Assessment of Acid Sulfate Soil Materials in Ramsar Wetlands of the Murray-Darling Basin: Currawinya Lakes (Currawinya National Park)

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Cover Photographs:

Typical landscape at the Currawinya Lakes Ramsar wetland. Photograph taken at Site RSCL 2 in the Currawinya Lakes wetland.

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EXECUTIVE SUMMARY

The Currawinya Lakes (Currawinya National Park) wetland consists of a mosaic of low dunefields, lakes, claypans and saltpans. The lower areas, prone to waterlogging, occupy a central strip between the rugged hills and scarps to the north and west which rise 50 m or more above the surrounding sand plains. The Currawinya Lakes wetland has the Queensland/New South Wales border as its southern-most boundary, with Hungerford being the nearest town, 36 km to the south east. The wetland system occupies an area of about 151,300 hectares.

The Murray-Darling Basin Authority (MDBA), in partnership with its Partner Governments and scientists, instigated the Murray-Darling Basin Acid Sulfate Soils 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.

Due to their ecological significance, a decision was made by the MDB Acid Sulfate Soils Risk Assessment Advisory Panel to prioritise the Ramsar-listed wetland complexes of the Murray-Darling Basin for immediate detailed acid sulfate soil assessment. This report provides the results of Phase 1 of a two-phased detailed acid sulfate soil assessment procedure for the Currawinya Lakes Ramsar wetland. This Phase 1 report is aimed solely at determining whether or not acid sulfate soil materials are present in the Currawinya Lakes Ramsar wetland.

Sulfuric soil materials were not observed in these wetlands. The reduced inorganic sulfur content of the samples was high in the salt lake areas (i.e. S_{CR} was up to 0.61%). Hypersulfidic soil materials were present in three soil profiles (one profile also contained hyposulfidic materials), and another two soil profiles contained hyposulfidic materials with $S_{CR} \geq 0.10\%$. 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.

Monosulfidic black oozes (MBOs) were observed in 11% (i.e. 2) of the sampling sites. Nine of the surficial soil materials contained water soluble sulfate in excess of the 100 mg kg^{-1} 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 Soils Risk Assessment Project, there were three high priority sites based on the presence of hypersulfidic material, and two high priority sites based on the presence of a hyposulfidic material with $S_{CR} \geq 0.10\%$. There were also a further three moderate priority sites based on the presence of a hyposulfidic material with $S_{CR} < 0.10\%$. In addition, 9 sampling sites had a high priority ranking for Phase 2 detailed assessment based on MBO formation hazard.

The potential hazards posed by acid sulfate soil materials at the Currawinya Lakes Ramsar wetland sites are as below:

- Acidification: The data indicate that with low titratable actual acidities (TAA) and only four hypersulfidic soil materials with low to moderate net acidities that the degree of acidification hazard is low.

- Deoxgenation: The water soluble sulfate contents of nine surface soil materials 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 produce excessive metal mobilisation. However, the potential for MBO formation identified in these wetlands 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.

While this study showed the presence of acid sulfate soil materials in the Currawinya Lakes Ramsar wetland, when considering the wetlands as a whole there is a low priority for further assessment to determine specific acid sulfate soil risks. As such, the Scientific Reference Panel of the Murray-Darling Basin Acid Sulfate Soils Risk Assessment Project agreed that Phase 2 detailed assessment of acid sulfate soil materials was not required for the Currawinya Lakes Ramsar wetland.

1. INTRODUCTION

1.1. *Wetland overview*

The formal name of this Ramsar wetland is the “Currawinya Lakes (Currawinya National Park)” and hereafter referred to as “Currawinya Lakes”. The Currawinya Lakes wetland consists of a mosaic of low dunefields, lakes, claypans and saltpans. The lower areas, prone to waterlogging, occupy a central strip between the rugged hills and scarps to the north and west which rise 50 m or more above the surrounding sand plains. There are numerous lakes and swamps scattered across alluvial areas of relatively uniform relief and similar geological age. However, the quality of water in these areas can vary considerably, ranging from freshwater to strongly brackish in near vicinity of each other and divided only by low levees. The Currawinya Lakes wetland has the Queensland/New South Wales border as its southern-most boundary, with Hungerford being the nearest town, 36 km to the south east. The wetland system occupies an area of about 151,300 hectares. The rugged hills and scarps on the north of the Park represent the southern extension of the Hoods Range. This range mostly consists of deeply weathered sediments of the Cretaceous Winton Formation. Current uses on the site are conservation management, recreation, and scientific study. Surrounding areas are used for extensive grazing.

The typical landscape observed in the Currawinya Lakes wetland at the time of sampling is shown in Figure 1-2, and a typical soil profile is given in Figure 1-3. Further information on characteristics of the Currawinya Lakes from the Ramsar Site Information Sheet can be found at Qld EPA (1999).

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).

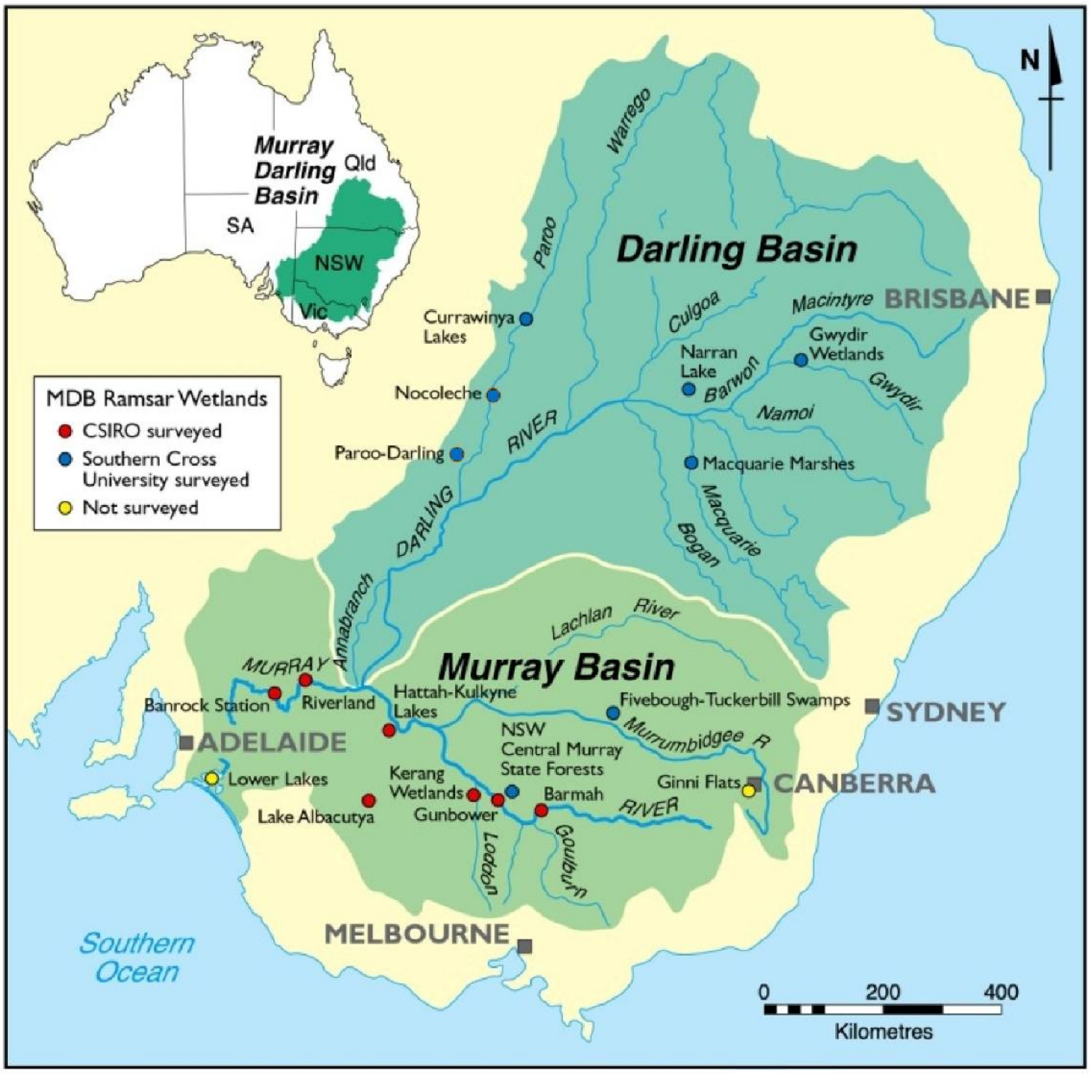

Figure 1-1 Map of Ramsar Wetlands surveyed in the Murray-Darling Basin.

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 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.* 2006; 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.

The project established a list of more than 10,000 wetlands that were then assessed against a number of criteria aimed at identifying those that had potential for acid sulfate soil occurrence. 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 (Figure 1-1). Wetlands within these complexes were then identified and selected for further assessment.

Southern Cross GeoScience carried out a detailed assessment at 18 representative sites within the Currawinya Lakes Ramsar wetland between the 4th and 6th August 2008 to determine whether acid sulfate soils were present, or if there was a potential for acid sulfate soil to form within these wetlands (Figure 1-4). 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.

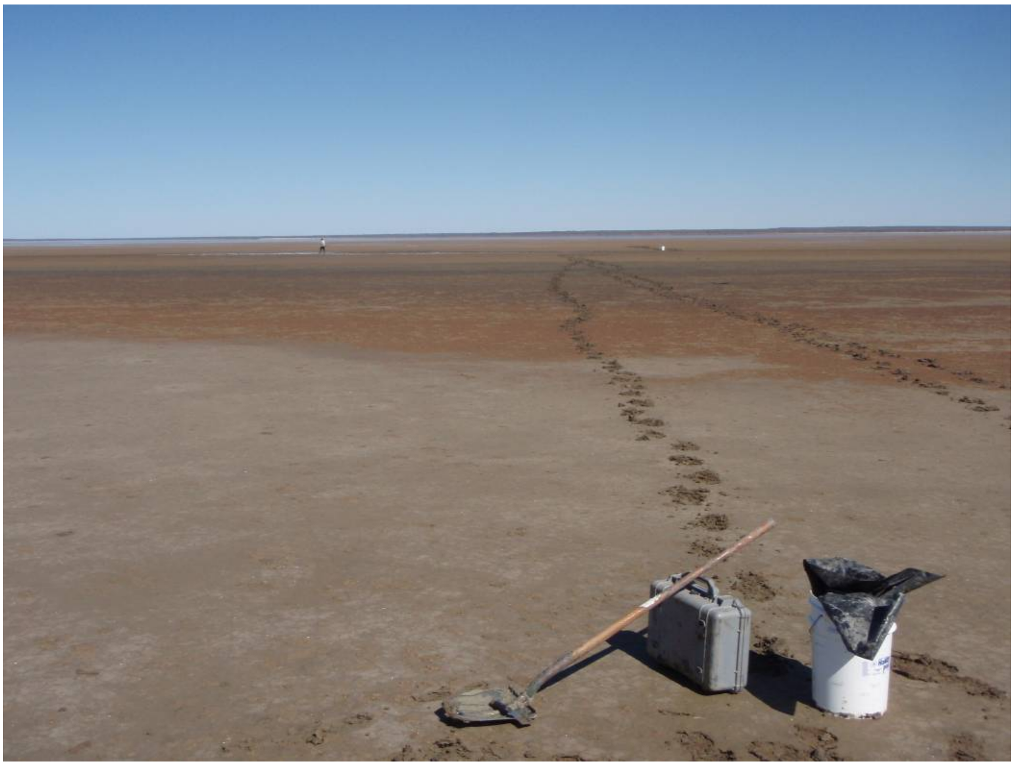

Figure 1-2 Typical landscape in the Currawinya Lakes Ramsar wetland. Photograph taken at the northern end of Lake Wyara (Site RSCL 2).

Figure 1-3 Typical waterlogged profile in the Currawinya Lakes Ramsar wetland (Site RSCL 1). Accumulations of black MBOs beneath a very thin brown clay veneer were present at the soil surface.

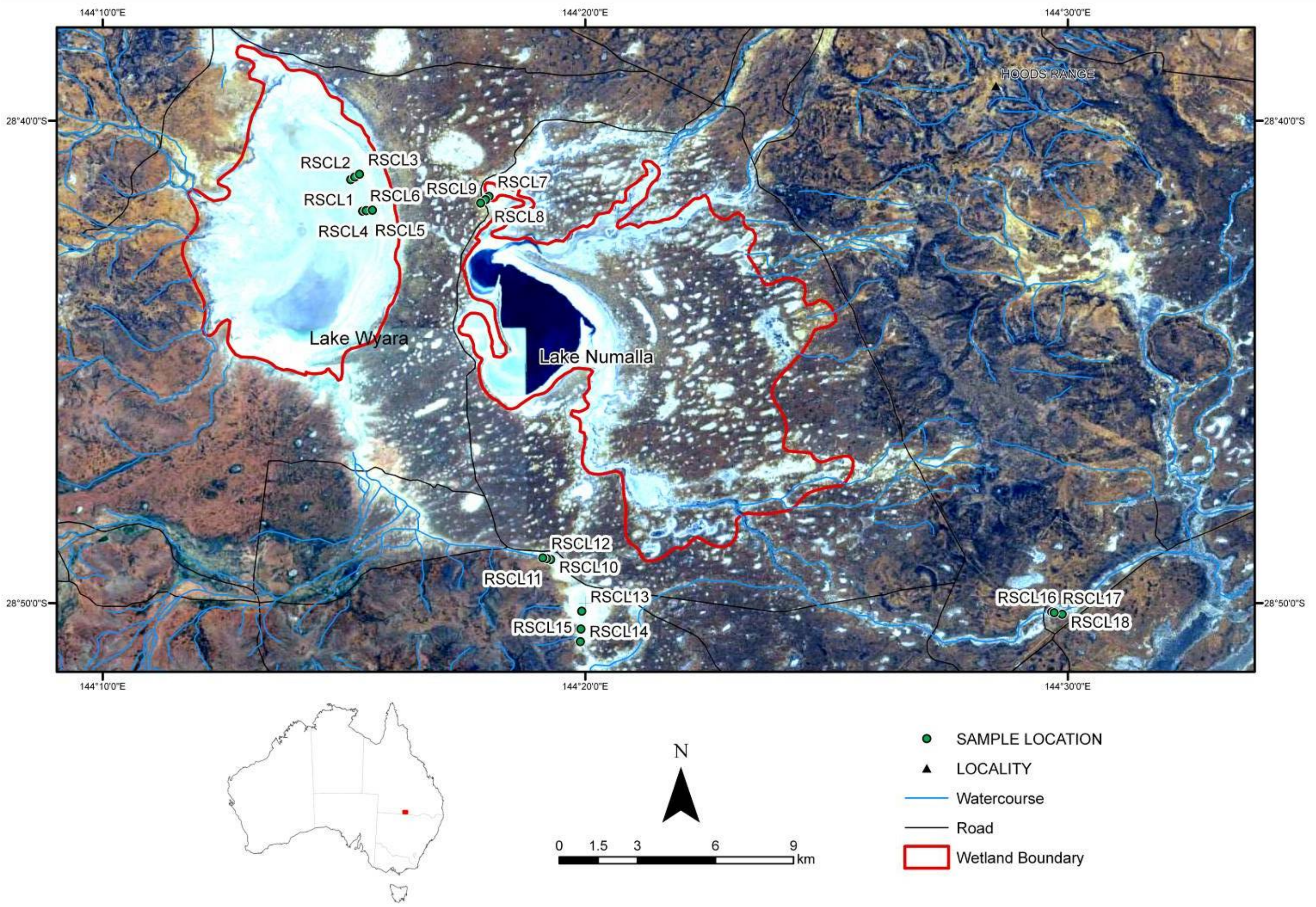

Figure 1-4 Map showing the areas assessed in the Currawinya Lakes Ramsar wetlands (RSCL 1-18).

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 being developed by the MDB ASS Risk Assessment Project Scientific Reference Panel requires a two-phase procedure.

Phase 1 aims to determine whether or not acid sulfate soil materials are present in each wetland by:

a. Consulting with relevant managers of that wetland.
b. Field descriptions of soils and sampling, including pH (e.g. using Merck test strips) and specific electrical conductance (SEC) testing.
c. Photographic record of sites and soil profiles.
d. Sampling and sub-sampling in chip trays.
e. Field testing of water quality parameters (pH, specific electrical conductance (SEC), redox potential (Eh), dissolved oxygen (DO), alkalinity by titration, and turbidity).
f. Laboratory analyses to conclusively identify the presence or absence of sulfuric, sulfidic or MBO acid sulfate soil materials using incubation (“ageing pH”) in chip trays, pH peroxide testing and sulfur suite and partial acid base accounting: S_{CR} (sulfide % S), pH_{KCl}, and TAA (titratable actual acidity: moles H^+/tonne), acid neutralising capacity (ANC) where soil materials were sulfidic, acid volatile sulfide (AVS) and water-extractable SO_4 (1:5 soil:water suspension).
g. Surface water and groundwater chemical and nutrient analyses.

Phase 2 is only pursued if results of Phase 1 dictate and the MDB ASS Risk Assessment Advisory Panel recommend further detailed investigation. Phase 2 aims to determine the nature and severity of the environmental hazards posed by the acid sulfate soil materials, if present, by:

a. Continued incubation of samples in chip trays.
b. More detailed acid/base accounting (e.g. elemental sulfur).
c. Rapid metal release.
d. Contaminant and metalloid dynamics.
e. MBO formation potential.
f. Mineralogy by X-ray diffraction (XRD).
g. Major and trace elements by X-ray fluorescence spectroscopy (XRF).
h. Archiving of all soil samples in CSIRO archive (as chip trays and bulk samples).

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 Currawinya Lakes Ramsar wetland.

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 (rewetting).

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 ABA applicable to acid sulfate soil is as described in Ahern *et al*. (2004) as shown below:

Net Acidity = Potential Sulfidic Acidity + Existing Acidity – ANC*/Fineness Factor

*** ANC = Acid Neutralizing Capacity**

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

Potential Sulfidic Acidity

The Potential Sulfidic Acidity is most easily and accurately determined by assessing the Chromium Reducible Sulfur. This method was developed specifically for analysing acid sulfate soil materials (Sullivan *et al*. 2000) to, inter alia, assess their Potential Sulfidic Acidity (PSA) also known as the ‘acid generation potential’ (AGP). The method is also described in Ahern *et al*. (2004), which includes the chromium reducible sulfur (S_{CR} or CRS: Method Code 22B) and its conversion to PSA.

Existing Acidity

This is the sum of the Actual Acidity and the Retained Acidity (Ahern *et al*. (2004). Titratable Actual Acidity (TAA) is a measure of the actual acidity in acid sulfate soil materials that have already oxidised. TAA measures the sum of both soluble and exchangeable acidity. The Retained Acidity is the acidity ‘stored’ in minerals such as jarosite, schwertmannite and other hydroxysulfate minerals. Although these minerals may be stable under acidic conditions, they can release acidity to the environment when these conditions change. The methods for determining both TAA and Retained Acidity are given by Ahern *et al*. (2004).

Acid Neutralising Capacity (ANC)

Soils with pH values > 6.5 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 is expressed in $CaCO_3$ equivalents. By accepted definition (Ahern *et al*. 2004), any acid sulfate soil material with a pH < 6.5 has a zero ANC. The methods for determining ANC are given by Ahern *et al*. (2004).

Fineness Factor (FF)

This 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 when 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.

Water extractable sulfate (1:5 soil:water suspension)

A 1:5 soil:water extract is prepared using 5g oven dried (80^{o}C) soil following the procedures described in Rayment and Higginson (1992). After shaking end-over-end for 4 hours, the suspensions are subject to 10 minutes centrifugation at 4000 rpm. The supernatant is filtered (0.45 μm) and sulfate concentration determined by turbidimetric analysis using a HACH spectrophotometer (or suitable alternative analytical technique for sulfate). Soluble sulfate content is expressed on a dry mass basis. Sulfate contents >10 mg L^{-1} in water of inland water bodies such as wetlands and rivers give a strong indication that the soil materials underlying those water bodies are able to sulfidise (Sullivan *et al*. 2002a, Baldwin *et al*. 2007, Sullivan *et al*. 2008a) forming monosulfidic black oozes (MBOs) or sulfidic sediments. In dry soils where there are no overlying water bodies, it is considered that water soluble sulfate contents of greater than or equal to 100 mg kg^{-1} in the surface soil layers (i.e. soil layers in the top 20 cm of the soil profile) would be able to create similar sulfate contents in overlying water bodies as a result of inundation. Therefore this soil sulfate content of greater than or equal to 100 mg kg^{-1} in surface soil layers has been selected to indicate whether or not surface soil materials from dry wetlands should be examined in the Phase 2 of the detailed assessment for the capacity of these soil materials to form monosulfidic soil materials upon inundation using the approach of Sullivan *et al*. (2008a).

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 new descriptive terminology and classification definitions of acid sulfate soil materials proposed by Sullivan *et al*. (2008b) at the 6th International Acid Sulfate Soil and Acid Rock Drainage Conference in September 2008 in Guangzhou, China. This new classification system for acid sulfate soil materials has also been recently (October 2008) adopted by the Scientific Reference Panel of the Murray-Darling Basin Acid Sulfate Soils Risk Assessment Project for use in the detailed assessment of acid sulfate soil 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 pHw < 4 as a result of sulfide oxidation.

2) ***Sulfidic materials** – soil materials containing detectable sulfide minerals (defined as containing ≥ 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.

In addition the Scientific Reference Panel of the Murray-Darling Basin Acid Sulfate Soils 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). Also the acidity present in field soils may be due to the accumulation of acidic organic matter and/or the leaching of bases. Of course, these acidic soil materials may also pose a risk to the environment and would be identified during the 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; or
   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. Currawinya Lakes site characteristics

Locations sampled in this study were uniformly flat and in many areas the surface soil was bare (e.g. Figure 2-2). The textures of the soil materials sampled ranged from clay loam to light-medium clay (Appendix 2).

Many of the Currawinya Lakes wetland sites were waterlogged at the time of sampling, and sampling transects were established to traverse the lake edge transition. At the northern end of Lake Wyara (a salt lake) there was no vegetative cover in the ~300m wide zone between the water's edge and the dunes that mark the lake's high water level edge. The Duty Ranger advised that water levels at the time of sampling were at ~20% capacity. Monosulfidic black oozes (MBO) were observed at two sites at the time of sampling (Sites RSCL 1 and 4).

A map giving the location of each of the sites sampled and the typical landscape in each of these areas is shown below in Figures 2-1 – 2.6.

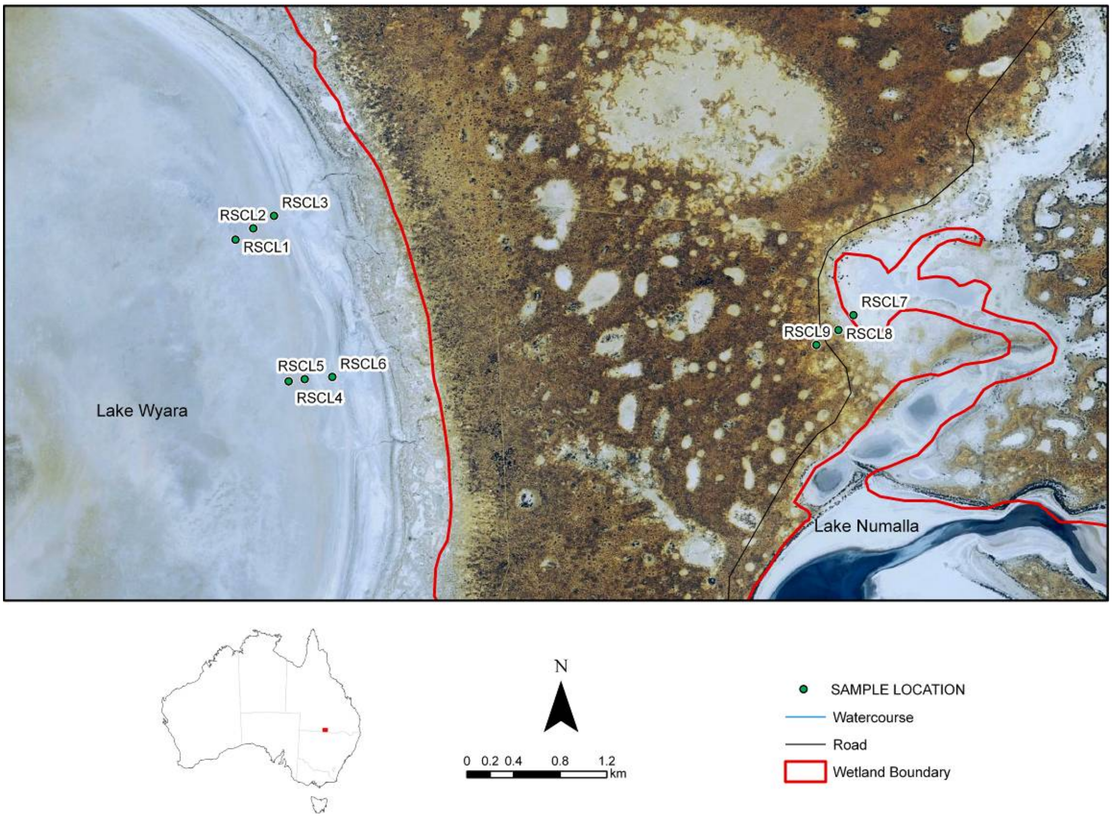

Figure 2-1 Map showing the areas assessed in the Currawinya Lakes Ramsar wetland (Sites RSCL 1-9).

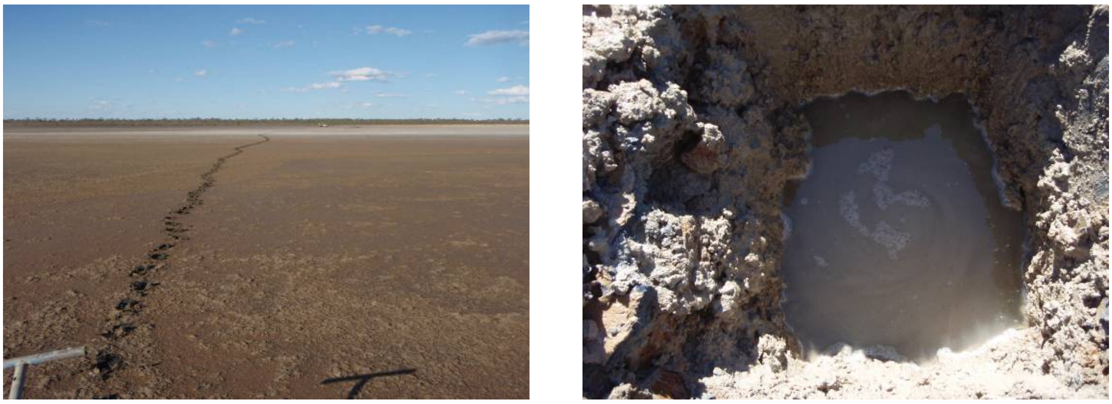

Figure 2-2 Typical landscape at Lake Wyara (Site RSCL 4) and waterlogged profile (Site RSCL 1) in the Currawinya Lakes Ramsar wetland. Site RSCL 1 also had accumulations of black MBO at the soil surface (see Figure 1-3).

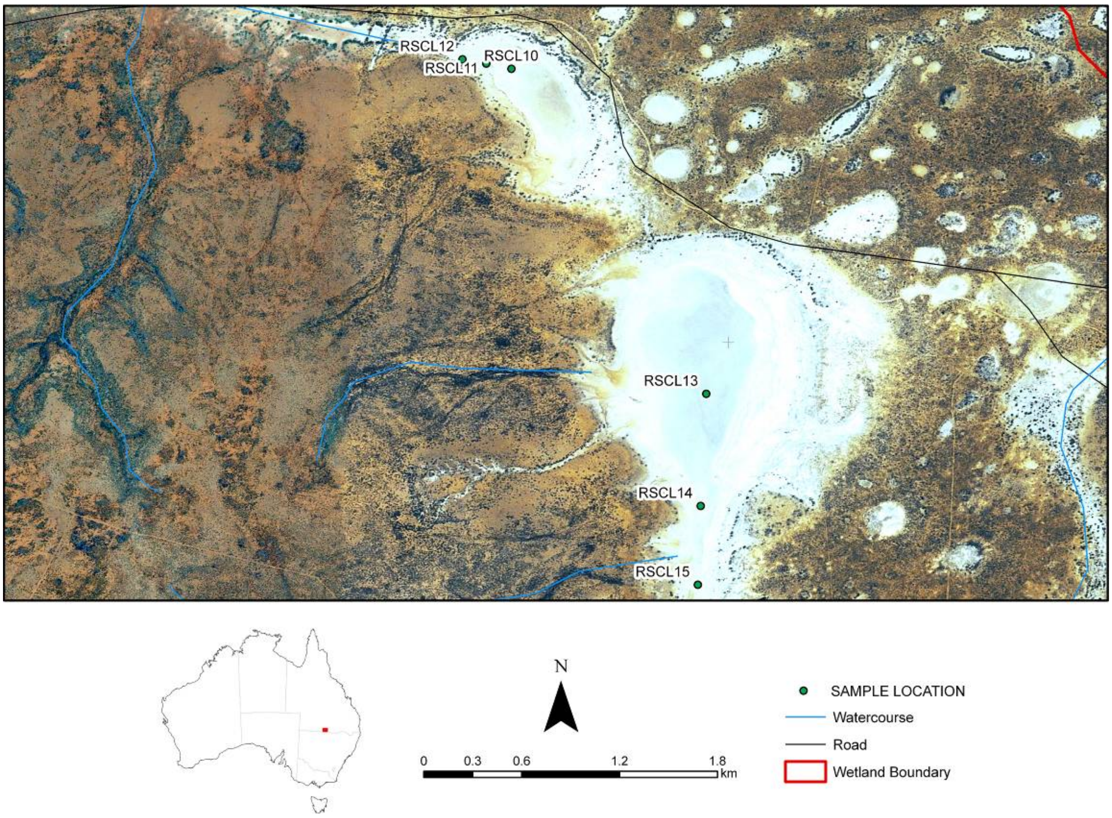

Figure 2-3 Map showing the areas assessed in the Currawinya Lakes Ramsar wetland (Sites RSCL 10-15).

Figure 2-4 Typical wet (Site RSCL 10) and dry (Site RSCL 15) landscapes in the Currawinya Lakes Ramsar wetland. Water quality sample collected and analysed at Site RSCL 10.

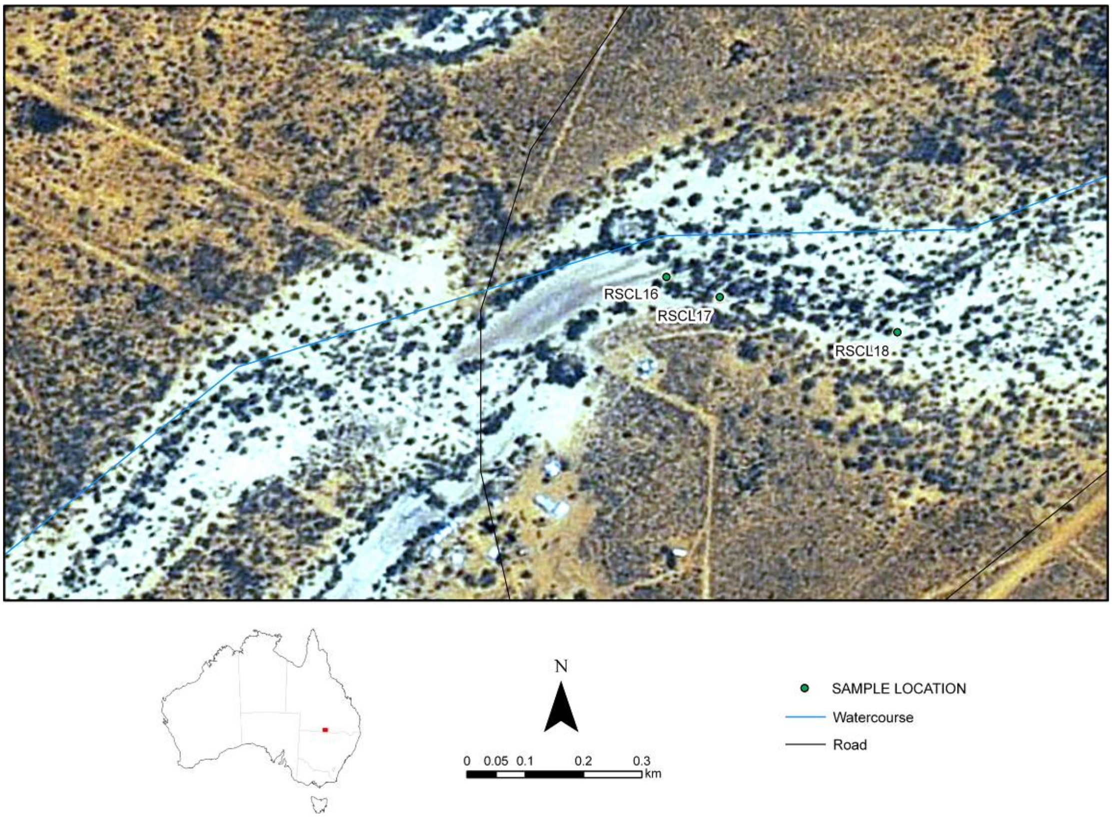

Figure 2-5 Map showing the areas assessed in the Currawinya Lakes Ramsar wetland (Sites RSCL 16-18).

Figure 2-6 Typical landscape (Site RSCL 17) in the Currawinya Lakes Ramsar wetland and soil sampling at Site RSCL 16. Water quality sample collected and analysed at Site RSCL 16.

2.2. Field sampling of soils and waters

Field sampling of the Currawinya Lakes Ramsar wetland sites was undertaken between the 4th and 6th August 2008. A total of 95 soil layers were collected and analysed from 18 representative soil profiles within the Currawinya Lakes to assess the current and potential environmental hazard due to the presence of acid sulfate soils.

Representative soil profiles were collected from 6 locations within the Currawinya Lakes Ramsar wetland. At each of these locations soil profiles were sampled along a toposequence. Where possible 3 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 4 sampling depths (to a maximum depth of 90 cm) using a range of implements (i.e. spades and augers). Samples were packed into plastic bags in which retained air was minimised. All soil samples were maintained at $\leq 4^{o}$C prior to analysis.

Site and profile descriptions including global positioning system (GPS) coordinates are presented in Appendix 1. The soil texture and Munsell colour of each sampled soil layer is presented in Appendix 2. Digital photographs were also taken to document each site and soil profile characteristics. Photographs for a selection of representative sites can be found in Section 2.1.

Surface water quality data was collected from 6 locations in the Currawinya Lakes (Site RSCL 1, 4, 7, 9, 10 and 16). Groundwater data was collected from 2 sites (Sites RSCL 1 and 4).

Surface water pH, specific electrical conductivity (SEC), dissolved oxygen (DO) and redox potential (Eh) were determined in the field using calibrated electrodes linked to a TPS 90-FLMV multi-parameter meter. Turbidity was measured using a calibrated TPS WP88 Turbidity meter. Alkalinity was also determined in the field by acid titration.

Surface water samples were collected in 1L polypropylene containers. Filtered (0.45 µm) and unfiltered surface water samples were collected at each location. All filtered samples were acidified with a couple of drops of concentrated nitric acid (HNO_3). Samples were stored at $< 4^{o}$C and sent to CSIRO for analysis.

2.3. Laboratory soil analysis methods

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

Several parameters were examined to determine whether acid sulfate soils were present, or if there was a potential for acid sulfate soil 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 and chromium reducible sulfur (S_{CR}).

The existing acidity of each soil layer (pH_W) was assessed by measuring the pH in a saturated paste (1:1 soil:water mixture). The pH_{FOX} was determined following oxidation with 30 % hydrogen peroxide (H_2O_2) (Method Code 23Bf) (Ahern *et al.* 2004). 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) (i.e. sum of soluble and exchangeable acidity) 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. The pH following incubation ($pH_{INCUBATION}$) was determined on duplicate moistened sulfidic soil materials (i.e. $S_{CR} \geq 0.01\%$ S) placed in chip trays using pH indicator strips. 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 prepared following the procedures described in Rayment and Higginson (1992), and 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).

Acid Neutralising Capacity, measured by the ANC_{BT} method (Method Code 19A2) (Ahern *et al.* 2004) was determined for sulfidic samples to enable Net Acidity to be estimated by the Acid Base Account method of Ahern *et al.* 2004.

Standard quality assurance (QA) procedures were followed including the monitoring of blanks, duplicates and standards in each batch.

2.4. Laboratory water analysis

The water quality parameters measured by CSIRO included (i) pH, EC, alkalinity, (ii) dissolved organic carbon, (iii) major anions/nutrients (Cl, Br, NO_2, NO_3, PO_4, SO_4, NH_4, total N & P, B, S), (iv) major cations (Na, K, Ca, Mg), and (v) trace metals (Al, Cd, Co, Cu, Fe, Mn, Mo, Ni, Pb, Se, Zn). EC, pH, alkalinity, nutrient (N and P) and major ion analyses were undertaken on unfiltered samples (centrifuged and no visible suspended solids present). Dissolved metals were analysed on filtered samples.

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 Soils 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 kg^{-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 Currawinya Lakes field and laboratory results

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

The pH_W, pH_{FOX}, pH_{KCl} and $pH_{INCUBATION}$ data for the Currawinya Lakes sites examined is presented in Table 7-2 (Appendix 2) and summarised in Table 3-1. The pH_W values ranged between 6.50 and 9.29, with the majority of the samples having a $pH_W > 7.0$. None of the soils in the Currawinya Lakes would be classified as being sulfuric materials as all soils had a $pH_W > 4$.

The pH_{FOX} values ranged between 3.03 and 9.32. The majority of the soils either showed a pH drop or minimal change in pH after treatment with peroxide (Figures 3-1 – 3-8), with a maximum decrease of 4.3 pH units. The pH_{FOX} results also indicate that 4 of the surface soils in the Currawinya Lakes may have the potential to acidify to pH < 4 as a result of sulfide oxidation. However, the S_{CR} data shows only 2 of these layers contain detectable sulfide (i.e. $S_{CR} \geq 0.01\%$ 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. None of the sulfidic soil materials (i.e. $S_{CR} \geq 0.01\%$ S) acidified to a pH of less than 4 after at least 8 weeks of incubation.

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

Parameter	Units	Minimum	Median	Maximum	n[1]
pH_W[2]		6.50	8.10	9.29	95
pH_{FOX}[3]		3.03	7.73	9.32	95
pH_{KCl}[4]		4.74	8.04	9.25	95
$pH_{INCUBATION}$[5]		4.9	7.3	8.1	23
TAA[6]	mole H^+/tonne	0.00	3.57	12.16	95
Soluble SO_4[7]	mg SO_4 kg^{-1}	15	1389	47334	95
S_{CR}[8]	Wt. %S	<0.01	<0.01	0.61	95
ANC* [9]	%$CaCO_3$	0.00	3.54	10.83	23
Net Acidity[10]	mole H^+/tonne	-1,405.2	-138.7	32.7	36

[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] ANC: Acid Neutralising Capacity: by definition, where pH_{KCl} < 6.5 ANC = 0. [10] Net Acidity here does not include allowance for Retained Acidity.

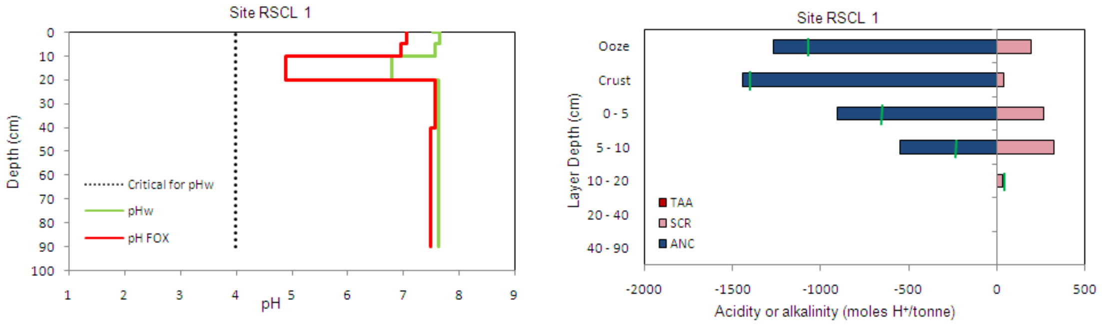

Figure 3-1 Soil pH and acid base accounting data for soil profile RSCL 1. Left Plot: Soil (pH$_W$: green line) and peroxide pH (pH$_{FOX}$: red line). Right Plot: TAA (red bar), S$_{CR}$ (pink bar), ANC (blue bar) and Net Acidity for sulfidic layers (green line). (Note: ANC was only required to be determined for sulfidic layers and was zero at this site for the 10-20 cm soil layer).

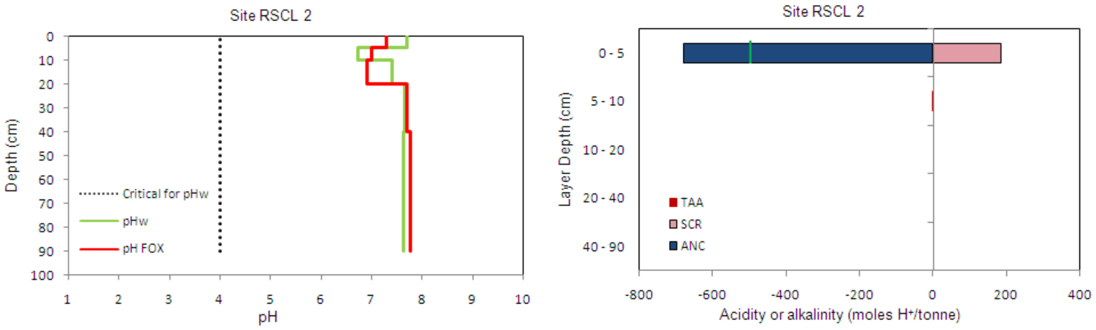

Figure 3-2 Soil pH and acid base accounting data for soil profile RSCL 2. Left Plot: Soil (pH$_W$: green line) and peroxide pH (pH$_{FOX}$: red line). Right Plot: TAA (red bar), S$_{CR}$ (pink bar), ANC (blue bar) and Net Acidity for sulfidic layers (green line). (Note: ANC was only required to be determined for sulfidic layers).

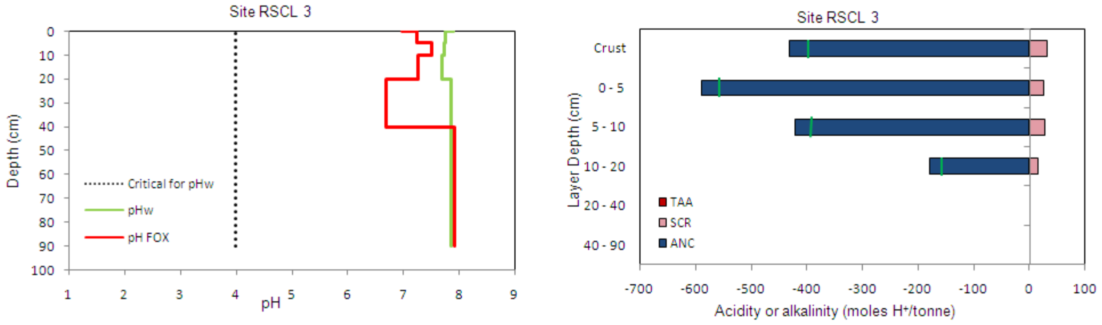

Figure 3-3 Soil pH and acid base accounting data for soil profile RSCL 3. Left Plot: Soil (pH$_W$: green line) and peroxide pH (pH$_{FOX}$: red line). Right Plot: S$_{CR}$ (pink bar), ANC (blue bar) and Net Acidity for sulfidic layers (green line). (Note: ANC was only required to be determined for sulfidic layers).

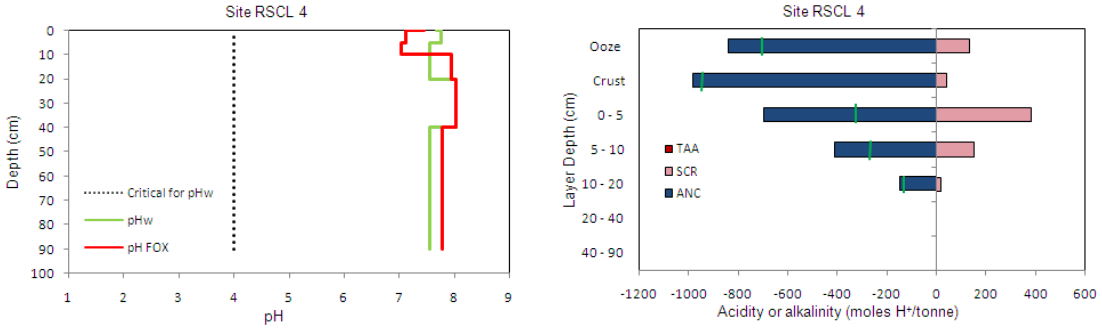

Figure 3-4 Soil pH and acid base accounting data for soil profile RSCL 4. Left Plot: Soil (pH_W: green line) and peroxide pH (pH_{FOX}: red line). Right Plot: S_{CR} (pink bar), ANC (blue bar) and Net Acidity for sulfidic layers (green line). (Note: ANC was only required to be determined for sulfidic layers).

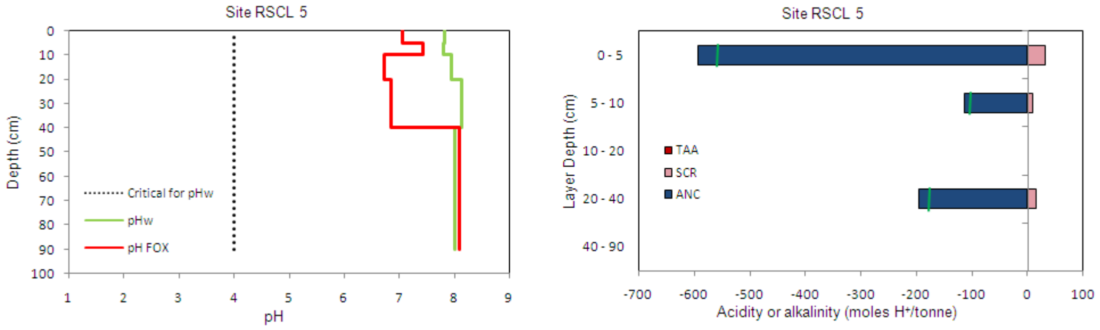

Figure 3-5 Soil pH and acid base accounting data for soil profile RSCL 5. Left Plot: Soil (pH_W: green line) and peroxide pH (pH_{FOX}: red line). Right Plot: S_{CR} (pink bar), ANC (blue bar) and Net Acidity for sulfidic layers (green line). (Note: ANC was only required to be determined for sulfidic layers).

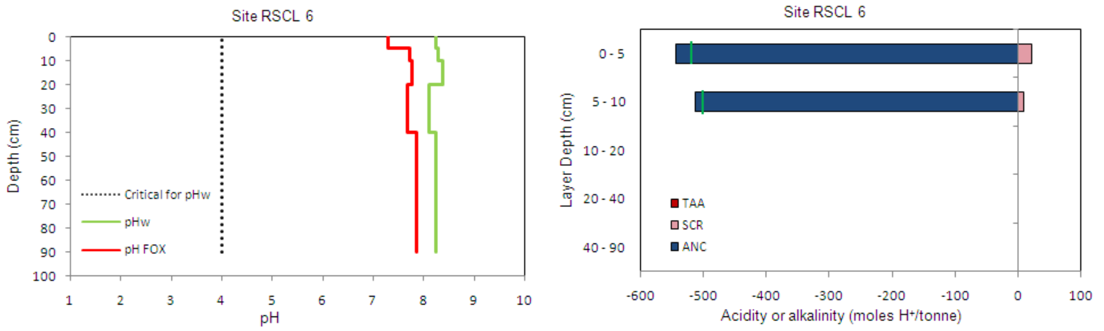

Figure 3-6 Soil pH and acid base accounting data for soil profile RSCL 6. Left Plot: Soil (pH_W: green line) and peroxide pH (pH_{FOX}: red line). Right Plot: S_{CR} (pink bar), ANC (blue bar) and Net Acidity for sulfidic layers (green line). (Note: ANC was only required to be determined for sulfidic layers).

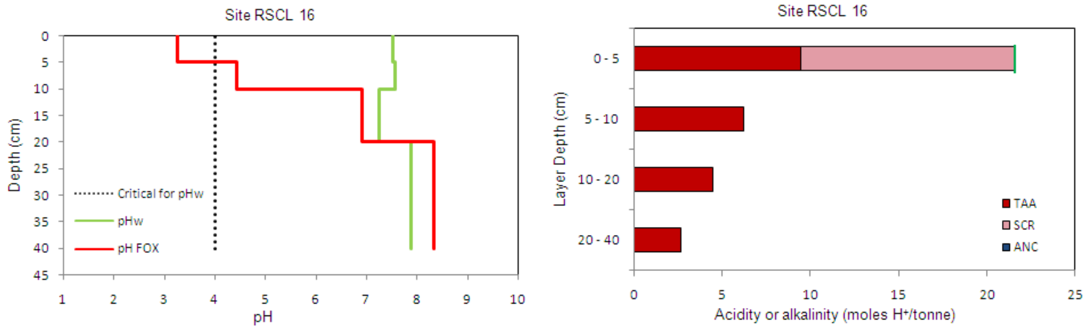

Figure 3-7 Soil pH and acid base accounting data for soil profile RSCL 16. Left Plot: Soil (pH$_W$: green line) and peroxide pH (pH$_{FOX}$: red line). Right Plot: TAA (red bar), S$_{CR}$ (pink bar) and Net Acidity for sulfidic layers (green line). (Note: ANC was only required to be determined for sulfidic layers and was zero at this site for this soil layer).

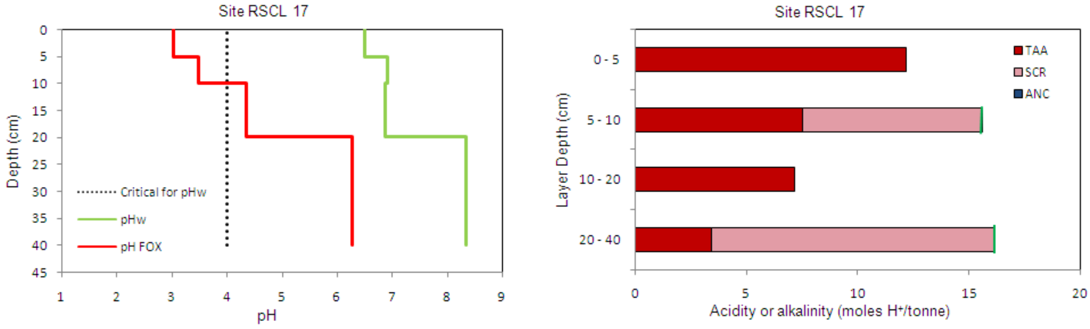

Figure 3-8 Soil pH and acid base accounting data for soil profile RSCL 17. Left Plot: Soil (pH$_W$: green line) and peroxide pH (pH$_{FOX}$: red line). Right Plot: TAA (red bar), S$_{CR}$ (pink bar) and Net Acidity for sulfidic layers (green line). (Note: ANC was only required to be determined for sulfidic layers and was zero at this site for the two soil layers).

3.1.2. Chromium Reducible Sulfur (S$_{CR}$)

The S$_{CR}$ data for the Currawinya Lakes sites examined is presented in Table 7-2 (Appendix 2) and summarised in Table 3-1. The S$_{CR}$ content of the soils in the Currawinya Lakes ranged between 0.00 and 0.61% S. Sulfidic soil materials (i.e. S$_{CR}$ ≥ 0.01% S) were present at 8 of the 18 sampling sites (Sites RSCL 1-6, 16 and 17), with 23 materials of the 95 samples collected greater than the sulfidic criterion. Only 4 of the soil materials collected were identified as being hypersulfidic (Samples RSCL 1.5, 16.3, 17.4 and 17.6). The monosulfidic black oozes (MBO) at sites RSCL 1 and RSCL 4 had S$_{CR}$ contents of 0.32 and 0.22% S respectively. Three sites in the Currawinya Lakes (Sites RSCL 1, 2 and 4) had S$_{CR}$ ≥ 0.10% S in at least one of the soil layers.

3.1.3. Acid Neutralising Capacity

The acid neutralising capacity (ANC) for the sulfidic soil materials ranged between zero and 10.8 %$CaCO_3$ (see Table 3-1).

3.1.4. Net Acidity

The acidification hazard from acid sulfate soil disturbance posed by the sulfidic soil materials is low. 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). The 4 hypersulfidic soil materials at the Currawinya Lake wetland sites (Samples RSCL 1.5, 16.3, 17.4 and 17.6) had low to moderate net acidities ranging between 15.6 and 32.7 H^+/tonne (Table 7-2, Appendix 2).

3.1.5. Water soluble SO_4

The water soluble SO_4 data for the Currawinya Lake wetland sites examined is presented in Table 7-2 (Appendix 2) and summarised in Table 3-1. The water soluble SO_4 in the soils in the Currawinya Lakes ranged between 15 and 47,334 mg kg^{-1}. At least 1 surface soil layer in 9 of the 18 sites examined had a water soluble SO_4 content exceeding the trigger value of > 100 mg kg^{-1} indicating that the formation of monosulfidic materials may be a potential hazard upon rewetting. All layers in 7 of 18 profiles had water soluble SO_4 contents exceeding the trigger value. A decrease in water soluble SO_4 content with depth was observed at the Wyara salt lake sites (Sites RSCL 1-6) (Figure 3-9), and an increase with depth was observed at the other sites (Figure 3-10).

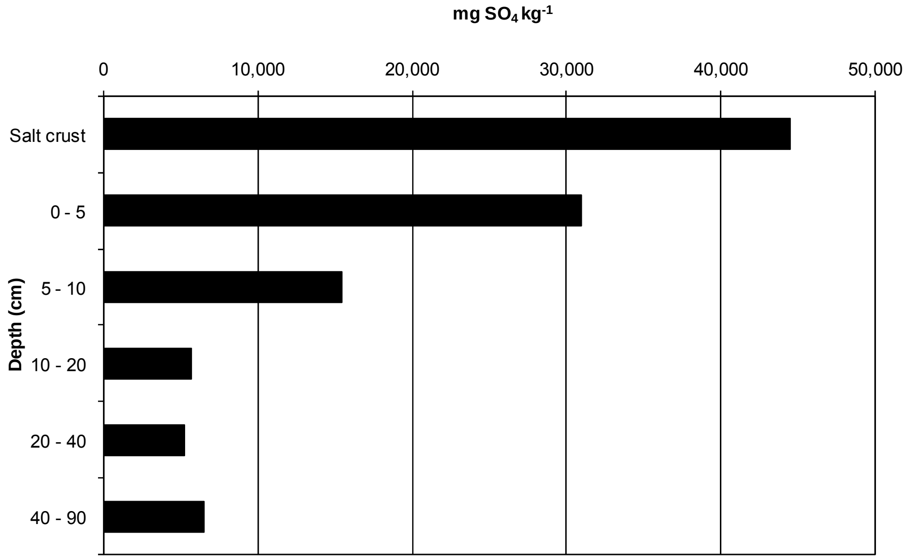

Figure 3-9 Variation in water soluble SO_4 (mg SO_4 kg^{-1}) with depth at Lake Wyara (Site RSCL 3).

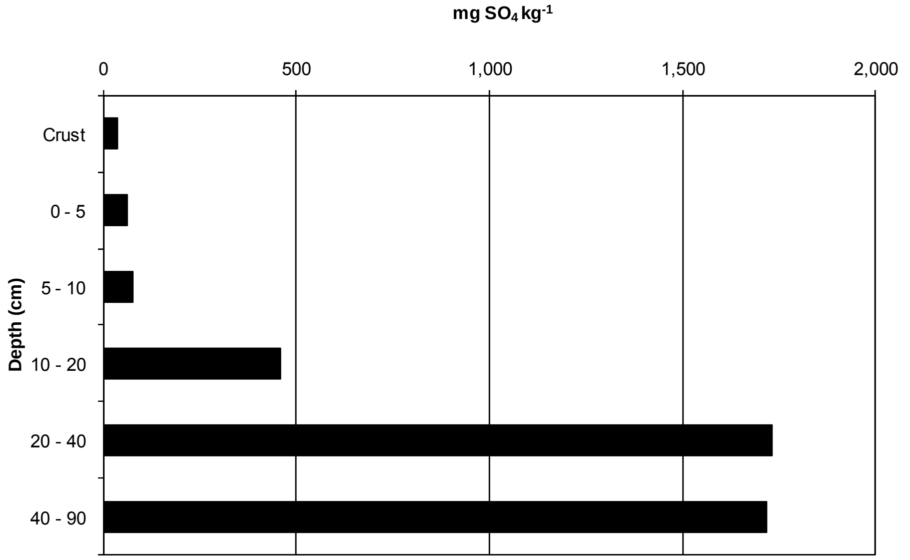

Figure 3-10 Variation in water soluble SO_4 (mg SO_4 kg^{-1}) with depth at site RSCL 13.

3.1.6. Titratable actual acidity (TAA)

The TAA data for the Currawinya Lakes sites examined is presented in Table 7-2 (Appendix 2) and summarised in Table 3-1. The TAA ranged between 0.00 and 12.16 mole H^+/tonne, with the majority of soil layers having no TAA. There was no TAA in 10 of the 18 soil profiles (i.e. all layers had a pH_{KCl} of $\geq$ 6.5). A decrease in the TAA with depth was observed at sites with a TAA profile (Figure 3-11).

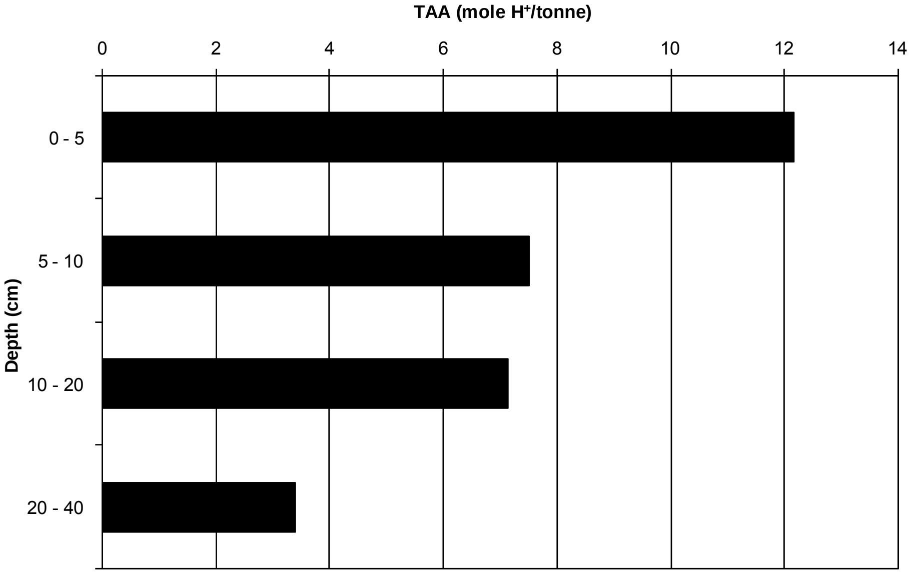

Figure 3-11 Variation in TAA (mole H^+/tonne) with depth at site RSCL 17.

3.2. Hydrochemistry

Surface water quality data was collected from 6 locations in the Currawinya Lakes (RSCL 1, 4, 7, 9, 10 and 16). As mentioned previously, many of the sites were waterlogged and groundwater quality data was collected from 2 sites (Sites RSCL 1 and 4).

A summary of the surface water and groundwater characteristics measured in the field are presented in Table 3-2 and 3-3. The results of the laboratory analyses are presented in Appendix 3.

The field pH of the surface waters ranged between 7.5 and 8.6 (Table 3-2) with 4 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 ranged between 2.50 and 14,706 mg L^{-1} (Table 7-4, Appendix 3).

Table 3-2 Summary of surface water hydrochemical characteristics (field).

	pH	SEC µS cm^{-1}	DO % sat.	Eh mV	Turbidity NTU	Alkalinity (mg L^{-1} as HCO_3)
Minimum	7.53	151	80.0	23	25	48
Median	8.40	1794	83.8	264	335	2683
Maximum	8.61	15210	101.0	411	OR	3830
n[1]	5	4	4	4	4	6

[1] n: number of samples. OR: Out of range.

The field pH of the groundwater at the 2 sites sampled was 6.45 and 7.12 indicating that the groundwater has not been affected by acidification (Table 3-3). The groundwater had high sulfate concentrations of 12,569 and 12,892 mg L^{-1} (Table 7-6, Appendix 3).

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

	pH	SEC µS cm^{-1}	DO % sat.	Eh mV	Turbidity NTU	Alkalinity (mg L^{-1} as HCO_3)
Minimum	6.45	OR	15	208	200	1300
Maximum	7.12	OR	31	249	200	1640
n[1]	2	2	2	2	1	2

[1] n: number of samples. OR: Out of range.

4. HAZARD ASSESSMENT

4.1. Interpretation of soil and water data

Sulfuric soil materials were not encountered in any of the sampling sites (Table 4-1).

Hypersulfidic materials occurred in the soil profile at three of the 18 sampling locations (Table 4.1). The sites where hypersulfidic materials occurred were in the lowest elevation drainage depressions where waterlogged and reducing conditions, suitable for the formation of sulfides, occur.

The acidification hazard from acid sulfate soil disturbance posed by these sites is low: the four hypersulfidic soil materials had low to moderate net acidities (i.e. the maximum of only 33 mole H^+/tonne). The water quality in Currawinya Lakes wetland also has very high alkalinity and buffering capacity to act against any acidification (Table 3-2).

Three sites contained hyposulfidic materials with $S_{CR} \geq 0.10\%$. Five sites contained hyposulfidic soil materials with $S_{CR} < 0.10\%$. Two sites had surficial accumulations of black oozes with high S_{CR} contents (most likely these are monosulfidic soil materials).

The water soluble sulfate contents of nine sites contained surface soil materials with water soluble sulfate contents > 100 mg kg^{-1} indicating that the formation of monosulfidic materials may be a potential problem upon rewetting the areas that are currently dry (Table 4-1).

The surface water data shows that this water has not been affected by acidification.

Table 4-1 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 = 18)	Proportion of total sampling sites (%)
Sulfuric	0	0
Hypersulfidic	3	17
Hyposulfidic ($S_{CR} \geq 0.10\%$)	3	17
Monosulfidic (observed)	2	11
Monosulfidic (potential)	9	50
Hyposulfidic ($S_{CR} < 0.10\%$)	5	28
Other acidic (pH_w &/or pH_{age}) 4 – 5.5	0	0
Other soil materials	10	56

5. CONCLUSIONS

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 the Currawinya Lakes Ramsar wetland. This Phase 1 report is aimed solely at determining whether or not acid sulfate soil materials are present in the Currawinya Lakes Ramsar wetland.

Sulfuric soil materials were not observed in these wetlands. The reduced inorganic sulfur content of the samples was high in the salt lake areas (i.e. S_{CR} was up to 0.61%). Hypersulfidic soil materials were present in three soil profiles (one profile also contained hyposulfidic materials), and another two soil profiles contained hyposulfidic materials with $S_{CR} \geq 0.10\%$. 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.

Monosulfidic black oozes (MBOs) were observed in 11% (i.e. 2) of the sampling sites. Nine of the surficial soil materials contained water soluble sulfate in excess of the 100 mg kg^{-1} 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 Soils Risk Assessment Project, there were three high priority sites based on the presence of hypersulfidic material, and two high priority sites based on the presence of a hyposulfidic material with $S_{CR} \geq 0.10\%$. There were also a further three moderate priority sites based on the presence of a hyposulfidic material with $S_{CR} < 0.10\%$. In addition, 9 sampling sites had a high priority ranking for Phase 2 detailed assessment based on MBO formation hazard.

The potential hazards posed by acid sulfate soil materials at the Currawinya Lakes Ramsar wetland sites are as below:

- Acidification: The data indicate that with low titratable actual acidities (TAA) and only four hypersulfidic soil materials with low to moderate net acidities that the degree of acidification hazard is low.

- Deoxgenation: The water soluble sulfate contents of nine surface soil materials 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 produce excessive metal mobilisation. However, the potential for MBO formation identified in these wetlands 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.

While this study showed the presence of acid sulfate soil materials in the Currawinya Lakes Ramsar wetland, when considering the wetlands as a whole there is a low priority for further assessment to determine specific acid sulfate soil risks. As such, the Scientific Reference Panel of the Murray-Darling Basin Acid Sulfate Soils Risk Assessment Project agreed that Phase 2 detailed assessment of acid sulfate soil materials was not required for the Currawinya Lakes Ramsar wetland.

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7. APPENDICES

APPENDIX 1. Site and sample descriptions

Table 7-1 Currawinya Lakes site and sample descriptions.

Profile	Date	Location	GPS Co-ords			Location Remarks	Profile remarks
			Zone	*East.*	*North.*		
RSCL1	4/08/08	Currawinya N.P.	55	231522	6823601	Northern end of Lake Wayara (salt lake). No vegetation cover approx. 300m from water edge and approx 300m from dunes that mark the shoreline of lake. Ranger said water level 20% capacity. Some surface water present near profile in shallow pools. Surface and groundwater samples taken but too shallow for water quality on surface water.	Light brown on surface but black mud layer underneath (20mm). Crust sample (2mm thick) taken as well as Ooze sample. Gas bubbles present under light brown slimy layer.
RSCL2	4/08/08	Currawinya N.P.	55	231654	6823701	On drier lighter coloured sediment approx 150m towards shoreline. No ground cover. No water	Mottled black/brown in top 5cm layer then some Iron mottling <20cm. Sandy at depth. Dug to 90cm.
RSCL3	4/08/08	Currawinya N.P.	55	231808	6823812	50m from dunes to the east of salt lake.	Very soft salt crust.
RSCL4	4/08/08	Currawinya N.P.	55	231951	6822399	2nd transect on Lake Wayara. 1.4km south of first transect. Transect running along small drainage into lake. This hole 50m from water edge.. Surface and groundwater samples taken. Surface water shallow (5cm) with muddy floc layer on top including bubbles.	Surface bare with reddish layer on top and black ooze underneath (sampled as 4.2 and 4 ooze)
RSCL5	4/08/08	Currawinya N.P.	55	232072	6822421	150m east of RSCL4. Salt crystals present on surface with no crust formed.	Reasonable uniform soil. Distinct sand layer 1cm thick at 30cm depth. Moist but no groundwater. Depth to 90cm.
RSCL6	4/08/08	Currawinya N.P.	55	232279	6822444	Further east. 20m from dunes on shoreline. Salt crystals on surface but again no defined crust.	Uniform brown grey sand.

Table 7-1 (continued) Currawinya Lakes site and sample descriptions.

Profile	Date	Location	GPS Co-ords			Location Remarks	Profile remarks
			Zone	*East.*	*North.*		
RSCL7	5/08/08	Currawinya N.P.	55	236199	6823063	Up northern end of Lake Numalla. Hole dug 1.5m from water edge in bare depression. Water shallow here. No surface vegetation.	Yellow brown clay.
RSCL8	5/08/08	Currawinya N.P.	55	236088	6822933	In slight depression where water ponds. Approx 100m west of CL7. Sparse groundcover of forbs and herbs.	Light brown down to 20cm then dry yellow soils with carbonate nodules.
RSCL9	5/08/08	Currawinya N.P.	55	235925	6822802	In clay pan which is 70% capacity. 2-4cm deep. Hole dug 1m from water edge. SW sample taken.	Very different soil. Cracked crust on surface (9.2). Thin red crust on top (2mm thick) (9.2). Very hard red layer underneath (~2cm deep) (9.3). Softer layer grading red-yellow to 10cm depth (9.4). Bottom layers (10-90cm) soft and 'fluffy' soils of yellow appearance. Salt like harder crystals at depth (70-90cm) at about 10mm in diameter. Yellow with some Iron mottling at depth (70-90cm)
RSCL10	5/08/08	Currawinya N.P.	55	238597	6809201	Transect running NW from northern end of North Kaponyee Lake. Site approx. 100m out in the lake from water edge. 10m off edge of Nardoo stand. 15cm of water cover. Water very turbid.	Hard sediment under 5cm of mud. Only dug to 40cm as gouge auger would not penetrate.
RSCL11	5/08/08	Currawinya N.P.	55	238461	6809230	Site in nardoo stand on edge of water.	Light grey/red sediment.
RSCL12	5/08/08	Currawinya N.P.	55	238332	6809253	Up creek draining into N end of North Kaponyee Lake. No vegetation cover. Muddy waterhole directly upstream of profile, but too muddy to sample.	Dry site with grey cracking crust (12.2). Red sands to 20cm then grey soils. Rocks hit at 50cm – couldn't dig any deeper.

Table 7-1 (continued) Currawinya Lakes site and sample descriptions.

Profile	Date	Location	GPS Co-ords			Location Remarks	Profile remarks
			Zone	*East.*	*North.*		
RSCL13	5/08/08	Currawinya N.P.	55	239690	6807240	In middle of dry Lake Kaponyee. No vegetation cover.	Cracking yellow brown clay to 10cm then into softer pillow soil. Uniform through to 60cm then gradual change to red colour to 75cm. Very sticky at depth.
RSCL14	5/08/08	Currawinya N.P.	55	239676	6806555	Further south of lake into heavier cover of herbs and roly poly. Similar cracking clay crust.	Crust thicker than RSCL13 (2cm). Change from brown to grey at 20cm. From grey to reddish grey at 60cm. Very sticky at depth. Dug to 75cm.
RSCL15	5/08/08	Currawinya N.P.	55	239671	6806073	Up the southern end of Lake Kaponyee. In channel (very slight).	Red sands/clays in surface, no crust. Red brown to grey at 20cm. Dug to 80cm.
RSCL16	6/08/08	Currawinya N.P.	55	255538	6807560	Transect running up creek from eastern end of billabong at back of Currawinya homestead. Profile dug in waterhole under 20cm of water. Lignum, river cooba and red gums lining bank. Surface water sample taken.	Dug down to 40cm, too hard to dig further.
RSCL17	6/08/08	Currawinya N.P.	55	2556030	6807547	Profile dug 5m adjacent to waterhole approx 100m east of CL16. Dug in moist depression with new shooting grasses.	Top layer <5cm brown mud grading to red sands. 5-20cm red sands. 20-40cm very hard yellow sandy material with iron mottling from 20-25cm. Dug to 40cm. No 17.7 sample taken.
RSCL18	6/08/08	Currawinya N.P.	55	255888	6807473	Further up creek in dry depression. No vegetation cover but surrounded by coolabah trees.	Dug to 40cm.

APPENDIX 2. Field and laboratory analytical soil data

Table 7-2 Currawinya Lakes field and laboratory analytical soil data.

Site / Sample	Depth (cm)	Texture	Colour	Mottle % / Colour	pH$_W$	pH$_{FOX}$	pH$_{FOX}$ reaction [1]	pH$_{KCl}$	pH$_{INCUBATION}$	TAA mole H$^+$/tonne	CRS %Scr	ANC %CaCO$_3$	Net Acidity mole H$^+$/tonne	Sulfate (mg SO$_4$ /kg)
RSCL / 1 ooze		FSZL	GLEY2.5/N	10% 2.5Y5/3	8.00	7.39	XXXX	8.88	7.3	-	0.317	9.54	-1072.99	21784.11
1.2	Crust	FSZL	GLEY2.5/5PB	15% 10YR6/3	7.53	7.06	XXXX	8.82	7.3	-	0.060	10.83	-1405.21	40289.15
1.3	0 - 5	MC	10YR5/2	10% Gley5/10B	7.65	7.05	XXXX	8.57	7.3	-	0.423	6.80	-641.42	22049.14
1.4	5 - 10	FSMC	GLEY6/5GY	15% 10YR6/2	7.56	6.95	XXXX	8.28	6.5	-	0.520	4.10	-222.14	22946.59
1.5	10 - 20	MC	2.5Y6/2		6.79	4.90	XXXX	5.90	5.0	3.71	0.046	0.00	32.69	11179.03
1.6	20 - 40	MC	2.5Y5/2		7.63	7.56	XXXX	8.20		-	< 0.01	-	-	9705.21
1.7	40 - 90	MHC	2.5Y5/2		7.63	7.49	XXXX	8.62		-	< 0.01	-	-	11550.33
RSCL / 2.3	0 - 5	SLC	2.5Y6/2		7.71	7.29	XXXX	8.74	6.5	-	0.298	5.10	-493.05	29715.29
2.4	5 - 10	LC	2.5Y6/2	2% 7.5YR6/8	6.74	7.01	XXXX	6.21		2.64	< 0.01	-	2.64	12439.08
2.5	10 - 20	SLC	2.5Y5/3	15% 7.5YR5/6	7.41	6.92	XXXX	7.42		-	< 0.01	-	-	11180.20
2.6	20 - 40	MC	2.5Y6/3		7.67	7.71	XXXX	8.38		-	< 0.01	-	-	8172.32
2.7	40 - 90	SLMC	2.5Y6/3		7.65	7.77	XXX	8.79		-	< 0.01	-	-	13603.07
RSCL / 3.1	Salt crust	SLMC	2.5Y5/3		7.89	6.96	XXXX	9.04	7.0	-	0.051	3.24	-398.98	44473.35
3.3	0 - 5	FSLMC	2.5Y5/3		7.75	7.23	XXXX	9.09	6.8	-	0.043	4.43	-562.97	30932.95
3.4	5 - 10	FSLMC	2.5Y5/2	7% 7.5YR7/8	7.74	7.50	XXXX	9.25	7.3	-	0.044	3.16	-393.07	15424.83
3.5	10 - 20	FSLMC	2.5Y6/3	10% 7.5YR7/8	7.69	7.25	XXXX	8.90	7.4	-	0.026	1.34	-161.98	5689.30
3.6	20 - 40	FSLMC	2.5Y6/3		7.86	6.68	XXXX	8.88		-	< 0.01	-	-	5213.33
3.7	40 - 90	FSLMC	2.5Y6/2		7.84	7.92	XXXX	8.64		-	< 0.01	-	-	6469.40
RSCL / 4 ooze		CL	GLEY2.5/10Y		7.52	7.12	XXXX	8.93	7.4	-	0.217	6.30	-704.35	20082.06
4.2	Crust	LMC	5Y4/5		7.68	7.45	XXXX	8.88	8.1	-	0.069	7.38	-939.46	47333.65
4.3	0 - 5	MC	10YR5/2	5% GLEY2.5/5PB	7.75	7.12	XXXX	8.42	7.4	-	0.613	5.23	-313.70	24449.13
4.4	5 - 10	LMC	10YR5/1		7.56	7.03	XXXX	8.56	7.4	-	0.244	3.09	-258.70	19880.54
4.5	10 - 20	LMC	10YR6/1		7.55	7.94	XXXX	7.92	7.4	-	0.027	1.12	-132.48	10344.73
4.6	20 - 40	LMC	10YR6/2		8.03	8.03	XXXX	8.30		-	< 0.01	-	-	6814.28
4.7	40 - 90	MC	10YR5/2		7.55	7.77	XXX	8.68		-	< 0.01	-	-	9715.53
RSCL / 5.3	0 - 5	FCLS	2.5Y5/3	10% GLEY2.5/5PB	7.83	7.06	XXXX	9.04	7.4	-	0.052	4.46	-561.40	25566.38
5.4	5 - 10	FCLS	2.5Y6/2		7.81	7.44	XXXX	9.08	7.4	-	0.015	0.85	-104.38	6583.34
5.5	10 - 20	FSLC	2.5Y6/3		7.95	6.73	XXXX	8.18		-	< 0.01	1.09	-144.90	4954.26
5.6	20 - 40	FSLC	2.5Y6/3		8.13	6.85	X	8.80	7.4	-	0.026	1.47	-179.91	5437.08
5.7	40 - 90	MC	2.5Y5/2		8.01	8.10	XX	8.49		-	< 0.01	-	-	8975.89
RSCL / 6.3	0 - 5	FSLMC	2.5Y5/3		8.23	7.30	XXXX	9.04	7.8	-	0.035	4.08	-522.28	25197.00
6.4	5 - 10	FSLMC	2.5Y5/3		8.29	7.73	XX	8.88	7.8	-	0.016	3.85	-503.10	20478.76
6.5	10 - 20	FSMC	2.5Y5/3		8.38	7.77	X	9.11		-	< 0.01	-	-	6018.06
6.6	20 - 40	FSMC	2.5Y6/3		8.10	7.69	X	8.80		-	< 0.01	-	-	20027.85
6.7	40 - 90	MC	2.5Y5/3		8.25	7.86	XX	8.75		-	< 0.01	-	-	12492.11
RSCL / 7.3	0 - 5	FSMC	2.5Y6/3		8.67	8.80	XXXX	8.06		-	< 0.01	-	-	92.11
7.4	5 - 10	FSMC	10YR6/2		8.82	8.97	XXXX	8.40		-	< 0.01	-	-	43.20
7.5	10 - 20	FSMC	10YR6/2		8.89	9.02	XXXX	8.70		-	< 0.01	-	-	44.34
7.6	20 - 40	FSMHC	10YR6/2		9.24	8.88	XXXX	8.73		-	< 0.01	-	-	54.25
7.7	40 - 90	FSMHC	2.5Y6/3		8.33	8.39	XXXX	8.67		-	< 0.01	-	-	170.61
RSCL / 8.3	0 - 5	LMC	10YR5/3		8.56	6.28	XXXX	6.63		-	< 0.01	-	-	31.07
8.4	5 - 10	LMC	10YR5/3		8.50	7.95	XXXX	6.43		0.92	< 0.01	-	0.92	33.97
8.5	10 - 20	MC	10YR5/3		8.39	8.49	XXXX	6.78		-	< 0.01	-	-	215.90
8.6	20 - 40	LC	5Y5/3		8.80	8.68	XXX	7.55		-	< 0.01	-	-	37.80
8.7	40 - 90	LMC	5Y6/3		8.80	9.01	X	8.88		-	< 0.01	-	-	400.01
RSCL / 9.2	Crust	i.s.	7.5YR3/4		8.65	6.69	XXX	8.04		-	< 0.01	-	-	88.45
9.3	0 - 5	SCL	7.5YR5/4		8.59	6.87	XXXX	6.41		2.73	< 0.01	-	2.73	34.13
9.4	5 - 10	CLS	7.5YR5/4		8.02	8.37	XXX	6.66		-	< 0.01	-	-	1389.04
9.5	10 - 20	FSLC	7.5YR5/4		7.60	7.94	X	6.89		-	< 0.01	-	-	7271.00
9.6	20 - 40	LMC	10YR6/4	15% 5YR6/8	8.08	7.95	X	7.84		-	< 0.01	-	-	8476.29
9.7	40 - 90	SLC	10YR7/4		8.43	8.47	X	8.96		-	< 0.01	-	-	13282.01
RSCL / 10.3	0 - 5	LC	7.5YR4/4		8.50	7.84	XXXX	6.85		-	< 0.01	-	-	21.55
10.4	5 - 10	LMC	7.5YR4/4		8.60	8.60	XXXX	6.99		-	< 0.01	-	-	16.43
10.5	10 - 20	LC	7.5YR5/4		8.80	8.88	XXXX	7.03		-	< 0.01	-	-	14.96
10.6	20 - 40	LC	7.5YR5/4		9.29	9.25	XXX	8.49		-	< 0.01	-	-	65.04
RSCL / 11.3	0 - 5	FSLMC	5YR5/4		8.04	6.57	XXXX	6.63		-	< 0.01	-	-	29.48
11.4	5 - 10	FSLMC	5YR5/4		8.16	8.22	XXXX	6.80		-	< 0.01	-	-	20.92
11.5	10 - 20	LMC	10YR6/3	30% 2.5YR5/6	8.42	8.73	XXXX	7.08		-	< 0.01	-	-	171.00
11.6	20 - 40	LMC	10YR6/4		8.15	8.64	XXX	7.57		-	< 0.01	-	-	3309.52
11.7	40 - 90	LMC	10YR7/4		7.97	8.43	X	8.79		-	< 0.01	-	-	2751.52
RSCL / 12.2	Crust	i.s.	7.5YR4/4		8.29	5.71	XXXX	7.35		-	< 0.01	-	-	134.41
12.3	0 - 5	KSL	5YR5/6		8.47	6.84	XXX	6.56		-	< 0.01	-	-	22.23
12.4	5 - 10	FSLMC	10YR6/2	50%2.5YR5/6	8.11	7.30	XXXX	6.45		1.47	< 0.01	-	1.47	22.66
12.5	10 - 20	SLC	2.5YR5/6	20% 10YR6/1	8.04	7.18	XXXX	6.36		1.37	< 0.01	-	1.37	29.52
12.6	20 - 40	KSLMC	2.5Y6/3		8.42	8.71	XXXX	6.99		-	< 0.01	-	-	175.12
12.7	40 - 50	SLC	2.5Y6/3		8.57	8.56	XXX	7.28		-	< 0.01	-	-	166.02
RSCL / 13.2	Crust	i.s.	10YR5/3		8.98	8.83	XXXX	7.81		-	< 0.01	-	-	35.00
13.3	0 - 5	LMC	10YR5/3		8.82	8.87	XXXX	8.04		-	< 0.01	-	-	61.50
13.4	5 - 10	LMC	7.5YR5/3		9.26	9.12	XXXX	7.89		-	< 0.01	-	-	74.17
13.5	10 - 20	LC	7.5YR5/4		9.10	9.20	XXX	7.88		-	< 0.01	-	-	458.30
13.6	20 - 40	LC	10YR6/3		8.79	8.95	X	8.88		-	< 0.01	-	-	1731.42
13.7	40 - 90	LC	2.5Y6/3	10% 7.5YR7/6	8.45	8.88	XXX	9.00		-	< 0.01	-	-	1717.07

[1] Soil reaction rating scale for pH$_{FOX}$ test: slight reaction (X), moderate reaction (XX), high reaction (XXX), and very vigorous reaction, gas evolution and heat generation commonly >80°C (XXXX) (Ahern *et al*. 2004).

Table 7-2 (continued) Currawinya Lakes field and laboratory analytical soil data.

Site / Sample	Depth (cm)	Texture	Colour	Mottle % / Colour	pH$_{W}$	pH$_{FOX}$	pH$_{FOX}$ reaction [1]	pH$_{KCl}$	pH$_{INCUBATION}$	TAA mole H^{+}/tonne	CRS %Scr	ANC %CaCO$_{3}$	Net Acidity mole H^{+}/tonne	Sulfate (mg SO$_{4}$ /kg)
RSCL / 14.2	Crust	i.s.	10YR5/3	20% 7.5YR5/3	8.96	8.35	XXXX	7.75		-	< 0.01	-	-	38.49
14.3	0 - 5	LMC	7.5YR5/4		8.89	8.42	XXXX	7.37		-	< 0.01	-	-	57.22
14.4	5 - 10	LMC	10YR5/2	10% 5YR5/6	9.19	8.96	XXXX	7.54		-	< 0.01	-	-	190.63
14.5	10 - 20	LMC	7.5YR4/4		9.26	9.32	XXXX	7.62		-	< 0.01	-	-	356.71
14.6	20 - 40	LC	2.5Y5/3		8.78	8.73	XX	8.80		-	< 0.01	-	-	1744.94
14.7	40 - 75	MC	7.5YR6/8	30% 2.5Y7/3	8.71	8.90	X	8.87		-	< 0.01	-	-	1360.58
RSCL / 15.3	0 - 5	FSLMC	2.5YR5/6	40% 10YR5/2	7.58	6.44	XXXX	6.63		-	< 0.01	-	-	1312.17
15.4	5 - 10	FSLMC	7.5YR4/4	10% 2.5YR5/8	7.78	7.65	XXXX	6.77		-	< 0.01	-	-	2696.37
15.5	10 - 20	FSLC	7.5YR4/4	10% 10YR6/2	7.87	8.54	XXXX	7.05		-	< 0.01	-	-	2448.19
15.6	20 - 40	FSCL	10YR6/4		8.23	8.40	X	8.16		-	< 0.01	-	-	3066.82
15.7	40 - 80	FSLC	7.5YR6/4	20% 2.5Y7/2	8.30	8.53	X	8.64		-	< 0.01	-	-	3382.42
RSCL / 16.3	0 - 5	SCL	7.5YR6/3	50% 7.5YR5/2	7.51	3.25	XXX	5.29	5.3	9.46	0.019	0.00	21.55	38.51
16.4	5 - 10	SLC	7.5YR6/2		7.56	4.42	XXXX	5.29		6.21	< 0.01	-	6.21	22.57
16.5	10 - 20	SMC	10YR6/2		7.24	6.91	XXX	5.47		4.49	< 0.01	-	4.49	38.44
16.6	20 - 40	FSMC	10YR6/2		7.89	8.34	XXXX	6.17		2.67	< 0.01	-	2.67	62.78
RSCL / 17.3	0 - 5	LMC	5YR5/6	40% 10YR5/2	6.50	3.03	XXX	4.74		12.16	< 0.01	-	12.16	27.47
17.4	5 - 10	S	7.5YR6/4	30% 10YR6/1	6.91	3.49	XXX	4.99	5.5	7.51	0.013	0.00	15.58	26.48
17.5	10 - 20	SMC	10YR6/2	10% 7.5YR5/8	6.88	4.36	XXXX	5.11		7.14	< 0.01	-	7.14	89.75
17.6	20 - 40	FSLMC	10YR7/4		8.33	6.27	X	6.21	4.9	3.42	0.020	0.00	16.13	73.83
RSCL / 18.3	0 - 5	FSMC	10YR6/2		6.84	3.32	XXXX	5.22		6.87	< 0.01	-	6.87	53.48
18.4	5 - 10	FSMC	7.5YR4/2		7.35	7.56	XXXX	5.74		2.99	< 0.01	-	2.99	53.21
18.5	10 - 20	FSMC	10YR6/4		8.10	7.67	XXXX	6.57		-	< 0.01	-	-	70.93
18.6	20 - 40	FSMC	7.5YR7/6	30% 10YR7/2	8.37	6.03	X	6.78		-	< 0.01	-	-	47.40

[1] Soil reaction rating scale for pH$_{FOX}$ test: slight reaction (X), moderate reaction (XX), high reaction (XXX), and very vigorous reaction, gas evolution and heat generation commonly >80°C (XXXX) (Ahern *et al*. 2004).

APPENDIX 3. Field and laboratory hydrochemistry data

Table 7-3 Currawinya Lakes field surface water hydrochemistry data.

Site	Units	RSCL 1	RSCL 4	RSCL 7	RSCL 9	RSCL 10	RSCL 16	Minimum	Median	Maximum	Range	n
Water type		Surface	Surface	Surface	Surface	Surface	Surface					
pH		n.a.	8.61	8.48	8.40	8.33	7.53	7.53	8.40	8.61	7.53 - 8.61	5
SEC	µS cm^{-1}	n.a.	15210	2420	n.a.	1168	151	151	1794	15210	151 - 15210	4
DO	% sat	n.a.	80.5	87.0	n.a.	101.0	80.0	80.0	83.8	101.0	80.0 - 101.0	4
Eh	mV	n.a.	23	411	n.a.	316	212	23	264	411	23 - 411	4
Turbidity	NTU	n.a.	25	Out of range	n.a.	520	150	25	335	Out of range	25 - OR	4
Alkalinity	(mg L^{-1} as HCO_3)	2365	785	3000	3830	3450	48	48	2683	3830	48 - 3830	6
Temperature	°C	n.a.	19.0	11.2	n.a.	15.1	9.5	9.5	13.2	19.0	9.5 - 19.0	4

Table 7-4 Currawinya Lakes laboratory analytical surface water hydrochemistry data.

Parameter	Units	RSCL 1	RSCL 4	RSCL 7	RSCL 9	RSCL 10	RSCL 16	Minimum	Median	Maximum	Range	n
pH		7.52	7.41	8.21	8.28	8.24	7.07	7.07	7.87	8.28	7.07 - 8.28	6
E.C.	dS/m	116.20	103.60	2.34	2.76	0.83	0.13	0.13	2.55	116.20	0.13 - 116.20	6
Alkalinity	meq/L	3.31	1.34	4.45	4.86	4.59	0.77	0.77	3.88	4.86	0.77 - 4.86	6
Ammonium (NH_4-N)	mg/L	3.442	2.025	0.153	0.114	4.267	0.081	0.081	1.089	4.267	0.081 - 4.267	6
Oxides of Nitrogen (NO_x-N)	mg/L	< 0.005	< 0.005	0.063	0.186	2.434	0.048	< 0.005	0.055	2.434	< 0.005 - 2.434	6
Nitrate (NO_3-N)	mg/L	< 0.005	< 0.005	0.047	0.164	0.057	< 0.005	< 0.005	< 0.005	0.164	< 0.005 - 0.164	0
Nitrite (NO_2-N)	mg/L	0.011	0.010	0.016	0.023	2.377	0.058	0.010	0.019	2.377	0.010 - 2.377	6
Phosphate (PO_4-P)	mg/L	0.072	0.055	0.681	0.392	10.746	0.052	0.052	0.232	10.746	0.052 - 10.746	6
Chloride (Cl^-)	mg/L	90044	64282	528	694	78.26	9.50	9.50	611	90044	9.50 - 90044	6
Bromide (Br^-)	mg/L	102	70.76	0.63	0.58	< 0.2	< 0.05	<0.05	0.61	102	< 0.05 - 102	6
Sulfate (SO_4^{2-})	mg/L	14706	11770	122	9.03	15.12	2.50	2.50	68.63	14706	2.50 - 14706	6
Calcium (Ca)	mg/L	1330	1710	22.08	11.76	63.28	3.46	3.46	42.68	1710	3.46 - 1710	6
Potassium (K)	mg/L	210	188	9.18	7.71	62.38	4.68	4.68	35.78	210	4.68 - 210	6
Magnesium (Mg)	mg/L	1970	1370	5.94	5.48	51.27	2.07	2.07	28.60	1970	2.07 - 1970	6
Sodium (Na)	mg/L	58000	42000	480	550	240	23.75	23.75	515	58000	23.75 - 58000	6
Sulfur (S)	mg/L	4900	3900	43.11	4.41	3.29	1.19	1.19	23.76	4900	1.19 - 4900	6
Total Organic Carbon (NPOC)	mg/L	111.00	78.65	16.97	33.77	45.98	12.94	12.94	39.88	111	12.94 - 111	6
Total Nitrogen (TN)	mg/L	11.820	8.230	1.080	3.210	12.00	0.360	0.360	5.720	12.00	0.36 - 12.00	6
Aluminium (Al)	mg/L	< 0.2	< 0.2	1.831	5.830	156.2	2.787	<0.2	2.309	156.2	<0.2 - 156.2	6
Boron (B)	mg/L	3.707	3.034	0.523	0.125	0.683	0.058	0.058	0.603	3.707	0.058 - 3.707	6
Copper (Cu)	mg/L	< 0.5	< 0.5	0.015	0.029	0.079	0.007	< 0.5	0.011	0.079	< 0.5 - 0.079	6
Iron (Fe)	mg/L	0.751	< 0.4	1.937	5.285	147.4	3.315	< 0.4	2.626	147.4	< 0.4 - 147.4	6
Manganese (Mn)	mg/L	< 0.6	< 0.6	0.011	0.048	1.675	0.029	< 0.6	0.020	1.675	< 0.6 - 1.675	6
Phosphorus (P)	mg/L	< 3	< 3	0.659	0.478	4.447	0.047	0.047	0.262	4.447	0.047 - 4.447	6
Zinc (Zn)	mg/L	< 0.3	< 0.3	0.007	0.016	0.268	0.012	< 0.3	0.010	0.268	< 0.3 - 0.268	6
Molybdenum (Mo)	mg/L	< 1	< 1	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 1	< 0.01 - < 1	6
Cobalt (Co)	mg/L	< 1	< 1	< 0.01	< 0.01	0.077	< 0.01	< 0.01	< 0.01	< 1	< 0.01 - < 1	6
Nickel (Ni)	mg/L	< 1	< 1	< 0.01	< 0.01	0.108	< 0.01	< 0.01	< 0.01	< 1	< 0.01 - < 1	6
Cadmium (Cd)	mg/L	< 0.3	< 0.3	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.003	< 0.3	< 0.003 - < 0.3	6
Lead (Pb)	mg/L	< 3	< 3	< 0.03	< 0.03	0.082	< 0.03	< 0.03	< 0.03	< 3	< 0.03 - < 3	6
Selenium (Se)	mg/L	< 10	< 10	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 10	< 0.1 - < 10	6

Table 7-5 Currawinya Lakes field groundwater hydrochemistry data.

Site	Units	RSCL 1	RSCL 4	Minimum	Maximum	n
Water type		Groundwater	Groundwater			
pH		6.45	7.12	6.45	7.12	2
SEC	µS cm^{-1}	Out of range	Out of range	Out of range	Out of range	2
DO	% sat	15	31	15	31	2
Eh	mV	249	208	208	249	2
Turbidity	NTU	200	n.a.	200	200	1
Alkalinity	(mg L^{-1} as HCO_3)	1640	1300	1300	1640	2
Temperature	°C	12.9	14.2	12.9	14	2

Table 7-6 Currawinya Lakes laboratory analytical groundwater hydrochemistry data.

Parameter	Units	RSCL 1	RSCL 4	Minimum	Maximum	n
pH		i.s.	7.18	7.18	7.18	2
E.C.	dS/m	i.s.	127.00	127.00	127.00	2
Alkalinity	meq/L	i.s.	2.09	2.09	2.09	2
Ammonium (NH_4-N)	mg/L	8.332	2.624	2.624	8.332	2
Oxides of Nitrogen (NO_x-N)	mg/L	0.467	7.214	0.467	7.214	2
Nitrate (NO_3-N)	mg/L	0.433	7.101	0.433	7.101	2
Nitrite (NO_2-N)	mg/L	0.034	0.113	0.034	0.113	2
Phosphate (PO_4-P)	mg/L	0.232	0.291	0.232	0.291	2
Chloride (Cl^-)	mg/L	77631	78263	77631	78263	2
Bromide (Br^-)	mg/L	84.10	86.68	84.10	86.68	2
Sulfate (SO_4^{2-})	mg/L	12892	12569	12569	12892	2
Calcium (Ca)	mg/L	930	970	930	970	2
Potassium (K)	mg/L	172	210	172	210	2
Magnesium (Mg)	mg/L	1500	1430	1430	1500	2
Sodium (Na)	mg/L	51000	51000	51000	51000	2
Sulfur (S)	mg/L	4300	4100	4100	4300	2
Total Organic Carbon (NPOC)	mg/L	45.38	54.13	45.38	54.13	2
Total Nitrogen (TN)	mg/L	10.390	12.030	10.390	12.030	2
Aluminium (Al)	mg/L	< 0.2	< 0.2	<0.2	< 0.2	2
Boron (B)	mg/L	0.718	0.544	0.544	0.718	2
Copper (Cu)	mg/L	< 0.5	0.506	0.506	0.506	2
Iron (Fe)	mg/L	< 0.4	< 0.4	<0.4	< 0.4	2
Manganese (Mn)	mg/L	8.158	0.623	0.623	8.158	2
Phosphorus (P)	mg/L	< 3	< 3	< 3	< 3	2
Zinc (Zn)	mg/L	< 0.3	< 0.3	< 0.3	< 0.3	2
Molybdenum (Mo)	mg/L	< 1	< 1	< 1	< 1	2
Cobalt (Co)	mg/L	< 1	< 1	< 1	< 1	2
Nickel (Ni)	mg/L	< 1	< 1	< 1	< 1	2
Cadmium (Cd)	mg/L	< 0.3	< 0.3	< 0.3	< 0.3	2
Lead (Pb)	mg/L	< 3	< 3	< 3	< 3	2
Selenium (Se)	mg/L	< 10	< 10	< 10	< 10	2

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