black gel, 2cm of salt.
2.4	15-20	5Y 2.5/1	n/a	W				n/a		6.35	Too wet to texture. Grey gel.
2.5	20-40	5Y 4/1	n/a	W				SB	S	6.47	Too wet to texture.
2.6	40-90	5Y 4/1	HC	W				SB	S	6.40	
3.1	0-3.5	5Y 5/1	LMC	M	4	M	GLEY 1 2.5/N	PL	S	5.91	
3.2	3.5-10	GLEY 1 2.5/N	n/a	W			n/a			6.46	Too wet to texture.
3.3	10-12.5	5Y 4/4	n/a	M	4	M	10YR 4/6	SB	S	6.69	Coarse salt crystals.
3.4	12-5-16.5	5Y 2.5/1	n/a	M			n/a	SB	S	6.36	Too wet to texture. Grey gel.
3.5	16.5-20	5Y 4/4	n/a	M	4	M	10YR 4/6			6.35	Coarse salt crystals.
3.6	20-40	5YR 4/1	MHC	M	1	M	5YR 4/6	SB	S	5.25	
3.7	40-90	5YR 4/1	HC	W	1	M	5YR 4/6	SB	S	5.45	Orange mottle ends at 52.5cm.

Table 8-22 (continued). Profile description data for acid sulfate soil assessment of Brickworks Lagoon (Wetland ID 40864).

Site and Sample No.	Horizon Depth Range (cm)	Soil Colour - moist	Texture Class	Moisture State	Redoximorphic Features Abundance	Redoximorphic Features - Kind	Redoximorphic Features - Colour	Structure - Type	Structure - Grade	pH (field measurement)	Comments (odour, fragments, minerals, plant material, inclusions, other)
4.1	0-5	5Y 6/1	FSMHC	D	1	M	n/a	SB	M	5.85	Salt present.
4.2	5-10	5Y 4/1	HC	T	1	M	5Y 2.5/1	SB	S	6.98	Salt present.
4.3	10-20	5Y 4/1	HC	T	1	M	5Y 2.5/1	SB	S	6.98	
4.4	20-40	5Y 4/1	HC	T	1	M	5Y 2.5/1	SB	S	7.04	Nodules present.
4.5	40-90	5Y 4/1	HC	T	1	M	5Y 2.5/1	SB	S	6.89	Salt present; nodules present.

8.5. Merbein Common-Catfish (Wetland ID 40805)

8.5.1. Location and setting description

Merbein Common-Catfish is an ox-bow lake situated approximately 10.7 km west-northwest of Mildura on the southern side of the River Murray, on the floodplain. The wetland extends for approximately 2.1 km in length and measures around 140 m in width at the widest point, and the overall area is 21 hectares. Apart from a small pool apparently created by a bogged vehicle, there was no surface water in the wetland at the time of sampling, and the bed of the channel was heavily marked by vehicle tyre tracks. Sites were distributed along the length of the wetland at different elevations and vegetation zones.

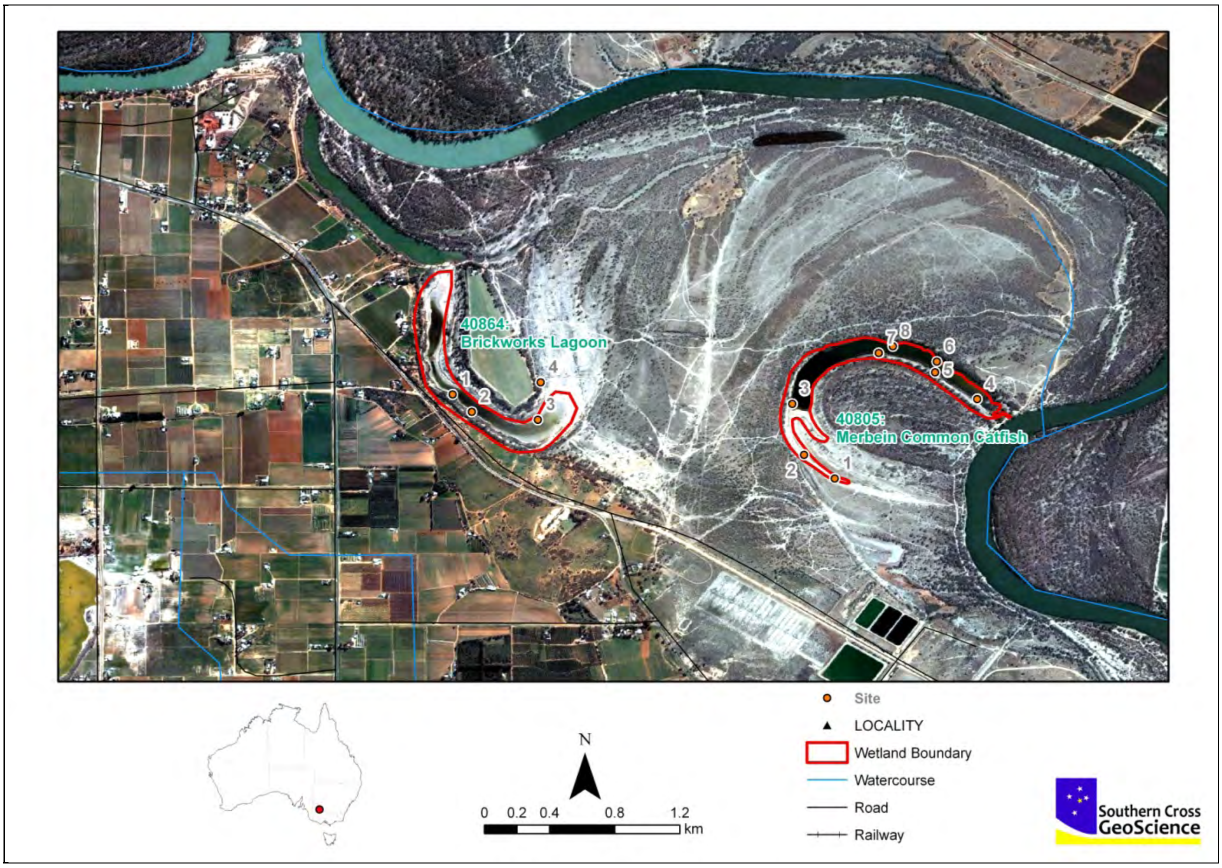


Figure 8-51. Merbein Common-Catfish Wetland and sample site locations.

8.5.2. Soil profile description and distribution

Eight sites were described and sampled. The soil subtype and general location description of each site are presented in Table 8-23. Sites were distributed throughout the wetland based on different surface features and locations in the wetland, and a transect approach was not used.

The profile 40805_1 (Figure 8-53) was situated in cracking clay with visible salt efflorescences, and featured low, succulent shrubs up to 1.5 m in diameter. The profile 40805_2 (Figure 8-54) was situated in bare, cracking, salt-encrusted clay heavily marked by wheel tracks. The profile 40805_3 (Figure 8-55) was situated in bare, cracking, salt-encrusted clay with a micro-relief of dips and mounds. The profile 40805_4 (Figure 8-56) as situated in a well vegetated area with forbs up to 60 cm in height with perennial ground cover in between. The profile 40805_5 (Figure 8-57) was situated in fine, cracking, soft clay without any evident salt, with minimal coverage by low, succulent vegetation. The profile 40805_6 (Figure 8-58) was situated in a depositional area adjacent to the bank, with a predominantly sandy surface. The profile 40805_7 (Figure 8-59) was situated in soft, cracking clay, which was mostly bare apart from dead groundcovers. The profile 40805_8 (Figure 8-60) was situated in the deepest part of the river end of the lake, with completely bare, cracking clays and visible salt efflorescences. Additional site and profile description data are presented in Tables 8-27 and 8-28, respectively.

Table 8-23. Soil identification, subtype and general location description for Merbein Common-Catfish Wetland.

Site ID	Easting UTM Zone 54H	Northing UTM Zone 54H	Acid sulfate soil subtype class	General location description
40805_1	597585	6221053	Hydrosol	Most SW reach of billabong. Centre of channel.
40805_2	597430	6221199	Hypersulfidic Soil	Mid SW reach of Billabong. Centre of channel.
40805_3	597374	6221512	Sulfuric Cracking Clay	Junction of two SW reaches. Centre of channel.
40805_4	598315	6221531	Hydrosol	Most eastern end of billabong. Near edge of wooded zone.
40805_5	598103	6221697	Hydrosol	Eastern end of billabong. In wooded zone.
40805_6	598112	6221763	Sulfuric Soil	Northern bank of billabong. Depositional area adjacent to dead reed beds.
40805_7	597817	6221818	Cracking Clay Soil	Central section of billabong. In channel along southern bank.
40805_8	597889	6221859	Cracking Clay Soil	Northern margin of billabong. In channel.

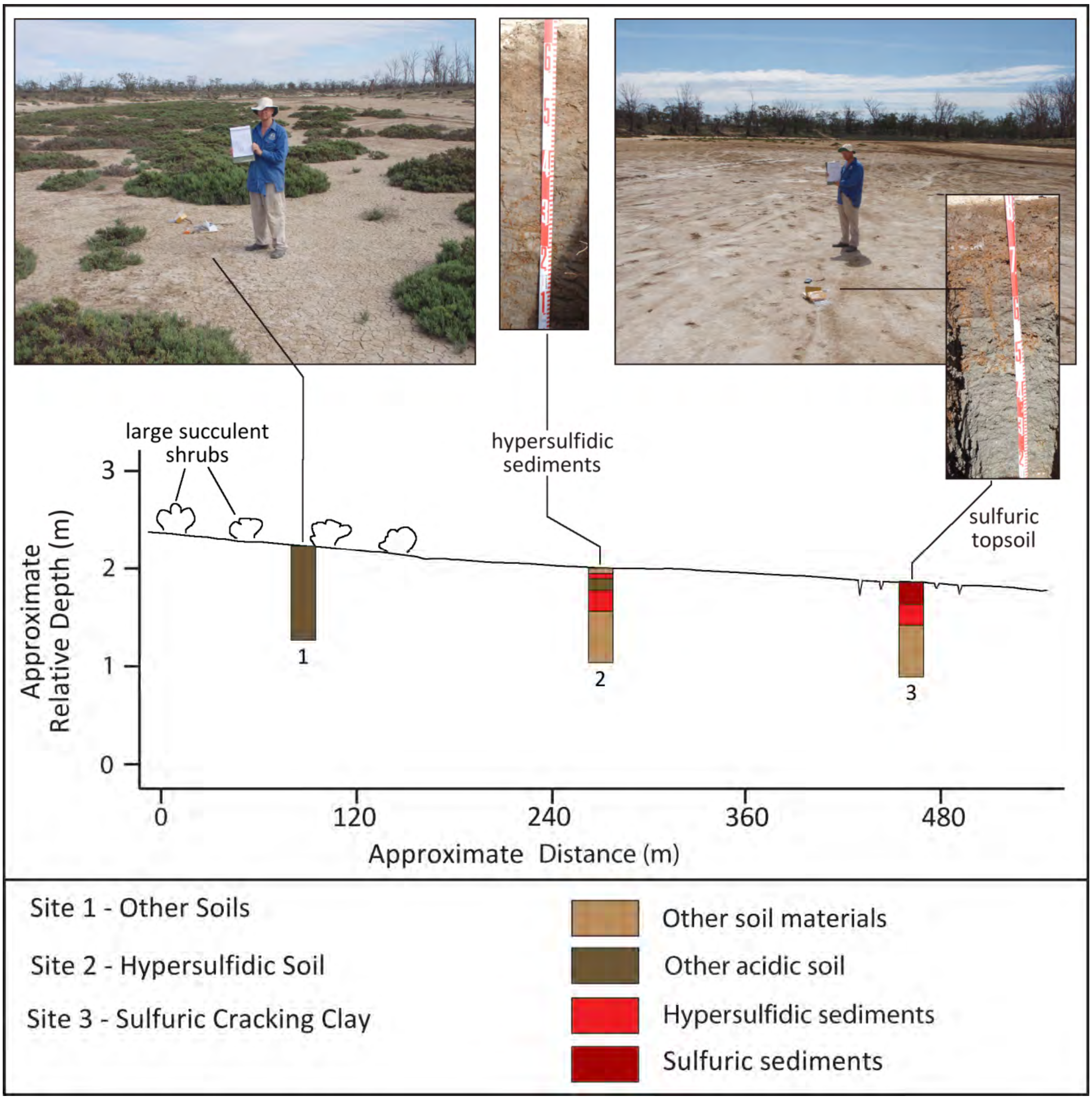


Figure 8-52. Conceptual cross section diagram showing the toposequence relationship of the Merbein Common-Catfish Wetland sediments/soil materials throughout the wetland.

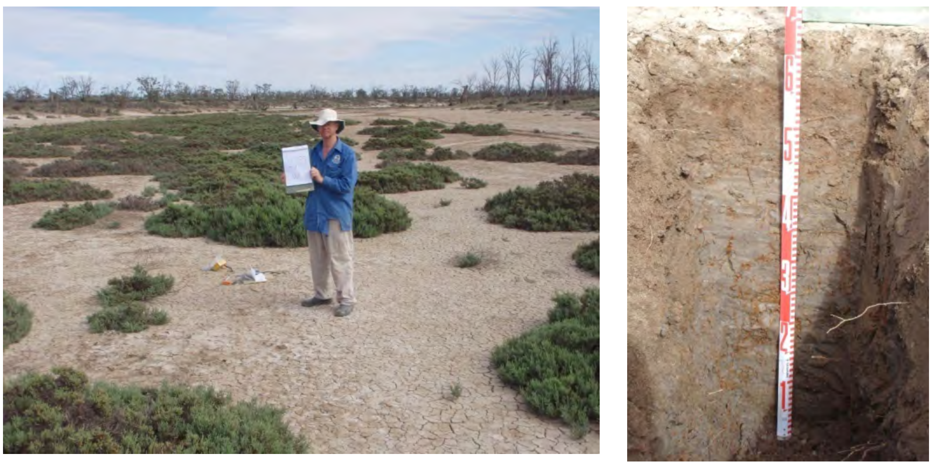


Figure 8-53. Photographs of site 40805_1, showing the cracking clay surface interspersed by low, spreading succulent shrubs, and the soil profile.

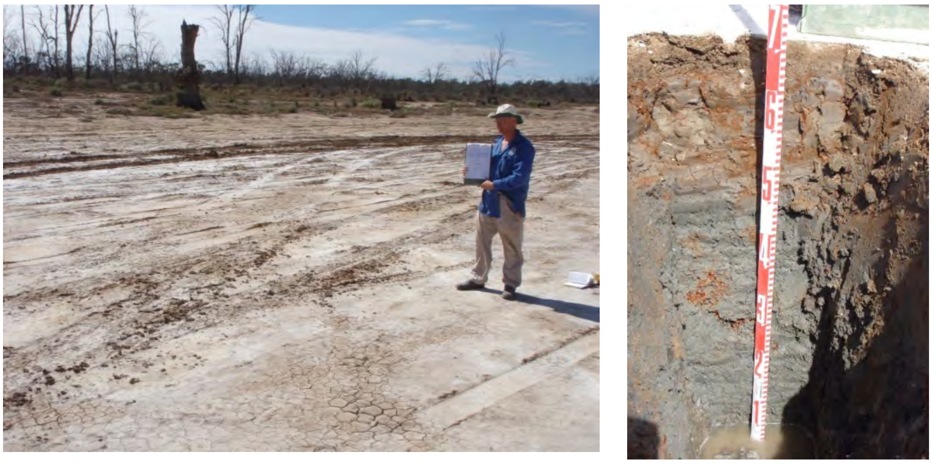


Figure 8-54. Photographs of site 40805_2, showing the bare cracking clay surface, and the soil profile.

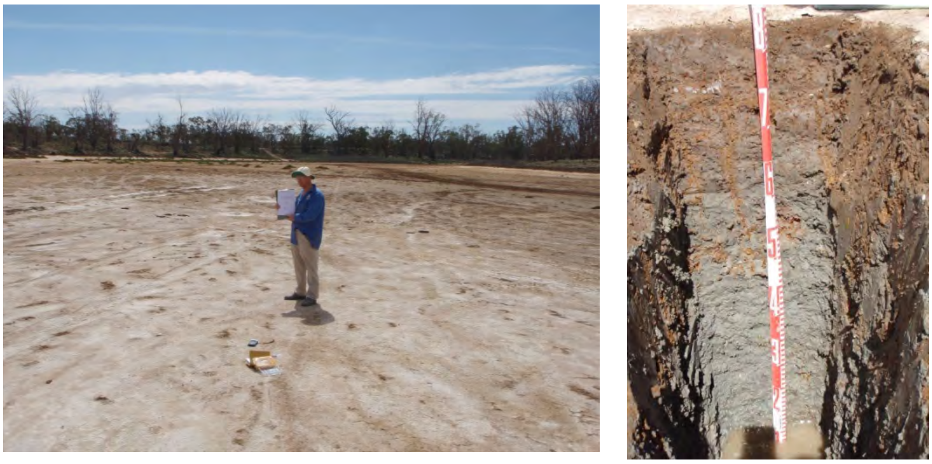


Figure 8-55. Photographs of site 40805_3, showing the bare cracking clay surface, and the soil profile.

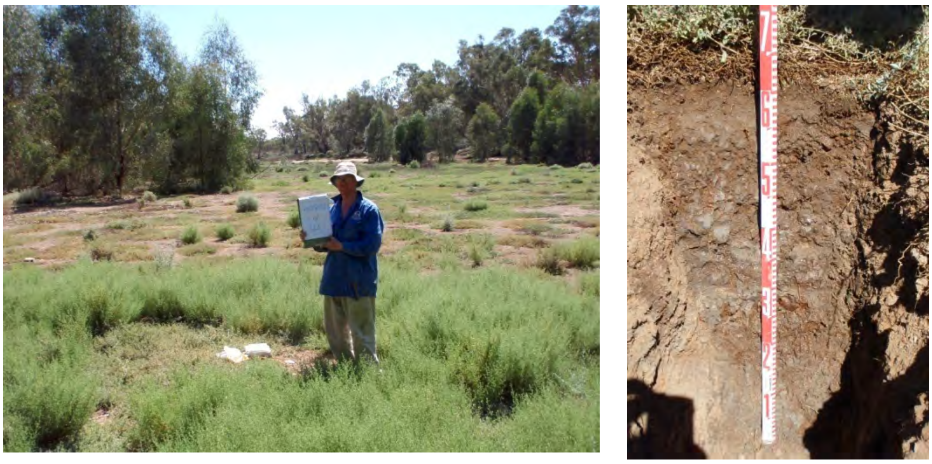


Figure 8-56. Photographs of site 40805_4, showing the location of the site amongst low forbs and groundcovers, and the soil profile.

Figure 8-57. Photographs of site 40805_5, showing the soft, cracking clay surface with minimal vegetation, and the soil profile.

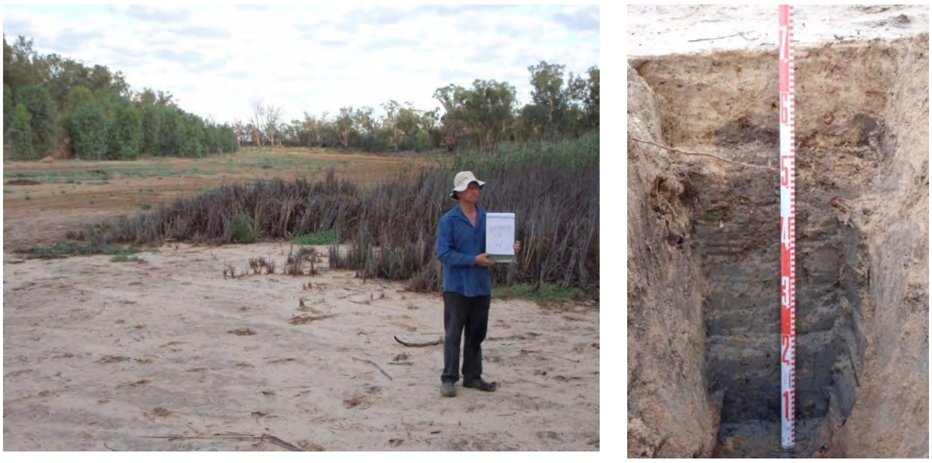


Figure 8-58. Photographs of site 40805_6, showing the sandy, depositional area adjacent to the bank, and the soil profile.

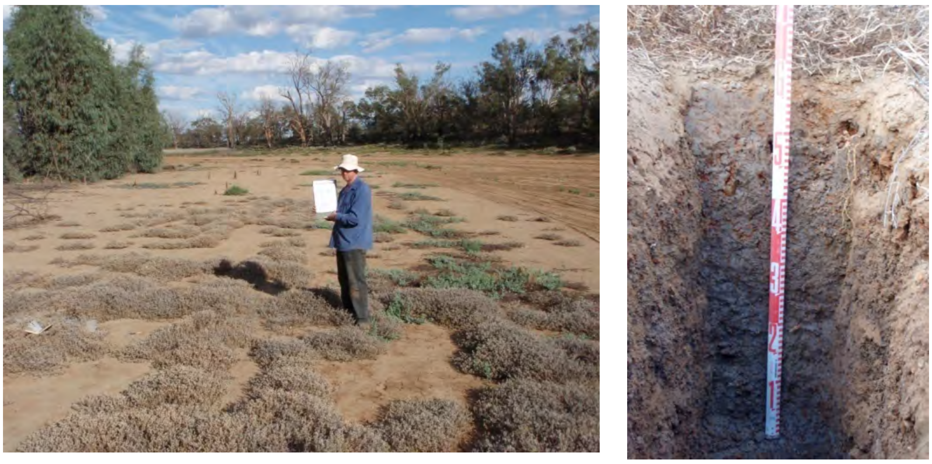


Figure 8-59. Photographs of site 40805_7, showing the dead, low vegetation amongst otherwise bare clay, and the soil profile.

Figure 8-60. Photographs of site 40805_8, showing the bare cracking clay surface from which the sample was taken, and the soil profile. In the background is a pool formed by a bogged vehicle (not sampled).

8.5.3. Laboratory data assessment

Soil pH testing (pH_W, pH_{FOX}, pH_{KCl}, $pH_{INCUBATION}$)

The pH data is provided in Table 8-24 and profiles for all the sites sampled are presented in Figures 8-61 and 8-62. The pH_W values ranged between 3.04 and 7.13. Sulfuric materials (i.e. $pH_W < 4$) were present at two of the eight sites examined (sites 40805_3 and 40805_6). The pH_{FOX} values ranged between 1.91 and 6.15. The pH_{FOX} results indicate that 12 of the 40 soils layers examined may have the potential to acidify to pH < 4 as a result of sulfide oxidation. However, the S_{CR} data shows many of these layers contained no detectable sulfide (i.e. S_{CR} < 0.01% S). One soil material at site 40805_3 (0-5 cm) had a pH_{FOX} < 2.5, although this soil material also contained no detectable sulfide. None of the sulfidic soil materials (i.e. S_{CR} ≥ 0.01% S) acidified to pH < 4 after at least 8 weeks of incubation. Other acidic soil materials were identified at seven of the eight sites examined, indicating acidity in the soil profile at levels where aluminium may mobilise. Some of the other acidic soils acidified to pH < 4 after at least 8 weeks of incubation.

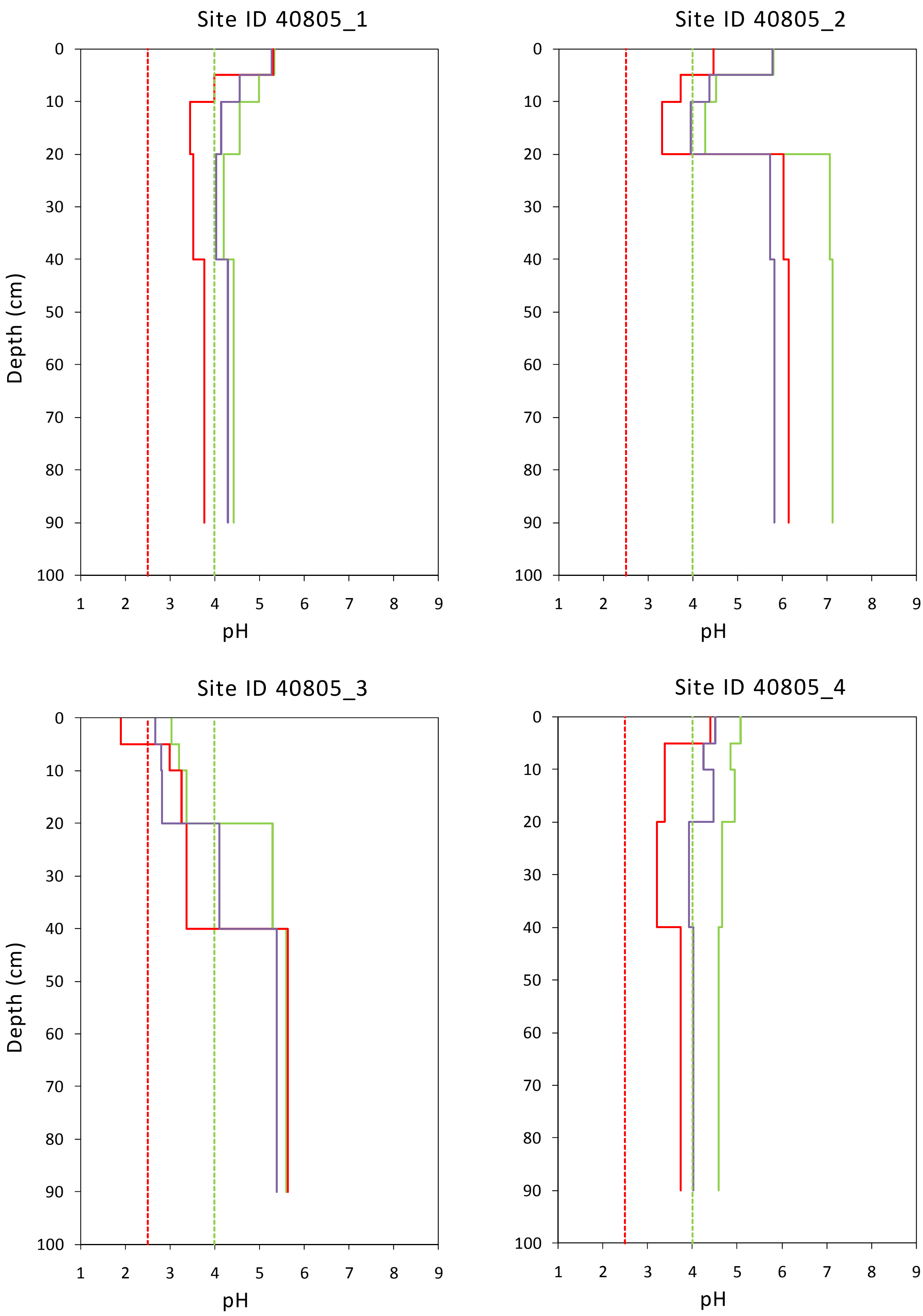


Figure 8-61. Depth profiles of soil pH for Merbein Common-Catfish Wetland (40805_1 – 40805_4), showing soil pH (pH_W as green line), peroxide treated pH (pH_{FOX} as red line) and ageing pH ($pH_{incubation}$ after at least eight weeks as purple line). Critical pH_W and $pH_{incubation}$ value of 4 (green dashed line) and critical pH_{FOX} value of 2.5 (red dashed line).

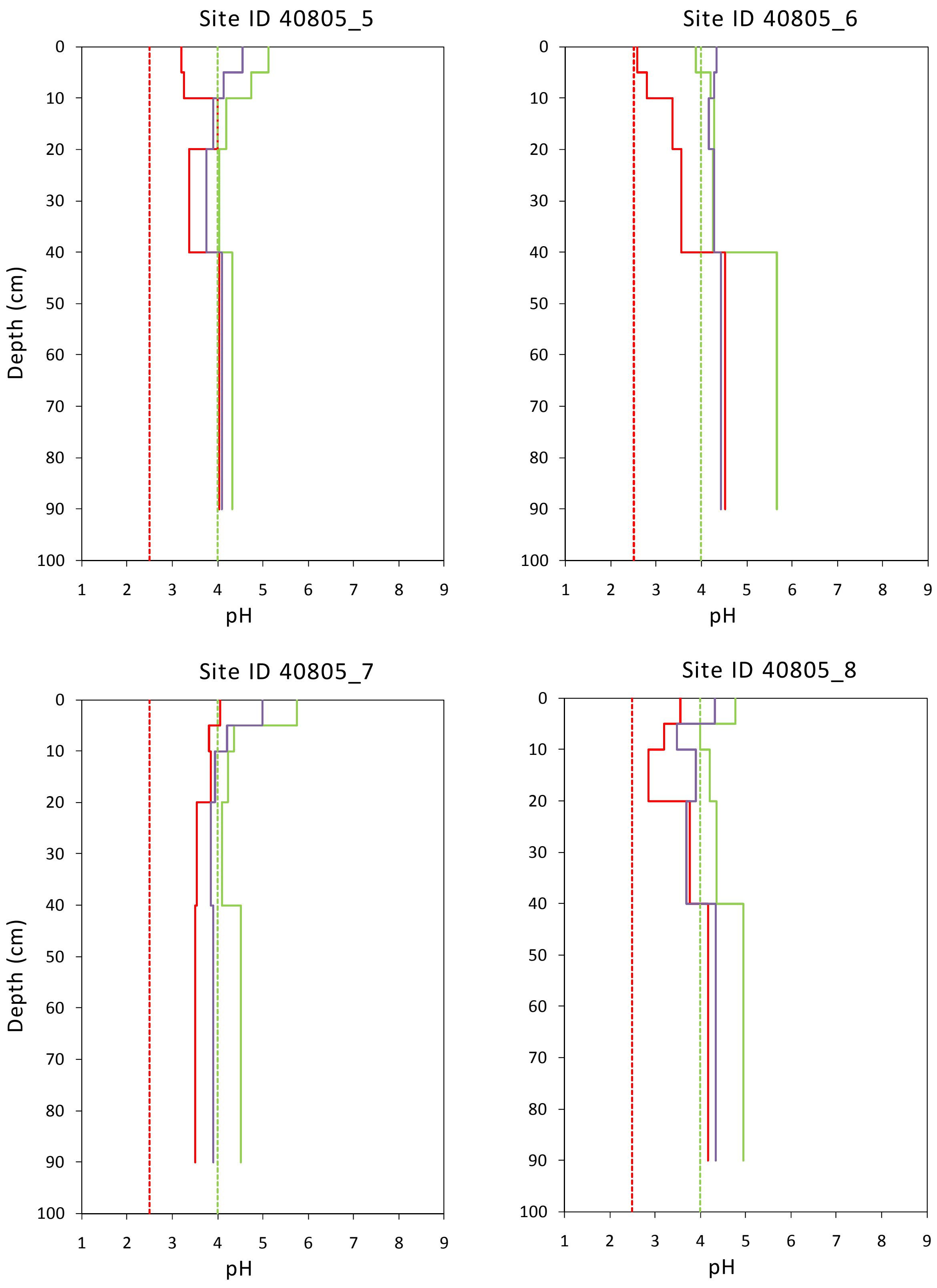


Figure 8-62. Depth profiles of soil pH for Merbein Common-Catfish Wetland (40805_5 – 40805_8), showing soil pH (pH_W as green line), peroxide treated pH (pH_{FOX} as red line) and ageing pH ($pH_{incubation}$ after at least eight weeks as purple line). Critical pH_W and $pH_{incubation}$ value of 4 (green dashed line) and critical pH_{FOX} value of 2.5 (red dashed line).

Acid-base accounting

The acid-base accounting data is provided in Table 8-24 and summarised in Figures 8-63 and 8-64.

Chromium reducible sulfur

Chromium reducible sulfur (S_{CR}) values ranged between < 0.01 and 0.03% S. Sulfidic soil materials (i.e. S_{CR} ≥ 0.01% S) were identified at two sampling sites (sites 40805_2 and 40805_3), with only 3 materials of the 40 samples collected equal to or greater than the sulfidic criterion.

Acid volatile sulfide

Monosulfidic soil materials (i.e. S_{AV} ≥ 0.01% S) were not found within this wetland.

Acid neutralising capacity

The acid neutralising capacity (ANC) was zero for all soil materials.

Titratable actual acidity

The titratable actual acidity (TAA) ranged between 3 and 85 mole H^+/tonne, with the majority of soil layers having a TAA < 40 mole H^+/tonne. An increase in the TAA with depth was often observed.

Retained acidity

Retained acidity was only analysed at sites 40805_3, 40805_4 and 40805_5, as all soil materials at other sites had a pH_{KCl} > 4.5. The retained acidity was only positive in four soil materials, ranging between 2 and 11 mole H^+/tonne.

Net acidity

The net acidity was positive for all samples, ranging between 3 and 87 mole H^+/tonne. The three hypersulfidic soil materials had moderate net acidities ranging between 26 and 36 mole H^+/tonne. The three sulfuric soils also had moderate net acidities, ranging between 69 and 87 mole H^+/tonne.

Water Soluble Sulfate

The water soluble sulfate in the surface soils (i.e. 0-5 cm) ranged between 366 and 18,900 mg/L. All of the surface soil layers examined had a soluble sulfate content exceeding the 100 mg/L trigger value for MBO formation potential.

Water Data

No surface water samples were collected for analysis. The groundwater data measured in the field and in the laboratory are presented in Tables 8-25 and 8-26, respectively. The field pH of the groundwater ranged between 4.6 and 5.8, indicating that the groundwater may have been affected by acidification. The groundwater had sulfate concentrations of between 1,120 and 3,936 mg/L.

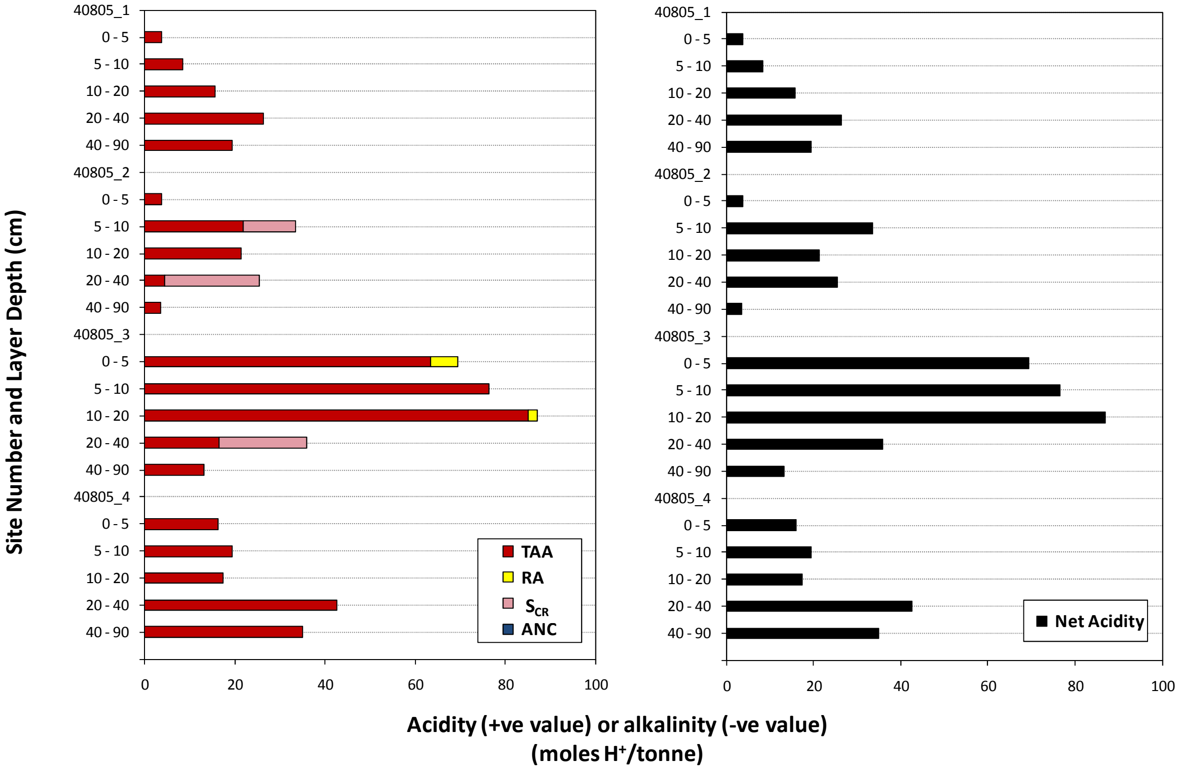


Figure 8-63. Acid-base accounting depth profiles for Merbein Common-Catfish Wetland (40805_1 – 40805_4). Left side shows the components: titratable actual acidity (TAA - red bar), acid generating potential (AGP as S_{CR} -pink bar), acid neutralising capacity (ANC - blue bar), retained acidity (RA - yellow bar), and right side shows net acidity.

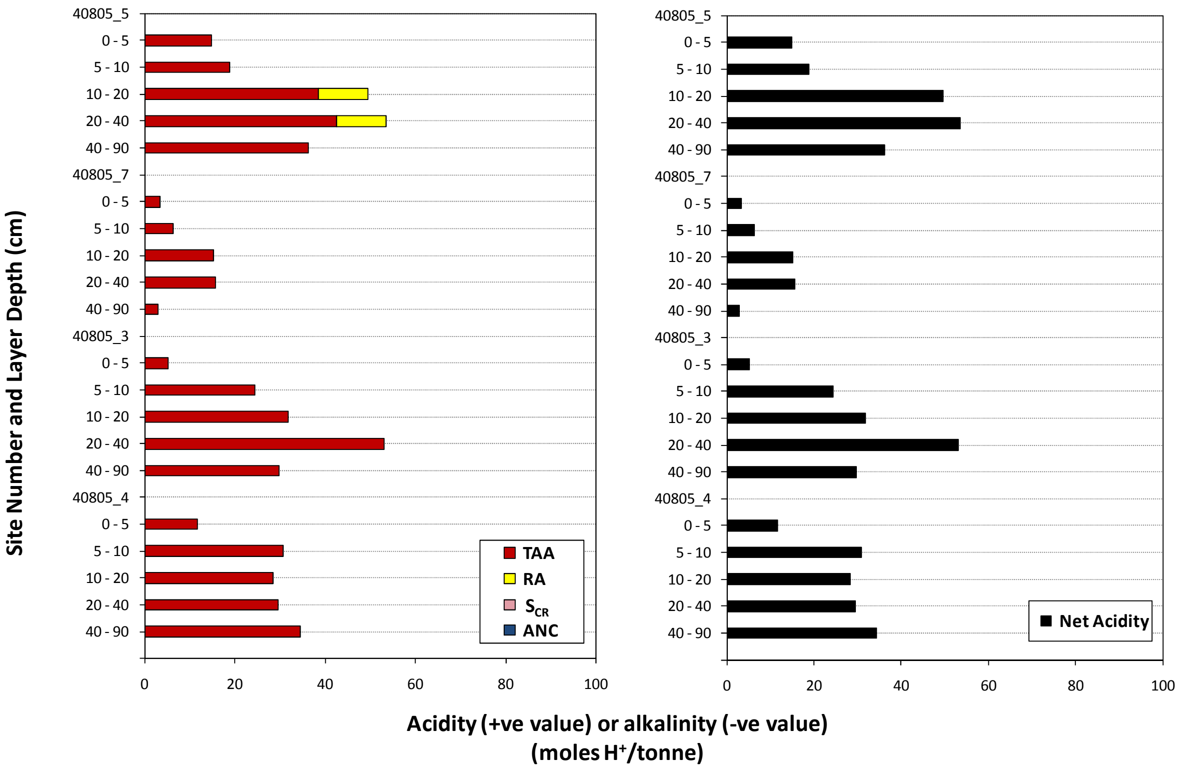


Figure 8-64. Acid-base accounting depth profiles for Merbein Common-Catfish Wetland (40805_5 – 40805_8). Left side shows the components: titratable actual acidity (TAA - red bar), acid generating potential (AGP as S_{CR} -pink bar), acid neutralising capacity (ANC - blue bar), retained acidity (RA - yellow bar), and right side shows net acidity.

8.5.4. Discussion

Acid sulfate soils occurred at two sites in the western area of the Merbein Common-Catfish wetland (i.e. site 40805_2 and 40805_3) and in the surface layer (0-5 cm) at site 40805_6. Sulfuric materials with low to moderate net acidities were observed at two sites (i.e. site 40805_3 and 40805_6). Hypersulfidic soil materials with moderate net acidities were present in two soil profiles. The reduced inorganic sulfur content of the sulfidic soil materials was low (i.e. S_{CR}. ≤ 0.03% S). These results indicate that minimal acidity would be produced upon oxidation of sulfides in these materials. All surficial soil materials contained soluble sulfate in excess of the 100 mg/L trigger value for MBO formation potential. Other acidic soil materials were also observed at an additional five sites, and some of these materials acidified to pH < 4 after at least 8 weeks of incubation.

Based on the priority ranking criteria adopted by the Scientific Reference Panel of the Murray-Darling Basin Acid Sulfate Soil Risk Assessment Project, there were two high priority sites based on the presence of sulfuric material, and two high priority sites based on hypersulfidic material. All eight sampling sites had a high priority ranking for Phase 2 detailed assessment based on MBO formation hazard.

The potential hazards at the wetland-scale posed by acid sulfate soil materials at the Merbein Common-Catfish wetland are:

- Acidification hazard: The data indicate that with some sulfuric soil materials with moderate net acidities, and sulfidic materials where the highest S_{CR} was only 0.03% S, that the degree of acidification hazard is moderate.

- Deoxygenation hazard: The soluble sulfate contents of surface soil materials at all eight sites were over the trigger value for MBO formation indicating the possible development of an appreciable deoxygenation hazard at those locations after prolonged wet conditions.

- Metal mobilisation: The moderate acidification hazard indicates that soil acidification may increase the solubility of metals. The potential for MBO formation identified in this wetland may also result in an appreciable metal release hazard depending on factors such as the potential for MBO formation and the metal loading in this wetland. Soil acidity may be sufficient for mobilisation of aluminium at all sites.

Summary of key findings for the Merbein Common-Catfish Wetland:

Soil materials:	Sulfuric materials were observed 2 sites. Sulfidic soil materials identified included: hypersulfidic (2 sites). Other acidic soil materials observed at an additional 5 sites. Low to moderate net acidities dominant within wetland.
Acid sulfate soil identification:	• Sulfuric cracking clay, sulfuric and hypersulfidic soils identified. • Cracking clay soil and hydrosols also identified.
Hazard assessment	• Acidification hazard - moderate level of concern • Deoxygenation hazard - high level of concern • Metal mobilisation hazard – high level of concern

Table 8-24. Laboratory analytical data for acid sulfate soil assessment of Merbein Common-Catfish Wetland (Wetland ID 40805).
(red printed values indicates data results of potential concern)

Site and Layer ID.	Depth Range (cm)	Soil Texture	pH water	pH peroxide	pH incubation	Sulfate (mg SO_4 / kg)	pH KCl	Titratable Actual Acidity (mole H^+/t)	Chromium Reducible Sulfur (%S_{CR})	Retained Acidity (mole H^+/t)	Acid Neutralising Capacity (%$CaCO_3$)	Net Acidity (mole H^+/t)	Acid Volatile Sulfide (%S_{AV})	Acid Sulfate Soil Material Classification
1.1	0-5	medium	5.33	5.31	5.28	10290	6.20	3.87	<0.01	0.00	0.00	3.87	<0.01	other acidic
1.2	5-10	fine	4.99	4.00	4.55		5.54	8.40	<0.01	0.00	0.00	8.40	<0.01	other acidic
1.3	10-20	fine	4.55	3.44	4.14		4.88	15.66	<0.01	0.00	0.00	15.66	<0.01	other acidic
1.4	20-40	fine	4.20	3.52	4.04		4.56	26.29	<0.01	0.00	0.00	26.29	<0.01	other acidic
1.5	40-90	fine	4.43	3.76	4.30		4.81	19.39	<0.01	0.00	0.00	19.39	<0.01	other acidic
2.1	0-5		5.80	4.47	5.78	18900	6.21	3.84	<0.01	0.00	0.00	3.84	<0.01	other soil materials
2.2	5-10	fine	4.53	3.74	4.37		4.84	21.83	0.02	0.00	0.00	33.50	<0.01	hypersulfidic[#]
2.3	10-20	fine	4.27	3.32	3.95		4.77	21.41	<0.01	0.00	0.00	21.41	<0.01	other acidic
2.4	20-40	fine	7.06	6.02	5.72*		6.19	4.37	0.03	0.00	0.00	25.50	<0.01	hypersulfidic[#]
2.5	40-90	fine	7.13	6.15	5.83		6.26	3.65	<0.01	0.00	0.00	3.65	<0.01	other soil materials
3.1	0-5		3.04	1.91	2.68	5940	3.88	63.38	<0.01	6.00	0.00	69.38	<0.01	sulfuric
3.2	5-10	fine	3.20	3.00	2.81		3.83	76.43	<0.01	0.00	0.00	76.43	<0.01	sulfuric
3.3	10-20	fine	3.38	3.25	2.82		3.80	85.01	<0.01	2.00	0.00	87.01	<0.01	sulfuric
3.4	20-40	fine	5.29	3.38	4.10		5.19	16.44	0.03	0.00	0.00	35.95	<0.01	hypersulfidic[#]
3.5	40-90	fine	5.59	5.64	5.38		5.19	13.25	<0.01	0.00	0.00	13.25	<0.01	other soil materials
4.1	0-5	medium	5.07	4.40	4.52	366	5.25	16.19	<0.01	0.00	0.00	16.19	<0.01	other acidic
4.2	5-10	medium	4.85	3.38	4.24		5.20	19.44	<0.01	0.00	0.00	19.44	<0.01	other acidic
4.3	10-20	fine	4.94	3.39	4.47		4.80	17.49	<0.01	0.00	0.00	17.49	<0.01	other acidic
4.4	20-40	fine	4.66	3.21	3.93		4.41	42.56	<0.01	0.00	0.00	42.56	<0.01	other acidic
4.5	40-90		4.58	3.73	4.03		4.42	35.00	<0.01	0.00	0.00	35.00	<0.01	other acidic
5.1	0-5		5.12	3.21	4.55	7950	5.31	14.87	<0.01	0.00	0.00	14.87	<0.01	other acidic
5.2	5-10	fine	4.75	3.25	4.13		4.96	18.78	<0.01	0.00	0.00	18.78	<0.01	other acidic
5.3	10-20	fine	4.19	4.00	3.90		4.45	38.53	<0.01	11.00	0.00	49.53	<0.01	other acidic
5.4	20-40	fine	4.04	3.37	3.75		4.34	42.55	<0.01	11.00	0.00	53.55	<0.01	other acidic
5.5	40-90	fine	4.33	4.04	4.09		4.35	36.22	<0.01	0.00	0.00	36.22	<0.01	other acidic
6.1	0-5	coarse	3.87	2.59	4.33	8235	5.74	3.37	<0.01	0.00	0.00	3.37	<0.01	sulfuric
6.2	5-10	coarse	4.20	2.80	4.28		5.74	6.39	<0.01	0.00	0.00	6.39	<0.01	other acidic
6.3	10-20	fine	4.28	3.36	4.17		5.07	15.15	<0.01	0.00	0.00	15.15	<0.01	other acidic
6.4	20-40	fine	4.25	3.55	4.27		4.93	15.67	<0.01	0.00	0.00	15.67	<0.01	other acidic
6.5	40-90	medium	5.67	4.52	4.43*		5.67	2.87	<0.01	0.00	0.00	2.87	<0.01	other acidic

***** Indicates that a stable pH has not yet been reached for this sample (after 16 weeks). [#] Classified as hypersulfidic based on positive net acidity.

Table 8-24 (continued). Laboratory analytical data for acid sulfate soil assessment of Merbein Common-Catfish Wetland (Wetland ID 40805).
(red printed values indicates data results of potential concern)

Site and Layer ID.	Depth Range (cm)	Soil Texture	pH water	pH peroxide	pH incubation	Sulfate (mg SO_4 / kg)	pH KCl	Titratable Actual Acidity (mole H^+/t)	Chromium Reducible Sulfur (%S_{CR})	Retained Acidity (mole H^+/t)	Acid Neutralising Capacity (%$CaCO_3$)	Net Acidity (mole H^+/t)	Acid Volatile Sulfide (%S_{AV})	Acid Sulfate Soil Material Classification
7.1	0-5	fine	5.75	4.06	4.98*	7035	6.02	5.13	<0.01	0.00	0.00	5.13	<0.01	other acidic
7.2	5-10	fine	4.36	3.81	4.21		4.91	24.50	<0.01	0.00	0.00	24.50	<0.01	other acidic
7.3	10-20	fine	4.22	3.84	3.94		4.54	31.86	<0.01	0.00	0.00	31.86	<0.01	other acidic
7.4	20-40	fine	4.09	3.54	3.85		4.56	52.99	<0.01	0.00	0.00	52.99	<0.01	other acidic
7.5	40-90	fine	4.51	3.51	3.91		4.59	29.71	<0.01	0.00	0.00	29.71	<0.01	other acidic
8.1	0-5	medium	4.77	3.55	4.32	11520	5.49	11.75	<0.01	0.00	0.00	11.75	<0.01	other acidic
8.2	5-10	medium	4.00	3.19	3.49		4.76	30.76	<0.01	0.00	0.00	30.76	<0.01	other acidic
8.3	10-20	medium	4.21	2.86	3.91		4.85	28.33	<0.01	0.00	0.00	28.33	<0.01	other acidic
8.4	20-40	fine	4.35	3.77	3.69		4.82	29.48	<0.01	0.00	0.00	29.48	<0.01	other acidic
8.5	40-90	fine	4.95	4.16	4.34		4.80	34.44	<0.01	0.00	0.00	34.44	<0.01	other acidic

***** Indicates that a stable pH has not yet been reached for this sample (after 16 weeks).

Table 8-25. Field hydrochemistry data for acid sulfate soil assessment of Merbein Common-Catfish Wetland (Wetland ID 40805).

Site and Layer ID.	Temperature (Deg C)	Specific Electrical Conductivity (µS/cm)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	pH	ORP	Redox potential (mV))	Turbidity (NTU)	HCO_3 (mg/L)	Comment
*Lowland River**		*125-2200*	*85-110*		*6.5-8.0*			*6-50*		
*Freshwater Lakes**		*20-30*	*90-110*		*6.5-8.0*			*1-20*		
40805_2 (PW)	26.2	36600		0.61	5.82		48	n.a.	75	Turbidity not measured
40805_3 (PW)	27.5	23750		1.21	4.57		36	n.a.	11	Turbidity not measured
40805_8 (PW)	24	17000		1.12	5.25		9	n.a.	150	Turbidity not measured

* ANZECC water quality guidelines for lowland rivers and freshwater lakes/reservoirs in South-east Australia are provided for relevant parameters (there are currently no trigger values defined for 'Wetlands') (ANZECC/ARMCANZ, 2000). Surface water values outside the ranges defined in the ANZECC guidelines are indicated with red text. (SW) and (PW) indicate whether the sample was taken from surface water or pore-water, respectively.

Table 8-26. Laboratory hydrochemistry data for acid sulfate soil assessment of Merbein Common-Catfish Wetland (Wetland ID 40805).

Parameter	units	ANZECC Guidelines	Site 2 (PW)	Site 3 (PW)	Site 8 (PW)
depth	cm				
Na	mg l^{-1}		10,128	10,009	1,556
K	mg l^{-1}		31	66	26
Ca	mg l^{-1}		590	831	1,141
Mg	mg l^{-1}		1,416	1,468	636
Si	mg l^{-1}		23.1	23.8	26.8
Br	mg l^{-1}		41.37	30.22	13.78
Cl	mg l^{-1}		12,617	9,352	4,511
NO_3	mg l^{-1}	0.7	0.335	0.041	0.095
NH_4-N	mg l^{-1}	0.01	3.689	14.137	21.387
PO_4-P[E]	mg l^{-1}	0.005	0.037	0.02	0.034
SO_4	mg l^{-1}		3,936	3,618	1,120
Ag	µg l^{-1}	0.05	<1	<1	<1
Al[A]	µg l^{-1}	55	8	150	<1
As[B]	µg l^{-1}	13	20	<10	<10
Cd	µg l^{-1}	0.2	2	<1	1
Co	µg l^{-1}	2.8	121	277	382
Cr[C]	µg l^{-1}	1	<5	<5	<5
Cu[H]	µg l^{-1}	1.4	9	<5	<5
Fe	µg l^{-1}	300	176,941	442,686	771,219
Mn	µg l^{-1}	1700	16,903	54,121	80,666
Ni[H]	µg l^{-1}	11	93	251	275
Pb[H]	µg l^{-1}	3.4	1	2	<1
Se	µg l^{-1}	11	n/a	n/a	n/a
Zn[H]	µg l^{-1}	8	89	51	114
DOC	mg l^{-1}		n/a	n/a	n/a

Notes.

The ANZECC guideline values for toxicants refer to the Ecosystem Protection – Freshwater Guideline for protection of 95% of biota in 'slightly-moderately disturbed' systems, as outlined in the Australian Water Quality Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000). For the nutrients NH_4 and PO_4, guideline values are provided for Freshwater Lakes and Reservoirs. Surface water values outside the ranges defined in the ANZECC guidelines are indicated with red text. (SW) and (PW) indicate whether the sample was taken from surface water or pit-water (groundwater that entered an excavated pit), respectively.

A *Guideline is for Aluminium in freshwater where pH > 6.5.*
B *Guideline assumes As in solution as Arsenic (AsV).*
C *Guideline is for Chromium is applicable to Chromium (CrVI) only.*
E *Guideline is for filterable reactive phosphorous (FRP).*
H *Hardness affected (refer to Guidelines).*

Table 8-27. Site description data for acid sulfate soil assessment of Merbein Common-Catfish Wetland (Wetland ID 40805).

Site No.	Depth to Water Table (cm)	Surface Condition	Earth Cover (Vegetation)	Location Notes	Rationale for site selection	ASS Soil Classification	Comments
1	Beyond sampling depth	Dry	Sparse succulent shrubs.	Most SW reach of billabong. Centre of channel.	Elevated site within channel.	Other acidic	Salt inflorescences.
2	55	Dry	Bare.	Mid SW reach of Billabong. Centre of channel.	Moderately elevated site within channel.	Hypersulfidic	
3	70	Dry	Bare.	Junction of two SW reaches. Centre of channel.	Moderately elevated site, at junction of two reaches.	Sulfuric	
4	Beyond sampling depth	Dry	Dense groundcovers and perennials.	Most eastern end of billabong. Near edge of wooded zone.	Most easterly point of inundated area.	Other acidic	
5	Beyond sampling depth	Dry	Sparse large succulents.	Eastern end of billabong. In wooded zone.	Elevated site in wooded zone.	Other acidic	
6	Beyond sampling depth	Moist	Sparse leaf litter.	Northern bank of billabong. Depositional area adjacent to dead reeds.	Moist site near reed bed zone of bank. Elevated site.	Sulfuric	
7	Beyond sampling depth	Dry	Sparse but dead groundcovers.	Central section of billabong. In channel along southern bank.	Zone of dead groundcover.	Other acidic	Slight mounding associated with groundcover.
8	42	Dry	Bare.	Northern margin of billabong. In channel.	Lowest point of billabong.	Other acidic	

Table 8-28. Profile description data for acid sulfate soil assessment of Merbein Common-Catfish Wetland (Wetland ID 40805).

Site and Sample No.	Horizon Depth Range (cm)	Soil Colour - moist	Texture Class	Moisture State	Redoximorphic Features Abundance	Redoximorphic Features - Kind	Redoximorphic Features - Colour	Structure - Type	Structure - Grade	pH (field measurement)	Comments (odour, fragments, minerals, plant material, inclusions, other)
1.1	0-5	10YR 5/2	LC	D	1	M	10YR 6/6	SB	S	5.22	Salt.
1.2	5-10	10YR 5/3	MHC	T	1	M	10YR 6/8	SB	S	4.56	Salt.
1.3	10-20	10YR 5/3	MHC	T	2	M	10YR 6/8	PL	S	4.51	
1.4	20-40	2.5YR 5/2	MC	T	2	M	5YR 5/6	SB	S	3.59	
1.5	40-90	2.5YR 5/2	MC	M	2	M	5YR 5/6	SB	S	3.95	
2.1	0-5	2.5Y 5/3	MC	T	1	M	7.5YR 5/6	SB	S	5.61	Salt.
2.2	5-10	2.5Y 4/2	MC	T	3	M	2.5YR 4/8	SB	S	4.15	
2.3	10-20	2.5Y 4/2	MC	T	3	M	2.5YR 4/8	SB	S	4.03	
2.4	20-40	5Y 4/1	HC	M	1	M	2.5YR 4/8	SB	S	5.50	
2.5	40-90	5Y 4/1	HC	M	1	M	2.5YR 4/8	SB	S	6.34	
3.1	0-5	2.5Y 5/3	LC	T	1	M	5YR 5/8	SB	S	2.53	
3.2	5-10	2.5Y 4/2	MC	T	2	M	5YR 5/8	SB	S	2.84	
3.3	10-20	5Y 4/1	MC	T	3	M	5YR 5/8	SB	S	2.85	
3.4	20-40	5Y 4/1	MC	M	2	M	2.5YR 3/6	SB	S	3.76	
3.5	40-90	5Y 5/1	MC	M	1	M	10YR 5/8	SB	S	5.49	
4.1	0-5	2.5Y 4/4	LC	D	1	M	5YR 4/6	SB	M	5.97	
4.2	5-10	2.5Y 4/4	LC	D	2	M	5YR 4/6	SB	S	5.39	
4.3	10-20	2.5Y 4/1	MC	D	3	M	5YR 4/6	SB	S	4.76	
4.4	20-40	2.5Y 4/1	MC	D	3	M	5YR 4/6	SB	S	4.20	
4.5	40-90	2.5Y 5/1	MHC	D	1	M	5YR 4/6	SB	S	4.11	

Table 8-28 (continued). Profile description data for acid sulfate soil assessment of Merbein Common-Catfish Wetland (Wetland ID 40805).

Site and Sample No.	Horizon Depth Range (cm)	Soil Colour - moist	Texture Class	Moisture State	Redoximorphic Features Abundance	Redoximorphic Features - Kind	Redoximorphic Features - Colour	Structure - Type	Structure - Grade	pH (field measurement)	Comments (odour, fragments, minerals, plant material, inclusions, other)
5.1	0-5	5Y 4/2	FSMC	D	4	M	7.5YR 5/6	SB	S	4.27	Salt.
5.2	5-10	5Y 4/2	FSMC	T	3	M	7.5YR 5/6	SB	S	4.08	
5.3	10-20	5Y 4/2	FSMC	T	2	M	7.5YR 4/6	SB	S	3.81	
5.4	20-40	5Y 4/1	MC	T	2	M	7.5YR 4/6	SB	S	3.92	
5.5	40-90	5Y 4/1	MC	T	2	M	7.5YR 4/6	SB	S	3.88	
6.1	0-5	2.5Y 6/2	LFS	T	1	M	10YR 4/4	n/a	G	4.33	Secondary mottle black.
6.2	5-10	2.5Y 5/3	CFS	T	1	M	10YR 4/4	n/a	G	4.22	Secondary mottle black.
6.3	10-20	2.5Y 4/2	FSLMC	T	2	M	10YR 4/4	SB	S	4.06	
6.4	20-40	5Y 4/1	FSLMC	T	2	M	10YR 4/4	SB	S	3.91	
6.5	40-90	5Y 4/1	FSLC	T	2	M	10YR 3/2	SB	S	5.97	Secondary mottle black.
7.1	0-5	2.5Y 4/2	MHC	D	4	M	10YR 5/6	SB	M	4.91	
7.2	5-10	2.5Y 4/1	MHC	T	4	M	5YR 4/6	SB	S	4.10	
7.3	10-20	5Y 5/1	MHC	T	3	M	5YR 4/6	SB	S	3.95	
7.4	20-40	5Y 5/1	FSMHC	T	3	M	5YR 4/6	SB	S	3.73	
7.5	40-90	5Y 5/1	MHC	T	2	M	7.5YR 4/6	SB	S	3.75	
8.1	0-5	5Y 4/2	LC	T	2	M	10YR 5/6	SB	M	4.57	
8.2	5-10	5Y 4/1	FSLC	M	2	M	7.5YR 5/8	SB	S	3.77	
8.3	10-20	5Y 4/1	FSLC	M	2	M	7.5YR 5/8	SB	S	3.90	Secondary mottle black.
8.4	20-40	5Y 4/1	MHC	M	2	M	2.5YR 3/6	SB	S	3.93	
8.5	40-90	5Y 4/1	MHC	W	1	M	2.5YR 3/6	SB	S	4.92	

8.6. Outlet Creek (Wetland ID 40856)

8.6.1. Location and setting description

Outlet Creek is situated approximately 22 km south-southeast of Mildura, on the southern side of the River Murray, on the floodplain. It consists of a 1.5 km stretch of Outlet Creek immediately downstream of Karadoc Swamp. The wetland reaches only 120 m at its widest point, and the total wetland area is 13 hectares. The channel morphology is essentially a chain of ponds, which all contained surface water at the time of sampling. The southern half (south of Johns Road) has had some remediation work undertaken, including stock exclusion fencing and vegetation plantings. To the north of Johns Road the wetland lacks groundcover and understorey vegetation, and the soil surface has visible salt efflorescences and is highly eroded. Many of the mature trees in the wetland were apparently dead or dying.

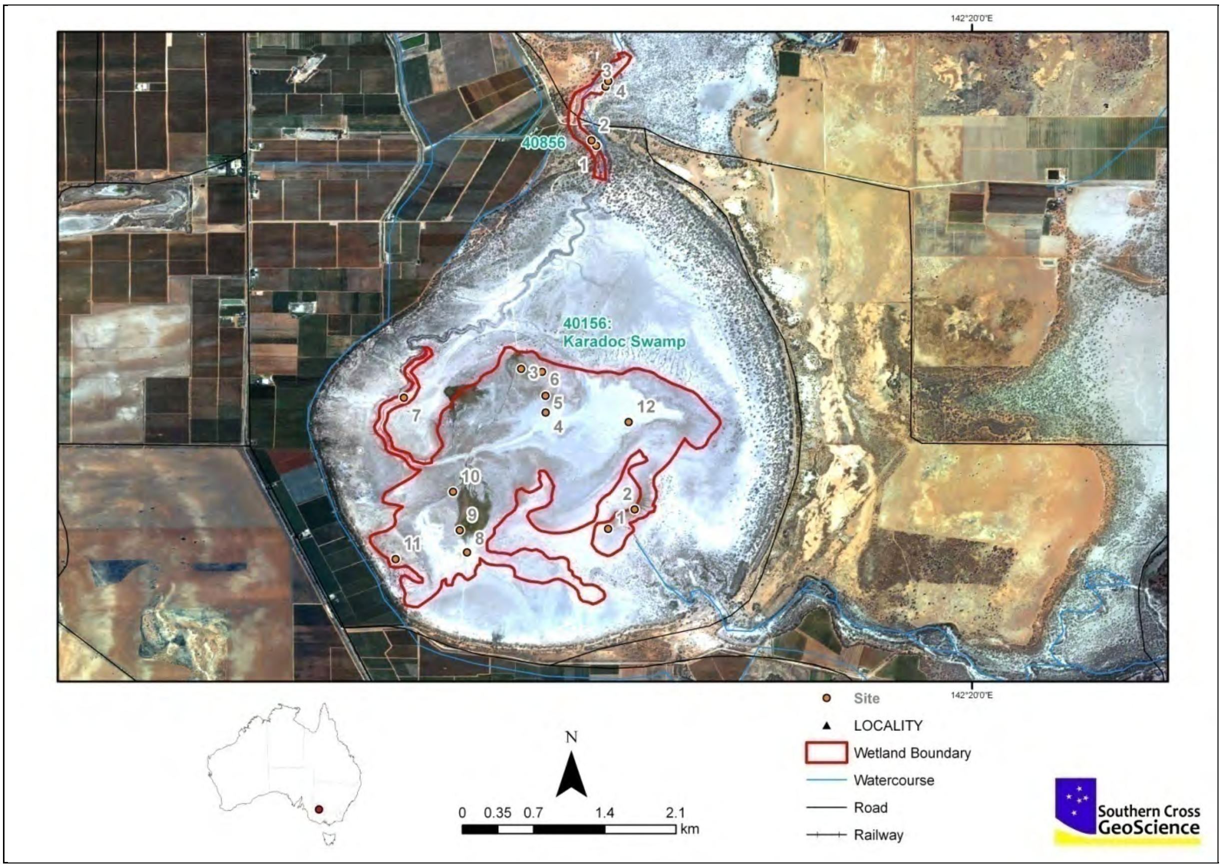


Figure 8-65. Outlet Creek and sample site locations.

8.6.2. Soil profile description and distribution

Four sites were described and sampled. The soil subtype and general location description of each site are presented in Table 8-29. Sites were distributed throughout the wetland based on different surface features and locations in the wetland, and a transect approach was not used.

The profiles 40856_1 (Figure 8-67) and 40856_2 (Figure 8-68) were situated in the southern half of the wetland, the former on a raised, vegetated point bar of the creek channel, and the latter in the bed of a pond with surface water. The profiles 40856_3 (Figure 8-69) and 40856_4 (Figure 8-70) were situated in the northern half of the wetland, the former on the bank adjacent to the largest pond in the wetland, and the latter in the centre of that pond.

Additional site and profile description data are presented in Tables 8-33 and 8-34, respectively.

Table 8-29. Soil identification, subtype and general location description for Outlet Creek.

Site ID	Easting UTM Zone 54H	Northing UTM Zone 54H	Acid sulfate soil subtype class	General location description
40856_1	619567	6197764	Hydrosol	Point bar in southern channel. Centre of vegetated section.
40856_2	619530	6197815	Hypermonosulfidic Subaqueous Soil	Centre of pond in southern channel. Surface cracking evident on bed indicating drying prior to recent inundation.
40856_3	619650	6198341	Hypomonosulfidic Soil	Eroded bank of pond in northern channel. Adjacent to pond.
40856_4	619674	6198395	Hypomonosulfidic Subaqueous Soil	Pond in northern channel. Centre of pond.

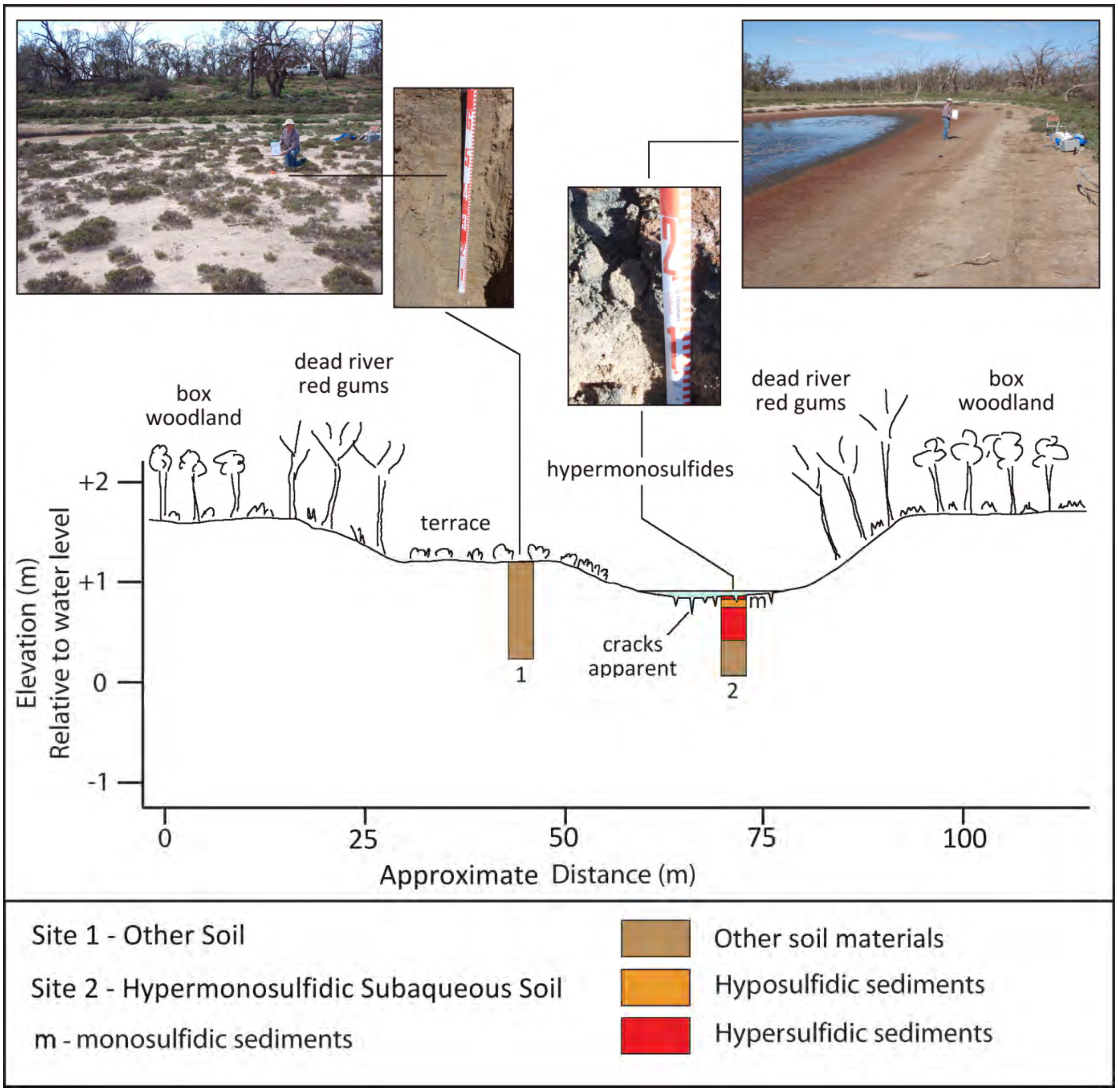


Figure 8-66. Conceptual cross section diagram showing the toposequence relationship of the Outlet Creek sediments/soil materials throughout the wetland.

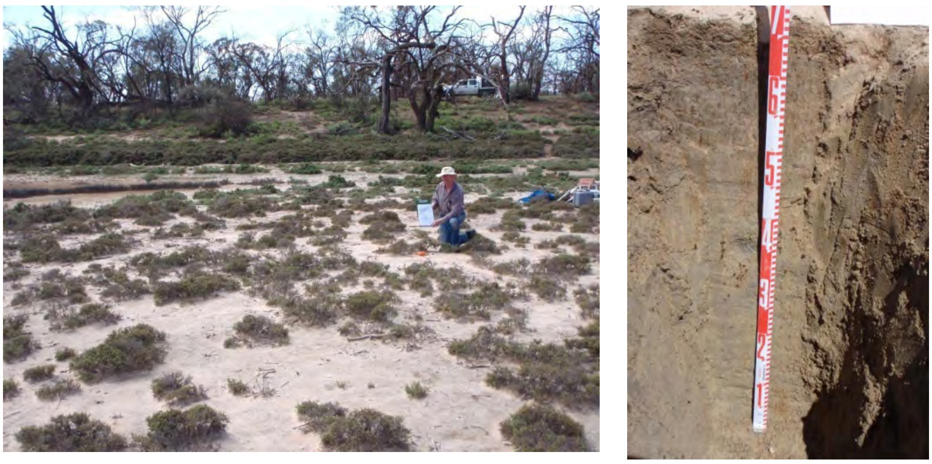


Figure 8-67. Photographs of site 40856_1, showing the location of the site amongst low succulent shrubs on a raised, bare surface, and the soil profile.

Figure 8-68. Photographs of site 40856_2, showing the pond from which the sample was taken, and the soil profile.

Figure 8-69. Photographs of site 40856_3, showing the bare banks of the pond from which the sample was taken, and the soil profile.

Figure 8-70. Photographs of site 40856_4, showing the pond from which the sample was taken, and the soil core.

8.6.3. Laboratory data assessment

Soil pH testing (pH_W, pH_{FOX}, pH_{KCl}, $pH_{INCUBATION}$)

The pH data is provided in Table 8-30 and profiles for all the sites sampled are presented in Figure 8-71. The pH_W values ranged between 4.79 and 7.16. Sulfuric materials (i.e. pH_W < 4) were not present. The pH_{FOX} values ranged between 3.89 and 7.70. The pH_{FOX} results indicate that one of the 20 surface soils examined may have the potential to acidify to pH < 4 as a result of sulfide oxidation. This sulfidic soil material (i.e. 40856_2 (20-40 cm)) also acidified to pH < 4 after at least 8 weeks of incubation; one other sulfidic soil also acidified to pH < 4 (i.e. 40856_2 (10-20 cm)). In addition, one other acidic soil material was identified, indicating acidity in the soil profile at levels where aluminium may mobilise.

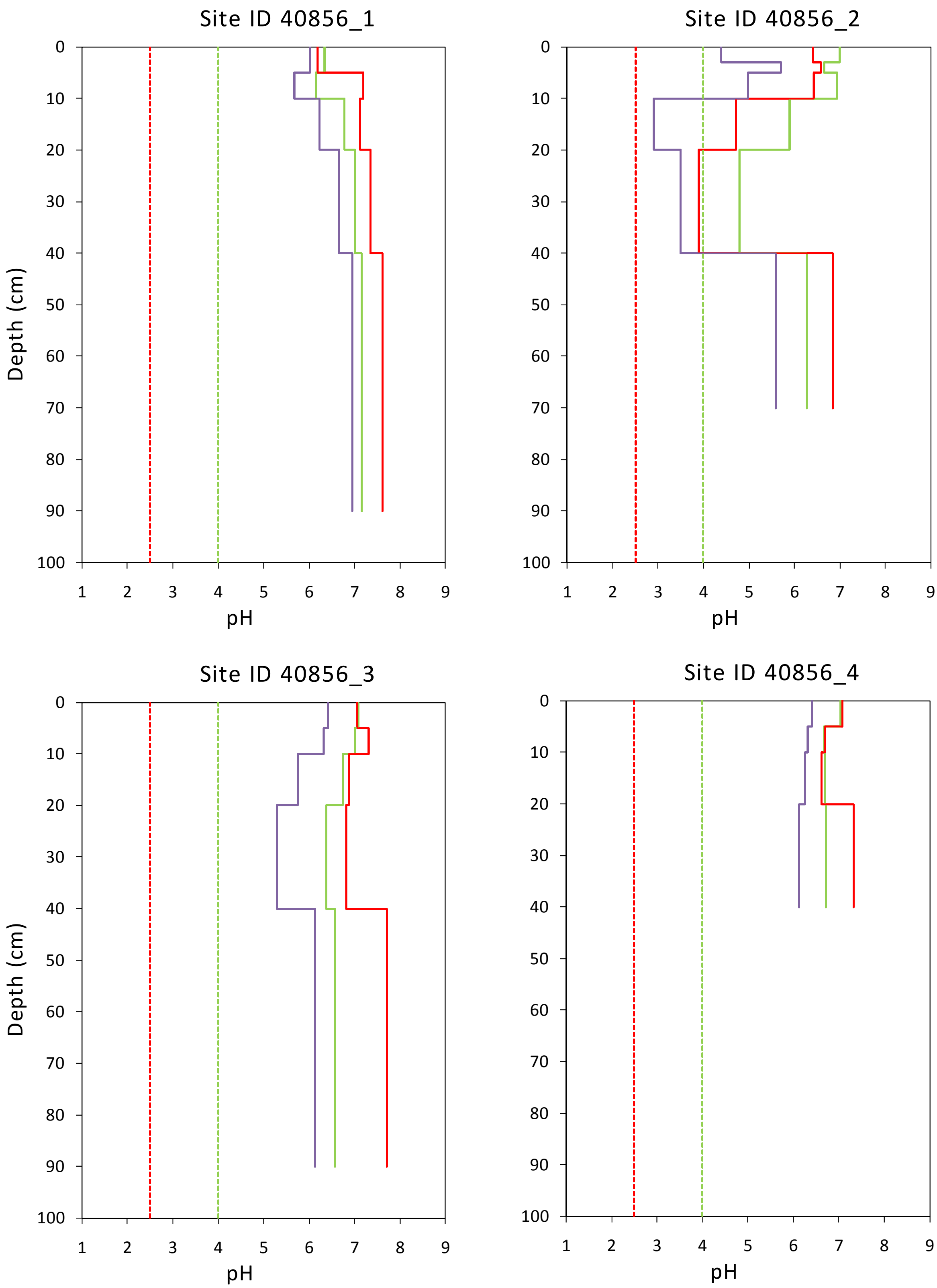


Figure 8-71. Depth profiles of soil pH for Outlet Creek (40856_1 – 40856_4), showing soil pH (pH_W as green line), peroxide treated pH (pH_{FOX} as red line) and ageing pH ($pH_{incubation}$ after at least eight weeks as purple line). Critical pH_W and $pH_{incubation}$ value of 4 (green dashed line) and critical pH_{FOX} value of 2.5 (red dashed line).

Acid-base accounting

The acid-base accounting data is provided in Table 8-30 and summarised in Figure 8-72.

Chromium reducible sulfur

Chromium reducible sulfur (S_{CR}) values ranged between < 0.01 and 0.44% S. Sulfidic soil materials (i.e. S_{CR} ≥ 0.01% S) were identified at three of the four sampling sites (sites 40856_2 – 40856_4), with 12 materials of the 20 samples collected equal to or greater than the sulfidic criterion.

Acid volatile sulfide

The acid volatile sulfide (S_{AV}) values ranged between < 0.01 and 0.31% S. Monosulfidic soil materials (i.e. S_{AV} ≥ 0.01% S) were found three of the four sampling sites (sites 40856_2 – 40856_4), with 7 materials of the 20 samples collected equal to or greater than the monosulfidic criterion.

Acid neutralising capacity

The acid neutralising capacity (ANC) ranged between 0.19 and 4.59% $CaCO_3$.

Titratable actual acidity

The titratable actual acidity (TAA) ranged between zero and 11 mole H^+/tonne, with all (except one) soil layers having no TAA.

Retained acidity

There was no retained acidity at any of the sites as all samples had a pH_{KCl} > 4.5.

Net acidity

Net acidity ranged between -561 and 63 mole H^+/tonne, with the majority of samples having negative net acidities. The three hypersulfidic soil materials had low to moderate net acidities of between -182 and 63 mole H^+/tonne.

Water Soluble Sulfate

The water soluble sulfate in the surface soils (i.e. 0-5 cm) ranged between 5,700 and 21,900 mg/L. All of the surface soil layers examined had a soluble sulfate content exceeding the 100 mg/L trigger value for MBO formation potential.

Water Data

The surface water data measured in the field and laboratory are presented in Tables 8-31 and 8-32, respectively. The groundwater data measured in the field are presented in Tables 8-31. The field pH of the two surface waters collected was 8.3 and 8.4, with both sites exceeding the most relevant ANZECC/ARMCANZ (2000) trigger value for aquatic ecosystems of 8.0. The water data indicates that the surface water has not been affected by acidification. The surface water sulfate concentrations were 1,671 and 4,755 mg/L. Some metal (i.e. Co, Cu, Fe, Ni, Zn) and nutrient (PO_4, NH_4) concentrations were found to exceed the most relevant ANZECC/ARMCANZ (2000) guideline value. The field pH of the single groundwater was 6.7, indicating that the groundwater has not been affected by acidification. A groundwater sample was not collected for analysis due to the proximity of the water body.

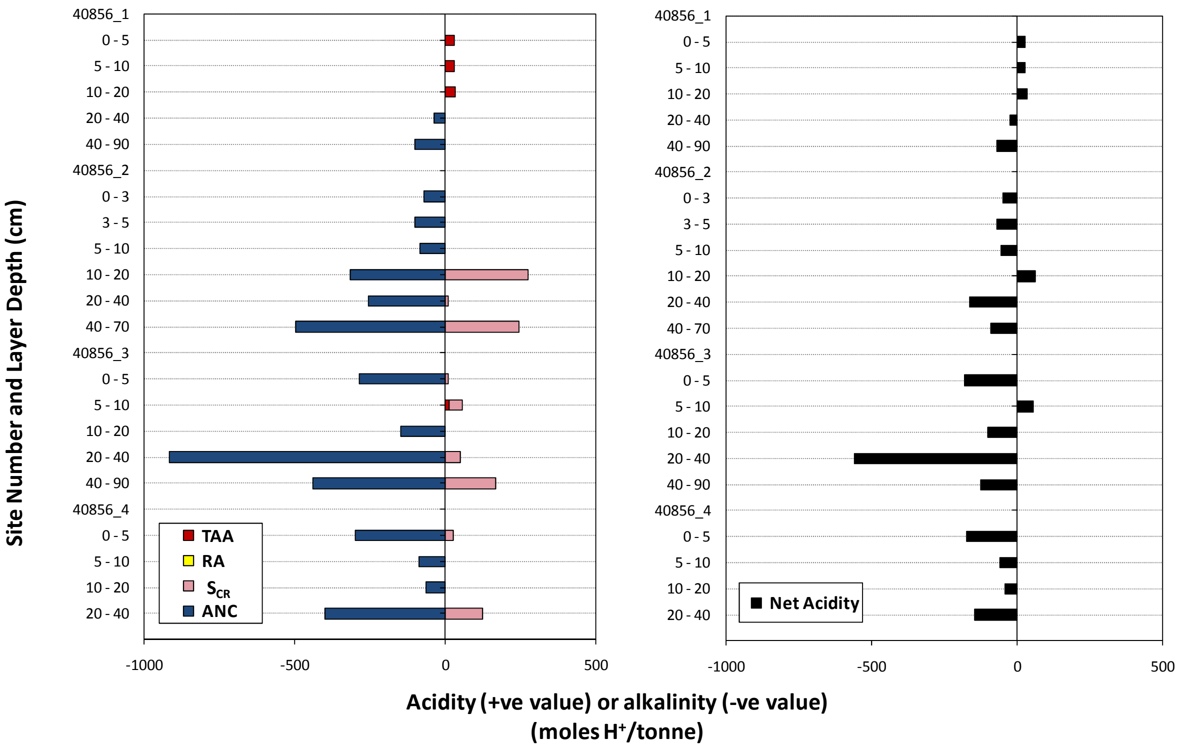


Figure 8-72. Acid-base accounting depth profiles for Outlet Creek (40856_1 – 40856_4). Left side shows the components: titratable actual acidity (TAA - red bar), acid generating potential (AGP as S_{CR} -pink bar), acid neutralising capacity (ANC - blue bar), retained acidity (RA - yellow bar), and right side shows net acidity.

8.6.4. Discussion

Acid sulfate soils occurred at three of the four sites examined in the Outlet Creek wetland (i.e. sites 40856_2 – 40856_4). The fourth profile contained other soil materials. Sulfuric materials were not observed. Reduced inorganic sulfur contents of up to 0.44% S_{CR} were observed at three sulfidic sites. Hypersulfidic soil materials with low to moderate net acidities were present in one soil profile (which also contained hyposulfidic materials), and another two soil profiles contained hyposulfidic materials (with both S_{CR} ≥ 0.10% and < 0.10%). Monosulfidic soil materials were observed in surface layers in the three sulfidic profiles, with S_{AV} contents of up to 0.31% S. These results indicate that acidity would be produced upon oxidation of sulfides in some of these materials. All surficial soil materials examined contained soluble sulfate in excess of the 100 mg/L trigger value for MBO formation potential.

Based on the priority ranking criteria adopted by the Scientific Reference Panel of the Murray-Darling Basin Acid Sulfate Soil Risk Assessment Project, there was one high priority site based on hypersulfidic material, three high priority sites based on hyposulfidic (S_{CR} ≥ 0.10%) material, and also three high priority sites based on monosulfidic material. There were three moderate priority sites based on the presence of a hyposulfidic material with S_{CR} < 0.10%. In addition, all four sampling sites had a high priority ranking for Phase 2 detailed assessment based on MBO formation hazard.

The potential hazards at the wetland-scale posed by acid sulfate soil materials at the Outlet Creek wetland are:

- Acidification hazard: Negative net acidities were dominant in this wetland, with only one hypersulfidic material having a moderate net acidity, indicating that the overall degree of acidification hazard is low.

- Deoxygenation hazard: High monosulfide concentrations (S_{AV} ≤ 0.31% S) in surface soils at three sites represent a high deoxygenation hazard. In addition, the soluble sulfate content of surface soil materials at all four sites were over the trigger value for MBO formation indicating the possible development of an appreciable deoxygenation hazard at those locations after prolonged wet conditions.

- Metal mobilisation: The low acidification hazard indicates that soil acidification is not likely to increase the solubility of metals. The presence of monosulfidic materials in some surface soils and the potential for MBO formation identified in this wetland may result in an appreciable metal release hazard. This would depend on factors such as the potential for MBO formation and the metal loading in this wetland. Soil acidity may be sufficient for mobilisation of aluminium.

Summary of key findings for the Outlet Creek:

Soil materials:	Sulfuric materials were not observed. Sulfidic soil materials identified included: hypersulfidic (1 site), monosulfidic (3 sites), hyposulfidic ≥ 0.10% S (3 sites) and hyposulfidic < 0.10% S (3 sites). Other soil materials observed at an additional site. Negative net acidities dominant within wetland.
Acid sulfate soil identification:	• Hypermonosulfidic subaqueous, hypomonosulfidic subaqueous and hypomonosulfidic soils identified. • Hydrosol soil also identified.
Hazard assessment	• Acidification hazard - low level of concern • Deoxygenation hazard - high level of concern • Metal mobilisation hazard – high level of concern

Table 8-30. Laboratory analytical data for acid sulfate soil assessment of Outlet Creek (Wetland ID 40856).
(red printed values indicates data results of potential concern)

Site and Layer ID.	Depth Range (cm)	Soil Texture	pH water	pH peroxide	pH incubation	Sulfate (mg SO_4 / kg)	pH KCl	Titratable Actual Acidity (mole H^+/t)	Chromium Reducible Sulfur (%S_{CR})	Retained Acidity (mole H^+/t)	Acid Neutralising Capacity (%$CaCO_3$)	Net Acidity (mole H^+/t)	Acid Volatile Sulfide (%S_{AV})	Acid Sulfate Soil Material Classification
1.1	0-5	fine	6.33	6.18	6.02	5700	6.87	0.00	<0.01	0.00	0.19	-25.18	<0.01	other soil materials
1.2	5-10	fine	6.14	7.19	5.68		6.59	0.00	<0.01	0.00	0.51	-67.71	<0.01	other soil materials
1.3	10-20	fine	6.78	7.12	6.22		6.76	0.00	<0.01	0.00	0.36	-48.25	<0.01	other soil materials
1.4	20-40	fine	7.00	7.35	6.66		7.01	0.00	<0.01	0.00	0.51	-68.23	<0.01	other soil materials
1.5	40-90	fine	7.16	7.62	6.94		7.58	0.00	<0.01	0.00	0.43	-56.65	<0.01	other soil materials
2.1	0-3		7.00	6.41	4.39	17250	7.94	0.00	0.44	0.00	1.58	63.20	0.31	hypermonosulfidic#
2.2	3-5		6.66	6.58	5.71		7.46	0.00	0.01	0.00	1.28	-162.10	<0.01	hyposulfidic (< 0.10)
2.3	5-10		6.93	6.43	4.98		8.15	0.00	0.39	0.00	2.49	-88.76	0.18	hypomonosulfidic (≥ 0.10)
2.4	10-20		5.89	4.72	2.90		6.64	0.00	0.01	0.00	1.43	-181.58	<0.01	hypersulfidic
2.5	20-40		4.79	3.89	3.50		5.38	11.36	0.07	0.00	0.32	14.63	<0.01	hypersulfidic
2.6	40-70		6.27	6.85	5.59		6.78	0.00	<0.01	0.00	0.74	-98.87	<0.01	other soil materials
3.1	0-5	fine	7.08	7.07	6.42	16950	8.35	0.00	0.08	0.00	4.59	-560.66	<0.01	hyposulfidic (< 0.10)
3.2	5-10	fine	7.01	7.30	6.32		8.36	0.00	0.27	0.00	2.21	-126.15	0.23	hypomonosulfidic (≥ 0.10)
3.3	10-20	fine	6.73	6.88	5.74		7.80	0.00	0.04	0.00	1.50	-172.88	0.04	hypomonosulfidic (< 0.10)/
3.4	20-40	fine	6.38	6.81	5.30		6.64	0.00	<0.01	0.00	0.44	-58.89	<0.01	other acidic
3.5	40-90	fine	6.56	7.70	6.12		7.06	0.00	<0.01	0.00	0.32	-42.70	<0.01	other soil materials
4.1	0-5		7.04	7.08	6.41	21900	8.38	0.00	0.20	0.00	2.01	-145.08	0.11	hypomonosulfidic (≥ 0.10)
4.2	5-10		6.67	6.70	6.31		8.41	0.00	0.25	0.00	1.80	-83.20	0.18	hypomonosulfidic (≥ 0.10)
4.3	10-20		6.69	6.62	6.25*		8.53	0.00	0.43	0.00	2.93	-123.40	0.29	hypomonosulfidic (≥ 0.10)
4.4	20-40		6.72	7.32	6.13*		7.85	0.00	0.09	0.00	0.84	-57.75	<0.01	hyposulfidic (< 0.10)

***** Indicates that a stable pH has not yet been reached for this sample (after 18 weeks). # Classified as hypermonosulfidic based on positive net acidity.

Table 8-31. Field hydrochemistry data for acid sulfate soil assessment of Outlet Creek (Wetland ID 40856).

Site and Layer ID.	Temperature (Deg C)	Specific Electrical Conductivity (µS/cm)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	pH	ORP	Redox potential (mV))	Turbidity (NTU)	HCO_3 (mg/L)	Comment
*Lowland River**		*125-2200*	*85-110*		*6.5-8.0*			*6-50*		
*Freshwater Lakes**		*20-30*	*90-110*		*6.5-8.0*			*1-20*		
40856_2 (SW)	27.6	69500		12.32	8.34		242	8.8	16	
40856_3 (PW)	23.5	159600		4.52	6.69		178	54.7		Pore-water measured but not collected due to proximity to water body
40856_4 (SW)	16.1	48700		11.55	8.36		203	8.0	21	

* ANZECC water quality guidelines for lowland rivers and freshwater lakes/reservoirs in South-east Australia are provided for relevant parameters (there are currently no trigger values defined for 'Wetlands') (ANZECC/ARMCANZ, 2000). Surface water values outside the ranges defined in the ANZECC guidelines are indicated with red text. (SW) and (PW) indicate whether the sample was taken from surface water or pore-water, respectively.

Table 8-32. Laboratory hydrochemistry data for acid sulfate soil assessment of Outlet Creek (Wetland ID 40856).

Parameter	units	ANZECC Guidelines	Site 2 (SW)	Site 4 (SW)
depth	cm			
Na	mg l^{-1}		10,888	9,846
K	mg l^{-1}		83	34
Ca	mg l^{-1}		1,739	675
Mg	mg l^{-1}		2,199	1,227
Si	mg l^{-1}		0.3	0.4
Br	mg l^{-1}		61.86	37.98
Cl	mg l^{-1}		20,197	16,875
NO_3	mg l^{-1}	0.7	0.014	0.054
NH_4-N	mg l^{-1}	0.01	1.585	0.034
PO_4-P^E	mg l^{-1}	0.005	0.011	<0.005
SO_4	mg l^{-1}		4,755	1,671
Ag	µg l^{-1}	0.05	<1	<1
Al^A	µg l^{-1}	55	<1	<1
As^B	µg l^{-1}	13	<10	<10
Cd	µg l^{-1}	0.2	<1	<1
Co	µg l^{-1}	2.8	4	3
Cr^C	µg l^{-1}	1	<5	<5
Cu^H	µg l^{-1}	1.4	10	5
Fe	µg l^{-1}	300	416	11
Mn	µg l^{-1}	1700	790	593
Ni^H	µg l^{-1}	11	32	9
Pb^H	µg l^{-1}	3.4	<1	<1
Se	µg l^{-1}	11	n/a	n/a
Zn^H	µg l^{-1}	8	16	7
DOC	mg l^{-1}		n/a	n/a

Notes.

The ANZECC guideline values for toxicants refer to the Ecosystem Protection – Freshwater Guideline for protection of 95% of biota in 'slightly-moderately disturbed' systems, as outlined in the Australian Water Quality Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000). For the nutrients NH_4 and PO_4, guideline values are provided for Freshwater Lakes and Reservoirs. Surface water values outside the ranges defined in the ANZECC guidelines are indicated with red text. (SW) and (PW) indicate whether the sample was taken from surface water or pit-water (groundwater that entered an excavated pit), respectively.

A *Guideline is for Aluminium in freshwater where pH > 6.5.*

B *Guideline assumes As in solution as Arsenic (AsV).*

C *Guideline is for Chromium is applicable to Chromium (CrVI) only.*

E *Guideline is for filterable reactive phosphorous (FRP).*

H *Hardness affected (refer to Guidelines).*

Table 8-33. Site description data for acid sulfate soil assessment of Outlet Creek (Wetland ID 40856).

Site No.	Depth to Water Table (cm)	Surface Condition	Earth Cover (Vegetation)	Location Notes	Rationale for site selection	ASS Soil Classification	Comments
1	Beyond sampling depth	Dry	Sparse low succulent shrubs	Point bar in southern channel. Centre of vegetated section.	Elevated site in remediated southern end of wetland.	Other	
2	-25	Sub-aqueous	Sub-aqueous	Pond in southern channel. Centre of pond.	Low, sub-aqueous site in remediated southern end of wetland.	Hypermonosulfidic	Algal mat on surface of substrate.
3	20	Moist	Bare with salt uplifting	Eroded bank of pond in northern channel. Adjacent to pond.	Elevated site in eroded northern end of wetland.	Hypomonosulfidic	
4	-28	Sub-aqueous	Sub-aqueous	Pond in northern channel. Centre of pond.	Low, sub-aqueous site in eroded northern end of wetland.	Hypomonosulfidic	Odoriferous

Table 8-34. Profile description data for acid sulfate soil assessment of Outlet Creek (Wetland ID 40856).

Site and Sample No.	Horizon Depth Range (cm)	Soil Colour - moist	Texture Class	Moisture State	Redoximorphic Features Abundance	Redoximorphic Features - Kind	Redoximorphic Features - Colour	Structure - Type	Structure - Grade	pH (field measurement)	Comments (odour, fragments, minerals, plant material, inclusions, other
1.1	0-5	2.5Y 5/3	KSLMC	T	2	M	7.5YR 4/6	PO	W	6.80	
1.2	5-10	2.5Y 5/2	KSMHC	T	2	M	7.5YR 4/6	PO	M	6.37	
1.3	10-20	2.5Y 5/2	KSMHC	T	3	M	7.5YR 4/4	PO	M	6.78	Secondary mottle 2.5Y 2.5/1.
1.4	20-40	2.5Y 5/3	KSMC	T	2	M	7.5YR 4/4	PO	M	7.28	Nodules from 29-44 cm.
1.5	40-90	2.5Y 5/3	KSMC	T	1	M	2.5Y 5/6	PO	W	7.26	Nodules from 29-44 cm.
2.1	0-3	10YR 2/1	n.a.	W				n.a.	V	6.51	Black MBO.
2.2	3-5	5Y 3/1	n.a.	W				n.a.	V	6.94	Too wet to texture.
2.3	5-10	5Y 3/1	LC	M	4	M	10YR 2/1	PO	S	6.53	
2.4	10-20	5YR 5/2	LC	W	3	M	10YR 2/1	PO	S	5.71	
2.5	20-40	5Y 4/1	LMC	M	4	M	10YR 2/1	PO	S	3.27	
2.6	40-70	5Y 4/1	LMC	M	3	M	10YR 6/1	PO	S	6.03	
3.1	0-5	5Y 4/1	MC	M	3	M	7.5YR 4/4	PO	M	6.82	
3.2	5-10	5Y 4/1	MC	M	3	M	7.5YR 4/4	PO	M	7.14	
3.3	10-20	5Y 5/2	MC	W	3	M	10YR 2/1	PO	M	7.22	Secondary mottle black.
3.4	20-40	5Y 4/1	FMC	W	3	M	7.5YR 4/4	PO	M	6.49	Fine sand.
3.5	40-90	GLEY 5/10GY	FMC	W	3	M	GLEY 2.5/N	n.a.	V	6.58	Increasing fine sand.
4.1	0-5	10YR 2/1		W						6.62	Black MBO.
4.2	5-10	10YR 2/1		W						5.98	Black MBO.
4.3	10-20	10YR 2/1		W						5.98	Black MBO.
4.4	20-40	GLEY 1 4/SG		W	3		GLEY 1 4/N	PO		5.62	

8.7. Boeill Creek / Lagoon Wetland Complex (Wetland ID 21920 / 21921)

8.7.1. Location and setting description

Boeill Creek/Lagoon wetland complex consists of two distinct wetland features, both on the northern side of the River Murray. The larger wetland (21920) is a dendritic channel system situated approximately 6.1 km northwest of Mildura, and occupies an area of 34 hectares, reaching 4 km in length and 180 m in width. The smaller wetland (21921) is an infilled prior channel situated approximately 9.2 km northwest of Mildura, and reaches 900 m in length and 120 m in width. The wetland 21920 runs through wooded country, pastoral and horticultural lands, with pools of water located in deeper sections of the channel during the time of sampling. The wetland 21921 is surrounded by pastoral lands and lacked surface water at the time of sampling.

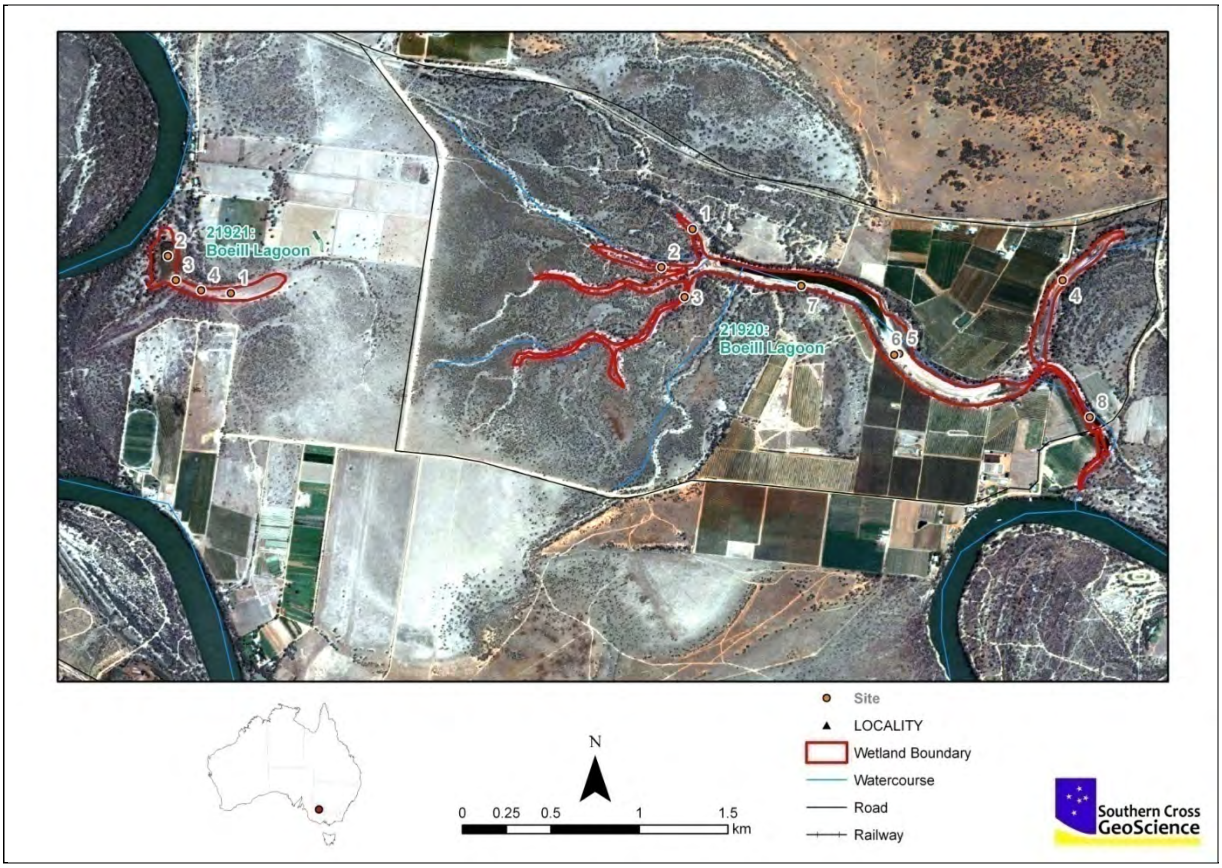


Figure 8-73. Boeill Creek/Lagoon wetland complex and sample site locations.

8.7.2. Soil profile description and distribution

Twelve sites were described and sampled. The soil subtype and general location description of each site are presented in Table 8-35. Sites were distributed throughout the wetland based on different surface features and locations in the wetland, and a transect approach was used in part.

The profiles 21920_1 (Figure 8-75), 21920_2 (Figure 8-76), 21920_3 (Figure 8-77) and 21920_4 (Figure 8-78) were all situated in the upper tributaries of the wetland, in wooded country (21920_4 was bordered by vineyards on the western side of the channel). The ground surface of these four sites ranged from bare clay in water-holding depressions to higher areas that were well vegetated with low shrubs. The profiles 21920_5 to 21920_7 form a hydro-toposequence within the main water-holding channel which was bordered by agricultural land, and profile 21920_8 is situated in a large pool in the main channel closer to the confluence of the wetland with the River Murray. The profiles 21921_1 and 21921_4 reflected the range of moisture at the wetland, including a moist site (21921_4) and a dry site (21921_1). The profile 21921_1 was vegetated with low, succulent shrubs. The profile (21921_2) was also dry but vegetated with dense forbs and herbs. The profile (21921_3) was situated on a point bar on the inside bend of the billabong.

Additional site and profile description data are presented in Tables 8-40 to 8-43.

Table 8-35. Soil identification, subtype and general location description for Boeill Creek/Lagoon wetland complex.

Site ID	Easting UTM Zone 54H	Northing UTM Zone 54H	Acid sulfate soil subtype class	General location description
21920_1	601900	6221647	Hydrosol	NW inlet channel. Centre of channel.
21920_2	601751	6221434	Cracking Clay Soil	W inlet channel. Depression in centre of channel.
21920_3	601858	6221265	Cracking Clay Soil	SW Inlet channel. Shallow pondage in centre of channel.
21920_4	603629	6221340	Hyposulfidic Soil	NE inlet channel. Centre of channel.
21920_5	602860	6220935	Hypermonosulfidic Soil	Main channel. NE bank adjacent to reed beds.
21920_6	602836	6220929	Hypermonosulfidic Soil	Main channel. Centre of channel.
21920_7	602405	6221322	Hypermonosulfidic Subaqueous soil	Large pond in main channel. Centre of pond.
21920_8	603747	6220568	Hypomonosulfidic Subaqueous soil	Hyper saline pond in main channel. Centre of pond.
21921_1	599734	6221309	Cracking clay soil	Eastern reach of billabong. Centre of channel.
21921_2	599441	6221522	Hydrosol	Northern section of billabong. Centre of channel.
21921_3	599477	6221385	Hypersulfidic Soil	Centre of billabong. Point bar.
21921_4	599595	6221327	Hypersulfidic Cracking Clay Soil	Centre of billabong. Only area with moist surface.

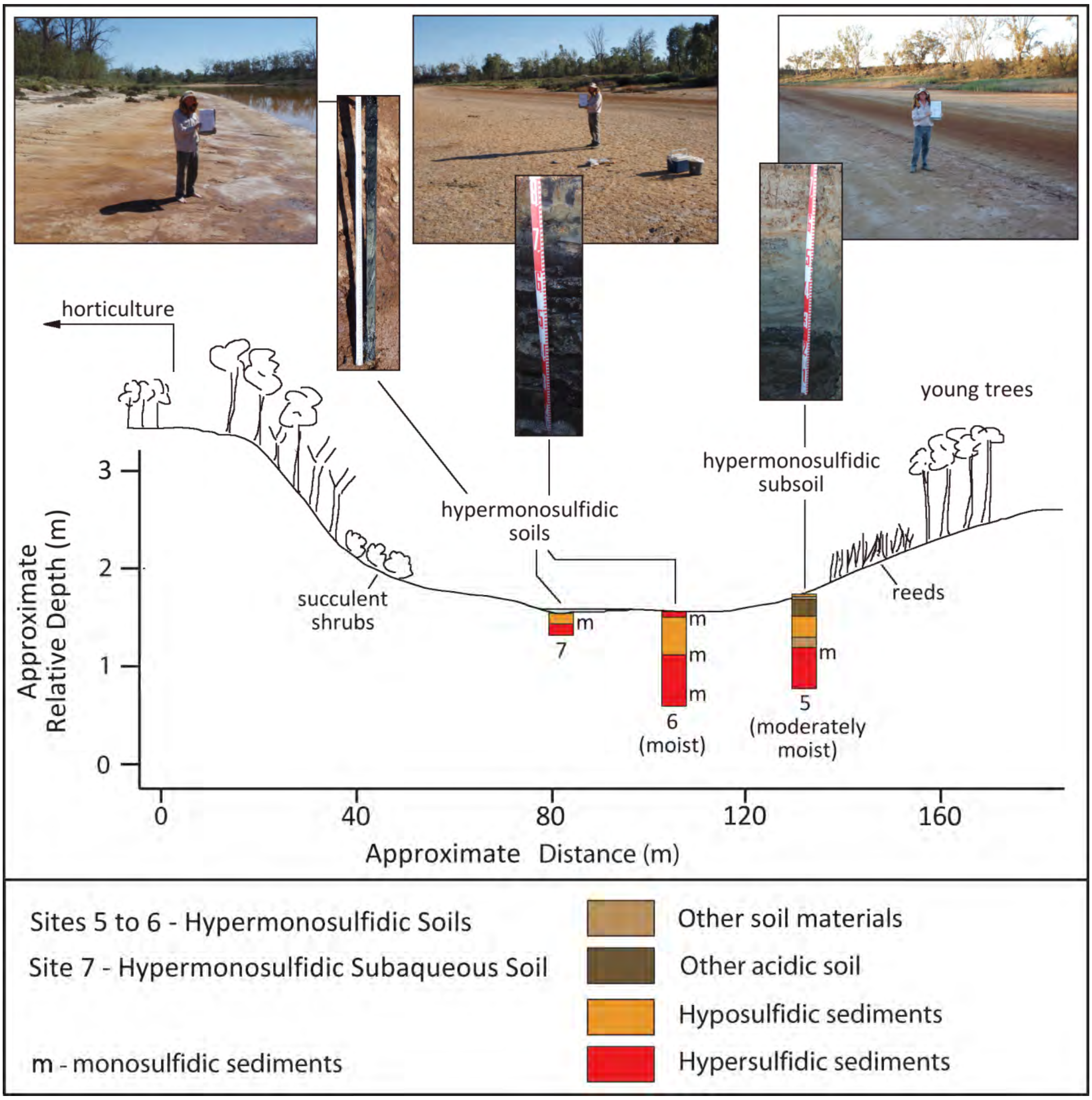
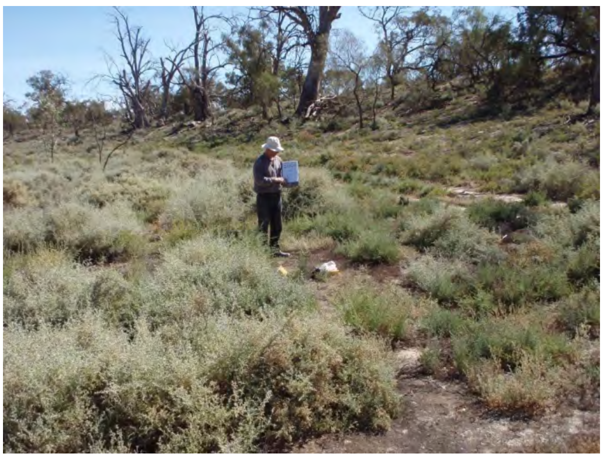


Figure 8-74. Conceptual cross section diagram showing the toposequence relationship of the Boeill Creek/Lagoon wetland complex sediments/soil materials for sites 21920_5 to 21920_8.



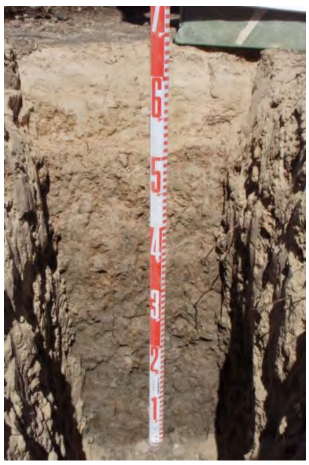


Figure 8-75. Photographs of site 21920_1, showing the location of the sampling site amongst

the covering of saltbush, and the soil profile.

Figure 8-76. Photographs of site 21920_2, showing the bare cracking clay surface, and the soil profile.

Figure 8-77. Photographs of site 21920_3, showing the situation of the site in a depression in a dried channel, and the soil profile.

Figure 8-78. Photographs of site 21920_4, showing the sampling site amongst saltbush and forbs, and the soil profile.

Figure 8-79. Photographs of site 21920_5, showing the situation of the site on the upper bank of the main channel, and the soil profile.

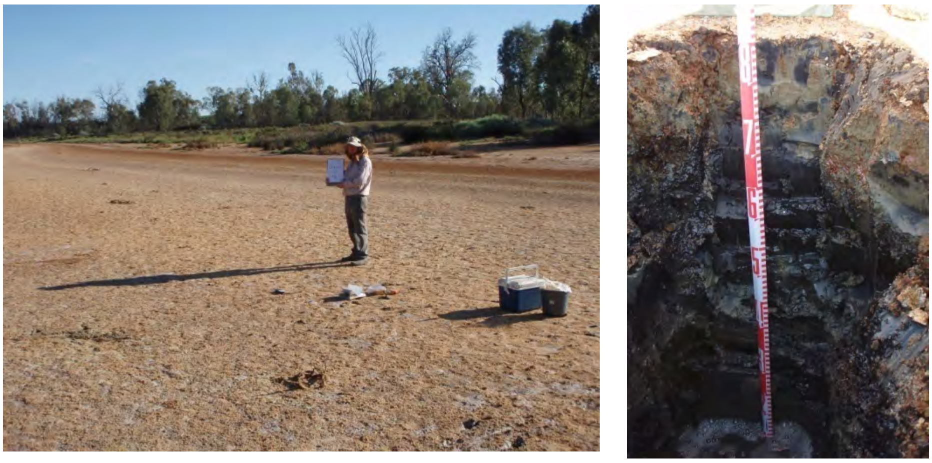


Figure 8-80. Photographs of site 21920_6, showing the site on the thalweg of the channel, with a heavy cover of salt efflorescences, and the soil profile showing the presence of MBO.

Figure 8-81. Photographs of site 21920_7, showing the waterbody (left of image) from which the sample was taken, and the soil core showing the presence of MBO.

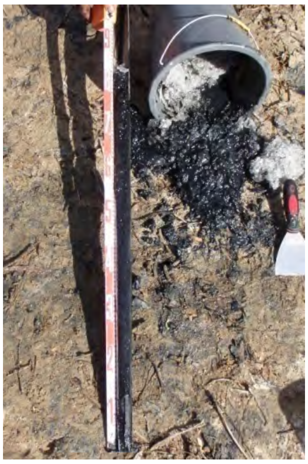


Figure 8-82. Photographs of site 21920_8, showing the water body from which the sample was taken (note the presence of MBO in the water at rear of image and along the water's edge in foreground), and the soil core showing the presence of MBO and thick salt crust.

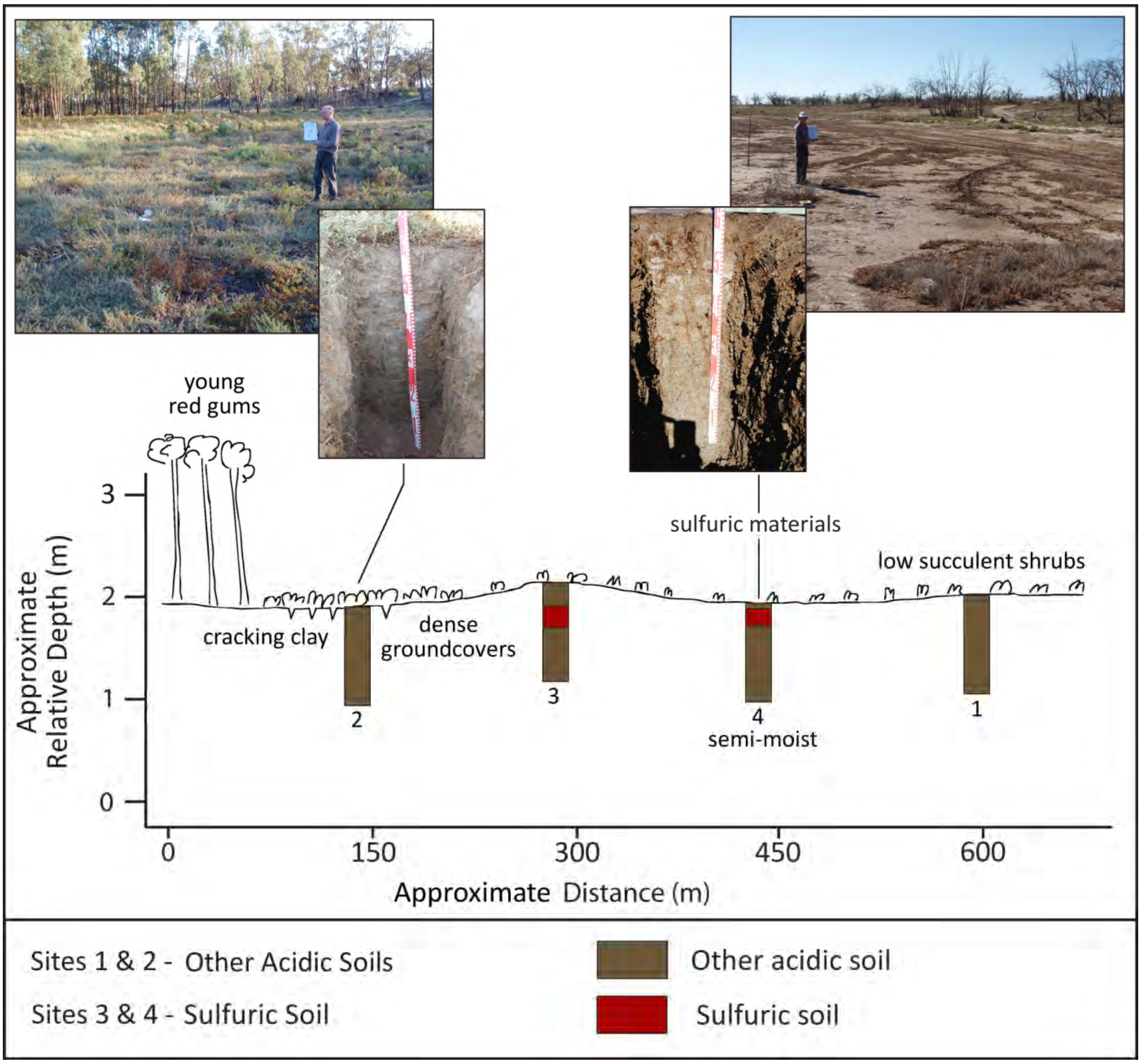


Figure 8-83. Conceptual cross section diagram showing the toposequence relationship of the Boeill Creek/Lagoon wetland complex sediments/soil materials for sites 21921_1 to 21921_4.

Figure 8-84. Photographs of site 21921_1, showing the cracking clay surface with low succulent shrubs, and the soil profile.

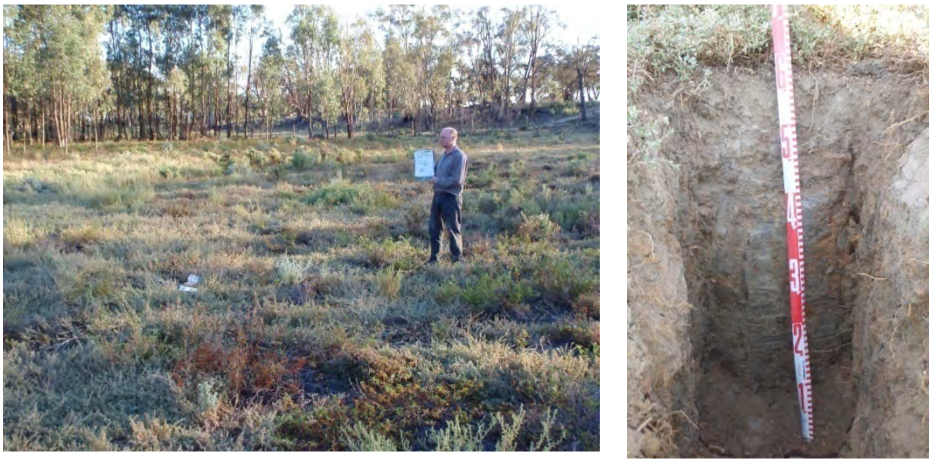


Figure 8-85. Photographs of site 21921_2, showing the situation of the site in dense vegetation, and the soil profile.

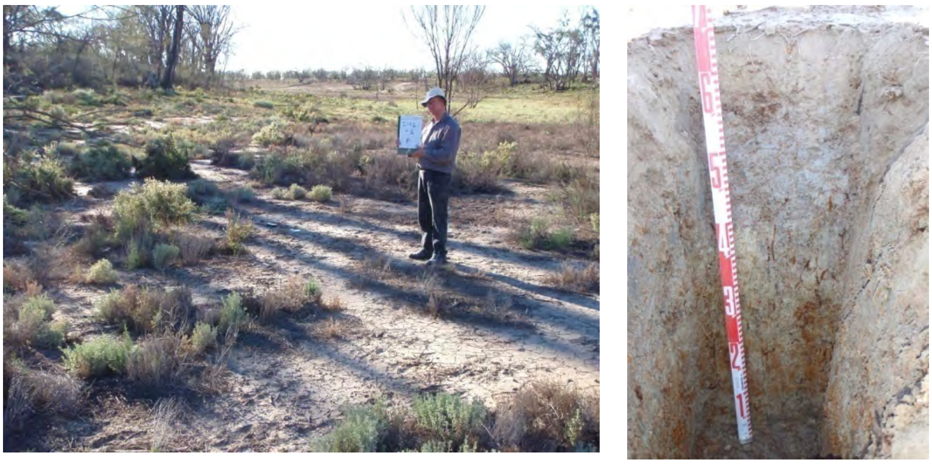


Figure 8-86. Photographs of site 21921_3, showing the mostly bare surface with low succulent shrubs, and the soil profile.

Figure 8-87. Photographs of site 21921_4, showing the moist clay surface with dense vehicle track damage, and the soil profile.

8.7.3. Laboratory data assessment

Soil pH testing (pH_W, pH_{FOX}, pH_{KCl}, $pH_{INCUBATION}$)

The pH data is provided in Tables 8-36 to 8-37 and profiles for all the sites sampled are presented in Figures 8-87 to 8-89. The pH_W values ranged between 4.32 and 7.30. Sulfuric materials (i.e. $pH_W < 4$) were not present. The pH_{FOX} values ranged between 3.33 and 7.48. The pH_{FOX} results indicate that one soil material at site 21920 and 10 soil materials at site 21921 may have the potential to acidify to pH < 4 as a result of sulfide oxidation. However, the S_{CR} data shows some of these layers contained no detectable sulfide (i.e. S_{CR} < 0.01% S). One of the hypersulfidic soil materials acidified to a pH < 4 after at least 8 weeks of incubation (i.e. 21921_4 (10-20 cm)). Other acidic soil materials were identified at nine of the 12 sites examined, indicating acidity in the soil profile at levels where aluminium may mobilise.

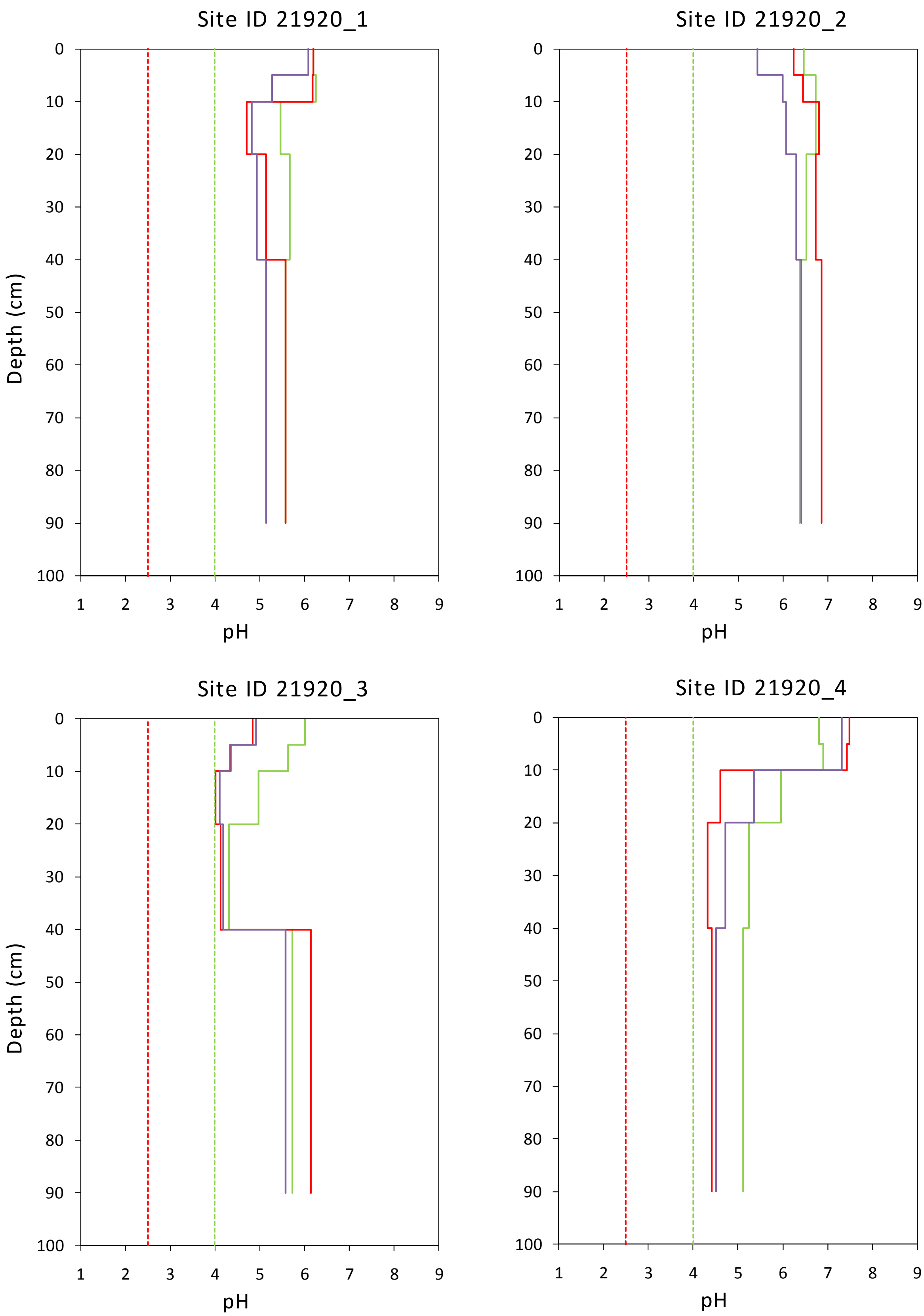


Figure 8-88. Depth profiles of soil pH for Boeill Creek/Lagoon wetland complex (21920_1 – 21920_4), showing soil pH (pH_W as green line), peroxide treated pH (pH_{FOX} as red line) and ageing pH ($pH_{incubation}$ after at least eight weeks as purple line). Critical pH_W and $pH_{incubation}$ value of 4 (green dashed line) and critical pH_{FOX} value of 2.5 (red dashed line).

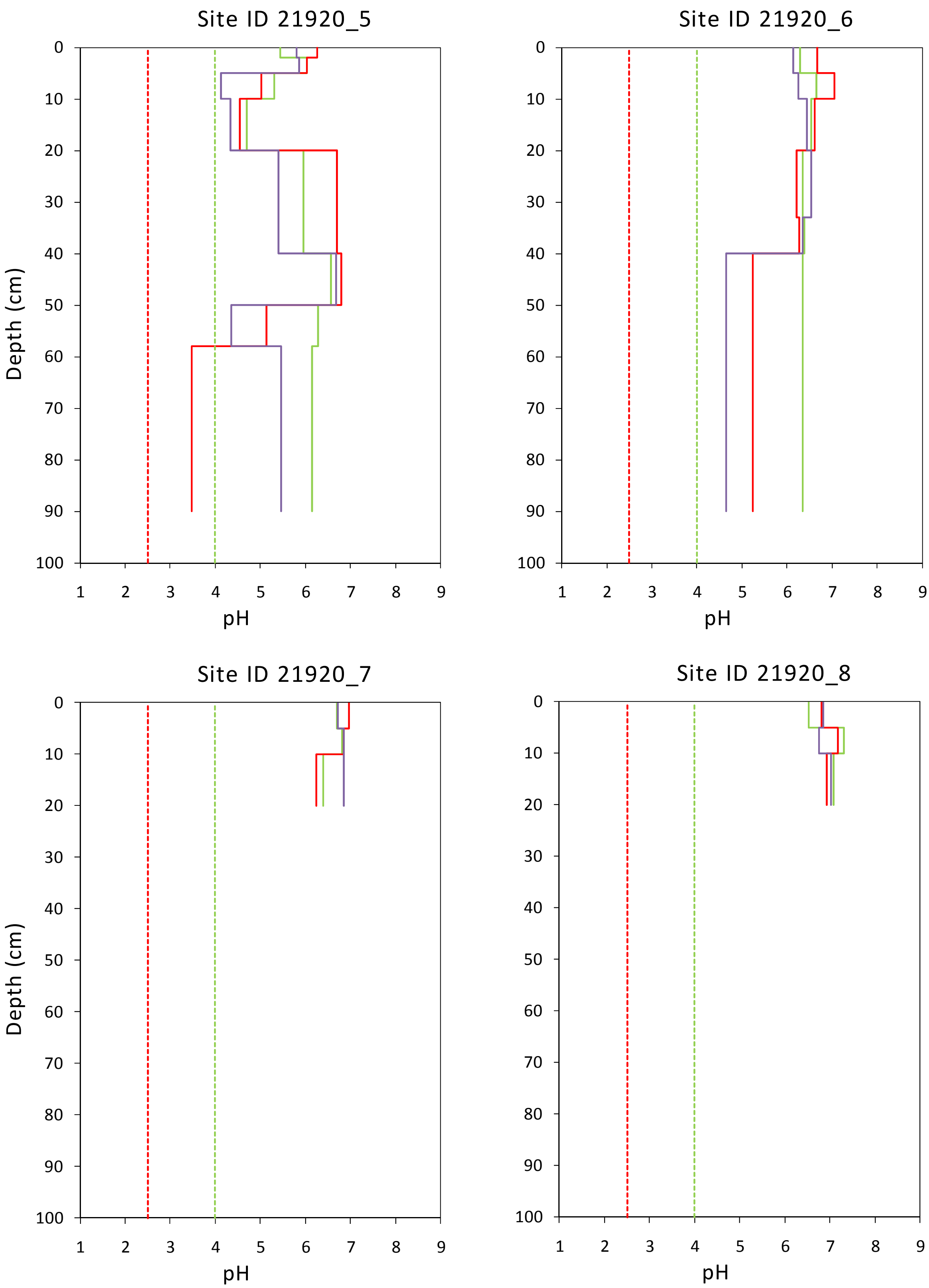


Figure 8-89. Depth profiles of soil pH for Boeill Creek/Lagoon wetland complex (21920_5 – 21920_8), showing soil pH (pH_W as green line), peroxide treated pH (pH_{FOX} as red line) and ageing pH ($pH_{incubation}$ after at least eight weeks as purple line). Critical pH_W and $pH_{incubation}$ value of 4 (green dashed line) and critical pH_{FOX} value of 2.5 (red dashed line).

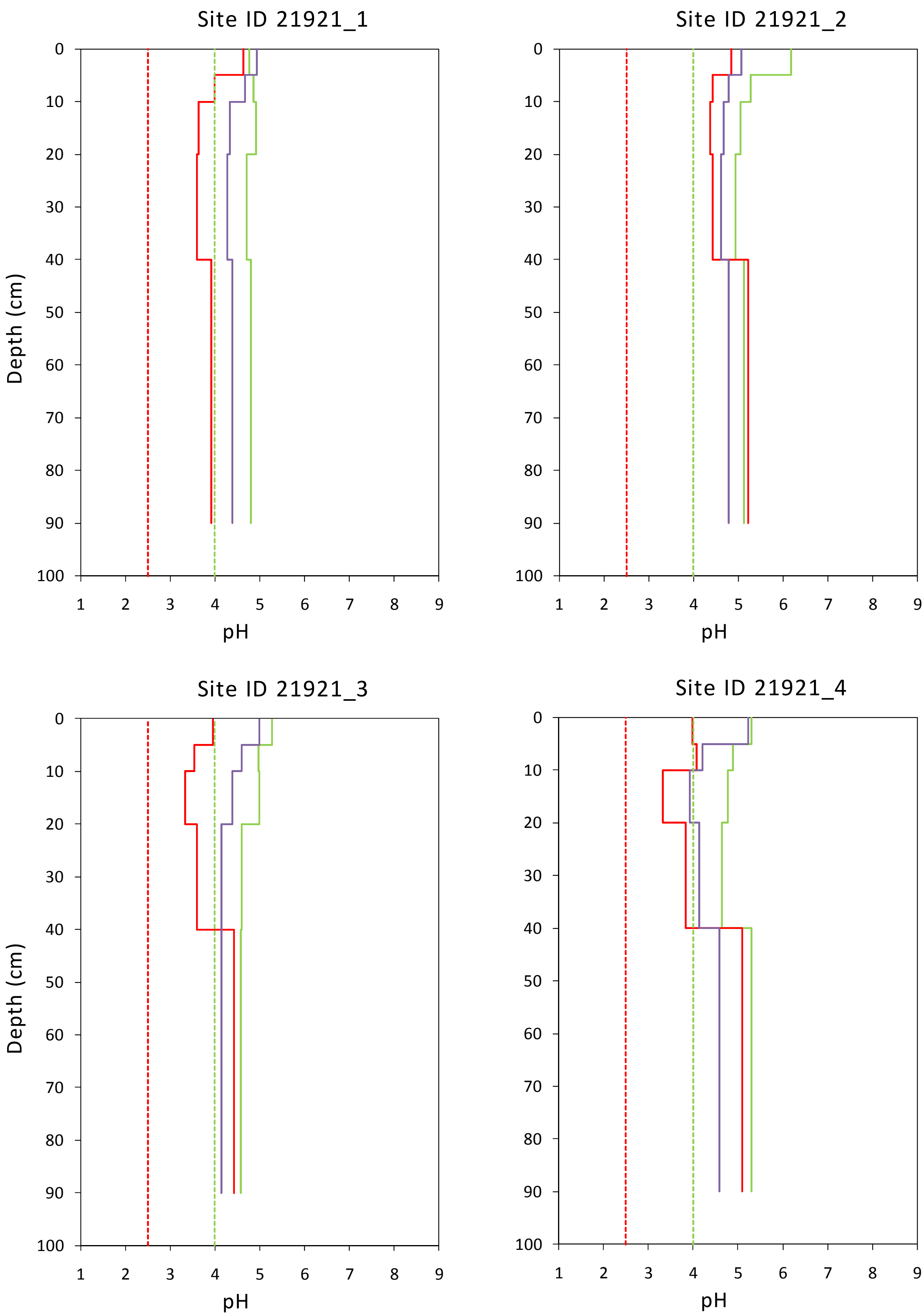


Figure 8-90. Depth profiles of soil pH for Boeill Creek/Lagoon wetland complex (21921_1 – 21921_4), showing soil pH (pH_W as green line), peroxide treated pH (pH_{FOX} as red line) and ageing pH ($pH_{incubation}$ after at least eight weeks as purple line). Critical pH_W and $pH_{incubation}$ value of 4 (green dashed line) and critical pH_{FOX} value of 2.5 (red dashed line).

Acid-base accounting

The acid-base accounting data is provided in Table 8-36 to 8-37 and summarised in Figures 8-90 to 8-92.

Chromium reducible sulfur

Chromium reducible sulfur (S_{CR}) values ranged between < 0.01 and 1.38% S. Sulfidic soil materials (i.e. S_{CR} ≥ 0.01% S) were identified at seven sampling sites (sites 21920_4 – 21920_8 and 21921_3 – 21921_4), with 21 materials of the 60 samples collected equal to or greater than the sulfidic criterion. Low S_{CR} values (i.e. S_{CR} ≤ 0.03% S) were observed at site 21921. The highest S_{CR} value was often found in the surface layers (i.e. 0-5 cm).

Acid volatile sulfide

The acid volatile sulfide (S_{AV}) values ranged between < 0.01 and 0.42% S. A total of 13 monosulfidic soil materials (i.e. S_{AV} ≥ 0.01% S) were found at four sites (sites 21920_5 - 21920_8).

Acid neutralising capacity

The acid neutralising capacity (ANC) ranged between zero and 8.13% $CaCO_3$. The ANC for all samples collected from wetland 21921 was zero.

Titratable actual acidity

The titratable actual acidity (TAA) ranged between zero and 41 mole H^+/tonne, with the majority of soil layers having a TAA < 20 mole H^+/tonne. An increase in the TAA with depth was often observed.

Retained acidity

There was no retained acidity at any of the sites as all samples had a pH_{KCl} > 4.5.

Net acidity

Net acidity ranged between -437 and 290 mole H^+/tonne, with all of the samples at site 21921 having low to moderate positive net acidities (i.e. ≤ 32 mole H^+/tonne). The eight hypersulfidic soil materials had moderate to high net acidities ranging between 19 and 290 mole H^+/tonne.

Water Soluble Sulfate

The water soluble sulfate in the surface soils (i.e. 0-5 cm) ranged between 36.2 and 16,950 mg/L. Eleven of the 12 surface soil layers examined had a soluble sulfate content exceeding the 100 mg/L trigger value for MBO formation potential.

Water Data

The surface water and groundwater data measured in the field and laboratory are presented in Tables 8-38 and 8-39, respectively. The field pH of the two surface waters collected was 7.1 and 7.4, indicating that the surface water has not been affected by acidification. The surface water sulfate concentrations were 4,395 and 10,089 mg/L. Some nutrient (i.e. NH_4, PO_4), metal (i.e. Ag, As, Cd, Co, Fe, Mn, Ni, Pb), turbidity and SEC values were found to exceed the most relevant ANZECC/ARMCANZ (2000) guideline value. The field pH of the single groundwater sample was 5.8, indicating that the groundwater may have been affected by acidification. The groundwater had a sulfate concentration of 286 mg/L.

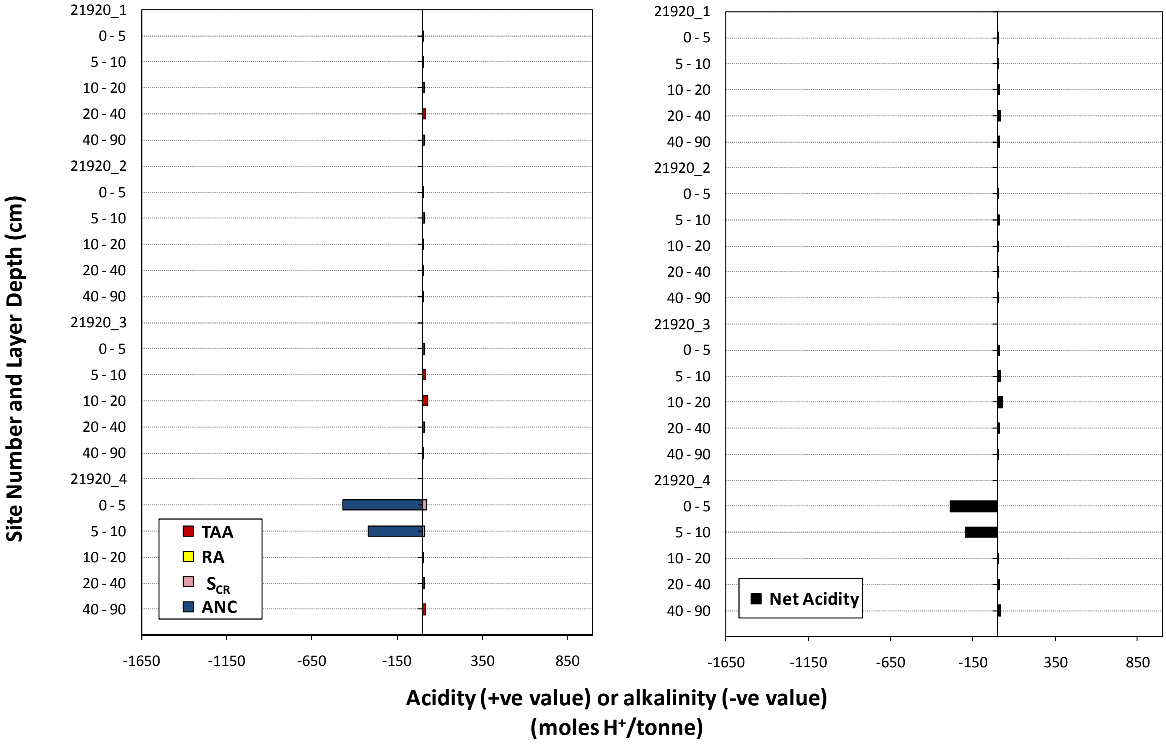


Figure 8-91. Acid-base accounting depth profiles for Boeill Creek/Lagoon wetland complex (21920_1 – 21920_4). Left side shows the components: titratable actual acidity (TAA - red bar), acid generating potential (AGP as S_{CR} -pink bar), acid neutralising capacity (ANC - blue bar), retained acidity (RA - yellow bar), and right side shows net acidity.

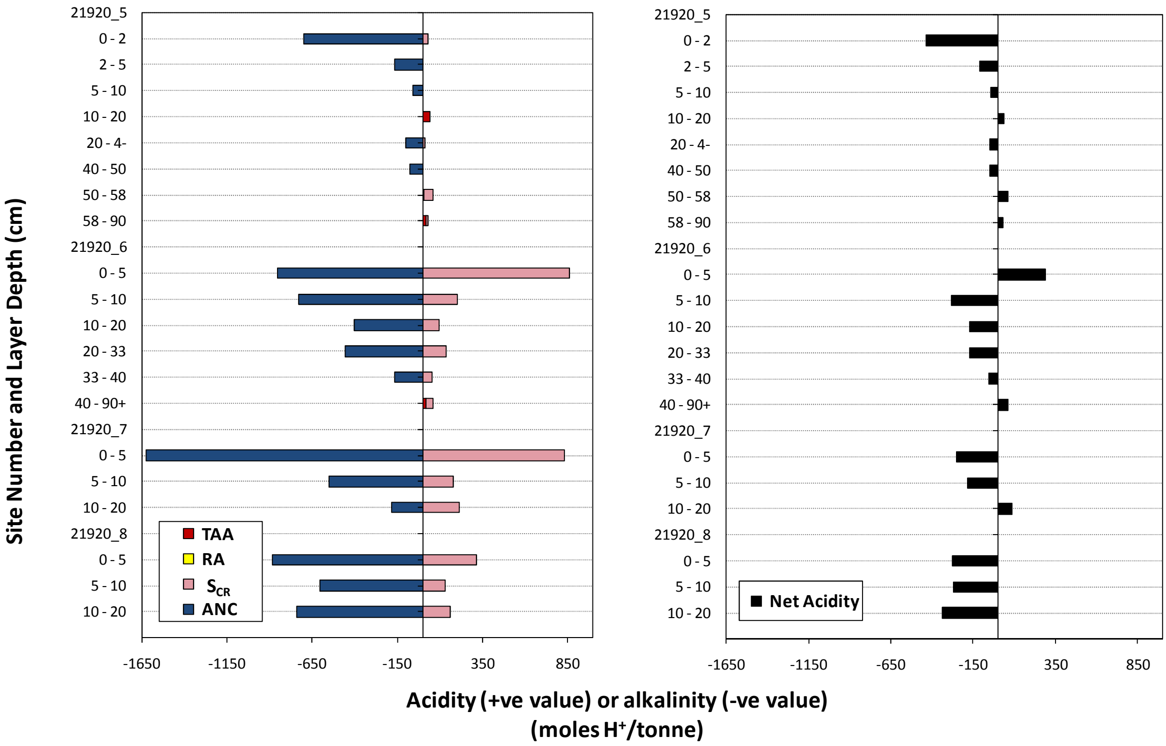


Figure 8-92. Acid-base accounting depth profiles for Boeill Creek/Lagoon wetland complex (21920_5 – 21920_8). Left side shows the components: titratable actual acidity (TAA - red bar), acid generating potential (AGP as S_{CR} -pink bar), acid neutralising capacity (ANC - blue bar), retained acidity (RA - yellow bar), and right side shows net acidity.

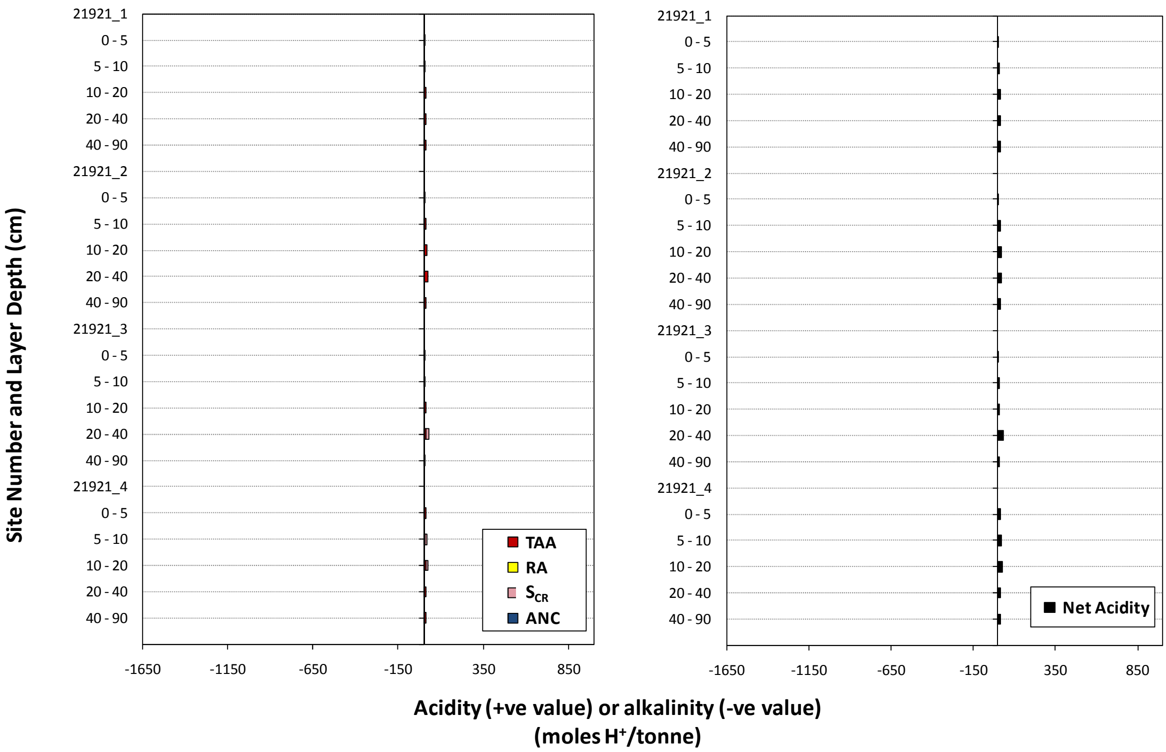


Figure 8-93. Acid-base accounting depth profiles for Boeill Creek/Lagoon wetland complex (21921_1 – 21921_4). Left side shows the components: titratable actual acidity (TAA - red bar), acid generating potential (AGP as S_{CR} -pink bar), acid neutralising capacity (ANC - blue bar), retained acidity (RA - yellow bar), and right side shows net acidity.

8.7.4. Discussion

Acid sulfate soils occurred at seven of the 12 sites examined in the Boeill Creek/Lagoon wetland complex (i.e. sites 21290_4 – 21290_8, 21291_3 and 21291_4). Sulfuric materials were not observed. Reduced inorganic sulfur contents of up to 1.38% S_{CR} were observed at seven sulfidic sites. Low reduced inorganic sulfur contents (i.e. S_{CR} ≤ 0.03% S) were observed at site 21921. Hypersulfidic soil materials were present in five soil profiles (three profiles also contained hyposulfidic materials), and another soil profile contained hyposulfidic materials with S_{CR} ≥ 0.10%. The hypersulfidic materials had moderate to high net acidities. Monosulfidic soil materials were observed at four of the sampling sites (i.e. sites 21290_5 – 21291_8), with S_{AV} contents of up to 0.42% S. Monosulfidic soil materials were observed throughout the profile at three sites (i.e. sites 21290_6 – 21291_8). An additional soil profile contained a hyposulfidic material with S_{CR} < 0.10%. These results indicate that acidity would be produced upon oxidation of sulfides in some of these materials. A total of 11 surficial soil materials contained soluble sulfate in excess of the 100 mg/L trigger value for MBO formation potential. Other acidic soil materials were also observed at an additional five sites.

Based on the priority ranking criteria adopted by the Scientific Reference Panel of the Murray-Darling Basin Acid Sulfate Soil Risk Assessment Project, there were five high priority sites based on hypersulfidic material, three high priority sites based on hyposulfidic (S_{CR} ≥ 0.10%) material, and four high priority sites based on monosulfidic material. There were three moderate priority sites based on the presence of a hyposulfidic material with S_{CR} < 0.10%. In addition, 11 sampling sites had a high priority ranking for Phase 2 detailed assessment based on MBO formation hazard.

The potential hazards at the wetland-scale posed by acid sulfate soil materials at the Boeill Creek/Lagoon wetland complex are:

- Acidification hazard: While low net acidities were dominant in this wetland, seven hypersulfidic materials had moderate net acidities (i.e. 12 % of layers), indicating that the overall degree of acidification hazard is moderate. Only one of the hypersulfidic materials had a high net acidity (i.e. 2 % of layers).

- Deoxygenation hazard: High monosulfide concentrations (S_{AV} ≤ 0.42% S) in surface soils at three sites represent a high deoxygenation hazard. In addition, the soluble sulfate content of surface soil materials at 11 sites were over the trigger value for MBO formation indicating the possible development of an appreciable deoxygenation hazard at those locations after prolonged wet conditions.

- Metal mobilisation: The moderate acidification hazard indicates that soil acidification may increase the solubility of metals. The presence of monosulfidic materials in some surface soils and the potential for MBO formation identified in this wetland may also result in an appreciable metal release hazard. This would depend on factors such as the potential for MBO formation and the metal loading in this wetland. Soil acidity may be sufficient for mobilisation of aluminium.

Summary of key findings for the Boeill Creek/Lagoon wetland complex:

Soil materials:	Sulfuric materials were not observed. Sulfidic soil materials identified included: hypersulfidic (5 sites), monosulfidic (4 sites), hyposulfidic ≥ 0.10% (1 site), and hyposulfidic < 0.10% S (1 site). Other acidic soil materials observed at an additional 5 sites. Low net acidities dominant within wetland.
Acid sulfate soil identification:	• Hypersulfidic, hypersulfidic cracking clay, hypermonosulfidic, hypermonosulfidic subaqueous, hyposulfidic and hypomonosulfidic subaqueous soils identified. • Hydrosol and cracking clay soils also identified.
Hazard assessment	• Acidification hazard - moderate level of concern • Deoxygenation hazard - high level of concern • Metal mobilisation hazard – high level of concern

Table 8-36. Laboratory analytical data for acid sulfate soil assessment of Boeill Lagoon (Wetland ID 21920).
(red printed values indicates data results of potential concern)

Site and Layer ID.	Depth Range (cm)	Soil Texture	pH water	pH peroxide	pH incubation	Sulfate (mg SO_4 / kg)	pH KCl	Titratable Actual Acidity (mole H^+/t)	Chromium Reducible Sulfur (%S_{CR})	Retained Acidity (mole H^+/t)	Acid Neutralising Capacity (%$CaCO_3$)	Net Acidity (mole H^+/t)	Acid Volatile Sulfide (%S_{AV})	Acid Sulfate Soil Material Classification
1.1	0-5	coarse	6.20	6.20	6.09	118	6.24	3.33	<0.01	0.00	0.00	3.33	<0.01	other soil materials
1.2	5-10	medium	6.25	6.18	5.27		5.94	5.33	<0.01	0.00	0.00	5.33	<0.01	other acidic
1.3	10-20	medium	5.47	4.71	4.83		5.08	14.33	<0.01	0.00	0.00	14.33	<0.01	other acidic
1.4	20-40		5.67	5.14	4.93		5.20	16.53	<0.01	0.00	0.00	16.53	<0.01	other acidic
1.5	40-90	fine	5.57	5.58	5.15		5.34	13.22	<0.01	0.00	0.00	13.22	<0.01	other soil materials
2.1	0-5		6.46	6.23	5.43	36.2	5.73	0.93	<0.01	0.00	0.00	0.93	<0.01	other acidic
2.2	5-10		6.73	6.45	6.00		5.56	10.86	<0.01	0.00	0.00	10.86	<0.01	other soil materials
2.3	10-20		6.72	6.81	6.06		5.78	7.28	<0.01	0.00	0.00	7.28	<0.01	other soil materials
2.4	20-40		6.51	6.73	6.29		5.86	7.76	<0.01	0.00	0.00	7.76	<0.01	other soil materials
2.5	40-90		6.36	6.85	6.41		6.03	7.62	<0.01	0.00	0.00	7.62	<0.01	other soil materials
3.1	0-5	fine	6.00	4.85	4.92	2355	5.52	13.86	<0.01	0.00	0.00	13.86	<0.01	other acidic
3.2	5-10	fine	5.64	4.36	4.34		5.10	17.96	<0.01	0.00	0.00	17.96	<0.01	other acidic
3.3	10-20	fine	4.98	4.02	4.11		4.66	32.21	<0.01	0.00	0.00	32.21	<0.01	other acidic
3.4	20-40	fine	4.32	4.12	4.19		5.15	13.13	<0.01	0.00	0.00	13.13	<0.01	other acidic
3.5	40-90	fine	5.73	6.14	5.58		5.81	6.51	<0.01	0.00	0.00	6.51	<0.01	other soil materials
4.1	0-5		6.81	7.48	7.32	12105	8.24	0.00	0.04	0.00	2.34	-288.70	<0.01	hyposulfidic (< 0.10)
4.2	5-10		6.91	7.43	7.31		7.79	0.00	0.03	0.00	1.59	-196.23	<0.01	hyposulfidic (< 0.10)
4.3	10-20		5.97	4.60	5.35		5.65	9.34	<0.01	0.00	0.00	9.34	<0.01	other acidic
4.4	20-40		5.25	4.32	4.71		5.24	14.71	<0.01	0.00	0.00	14.71	<0.01	other acidic
4.5	40-90		5.12	4.42	4.52		4.94	21.12	<0.01	0.00	0.00	21.12	<0.01	other acidic
5.1	0-2	medium	5.44	6.25	5.81	12765	8.71	0.00	0.05	0.00	3.49	-436.60	<0.01	hyposulfidic (< 0.10)
5.2	2-5	coarse	6.02	6.02	5.86		8.56	0.00	<0.01	0.00	0.83	-110.66	<0.01	other soil materials
5.3	5-10	coarse	5.31	5.01	4.13		6.54	0.00	<0.01	0.00	0.30	-40.09	<0.01	other acidic
5.4	10-20	medium	4.69	4.54	4.33		5.84	40.74	<0.01	0.00	0.00	40.74	<0.01	other acidic
5.5	20-40	coarse	5.95	6.69	5.41		6.97	0.00	0.02	0.00	0.49	-50.83	<0.01	hyposulfidic (< 0.10)
5.6	40-50	medium	6.56	6.79	6.68		8.25	0.00	<0.01	0.00	0.37	-49.16	<0.01	other soil materials
5.7	50-58		6.27	5.13	4.36*		6.14	5.07	0.09	0.00	0.00	60.24	0.02	hypermonosulfidic#
5.8	58-90		6.15	3.47	5.46		5.23	19.17	0.02	0.00	0.00	29.06	<0.01	hypersulfidic#

***** Indicates that a stable pH has not yet been reached for this sample (after 17 weeks). # Classified as hypersulfidic/hypermonosulfidic based on positive net acidity.

Table 8-36 (continued). Laboratory analytical data for acid sulfate soil assessment of Boeill Lagoon (Wetland ID 21920).
(red printed values indicates data results of potential concern)

Site and Layer ID.	Depth Range (cm)	Soil Texture	pH water	pH peroxide	pH incubation	Sulfate (mg SO_4 / kg)	pH KCl	Titratable Actual Acidity (mole H^+/t)	Chromium Reducible Sulfur (%S_{CR})	Retained Acidity (mole H^+/t)	Acid Neutralising Capacity (%$CaCO_3$)	Net Acidity (mole H^+/t)	Acid Volatile Sulfide (%S_{AV})	Acid Sulfate Soil Material Classification
6.1	0-5		6.28	6.66	6.14	13770	8.38	0.00	1.38	0.00	4.28	290.03	0.30	hypermonosulfidic#
6.2	5-10		6.65	7.04	6.25		8.48	0.00	0.33	0.00	3.66	-283.96	0.16	hypomonosulfidic (≥ 0.10)
6.3	10-20		6.53	6.61	6.43		8.32	0.00	0.15	0.00	2.01	-172.37	0.07	hypomonosulfidic (≥ 0.10)
6.4	20-33		6.35	6.21	6.53		8.38	0.00	0.22	0.00	2.28	-168.72	0.11	hypomonosulfidic (≥ 0.10)
6.5	33-40		6.38	6.26	6.35		7.46	0.00	0.09	0.00	0.83	-56.09	0.05	hypomonosulfidic (< 0.10)
6.6	40-90		6.34	5.23	4.64*		5.39	17.74	0.07	0.00	0.00	59.24	0.02	hypermonosulfidic#
7.1	0-5		6.69	6.96	6.72	10515	8.90	0.00	1.33	0.00	8.13	-253.15	0.42	hypomonosulfidic (≥ 0.10)
7.2	5-10		6.81	6.85	6.84		8.43	0.00	0.29	0.00	2.76	-185.53	0.18	hypomonosulfidic (≥ 0.10)
7.3	10-20		6.40	6.24	6.84		6.74	0.00	0.34	0.00	0.93	88.53	0.20	hypermonosulfidic#
8.1	0-5		6.53	6.81	6.85	16950	8.78	0.00	0.50	0.00	4.42	-275.16	0.39	hypomonosulfidic (≥ 0.10)
8.2	5-10		7.30	7.17	6.76		8.74	0.00	0.21	0.00	3.01	-267.85	0.04	hypomonosulfidic (≥ 0.10)
8.3	10-20		7.08	6.92	7.02		8.82	0.00	0.26	0.00	3.72	-334.05	0.17	hypomonosulfidic (≥ 0.10)

***** Indicates that a stable pH has not yet been reached for this sample (after 17 weeks). # Classified as hypermonosulfidic based on positive net acidity.

Table 8-37. Laboratory analytical data for acid sulfate soil assessment of Boeill Lagoon (Wetland ID 21921).
(red printed values indicates data results of potential concern)

Site and Layer ID.	Depth Range (cm)	Soil Texture	pH water	pH peroxide	pH incubation	Sulfate (mg SO_4 / kg)	pH KCl	Titratable Actual Acidity (mole H^+/t)	Chromium Reducible Sulfur (%S_{CR})	Retained Acidity (mole H^+/t)	Acid Neutralising Capacity (%$CaCO_3$)	Net Acidity (mole H^+/t)	Acid Volatile Sulfide (%S_{AV})	Acid Sulfate Soil Material Classification
1.1	0-5	fine	4.76	4.63	4.94	6240	6.16	3.12	<0.01	0.00	0.00	3.12	<0.01	other acidic
1.2	5-10	fine	4.86	4.00	4.67		5.52	7.15	<0.01	0.00	0.00	7.15	<0.01	other acidic
1.3	10-20	fine	4.91	3.64	4.33		5.06	14.38	<0.01	0.00	0.00	14.38	<0.01	other acidic
1.4	20-40	fine	4.71	3.60	4.28		4.86	15.97	<0.01	0.00	0.00	15.97	<0.01	other acidic
1.5	40-90	fine	4.80	3.92	4.38		4.94	12.92	<0.01	0.00	0.00	12.92	<0.01	other acidic
2.1	0-5	fine	6.18	4.85	5.06	362	5.94	3.05	<0.01	0.00	0.00	3.05	<0.01	other acidic
2.2	5-10	fine	5.28	4.43	4.79		5.30	14.07	<0.01	0.00	0.00	14.07	<0.01	other acidic
2.3	10-20	fine	5.05	4.38	4.67		4.77	19.29	<0.01	0.00	0.00	19.29	<0.01	other acidic
2.4	20-40	fine	4.94	4.43	4.62		4.84	22.85	<0.01	0.00	0.00	22.85	<0.01	other acidic
2.5	40-90	fine	5.13	5.22	4.79		4.94	16.07	<0.01	0.00	0.00	16.07	<0.01	other acidic
3.1	0-5	medium	5.27	3.95	4.99	4230	5.94	4.97	<0.01	0.00	0.00	4.97	<0.01	other acidic
3.2	5-10	medium	4.98	3.55	4.59		5.40	9.52	<0.01	0.00	0.00	9.52	<0.01	other acidic
3.3	10-20	fine	5.00	3.34	4.39		5.26	11.08	<0.01	0.00	0.00	11.08	<0.01	other acidic
3.4	20-40	fine	4.59	3.60	4.15		5.13	11.12	0.03	0.00	0.00	32.23	<0.01	hypersulfidic#
3.5	40-90	fine	4.58	4.43	4.14		5.25	10.14	<0.01	0.00	0.00	11.09	<0.01	other acidic
4.1	0-5	fine	5.30	3.99	5.22	8340	6.44	16.10	<0.01	0.00	0.00	17.91	<0.01	other acidic
4.2	5-10	fine	4.88	4.07	4.21*		5.43	10.13	0.01	0.00	0.00	18.82	<0.01	hypersulfidic#
4.3	10-20	fine	4.77	3.33	3.93		5.19	12.33	0.02	0.00	0.00	24.89	<0.01	hypersulfidic
4.4	20-40	fine	4.65	3.84	4.14		5.12	12.80	<0.01	0.00	0.00	12.80	<0.01	other acidic
4.5	40-90	fine	5.31	5.10	4.59		5.12	13.41	<0.01	0.00	0.00	13.41	<0.01	other acidic

***** Indicates that a stable pH has not yet been reached for this sample (after 17 weeks). # Classified as hypersulfidic based on positive net acidity.

Table 8-38. Field hydrochemistry data for acid sulfate soil assessment of Boeill Lagoon (Wetland ID 21920/21921).

Site and Layer ID.	Temperature (Deg C)	Specific Electrical Conductivity (µS/cm)	Dissolved Oxygen (%)	Dissolved Oxygen (mg/L)	pH	ORP	Redox potential (mV))	Turbidity (NTU)	HCO_3 (mg/L)	Comment
*Lowland River**		*125-2200*	*85-110*		*6.5-8.0*			*6-50*		
*Freshwater Lakes**		*20-30*	*90-110*		*6.5-8.0*			*1-20*		
21920_6 (PW)	24.4	24370		0.52	5.77		-15	n.a.	270	Turbidity not measured
21920_7 (SW)	32.2	249100		n.a.	7.54		224	305.0	215	DO out of range
21920_8 (SW)	26.5	406000		0.24	7.07		-271	159.9	600	

* ANZECC water quality guidelines for lowland rivers and freshwater lakes/reservoirs in South-east Australia are provided for relevant parameters (there are currently no trigger values defined for 'Wetlands') (ANZECC/ARMCANZ, 2000). Surface water values outside the ranges defined in the ANZECC guidelines are indicated with red text. (SW) and (PW) indicate whether the sample was taken from surface water or pore-water, respectively.

Table 8-39. Laboratory hydrochemistry data for acid sulfate soil assessment of Boeill Lagoon (Wetland ID 21920/21921).

Parameter	units	ANZECC Guidelines	Site 6 (PW)	Site 7 (SW)	Site 8 (SW)
depth	cm				
Na	mg l^{-1}		5,154	56,732	75,510
K	mg l^{-1}		37	330	216
Ca	mg l^{-1}		353	2,679	825
Mg	mg l^{-1}		795	9,623	9,610
Si	mg l^{-1}		27.5	2.9	5.2
Br	mg l^{-1}		35.9	493.22	745.38
Cl	mg l^{-1}		11,858	171,277	211,720
NO_3	mg l^{-1}	0.7	0.289	0.014	0.023
NH_4-N	mg l^{-1}	0.01	36.443	3.572	3.972
PO_4-P[E]	mg l^{-1}	0.005	0.027	0.166	0.393
SO_4	mg l^{-1}		286	4,395	10,089
Ag	µg l^{-1}	0.05	<1	2	1
Al[A]	µg l^{-1}	55	14	<1	<1
As[B]	µg l^{-1}	13	<10	38	317
Cd	µg l^{-1}	0.2	<1	1	1
Co	µg l^{-1}	2.8	7	19	18
Cr[C]	µg l^{-1}	1	<5	<5	<5
Cu[H]	µg l^{-1}	1.4	<5	<5	<5
Fe	µg l^{-1}	300	95,529	1,246	742
Mn	µg l^{-1}	1700	16,911	27,952	6,248
Ni[H]	µg l^{-1}	11	<5	28	<5
Pb[H]	µg l^{-1}	3.4	8	5	2
Se	µg l^{-1}	11	n/a	n/a	n/a
Zn[H]	µg l^{-1}	8	16	<5	7
DOC	mg l^{-1}		n/a	n/a	n/a

Notes.

The ANZECC guideline values for toxicants refer to the Ecosystem Protection – Freshwater Guideline for protection of 95% of biota in 'slightly-moderately disturbed' systems, as outlined in the Australian Water Quality Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ, 2000). For the nutrients NH_4 and PO_4, guideline values are provided for Freshwater Lakes and Reservoirs. Surface water values outside the ranges defined in the ANZECC guidelines are indicated with red text. (SW) and (PW) indicate whether the sample was taken from surface water or pit-water (groundwater that entered an excavated pit), respectively.

A *Guideline is for Aluminium in freshwater where pH > 6.5.*
B *Guideline assumes As in solution as Arsenic (AsV).*
C *Guideline is for Chromium is applicable to Chromium (CrVI) only.*
E *Guideline is for filterable reactive phosphorous (FRP).*
H *Hardness affected (refer to Guidelines).*

Table 8-40. Site description data for acid sulfate soil assessment of Boeill Lagoon (Wetland ID 21920).

Site No.	Depth to Water Table (cm)	Surface Condition	Earth Cover (Vegetation)	Location Notes	Rationale for site selection	ASS Soil Classification	Comments
1	Beyond sampling depth	Dry	Dense microbiotic crust	NW inlet channel. Centre of channel.	Spatial representation of inlet channels.	Other acidic	
2	Beyond sampling depth	Dry	Dense microbiotic crust	W inlet channel. Depression in centre of channel.	Spatial representation of inlet channels.	Other acidic	
3	Beyond sampling depth	Dry	Bare	SW inlet channel. Shallow pondage in centre of channel.	Spatial representation of inlet channels.	Other acidic	
4	Beyond sampling depth	Dry	Moderate Salt bush and Leaf Litter	NE inlet channel. Centre of channel.	Spatial representation of inlet channels.	Hyposulfidic	
5	Beyond sampling depth	Moist	Bare	Main channel. NE bank adjacent to reed beds.	Elevated site.	Hypermonosulfidic	
6	14	Moist	Bare	Main channel. Centre of channel.	Moderately elevated site.	Hypermonosulfidic	Thick salt crust of different colours.
7	-6	Sub-aqueous	Sub-aqueous	Pond in main channel. Centre of pond.	Low point in main channel.	Hypermonosulfidic	Strong H_2S odour on disturbance. Salt crust on bed.
8	-90	Sub-aqueous	Sub-aqueous	Hyper saline pond in main channel. Centre of pond.	Low point near River Murray.	Hypomonosulfidic	Black cloudiness in water disturbed by wind.

Table 8-41. Site description data for acid sulfate soil assessment of Boeill Lagoon (Wetland ID 21921).

Site No.	Depth to Water Table (cm)	Surface Condition	Earth Cover (Vegetation)	Location Notes	Rationale for site selection	ASS Soil Classification	Comments
1	Beyond sampling depth	Dry	Sparse low succulent perennials	Eastern reach of billabong. Centre of channel.	Elevated site.	Other acidic	
2	Beyond sampling depth	Dry	Dense groundcovers	Northern section of Billabong. Centre of channel.	Low point in vegetated section.	Other acidic	
3	Beyond sampling depth	Dry	Moderate succulent perennials and leaf litter	Centre of billabong. Point bar.	Elevated site on point bar.	Hypersulfidic	
4	Beyond sampling depth	Moist	Bare	Centre of Billabong. Only area with moist surface.	Low point in bare section.	Hypersulfidic	

Table 8-42. Profile description data for acid sulfate soil assessment of Boeill Lagoon (Wetland ID 21920).

Site and Sample No.	Horizon Depth Range (cm)	Soil Colour - moist	Texture Class	Moisture State	Redoximorphic Features Abundance	Redoximorphic Features - Kind	Redoximorphic Features - Colour	Structure - Type	Structure - Grade	pH (field measurement)	Comments (odour, fragments, minerals, plant material, inclusions, other)
1.1	0-5	5Y 6/3	FCS	D	1	M	2.5Y 6/8	SB	M	5.41	
1.2	5-10	5Y 6/3	FSL	D	2	M	2.5Y 6/8	SB	M	4.94	
1.3	10-20	5Y 4/2	ZLC	D	2	M	2.5Y 6/8	SB	M	4.83	
1.4	20-40	5Y 3/2	MC	D	2	M	2.5Y 6/8	SB	S	4.92	
1.5	40-90	5Y 3/2	MHC	D	1	M	2.5Y 6/8	SB	S	4.94	
2.1	0-5	2.5Y 4/1	HC	D	1	M	2.5Y 6/6	SB	S	6.25	
2.2	5-10	2.5Y 4/1	HC	D	1	M	2.5Y 6/6	SB	S	6.00	
2.3	10-20	2.5Y 4/1	HC	D	1	M	2.5Y 6/6	SB	S	6.30	
2.4	20-40	5Y 4/1	HC	D	1	M	2.5Y 5/6	SB	S	6.41	Gravel present.
2.5	40-90	5Y 3/1	HC	T	1	M	2.5Y 5/6	SB	S	6.44	
3.1	0-5	2.5Y 3/4	LMC	D	2	M	7.5YR 5/8	SB	S	5.81	
3.2	5-10	2.5Y 5/4	MC	D	1	M	7.5YR 4/6	SB	S	5.12	Salt present.
3.3	10-20	2.5Y 4/1	MC	T	3	M	10YR 5/8	SB	S	5.14	
3.4	20-40	2.5Y 4/1	MHC	T	1	M	10YR 5/8	SB	S	4.46	
3.5	40-90	2.5Y 4/1	MC	T	1	M	10YR 4/6	SB	S	5.82	
4.1	0-5	2.5Y 4/3	FSCL	D	3	M	7.5YR 4/6	SB	S	7.66	
4.2	5-10	2.5Y 4/3	MHC	D	4	M	7.5YR 4/6	SB	S	6.92	Vesicles present.
4.3	10-20	2.5Y 5/3	ZMHC	D	3	M	7.5YR 4/6	SB	S	5.09	
4.4	20-40	2.5Y 5/3	MHC	D	3	M	7.5YR 4/6	SB	S	4.72	
4.5	40-90	2.5Y 4/2	MHC	T	3	M	2.5YR 3.6	SB	S	4.57	

Table 8-42 (continued). Profile description data for acid sulfate soil assessment of Boeill Lagoon (Wetland ID 21920).

Site and Sample No.	Horizon Depth Range (cm)	Soil Colour - moist	Texture Class	Moisture State	Redoximorphic Features Abundance	Redoximorphic Features - Kind	Redoximorphic Features - Colour	Structure - Type	Structure - Grade	pH (field measurement)	Comments (odour, fragments, minerals, plant material, inclusions, other)
5.1	0-2	5Y 4/2	FSCL	M	2	M	10YR 3/4	SB	W	5.44	Secondary mottle black.
5.2	2-5	5Y 5/3	CLFS	M	2	M	7.5YR 4/6	SB	W	5.25	
5.3	5-10	5Y 5/3	CLFS	M	2	M	7.5YR 4/6	SB	W	5.03	
5.4	10-20	5Y 6/4	FSCL	M	2	M	7.5YR 4/6	SB	W	5.38	Sand lenses.
5.5	20-40	5Y 6/2	CFS	M	1	M	7.5YR 4/6	SB	W	6.86	
5.6	40-50	5Y 5/1	FSC	M	0			SB	W	6.12	
5.7	50-58	5Y 3/1	n/a	M	0			SB	S	5.97	Too wet to field texture.
5.8	58-90	5Y 5/1	n/a	M	0			SB	S	5.92	Too wet to field texture.
6.1	0-5	5Y 5/3	n/a	M	4	M	10R 3/6	SB	S	5.99	Secondary mottle black. Too wet to field texture.
6.2	5-10	5Y 5/3	n/a	M	3	M	10R 3/6	SB	S	6.04	Too wet to field texture.
6.3	10-20	BLACK GEL	n/a	W	0					5.89	Too wet to field texture.
6.4	20-33	BLACK GEL	n/a	W	0					5.89	Too wet to field texture.
6.5	33-40	5Y 4/1	n/a	W	0		GREY GEL			6.12	Too wet to field texture.
6.6	40-90	5Y 4/1	n/a	W	0			SB	S	5.92	Too wet to field texture.
7.1	0-5	GLEY 1 2.5/N	n/a	W						6.34	Black MBO.
7.2	5-10	GLEY 1 2.5/N	n/a	W						6.21	Black MBO.
7.3	10-20	GLEY 1 2.5/N	n/a	W						6.22	Black MBO.
8.1	0-5	GLEY 1 2.5/N	n/a	W						6.46	Black MBO.
8.2	5-10	GLEY 1 2.5/N	n/a	W						6.52	Black MBO.
8.3	10-20	GLEY 1 2.5/N	n/a	W						6.78	Black MBO.

Table 8-43. Profile description data for acid sulfate soil assessment of Boeill Lagoon (Wetland ID 21921).

Site and Sample No.	Horizon Depth Range (cm)	Soil Colour - moist	Texture Class	Moisture State	Redoximorphic Features Abundance	Redoximorphic Features - Kind	Redoximorphic Features - Colour	Structure - Type	Structure - Grade	pH (field measurement)	Comments (odour, fragments, minerals, plant material, inclusions, other)
1.1	0-5	5Y 4/2	LMC	T	1	M	5YR 6/8	n.a.	V	4.64	Salt fissures. V/D2.
1.2	5-10	5Y 5/1	LMC	T	3	M	10YR 5/8	SB	M	4.56	
1.3	10-20	5Y 5/1	HC	T	2	M	10YR 5/8	SB	S	4.47	
1.4	20-40	5Y 5/1	HC	T	3	M	10YR 5/8	SB	S	4.46	
1.5	40-90	5Y 4/2	MHC	T	2	M	10YR 5/8	SB	S	4.55	
2.1	0-5	5Y 5/1	LMC	D	1	M	10YR 5/8	SB	W	5.68	Hydrophobic, dense roots present.
2.2	5-10	5Y 5/1	MC	D	1	M	10YR 5/8	SB	M	5.38	Salt present.
2.3	10-20	2.5Y 4/2	MC	D	3	M	10YR 5/8	SB	S	4.88	
2.4	20-40	2.5Y 5/1	HC	D	2	M	10YR 5/8	SB	S	4.86	
2.5	40-90	2.5Y 5/1	HC	T	1	M	10YR 5/8	SB	S	5.16	
3.1	0-5	2.5Y 4/2	FLC	D				SB	W	5.41	
3.2	5-10	2.5Y 4/2	FLC	M	2	M	10YR 5/8	SB	M	4.59	Salt present.
3.3	10-20	2.5Y 4/2	FMHC	M	2	M	10Y 4/6	SB	S	4.67	
3.4	20-40	5Y 4/2	FMC	M	2	M	7.5YR 4/6	SB	M	4.40	
3.5	40-90	2.5Y 4/2	FLMC	M	4	M	2.5YR 4/6	SB	M	4.76	
4.1	0-5	5Y 4/2	LMC	T				SB	M	5.10	
4.2	5-10	5Y 4/2	LMC	T	3	M	10YR 3/3	SB	S	4.53	
4.3	10-20	5Y 4/2	MHC	T	2	M	10YR 3/3	SB	S	4.33	
4.4	20-40	5Y 5/2	MC	T	2	M	7.5YR 4/4	SB	S	4.37	
4.5	40-90	5Y 5/2	MHC	M	2	M	7.5YR 4/4	SB	S	4.64	Seepage at 60 cm depth.

APPENDIX 2. ASSRAP screening criteria

Table 8-44: Screening criteria for selecting detailed acid sulfate soil assessment study areas developed by the Scientific Reference Panel of the Acid Sulfate Soils Risk Assessment Project (source: MDBA 2010).

Parameter	Trigger value	Action required	Priority
pH soil*	<4 4 – 5.5 >5	Detailed assessment Detailed assessment No further assessment	Extreme Moderate N/A
pH water	<5.5 5.5 – 6.5 >6.5	Detailed assessment Detailed assessment No further assessment	High Moderate N/A
EC soil (1:5)	>1000 µS cm^{-1} 400 – 1000 µS cm^{-1} <400 µS cm^{-1}	Detailed assessment Detailed assessment No further assessment	High Moderate N/A
EC water	>5000 µS cm^{-1} 1750 – 5000 µS cm^{-1} <1750 µS cm^{-1}	Detailed assessment Detailed assessment No further assessment	High Moderate N/A
Sulfate soil	>500 mg/L 100 – 500 mg/L <100 mg/L	Detailed assessment Detailed assessment No further assessment	High Moderate N/A
Sulfate water	>50 mg/L 10 – 50 mg/L <10 mg/L	Detailed assessment Detailed assessment No further assessment	High Moderate N/A

* As determined by both in-field measurements and subsequent analysis of samples collected in chip-trays.