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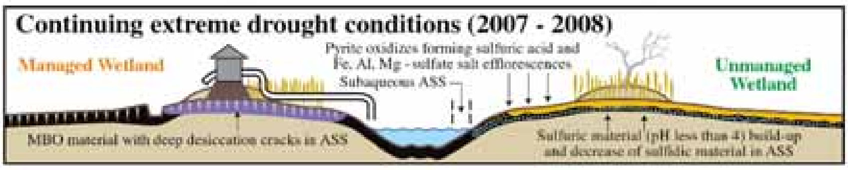
Acid sulfate soils in subaqueous, waterlogged and drained soil environments of nine wetlands below Blanchetown (Lock 1), South Australia: properties, genesis, risks and management

R.W. Fitzpatrick, P. Shand, M. Thomas, R.H. Merry, M.D. Raven and S.L. Simpson

Report prepared for South Australian Murray-Darling Basin Natural Resources Management Board



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Cover Photographs

Left: Photograph of sulfuric material in the drained Swanport wetland showing accumulation of scale-like, bright golden yellow crystals of metavoltine [$K_2Na_6Fe^{2+}Fe^{3+}6(SO_4)_{12}O_2$ $18H_2O$], yellow crystals of natrojarosite and white crystals of alunogen [$Al_2(SO_4)_3$ $17H_2O$], which have formed in cracks as a result of aqueous, acidic (pH < 2.5), sulfate-bearing solutions percolating through the soil and reacting with iron sulfides and layer silicates. These localised solutions were rich in ferrous and ferric iron and also contained leached potassium and sodium. Metavoltine and alunogen are presumed to be the last minerals to form (Photographer: Paul Shand © 2008 CSIRO).

Right: Mooring post in a sandy, now-saline profile in the Devon Downs South wetland; the post shows the usual water level (Photographer: Paul Shand © 2008 CSIRO).

Below: Generalised schematic cross section model for the lower-River Murray banks and wetlands; illustrating the formation of: (i) sulfuric material (pH <4) by oxidation of sulfides in sulfidic material, (ii) sulfate-rich salt efflorescences (metavoltine and natrojarosite) and (iii) deep desiccation cracks; due to continued lowering of water levels under extreme drought conditions during 2007 – 2008. (Photographer: Rob Fitzpatrick © 2008 CSIRO).

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

The aim of this project was to investigate the response of nine hydrologically unmanaged River Murray wetlands, located between Lock 1 and Wellington on the River Murray, South Australia, that have undergone significant drying as a result of low water levels. These wetlands are not usually disconnected from the main River Murray channel. The water level drawdown that has been experienced during the current drought is considered to be an extreme event. The information sought from this project, which comprised a baseline assessment of acid sulfate soils (ASS) and development of a vegetation monitoring programme, has a specific focus on improving understanding of drought response and predicting possible outcomes that might occur when the wetlands are reconnected to the River in the future.

For vegetation monitoring, this required a departure from methods used in previous baseline surveys. As a result Australian Water Environments developed appropriate vegetation survey methodologies to measure change in the nature and condition of the wetland vegetation during changes in hydrological conditions and applied them during the drawdown period. CSIRO Land and Water used a combination of existing testing procedures and developed a new protocol for sample collection and analyses to investigate and record the presence of acid sulfate soils at the nine wetlands. In addition an assessment of tree health was undertaken at these wetlands using the method documented in Tucker (2004). The vegetation survey also collected information in regard to possible vegetation indicators of acid sulfate soils.

The data collected provides a snapshot of acid sulfate soil status and ecological response to the current period of drawdown, and the monitoring programme will allow future surveys to discern major trends in response to changing hydrological conditions including prolonged drought and alleviation of drought conditions.

The results and detailed discussion of acid sulfate soil investigations are presented in *Acid sulfate soil materials in subaqueous and wetland soil environments of nine wetlands below Blanchetown (Lock 1), South Australia: Prooperties, risks and management* (CSIRO 2008). The results and detailed discussion of vegetation investigations are presented in *Wetland Drought Monitoring Lock 1 to Wellington:Vegetation Component* (AWE 2008).

References

Fitzpatrick RW, Shand P, Thomas M, Merry RH, Raven MD, Simpson SL (2008) Acid sulfate soils in subaqueous, waterlogged and drained soil environments of nine wetlands below Blanchetown (Lock 1), South Australia: properties, genesis, risks and management. Prepared for South Australian Murray-Darling Basin Natural Resources Management Board. CSIRO Land and Water Science Report 42/08. CSIRO, Adelaide, 135. pp. http://www.clw.csiro.au/publications/science/2008/sr42-08.pdf

Australian Water Environments (2008) Wetland Drought Monitoring, Lock 1 to Wellington: Vegetation Assessment. Prepared for the South Australian Murray-Darling Basin Natural Resource Management Board. Australian Water Environments Report 47915a_R004, 250pp.

Acid Sulfate Soil Investigation

Soil samples were collected from nine unmanaged wetlands along the River Murray between Blanchetown (Lock 1) and Wellington in SA in order to assess current and potential impacts of acid sulfate soils (ASS). A total of 154 samples were collected from 38 profiles. A new protocol has been developed to collect samples for soil and water analyses. The analyses performed on the samples included morphological, chemical, mineralogical and physical properties, which we used as a basis for ASS risk assessment for the wetlands that were drying – or dried - due to the current drought conditions. The following five independent standard methodologies have been applied to classify the various subtypes of ASS (e.g. sulfidic subaqueous clayey soils) and non-ASS (e.g. cracking clay soils) to assess the ASS risk of subaqueous, waterlogged and drained (dried) soil environments: (a) soil morphology, (b) pH testing in water, (c) peroxide pH testing, (d) acid-base accounting, and (e) ageing experiments.

In most of the drained 9 wetlands, ASS subtypes with sulfuric (pH range <4) and sulfidic materials were the only soils present. The large number of individual ASS subtypes in this region is staggering. As a group, these wetlands were unique in that there is no other region known in the world that can match the concentration and diversity of inland ASS subtypes exhibited in these wetlands. The individual wetlands have been classified according to ASS risk into the following five categories:

ASS Risk	Wetland	Dominant ASS material
Extremely High	**Ukee and Swanport**	**Sulfuric (pH 2.5 to 4.0)**
High	Murrundi (North Wellington) Lake Carlet	Sulfidic
High to Moderate	Kroehns Landing, Devon Downs North	Sulfidic
Moderate to High	Noonawirra, North Purnong	Sulfidic
Moderate	Devon Downs South	Hyposulfidic

Despite decades of scientific investigation of the ecological, hydrological (salinity) and geological features of these wetlands we have only in the past year advanced far enough to appreciate the wide spectrum of ASS subtypes and processes that are operating in the modern settings, especially from continued lowering of river water levels. We have developed conceptual and schematic soil-landscape models to:

- Explain and predict the sequential formation and transformation of the various subtypes of ASS due to lowering of water levels from “Deep-water ASS” → “Subaqueous ASS” → “Waterlogged/saturated ASS” (all containing sulfidic material with high sulfide concentrations and pH>4) to → “Drained and unsaturated or dried ASS” containing sulfuric material (pH<4) in the upper aerated soil layers (i.e. ASS processes from 5,500 BC to extreme drought conditions of 2006-2008).
- Explain and predict the widespread occurrences of sulfide minerals in sulfidic material and sulfate-containing minerals in acidic salt efflorescences.
- Predict impacts of further drought on ASS formation and decline in water quality.
- Develop remediation and management options for specific ASS environments.

Wetland Basin Vegetation Survey

Australian Water Environments, in association with Janet Pedler, developed a vegetation survey methodology to specifically investigate vegetation response to draw-down on wetlands. The methodology developed to survey vegetation at the nine wetlands was designed to:

- Identify zonation within wetlands;
- Identify and describe vegetation associations and their spatial distribution;
- Collect quantitative data on composition, cover, regeneration and health of those vegetation associations;
- Observe perennial tree health;
- Observe floodplain vegetation association general health and regeneration;
- Identify other threatening processes, such as grazing, pest plant and animal invasion, and the role of sulfidic and /or sulfuric soils.

These observations were made by establishing cross-sectional transects across the wetland basins, perpendicular to the basin edge, that allowed the identification and description of zones. Quantitative quadrat surveys were undertaken within each identified zone along this transect.

Past surveys at these wetlands collected ‘baseline’ data for each site in their wet phase, under circumstances where they were understood to operate as ‘permanent’ wetlands. The 2007/08 survey collected baseline data on ecological response to draw-down, and is the first collection of data for most of these wetlands in dry basin circumstances. It has documented the extent and diversity of vegetation colonisation of the drying wetland beds, as well as the impacts on types of wetland vegetation that require standing water for optimal condition.

The data collected has provided baseline information about the state of vegetation at each particular wetland during draw down at the time of survey. It has also been used to describe characteristic changes in health and distribution of different vegetation types across all wetlands to describe a generic wetland vegetation response to draw-down.

A set of management recommendations which apply to all wetlands has been developed, with other specific recommendations made for individual wetlands where appropriate.

SUMMARY OF FINDINGS

Acid Sulfate Soils Component

Acid sulfate soils (ASS) are soils that either contain sulfuric acid (sulfuric material), or have the potential to form sulfuric acid when exposed to oxygen in the air because of high concentrations of sulfide minerals (sulfidic material). As water levels in the lower River Murray system between Blanchetown (Lock 1) and Wellington lower during the current, unprecedented drought conditions, the anaerobic sulfidic material in the subaqueous soils that were once covered by water are now exposed to air at the river margins and in adjacent wetlands. With continued lowering of water levels the sulfidic material becomes oxidised and transforms to sulfuric material (pH range <4) - with consequent water quality, ecological and possible public health issues.

The prime objective of this report is to:

- Verify the presence (or absence) of the three main types of ASS materials (sulfidic, sulfuric and monosulfidic black ooze materials) in nine unmanaged wetlands and in selected sites in the adjacent River Murray, and assess the potential risk that exposed soil materials might pose to infrastructure and environmental assets due to possible presence of ASS and salt efflorescences, caused by the lowering of water level in the River Murray.

- Identify various subtypes of ASS (e.g. sulfidic subaqueous clayey soil or sulfuric cracking clay soil) and non-ASS (e.g. cracking clay soil) present, and provide predictive capability of current acidification and potential acidification and hazards of ASS present when the wetlands continue to drain and are re-flooded.

Between August 2007 and April 2008 we collected and analysed 154 soil samples from 38 representative soil profiles (i.e. a wide range of subaqueous, waterlogged and drained soils) located in a selection of nine River Murray wetlands along the section below Lock 1 and above Wellington. A new protocol has been developed to collect samples for soil and water analyses. At each site, the geomorphological characteristics were identified and sites selected along a transect to produce a soil toposequence, which typically included subaqueous, waterlogged and drained soils. Samples were collected in chip trays: one for visualisation and as a record for posterity, and a second for ageing; and a number of samples collected in sealed plastic bags and bottles. The analyses performed on the samples included morphological, chemical, mineralogical and physical properties, which we used as a basis for ASS risk assessment for the wetlands that were drying – or dried - due to the current drought conditions.

Samples obtained in this survey provided an adequate baseline for soil condition of subaqueous, waterlogged or drained soils near shores of the River Murray and in nine adjacent wetlands. Recorded locations and long-term storage of the samples will allow for future re-sampling and analysis, if required. Five independent standard methodologies have been applied to all samples to correctly identify (classify) all soils and determine ASS risk: (a) soil morphology (soil colour and texture), (b) pH testing in water; (c) peroxide pH testing; (d) acid-base accounting; and (e) ageing experiments. Risk factors for each have been determined and combined to produce an overall risk of each soil profile sampled.

We applied the user-friendly "Soil Identification Key", developed for ASS in the River Murray and Lower Lakes systems to identify and classify the various subtypes of ASS and

non-ASS in the River Murray and adjacent wetland areas. Classification of the various subtypes of ASS and non-ASS enabled us to assess the risk of all the subaqueous, waterlogged and drained (dried) soils. An understanding of the detailed properties, distribution and interrelationships of the subtypes of ASS and non-ASS identified has been vital for effective "evaluation of the environmental risk" and "lime treatment category" posed by ASS disturbance.

We identified a range of ASS subtypes (e.g. sulfidic subaqueous clayey soils, sulfidic cracking clay soils and sulfuric clayey soils). We established that occurrence of sulfuric materials is a major risk because these ASS subtypes were extremely acidic (pH 1.9 to 4.0) and have low acid neutralising capacities (i.e. low carbonate concentrations). Field and laboratory tests concluded that ***significant acidification is present and also likely to increase*** and become a problem for some wetlands in their current state. In some cases these ASS will pose a major threat to these ecosystems, and to River Murray water quality. The individual wetlands have been classified according to risk into the following five categories:

[1]ASS Risk	Wetland	[1]Dominant Acid Sulfate Soil (ASS)	
		Material	[1]Classification (ASS subtypes)
Extremely High	**Ukee and Swanport**	**Sulfuric**	**[2]Sulfuric cracking clay soil**
High	Murrundi (North Wellington) Lake Carlet	Sulfidic	[2]Sulfuric organic soil [3]Sulfidic subaqueous clayey soil
High to Moderate	Kroehns Landing Devon Downs North	Sulfidic	[4]Sulfidic cracking clay soils
Moderate to High	Noonawirra North Purnong	Sulfidic	[4]Sulfidic cracking clay soils
Moderate	Devon Downs South	Hypo-Sulfidic	[5]Cracking clay soil containing some sulfides

[1]The ASS risk and occurrence of various other subtypes of ASS within individual wetlands is variable. [2]Sulfuric clayey or organic soils are currently extremely acidic with Extremely High ASS Risk and will require high to extremely high levels of lime treatment. [3]Sulfidic subaqueous clayey soils will only become acidic when exposed to air, hence they are "potentially High ASS Risk" and will only require high to moderate levels of lime treatment when drained. [4]Sulfidic cracking clay soils are either dried, partly dried or saturated and will progressively become acidic when they are continually exposed to air, hence they are "potentially High to Moderate ASS Risk" and will require high to moderate levels of lime treatment, (iii) [5]Cracking clay soil containing some sulfides are "potentially Moderate ASS Risk" and will require moderate levels of lime treatment.

Salt efflorescences containing mainly a yellowish brown (golden) mineral called metavoltine [$Na_6K_2FeFe_6(SO_4)_{12}O_2.18H_2O$], which forms botryoidal encrustations on edges of cracks and is as an alteration product of weathered pyrite in the sulfidic material was identified in the Swanport wetland. This documents only the first occurrence of metavoltine in Australia. The minerals natrojarosite [$NaFe_3(SO_4)_2(OH)_6$], sideronatrite [$Na_2Fe(SO_4)_2.OH.3H_2O$], tamarugite [$Na_2Al(SO_4)_2.OH.3H_2O$], alunogen [$Al_2(SO_4)_3$ $17H_2O$], hexahydrite ($MgSO_4.6H_2O$) and gypsum were also present. These minerals are general indicators of very acidic soil conditions and the presence of pyrite. The majority of these minerals were also identified in sulfuric materials in the Ukee wetland. These salts are likely to form if water levels decrease and have the potential to become a problem during re-flooding if not managed properly. The significance of the minerals found in these salt efflorescences is that they appear each summer or in a dry period, and are environmental indicators. Salt efflorescences also have potential for aerial transport and to be dissolved in water. There is a need to prevent stock from ingesting these salts (similar to Epsom salts) because this is likely to lead to scouring in sheep and cattle. Magnesium salts are toxic when ingested in high levels.

The potential for mobilisation of acid, metals and nutrients following the rewetting of a range of dried acid sulfate soil subtypes from Murrundi, Ukee and Swanport was assessed by Simpson *et al.* (2008). They found releases of nutrients were generally not high. However, the dissolved metal concentrations exceeded water quality guidelines (WQGs) for all of the metals studied for which guidelines exist. The metals that most often exceeded the WQGs were Al, Mn, Ni, Cu, Zn, Co and Cd. The number of WQG exceedances after applying a dilution factor (10×, 100×, 1000×), as would occur when these waters mix with river or lake water, was also calculated by Simpson *et al.* (2008). For most of these metals, there were significant relationships between the pH of the soils and the concentrations of dissolved metals released. The soil rewetting experiments and relationships between pH and metal release indicated that exceedances of WQGs in the River Murray system are likely if the mixed waters have pH 5 - but possible at pH 6 - if attenuation processes are inadequate. In the absence of additional attenuation processes, the large amounts of aluminium, iron and some trace metals released during the re-wetting of ASS have the potential to cause direct acute toxicity from aluminium and some trace metals, or indirect effects from precipitation and particulate iron and aluminium. The concentrations of aluminium and cobalt were very high and even at 1:1,000 dilution (in the River Murray), chronic toxicity is a potential risk to aquatic biota due to metal release from rewetted ASS in Ukee and Swanport. Trace metal-enriched precipitates may form and may cause chronic toxicity to a variety of filter feeding or benthic organisms. All sulfuric materials and half the sulfidic materials were classified as high risk by Simpson *et al.* (2008). The sulfidic soils will also be expected to develop further acidity if suitable field conditions exist in the future for them to dry naturally.

We developed a series of conceptual models/schematic soil-landscape cross-sections to:

- Explain and predict the sequential formation and transformation of the various subtypes of ASS due to lowering of water levels from “Deep-water ASS” → “Subaqueous ASS” → “Waterlogged/saturated ASS” (all containing sulfidic material with high sulfide concentrations and pH>4) → “Drained and unsaturated or dried ASS” containing sulfuric material (pH<4) in the upper aerated soil layers (i.e. ASS processes from 5,500 BC to extreme drought conditions of 2006-2008).
- Explain and predict the widespread occurrences of sulfide minerals in sulfidic material and sulfate-containing minerals in acidic salt efflorescences.
- Predict impacts of further drought on ASS formation and decline in water quality.
- Develop remediation and management options for specific ASS environments.

Careful monitoring of soils and waters is recommended as the water levels return to re-wet the now-dry soils after flushing (e.g. through upstream water allocations and/or strong rainfall) of the wetlands and along river banks, and trigger values for soils and water should be established. We recommend a continued detailed monitoring strategy be formulated based on key ASS indicators identified in the study of the nine wetlands studied here.

A range of “generic management and remediation options” have been proposed for the various ASS Subtypes identified in the nine wetlands.

Wetland Vegetation Component

The normal pool level in this reach of the River Murray wetlands has been held artificially high at 0.8m AHD (Australian Height Datum) and relatively stable for more than 50 years by managed flow conditions and the presence of the barrages in the Lower Lakes. These conditions have supported the establishment of vegetation and ecological processes in these wetlands that are more typical of permanent wetlands. With water levels falling by at least 60 cm prior to the survey commencement in October 2007, these wetlands have undergone the first drying phase in over 50 years and it is possible that the effect of prolonged drying on these wetlands may be more detrimental than might be expected for wetlands still undergoing frequent, natural wetting and drying cycles.

Temporary changes in water level can benefit the ecological community of wetlands by allowing expression of flora species that are usually dormant, or by triggering reproduction in species that may not otherwise regenerate in a system with a stable water level. This often has follow on effects by creating changes in habitat structure and resource availability for fauna species. In addition, the wet/dry cycle may present critical timeframes for management intervention, for example undertaking weed control for species that are disadvantaged by the hydrological changes occurring.

The primary objectives of the vegetation component of this project were to:

- Collect data to increase our understanding of the impacts of drought over an ecologically and morphologically diverse range of nine wetlands;
- To develop a monitoring methodology that can be used to monitor the wetlands durring this on-going drought and the post-drought recovery phase;
- Identify areas of suspected acid sulfate soil activity for further investigation by the soil survey team, and to record any apparent indicators in vegetation; and
- Recommend management actions and identify requirements for further research.

Australian Water Environments surveyed 22 transects at the nine wetlands between October 2007 and January 2008. The surveys comprised 2,386 linear metres (one metre each side of transect line surveyed) of survey. Eighty one quadrats of 30 x 1 metre were surveyed along these transects. The methodology used is described in the main report and the raw data is provided on a CD accompanying the report.

A summary of the key findings for each wetland is included at the end of this summary report. A general description of drought impacts and ecological response to draw-down across all wetlands is summarised below.

- Good successional expansion of plant species adapted to colonising the drying wetland basin bed was observed in some wetlands, and factors that may explain the varied responses in other wetlands have been described in relation to particular sites.

- There is a likelihood of decline in species diversity if there is continued drought, due to complete desiccation of underground tubers and corms and loss of viability of the seed-bank of those species that are unsuited to the current dry conditions. This will be the case even in those wetlands that did respond well to draw-down, if there is continued drought.

- As dry conditions continue, there will be an increasing loss of drought refuges across the whole Lower Murray-Darling Basin eco-system. This will impact on recovery potential for both plant and animal species, with fewer and fewer individual wetlands harbouring populations of plants and animals that can re-colonise the dry wetlands on re-flooding.

- Specific habitat types are being lost across many wetlands. These habitats include open water, reedbeds, and inundated herblands. Loss of these habitats is progressing differentially at specific wetlands related to their local topography and geomorphical form, and their relative elevation in comparison with the main River Murray channel pool level.

- There is an increasing loss of shallow, slow moving water and protected breeding sites for fish, frogs and macro-invertebrates. For short-lived species this presents a system wide risk of population collapse, with several seasons of breeding impacted by a massively diminished number of suitable breeding sites and conditions.

- The impacts of acidity and metal toxicity due to acid sulfate soils are at varying stages of development, with the potential to affect almost all sites surveyed under continued drying, as a legacy of preventing natural wetting and drying of these wetlands over many decades. There is a high potential for acid sulfate soils to destroy eggs and resting/estivating stages of frogs, reptiles and macro-invertebrates.

- Additional access to previously inaccessible parts of wetlands has been opened up to domestic stock by the loss of open water. Grazing by domestic stock, feral animals and over-abundant native animals, that seek drought refuge in wetlands, has the potential to impact heavily on wetland capacity for recovery. This is due to grazing out flowering and fruiting plants that should contribute to the soil seed bank, and trampling damage and grazing of corms and tubers of vegetatively reproducing species. Domestic stock also contribute to erosion of dry basin edges particularly where the basin edge is steep. This will contribute turbidity in the re-wetting phase, and reduces habitat for fringing reed beds and the fauna that rely on them.

- Floodplain vegetation will continue to lose diversity and condition under continuing drought with salinisation of floodplains being a major impact.

Australian Water Environments staff were introduced to visual surface indicators of different types of sulfuric and sulfidic soils by CSIRO experts at the beginning of the fieldwork programme and were also provided with pH strips and shown how to undertake basic soil surface pH testing. This enabled the vegetation surveyors to identify areas of suspected acid sulfate soil activity for further investigation by the soil survey team, and to record apparent indicators in vegetation. A number of parameters observed during cross-sectional transect and quadrat surveys were included (in part) for their possible potential to be indicators of acid sulfate soil impacts. The parameters that were considered could be potential indicators were:

- composition of species;
- density of vegetative cover;
- regeneration or colonisation success or suppression; and
- signs of poor condition such as discoloration and abnormal growth.

Where full laboratory soil test samples were collected by CSIRO from locations on vegetation transects, there was good concurrence between low surface pH results recorded by the vegetation surveyors and detection of sulfuric material through laboratory analysis of the soil samples.

Visual signs of plant pathology could not be readily used as an indicator. During this study potential signs of acidic soil effects shown by plant pathology could not be definitively separated from the signs occurring concurrently of moisture stress and desiccation with elevated soil salinity brought on by drought conditions.

However, a combination of poor plant health and poor recruitment /colonisation did emerge as a pattern present at the highly acidic soil sites which would be clearly recognisable to an experienced observer.

Essentially, the observed pattern is one of low colonisation of herbs (low cover / abundance) on the damp edge of the receding waterline, combined with observations of very poor health of those plants sparsely present. Critically, this observation is only of significance where all other conditions appear to be suitable for 'normal' or expected wetland colonisation response. Some species, such as *Typha* sp. and *Phragmites australis,* require underground freshwater flushing to maintain good condition under drought conditions, where they have been stranded well above the waterline. Where such species are observed to be in good health in the absence of surface water, this may indicate areas where there is potential for leaching of acid and metals generated by acid sulfate soil. That is, they indicate there is a direct sub-surface movement of water between the main river channel and the wetland. These observations are further discussed in the main report.

Generic management recommendations appropriate to all nine wetlands are as follows:

- Consider incentive weed control programs on wetlands undergoing drying, and provision of assistance to prepare weed control plans based on weed threat, local environmental values and environmental conditions.

- Consider incentive or assistance for feral animal control programs on wetlands undergoing drying.

- Property level plans should be prepared for exclusion of domestic stock from wetlands during drought, and for sustainable rotation at other times. This should be supported by best practice policy and information to be developed/supplied by regional authorities, and potentially supported by land management incentives programme.

- In any decision on hydrological manipulation, each wetland should be considered separately with all available best information, ideally supported by monitoring data as detailed below, before allocating wetland flows or installing control structures and there should be consideration of the benefits/cost in the wider framework of biodiversity benefits to the wider South Australian Murray-Darling Basin.

- Compile detailed topographic information on wetlands, including all connections to the River Murray.

- Monitoring Recommendations:
    - Regularly monitor piezometers in order to understand groundwater influence at each wetland.
    - Establish and monitor surface water monitoring sites at representative locations. Collect data on both a regular and a responsive event-based basis, in order to sufficiently understand water quality response to drying and flooding.
    - Establish permanently marked tree health transects for regular monitoring, with placement based on a consideration of wetland form, and supposed surface and groundwater influences.
    - Continue to collect vegetation composition and condition data to track long term decline or improvement. Ensure that monitoring occurs in dry as well as wet periods.
    - Adopt and regularly collect data on a measure/index of grazing pressure, so that adaptive changes to domestic grazing management and feral animal control are able to be triggered before irreversible damage occurs.
    - Store all monitoring data in a central location.

Specific management recommendations that relate to the individual wetlands are included in the site summary tables at the end of this Summary Report.

A number of recommendations for further research have been identified and they are:

- Investigate the potential hazards of lime application in aquatic systems, in particular, the impacts on all stages of the life-cycle of invertebrate fauna, fish and frogs.
- Test the accuracy of calculation of amount of lime required for treatment in wetland basins, (if this is considered the most viable option for remediation and rehabilitation) on the basis that over-dosing with lime will cause ecological impacts as extensive as the acidic conditions that are intended to be ameliorated.
- Improve the accuracy and precision of our understanding of the mobilisation, transport and fate of acid and metal compounds at a system wide scale to help determine triggers, and the appropriate location and nature of management intervention (eg prevention of development of ASS, containment of impacts or treatment of consequences).
- Develop detailed procedures, monitoring protocols and trigger-based intervention actions to plan and manage remedial re-wetting of acid sulfate soil affected wetlands, with or without the application of lime.
- Further investigate the use of vegetation communities and their health as biological indicators and as adjunct to understanding impacts and recovery processes in acid sulfate soil impacted wetlands.

Summary of Findings for Wetlands

A summary of the findings for each individual wetland is provided in a series of tables on the following pages. Some baseline survey data is also provided for comparison, however, note that the method used for this survey differed from the previous methods because it was required to specifically to assess change caused by drawdown, and had a basin vegetation focus.

The vegetation associations documented by the 2007/2008 survey and the baseline surveys are shown for each wetland, so that an appreciation may be gained of the potential overlap, and therefore comparability of the species numbers recorded. The area of transects and quadrats surveyed quantitatively (not including 'ramble' survey and opportunistic recordings) for each survey is also provided, again to provide context for comparability. The 2007/2008 survey surveyed a smaller area at each wetland than the 2003/2004 and 2005 baseline surveys, and at many sites the vegetation associations sampled were different (floodplain focus for these baseline surveys). In general, the 2007/2008 survey documented a larger area for each wetland than the 2006 baseline surveys, but with better overlap in basin vegetation associations sampled. Direct comparison of species numbers (including exotic vs native and number of species of conservation significance) is not therefore a valid exercise. Such comparisons would only be valid if the same quadrats had been re-sampled at each site, using the same methodology.

<table>
<tr><th>Wetland Name</th><th colspan="8">Murrundi (Wellington North)</th></tr>
<tr><td>Date Survey</td><td colspan="8">2/11/07</td></tr>
<tr><td rowspan="2">In-Basin Transects surveyed</td><td>Name</td><td colspan="2">Coordinates</td><td>Length (m)</td><td colspan="2">Orientation (◦N)</td><td colspan="2">Number of Zones</td></tr>
<tr><td>MURR_01</td><td colspan="2">352448 E , 6091000 N</td><td>180</td><td colspan="2">90</td><td colspan="2">7</td></tr>
<tr><td>Presence of surface water at time of vegetation survey</td><td colspan="8">Small pool near western edge, much contracted in comparison with extent of open water recorded at baseline survey.</td></tr>
<tr><td>Habitat types, floodplain/river edge</td><td colspan="8">Narrow band of willow woodland/forest on north, east and south sides, narrow band of planted River Red Gum woodland on western side. Woodlands have a low diversity of native understorey with many herbaceous exotic species. Limited area of floodplain due to physical form (former levelled irrigation flat which rises sharply to terrestrial exotic pasture).</td></tr>
<tr><td>Habitat types, basin</td><td colspan="8">Closed rush and sedgelands, open water (contracting under conditions of draw-down), damp basin edge herblands.</td></tr>
<tr><td>Vegetation Summary</td><td colspan="8"></td></tr>
<tr><td rowspan="2">Vegetation Associations Documented</td><td colspan="4">2007-2008 survey (540 m² surveyed)</td><td colspan="4">Baseline Survey (2005, 18,900 m² surveyed)</td></tr>
<tr><td colspan="4">• Juncus usitatus Eleocharis acuta sedgeland
• Persicaria decipiens and other mixed herb species herbland
• Typha orientalis, Bolboschoenus caldwellii sedgeland
• Phragmites australis closed grassland
• Phragmites australis, over Carex appressa open grassland
• Phragmites australis, over Bolboschoenus caldwellii grassland</td><td colspan="4">• Triglochin procerum herbland
• Eleocharis acuta sedgeland
• Typha sp. sedgeland
• Phragmites australis grassland
• Paspalum distichum grassland / Eleocharis acuta sedgeland
• Vallisneria sp. submerged herbland</td></tr>
<tr><td>Tree Health Summary</td><td colspan="8">Excellent tree health, majority planted. Unchanged from baseline survey condition.</td></tr>
<tr><td rowspan="3">Number of Weed and Native Species</td><td colspan="2"></td><td>2007-2008 survey</td><td colspan="5">Baseline Survey</td></tr>
<tr><td colspan="2">Native</td><td>31</td><td colspan="5">19</td></tr>
<tr><td colspan="2">Exotic</td><td>30</td><td colspan="5">23</td></tr>
<tr><td rowspan="3">Rare and Threatened flora</td><td>Baseline</td><td>07/08</td><td colspan="2">Species</td><td>Common Name</td><td>AU</td><td>SA</td><td>MU</td></tr>
<tr><td></td><td>✓</td><td colspan="2">Carex appressa</td><td>Tall Sedge</td><td></td><td></td><td>K</td></tr>
<tr><td></td><td>✓</td><td colspan="2">Cyperus vaginatus</td><td>Stiff Flat-sedge</td><td></td><td></td><td>K</td></tr>
</table>

Wetland Name	Murrundi (Wellington North)						
		✓	*Epilobium pallidiflorum*	Showy Willow-herb			K
		✓	*Calystegia sepium*	Large Bindweed			U
		✓	*Distichlis distichophylla*	Emu-grass			U
		✓	*Isolepis nodosa*	Knobby Club-rush			U
	✓		*Persicaria lapathifolia*	Pale Knotweed			U
		✓	*Epilobium hirtigerum*	Hairy Willow-herb			R
		✓	*Lycopus australis*	Australian Gipsywort			R
	✓	✓	*Eleocharis sphacelata*	Tall Spike-rush			V
		✓	*Isolepis inundata*	Swamp Club-rush			T
High threat weed species	Aster weed *Aster subulatus*, Fennel *Foeniculum vulgare*, Kikuyu *Pennisetum clandestinum*, Yellow Marsh-cress *Rorippa palustris*, Willows *Salix* sp.						
Conservation Significance & Current Condition of Vegetation	The main basin has a low diversity of species, but provides excellent sheltered fauna habitat and has a low level of weed invasion. A range of plant species of conservation significance were recorded. Species that require standing water were starting to show signs of poor health and lack of recruitment.						
Summary Management Issues							
Grazing	No domestic stock grazing. No significant impacts from feral herbivores noted.						
Feral Animals	Abundant dog scats observed.						
Acid Sulfate Soil (all information from Fitzpatrick et al 2008)	*Risk*	*Dominant Acid Sulfate Soil Material*		*Classification (Acid Sulfate Soil subtypes)*			
	High	Sulfidic		Sulfuric organic clayey soil, Sulfidic cracking clay soil Sulfidic subaqueous clayey soil			
Drought Effects	Continued drying is likely to lead to a shift in species composition to Common Reed *Phragmites australis* with loss of Bulrush *Typha* sp and Salt Club-rush *Bolboschoenus caldwellii*. Further development of sulfuric soils may begin to suppress seasonal recruitment of rushes and sedges. Potential for primary ecological response to re-flooding to be suppressed due to inhospitable water chemistry resulting from acid sulfate soil impacts. Potential for acid sulfate soils to destroy eggs and resting/estivating stages of frogs, reptiles and macro-invertebrates.						
Other threatening processes	Immediate proximity and direct interchange of surface and sub-surface water with the River Murray channel allows for leaching of acid, aluminium and heavy metals from acid sulfate soils.						

Wetland Name	Murrundi (Wellington North)
Other	Active management by a community wetland group that has undertaken significant weed control and revegetation works. Public access, council owned wetland. Has been development of informal foot tracks into basin vegetation on the eastern side of the wetland.
Management recommendations	
	All general management recommendations apply with the exception of those relating to domestic stock grazing. Additionally: • Consider rationalising and barring entry to some of the informal tracks that have developed on the eastern side of the main basin. • Assess risks to the public as a result of acid sulfate soil and manage access as appropriate.

Wetland Name	Swanport				
Date Survey	26/10/07				
In-Basin Transects surveyed	*Name*	*Coordinates*	*Length (m)*	*Orientation (◦N)*	*Number of Zones*
	SWAN_01	346402 E, 6109146 N	100	120	4
	SWAN_02	346407 E, 6109004 N	110	50	4
Presence of surface water at time of vegetation survey	None.				
Habitat types, floodplain/river edge	Upper floodplain Lignum Shrubland. River edge with extensive reedbeds, and mixed Willow and River Red Gum woodland.				
Habitat types, basin	Upper basin lined with rush and sedgelands, Open water and submerged herblands in wet phase. Extensive damp mud areas in drying phase.				
Vegetation Summary					
Vegetation Associations Documented	*2007-2008 survey (680 m^2 surveyed)*			*Baseline Survey (2003/04, , 3,600 m^2 surveyed)*	
	• **Paspalum distichum* grassland • (Former/dormant or dead) *Schoenoplectus validus*, *Eleocharis acuta* closed sedgeland • Former/dormant or dead) *Schoenoplectus validus*			• *Typha domingensis* Sedgeland over *Triglochin procerum* • *Eleocharis acuta* and *Triglochin procerum* Sedgeland over **Paspalum* sp	

Wetland Name	Swanport						
	closed sedgeland • *Juncus aridicola* closed sedgeland • *Persicaria lapathifolia*, **Chenopodium album* +/- *Juncus aridicola* herbland • *Salix babylonica* +/- *Eucalyptus camaldulensis* open forest over *Iris sp, *Epilobium pallidiflorum* and *Triglochin procerum*. • *Typha orientalis* sedgeland over *Triglochin procerum*			• *Eleocharis sphacelata* Closed Sedgeland; and • *Halosarcia pergranulata ssp. pergranulata* Low Open Shrubland.			
Tree Health Summary	No tree health survey.						
Number of Weed and Native Species			**2007-2008 survey**	**Baseline Survey**			
	Native		**28**	**20**			
	Exotic		**20**	**12**			
Rare and Threatened flora	*Baseline*	*07/08*	*Species*	*Common Name*	*AU*	*SA*	*MU*
	✓		*Apium prostratum*	Native Celery			K
	✓		*Carex appressa*	Tall Sedge			K
	✓		*Carex fascicularis*	Tassel Sedge			K
		✓	*Epilobium pallidiflorum*	Showy Willow-herb			K
	✓		*Centella asiatica*	Asian Centella			Q
		✓	*Distichlis distichophylla*	Emu-grass			U
		✓	*Persicaria lapathifolia*	Pale Knotweed			U
	✓	✓	*Lycopus australis*	Australian Gipsywort			R
		✓	*Senecio glomeratus ssp. glomeratus*	Swamp Groundsel			R
	✓		*Ranunculus amphitrichus*	Small River Buttercup			R
	✓	✓	*Eleocharis sphacelata*	Tall Spike-rush			V
High threat weed species	Aster weed *Aster subulatus*, *Paspalum* sp., Yellow Marsh-cress *Rorippa palustris*, Willows *Salix* sp.						
Conservation Significance &	This wetland has substantial areas of remnant vegetation of a number of types from Lignum Shrublands to diverse						

Wetland Name	**Swanport**		
Current Condition of Vegetation	sedgelands and herbland with several species of high conservation significance. Condition prior to drying out generally excellent. Draw-down has led to drop in condition, including death or dormancy, in some rush and sedge species.		
Summary Management Issues			
Grazing	No grazing of domestic stock.		
Feral Animals	No major impacts noted		
Acid Sulfate Soil (all information from Fitzpatrick et al 2008)	*Risk*	*Dominant Acid Sulfate Soil Material*	*Classification (Acid Sulfate Soil subtypes)*
	Extremely High	Sulfuric	Sulfuric cracking clay soil Sulfidic subaqueous clayey soil (sandy) Sulfidic cracking clay soil
Drought Effects	Complete drying out of wetland has allowed temporary expansion of some types of vegetation, e.g. herbland, but has clearly also lead to detrimental affects on other permanent, standing vegetation, including on upper floodplain. Loss of open water habitat. Declining health of fringing reed beds, with total loss possible under continued drought conditions in areas where there is no access to fresh sub-surface water. Potential for primary ecological response to re-flooding to be suppressed due to inhospitable water chemistry resulting from acid sulfate soil impacts. Potential for acid sulfate soils to destroy eggs and resting/estivating stages of frogs, reptiles and macro-invertebrates.		
Other threatening processes	Increase in salinity on upper & lower floodplain areas without freshwater inputs. Immediate proximity and direct interchange of surface and sub-surface water with the River Murray channel allows for leaching of acid, aluminium and heavy metals from acid sulfate soils.		
Other	Friends group on this wetland very active in its care and management - carry out significant work annually and have taken part in recent remedial work with Willow removal program. Forms vital part of community education resources for both general public and large no. of school children visiting Aquatic centre across the river.		
Management recommendations			
	All general management recommendations apply with the exception of those relating to domestic stock grazing. Additionally: • Assess risks to the public as a result of acid sulfate soil and manage access as appropriate. • Control pedestrian access on the dry basin bed.		

Wetland Name	Ukee Boat Club
Date Survey	14/1/08

In-Basin Transects surveyed	*Name*	*Coordinates*	*Length (m)*	*Orientation (∘N)*	*Number of Zones*
	UKEE_01	344405 E, 6111915 N	100	0	6

Presence of surface water at time of vegetation survey	None. Wet mud at inlet/outlet.
Habitat types, floodplain/river edge	Mixed Willow and River Red Gum woodlands with exotic grass understorey on river bank and low diversity mixed native and exotic understorey on other edges. Surrounded by irrigated grazing land.
Habitat types, basin	Closed, Tall Sedgeland and Grasslands. Open water and submerged herblands in wet phase. Diverse fringing herblands in wet phase. Herblands in drying phase, but affected by acid sulfate soils during draw-down.
Vegetation Summary	

Vegetation Associations Documented	*2007-2008 survey (380 m^2 surveyed)*	*Baseline Survey (2005, 8,100 m^2 surveyed)*
	• **Paspalum distichum* grassland • *Typha orientalis* +/-*Schoenoplectus validus* sedgeland • *Typha orientalis* sedgeland • **Rorippa palustris* closed herbland. • *Phragmites australis* very open grassland • *Phragmites australis* grassland	• *Phragmites australis* grassland • *Triglochin procerum* herbland • *Phragmites australis* / *Typha* sp. sedgeland

Tree Health Summary	Good to excellent. Only 9 trees sampled in both the baseline and 2007/2008 surveys. Four trees were scored as having dropped one condition category from 5 to 4. The other five trees scored 5, unchanged from the baseline survey.

Number of Weed and Native Species		**2007-2008 survey**	**Baseline Survey**
	Native	**25**	**21**
	Exotic	**16**	**19**

Rare and Threatened flora	*Baseline*	*07/08*	*Species*	*Common Name*	*AU*	*SA*	*MU*
		✓	*Carex appressa*	Tall Sedge			K
	✓		*Ceratophyllum demersum*	Hornwort		R	K
		✓	*Epilobium pallidiflorum*	Showy Willow-herb			K

Wetland Name	Ukee Boat Club						
		✓	*Calystegia sepium*	Large Bindweed			U
		✓	*Myoporum insulare*	Common Boobialla			U
	✓		*Persicaria lapathifolia*	Pale Knotweed			U
		✓	*Urtica incisa*	Scrub Nettle			U
		✓	*Lycopus australis*	Australian Gipsywort			R
		✓	*Lythrum salicaria*	Purple Loosestrife		R	R
	✓	✓	*Eleocharis sphacelata*	Tall Spike-rush			V
High threat weed species	Aster weed *Aster subulatus*, Ash trees *Fraxinus* sp., *Paspalum* sp., Yellow Marsh-cress *Rorippa palustris*, Willows *Salix* sp.						
Conservation Significance & Current Condition of Vegetation	A small wetland which, in its wet phase, provides good Closed Sedge and Rush habitat to fauna, with Open water and Submerged and Emergent (Triglochin) Herblands. The wetland supports a number of plant species of conservation significance. Its value is compromised by acidic soils impacts as a result of draw-down.						
Summary Management Issues							
Grazing	No domestic stock grazing.						
Feral Animals	No major impacts of feral animals noted.						
Acid Sulfate Soil (all information from Fitzpatrick et al 2008)	*Risk*	*Dominant Acid Sulfate Soil Material*		*Classification (Acid Sulfate Soil subtypes)*			
	Extremely High	Sulfuric		Sulfuric cracking clay soil Sulfidic subaqueous clayey soil Sulfidic cracking clay soil			
Drought Effects	Loss of open water and submerged herbland habitat zones. Wet mud colonization by rush, sedge and herb species in response to draw-down threatened by acid sulfate soil impacts. Potential for primary ecological response to re-flooding to be suppressed due to inhospitable water chemistry resulting from acid sulfate soil impacts. Potential for acid sulfate soils to destroy eggs and resting/estivating stages of frogs, reptiles and macro-invertebrates.						
Other threatening processes	Immediate proximity and direct interchange of surface and sub-surface water with the River Murray channel allows for leaching of acid, aluminium and heavy metals from acid sulfate soils.						
Other	Site of high public use (though not open access).						
Management recommendations							
	All general management recommendations apply with the exception of those relating to domestic stock grazing. Additionally:						

<table>
<tr><th>Wetland Name</th><th>Ukee Boat Club</th></tr>
<tr><td></td><td>Assess risks to the public as a result of acid sulfate soil and manage access as appropriate.
Develop a management plan that will inform any future proposed development on site (eg inner area for mooring small boats) and assist to identify the risks associated with ASS and any potential impacts on biodiversity if further development occurs.</td></tr>
</table>

<table>
<tr><th>Wetland Name</th><th colspan="5">Lake Carlet</th></tr>
<tr><td>Date Survey</td><td colspan="5">8/11/07, 9/11/07, 15/11/07</td></tr>
<tr><td rowspan="6">In-Basin Transects surveyed</td><td>Name</td><td>Coordinates</td><td>Length (m)</td><td>Orientation (∘N)</td><td>Number of Zones</td></tr>
<tr><td>LCAR_01</td><td>365143 E, 6140268 N</td><td>9</td><td>190</td><td>5</td></tr>
<tr><td>LCAR_02</td><td>364790 E, 6139790 N</td><td>105</td><td>330</td><td>5</td></tr>
<tr><td>LCAR_03</td><td>361433 E, 6140304 N</td><td>168</td><td>40</td><td>6</td></tr>
<tr><td>LCAR_04</td><td>358146 E, 6142081 N</td><td>47</td><td>175</td><td>7</td></tr>
<tr><td>LCAR_05</td><td>357928 E, 6142040 N</td><td>28</td><td>170</td><td>4</td></tr>
<tr><td>Presence of surface water at time of vegetation survey</td><td colspan="5">Yes and connected to main channel at east and west ends with through-flow.</td></tr>
<tr><td>Habitat types, floodplain/river edge</td><td colspan="5">Black Box (in small areas on levee) and River Red Gum Woodlands with mixed condition understorey, samphire shrublands (on levee), lignum shrublands (more extensive on levee), limestone cliffs.</td></tr>
<tr><td>Habitat types, basin</td><td colspan="5">Open water, localized submerged herblands, reed beds, extensive exposed damp mud at wetland edge and exposed mud bars as a result of drawdown, damp basin bed colonizing herblands and mat plants.</td></tr>
<tr><td>Vegetation Summary</td><td colspan="5"></td></tr>
<tr><td rowspan="2">Vegetation Associations Documented</td><td colspan="3">2007-2008 survey (1,074 m^2 surveyed)</td><td colspan="2">Baseline Survey (2005, 16,200 m^2 surveyed)</td></tr>
<tr><td colspan="3">Eucalyptus camaldulensis open woodland over Enchylaena tomentosa
Muehlenbeckia florulenta shrubland
*Cynodon dactylon grassland
*Paspalum distichum grassland with emergent Cyperus gymnocaulos
*Trifolium fragiferum closed herbland</td><td colspan="2">Vallisneria sp. submerged herbland
Phragmites australis / Eleocharis sphacelata sedgeland
Typha sp. sedgeland
Phragmites australis grassland
Phragmites australis / Schoenoplectus validus sedgeland</td></tr>
</table>

<table>
<tr><th>Wetland Name</th><th colspan="7">Lake Carlet</th></tr>
<tr><td></td><td colspan="4">• *Paspalum distichum grassland with Hydrocotyle verticillata
• Phragmites australis grassland
• Phragmites australis open grassland
• Phragmites australis, Schoenoplectus validus low open sedgeland
• Schoenoplectus validus sedgeland
• (former/dead or dormant) Schoenoplectus validus closed sedgeland
• Juncus aridicola very open sedgeland
• Juncus usitatus sedgeland over diverse herbs
• Juncus usitatus open sedgeland
• Typha domingensis sedgeland
• (former/dead or dormant) Typha domingensis open sedgeland
• *Aster subulatus very open herbland
• Myriophyllum sp very open submerged herbland</td><td colspan="3">• Diverse herbland</td></tr>
<tr><td>Tree Health Summary</td><td colspan="7">Highly variable at different locations. Baseline survey also noted high variability in condition. Insufficient overlap in sampled trees due to access difficulties and lack of permanent markers on trees to draw conclusions on trend. In the area of overlap between the two surveys, located adjacent samphire midway along the levee, there appears to have been an average drop of one condition class since the baseline survey.</td></tr>
<tr><td rowspan="3">Number of Weed and Native Species</td><td colspan="2"></td><td>2007-2008 survey</td><td colspan="4">Baseline Survey</td></tr>
<tr><td colspan="2">Native</td><td>62</td><td colspan="4">34</td></tr>
<tr><td colspan="2">Exotic</td><td>42</td><td colspan="4">23</td></tr>
<tr><td rowspan="4">Rare and Threatened flora</td><td>Baseline</td><td>07/08</td><td>Species</td><td>Common Name</td><td>AU</td><td>SA</td><td>MU</td></tr>
<tr><td></td><td>✓</td><td>Centipeda minima ssp. minima</td><td>Spreading Sneezeweed</td><td></td><td></td><td>U</td></tr>
<tr><td></td><td>✓</td><td>Distichlis distichophylla</td><td>Emu-grass</td><td></td><td></td><td>U</td></tr>
<tr><td></td><td>✓</td><td>Eclipta platyglossa</td><td>Yellow Twin-heads</td><td></td><td></td><td>U</td></tr>
</table>

Wetland Name	Lake Carlet						
		✓	*Eremophila divaricata* ssp. *divaricata*	Spreading Emubush			U
		✓	*Limosella australis*	Australian Mudwort			U
		✓	*Myoporum insulare*	Common Boobialla			U
	✓	✓	*Persicaria lapathifolia*	Pale Knotweed			U
		✓	*Schoenoplectus pungens*	Spiky Club-rush			U
		✓	*Teucrium racemosum*	Grey Germander			U
		✓	*Urtica incisa*	Scrub Nettle			U
		✓	*Brachyscome basaltica* var. *gracilis*	Swamp Daisy		R	R
		✓	*Juncus holoschoenus*	Joint-leaf Rush			R
		✓	*Lycopus australis*	Australian Gipsywort			R
		✓	*Samolus repens*	Creeping Brookweed			R
		✓	*Schoenoplectus litoralis*	Shore Club-rush			R
		✓	*Senecio glomeratus* ssp. *glomeratus*	Swamp Groundsel			R
		✓	*Isolepis inundata*	Swamp Club-rush			T
High threat weed species	Bridal Creeper, *Asparagus asparagoides*, Boxthorn *Lycium ferocissimum*, Lippia *Phyla canescens*, Aster weed *Aster subulatus*						
Conservation Significance & Current Condition of Vegetation	Highly significant for conservation due to ability to provide drought refuge and due to diversity of habitat resulting from complexity of wetland physical form (eg minor basins, deltas and changes in topography associated with the levee which separates the main basin from the River Murray). Many significant flora species.						
Summary Management Issues							
Grazing	Heavy grazing impacts from domestic stock evident at the western end, moderate grazing impacts at eastern end of levee. Western end of levee shows minor impacts of past stock grazing with good recovery. Kangaroo scats observed in western levee and some light browsing of select species of plants.						
Feral Animals	Rabbit activity evident at western end.						
Acid Sulfate Soil (all information from Fitzpatrick et al 2008)	*Risk*	*Dominant Acid Sulfate Soil Material*		*Classification (Acid Sulfate Soil subtypes)*			
	High	Sulfidic		Sulfidic cracking clay soil Sulfidic subaqueous clayey soil			
Drought Effects	Draw-down exposing damp muds, and stranding reed beds. In some areas there has been good colonization of rush, sedge and herb species following the waterline and in minor basin beds and deltas on the levee. Continued drought will lead to						

Wetland Name	**Lake Carlet**
	loss of these colonized sedge, rush and herblands with replacement by more terrestrial vegetation. Pockets of drought refuge habitat will eventually be lost under continued drying.
Other threatening processes	Potential for increase in salinity on upper & lower floodplain areas.
Other	
Management recommendations	
	All general management recommendations apply. Additionally: • Foster support and assist with the development of a multi-property, wetland scale management plan.

Wetland Name	**North Purnong**				
Date Survey	5/12/07, 7/12/07				
In-Basin Transects surveyed	*Name*	*Coordinates*	*Length (m)*	*Orientation (°N)*	*Number of Zones*
	NPUR_01	369420 E, 6144778 N	130	40	8
	NPUR_02	370617 E, 6144045 N	230	5	6
	NPUR_03	370646 E, 6144292 N	96	10	4
Presence of surface water at time of vegetation survey	None				
Habitat types, floodplain/river edge	River Red Gum woodlands with a diminished understorey in most areas, with some areas having better structural diversity and more diverse understorey species (namely the 'islands' and outlet/inlet areas). Limestone cliffs. Lignum shrublands, salt-tolerant chenopod herblands, and poor condition sparse samphire shrublands.				
Habitat types, basin	Narrow band of fringing reed beds. Submerged herbland and open water in wet phase. Very sparse herbland on dry basin bed.				
Vegetation Summary					
Vegetation Associations Documented	*2007-2008 survey (1,392 m^2 surveyed)*		*Baseline Survey (2003/04, 3,600 m^2 surveyed)*		
	• *Paspalum distichum* grassland • *Paspalum distichum* closed grassland • (former/dead or dormant) *Schoenoplectus validus*, *Typha domingensis* sedgeland		• *Eucalyptus camaldulensis var. camaldulensis* Low Open Forest over *Muehlenbeckia florulenta* and *Eleocharis acuta* • *Halosarcia ?pergranulata* Low shrubland		

Wetland Name	North Purnong						
	• *Schoenoplectus validus* open sedgeland • (former/dormant or dead) *Typha domingensis* closed sedgeland • *Typha domingensis* closed sedgeland • *Typha domingensis* open sedgeland • (seedling) *Typha domingensis* very open sedgeland • *Typha domingensis*, *Bolboschoenus caldwellii* very open sedgeland over **Aster subulatus*, *Mimulus repens* mixed very open herbs • *Phragmites australis* grassland • **Paspalum distichum*, *Lachnagrostis filiformis* very open grassland with emergent *Phragmites australis*.			• *Typha domingensis* Closed sedgeland over *Azolla filiculoides* • *Eucalyptus camaldulensis var. camaldulensis* Low Open Forest over *Muehlenbeckia florulenta.*			
Tree Health Summary	Generally Moderate, but variable. A drop of one condition class category since the baseline survey.						
Number of Weed and Native Species			**2007-2008 survey**	**Baseline Survey**			
	Native		**34**	**21**			
	Exotic		**18**	**18**			
Rare and Threatened flora	*Baseline*	*07/08*	*Species*	*Common Name*	*AU*	*SA*	*MU*
		✓	*Cyperus vaginatus*	Stiff Flat-sedge			K
		✓	*Centipeda minima* ssp. *minima*	Spreading Sneezeweed			U
		✓	*Cressa cretica*	Rosinweed			U
		✓	*Limosella australis*	Australian Mudwort			U
		✓	*Persicaria lapathifolia*	Pale Knotweed			U
		✓	*Senecio runcinifolius*	Thistle-leaf Groundsel			U
		✓	*Urtica incisa*	Scrub Nettle			U
		✓	*Lycopus australis*	Australian Gipsywort			R
		✓	*Carex gaudichaudiana*	Fen Sedge			X

Wetland Name	**North Purnong**		
High threat weed species	Spear thistles Cirsium vulgare, in the eastern lower floodplain		
Conservation Significance & Current Condition of Vegetation	The majority of the floodplain at this wetland is in poor to very poor condition (though there are some better areas) due to prolonged and heavy grazing. Salinity impacts are evident in floodplain areas. The drying wetland basin has demonstrated a much reduced colonization response to draw-down (in comparison with other wetlands) due to grazing and possibly salinity effects. Rush and sedgelands are significantly damaged by grazing. Five of the nine species of conservation significance were found only in the better condition eastern inlet/outlet area.		
Summary Management Issues			
Grazing	Prolonged and heavy domestic stock grazing with resulting impacts on wetland ecology.		
Feral Animals	Considerable rabbit activity evident along the levee floodplain (scats and warrens).		
Acid Sulfate Soil (all information from Fitzpatrick et al 2008)	*Risk*	*Dominant Acid Sulfate Soil Material*	*Classification (Acid Sulfate Soil subtypes)*
	Moderate to High	Sulfidic	Sulfidic cracking clay soil Cracking clay soil Sulfuric cracking clay soil
Drought Effects	Drought has opened up access to reed-beds and islands by domestic stock in places where these were previously inaccessible due to standing water. The drying wetland basin has demonstrated a much reduced colonization response to draw-down (in comparison with other wetlands) due to grazing and possibly salinity effects. Loss of open water and submerged herbland habitats. Declining health of fringing reed beds, with total loss possible under continued drought conditions in areas where there is no access to fresh sub-surface water.		
Other threatening processes	Further increase in salinity on upper & lower floodplain areas without freshwater inputs. Areas of Typha survival where there is no surface water indicate there is flushing occurring from the River Murray channel which has the potential to lead to mobilization of acid, aluminium and heavy metals from acid sulfate soils.		
Other			
Management recommendations			
	All general management recommendations apply.		

<table>
<tr><th>Wetland Name</th><th colspan="5">Kroehn’s Landing</th></tr>
<tr><td>Date Survey</td><td colspan="5">30/11/07</td></tr>
<tr><td rowspan="4">In-Basin Transects surveyed</td><td>Name</td><td>Coordinates</td><td>Length (m)</td><td>Orientation (°N)</td><td>Number of Zones</td></tr>
<tr><td>KROE_01</td><td>369968 E, 6159190 N</td><td>130</td><td>110</td><td>3</td></tr>
<tr><td>KROE_02</td><td>370126 E, 6159078 N</td><td>250</td><td>110</td><td>3</td></tr>
<tr><td>KROE_03</td><td>370382 E, 6158968 N</td><td>28</td><td>290</td><td>3</td></tr>
<tr><td>Presence of surface water at time of vegetation survey</td><td colspan="5">None</td></tr>
<tr><td>Habitat types, floodplain/river edge</td><td colspan="5">River Red Gum and Black Box woodlands with variable condition understorey, willow forests, limestone cliffs, lignum shrublands, samphire shrublands, chenopod herblands</td></tr>
<tr><td>Habitat types, basin</td><td colspan="5">Open water in wet phase, riparian channels and deltas, narrow bands of reed beds, islands, exposed muds in drying phase, colonizing herblands.</td></tr>
<tr><td>Vegetation Summary</td><td colspan="5"></td></tr>
<tr><td rowspan="2">Vegetation Associations Documented</td><td colspan="3">2007-2008 survey (1,086 m^2 surveyed)</td><td colspan="2">Baseline Survey (2003/04, 1,800 m^2 surveyed)</td></tr>
<tr><td colspan="3">• Phragmites australis grassland over Atriplex semibaccata
• Phragmites australis grassland with emergent Eucalyptus camaldulensis
• Phragmites australis grassland
• (former/dead or dormant) Phragmites australis closed grassland
• Juncus usitatus sedgeland
• Juncus usitatus, over Lachnagrostis filiformis very open sedgeland
• Persicaria lapathifolia, Atriplex suberecta open herbland
• Persicaria lapathifolia very open herbland
• Persicaria lapathifolia tall open herbland over mixed herbs and Juncus aridicola
• Persicaria lapathifolia, Maireana brevifolia over Atriplex suberecta very open herbland</td><td colspan="2">• Eucalyptus camaldulensis var. camaldulensis Open Forest over Phragmites australis
• Halosarcia pergranulata ssp. pergranulata Low Shrubland.</td></tr>
<tr><td>Tree Health Summary</td><td colspan="5">Moderate to good tree health. Complex hydrology means tree health is likely to be variable across wetland. The original tree</td></tr>
</table>

Wetland Name	**Kroehn's Landing**						
	health transect was unable to be located, but it was reported that tree health was generally good along this transect at the time of the baseline survey. Therefore it is possible that there has been a decline in average tree health.						
Number of Weed and Native Species			**2007-2008 survey**	**Baseline Survey**			
	Native		**43**	**21**			
	Exotic		**21**	**15**			
Rare and Threatened flora	*Baseline*	*07/08*	*Species*	*Common Name*	*AU*	*SA*	*MU*
	✓	✓	*Apium prostratum*	Native Celery			K
	✓	✓	*Swainsona greyana*	Darling Pea			K
	✓		*Atriplex leptocarpa*	Slender-fruit Saltbush			U
		✓	*Calystegia sepium*	Large Bindweed			U
	✓	✓	*Eclipta platyglossa*	Yellow Twin-heads			U
		✓	*Limosella australis*	Australian Mudwort			U
		✓	*Persicaria lapathifolia*	Pale Knotweed			U
		✓	*Senecio runcinifolius*	Thistle-leaf Groundsel			U
		✓	*Brachyscome basaltica* var. *gracilis*	Swamp Daisy		R	R
		✓	*Calotis scapigera*	Tufted Burr-daisy		R	R
		✓	*Epilobium hirtigerum*	Hairy Willow-herb			R
		✓	*Lycopus australis*	Australian Gipsywort			R
		✓	*Carex gaudichaudiana*	Fen Sedge			X
High threat weed species	Aster weed *Aster subulatus,* Bridal Creeper, *Asparagus asparagoides*, Boxthorn *Lycium ferocissimum*, Olive *Olea europaea*, *Paspalum* sp.						
Conservation Significance & Current Condition of Vegetation	The floodplain areas of this wetland are variable in condition but tend to be in moderate to poor condition due to past grazing impacts. Colonisation of herbs, rushes and sedges onto the drying basin was sparse. The structural complexity of this wetland offers a wide variety of habitat niches. A range of flora species of conservation significance were recorded.						
Summary Management Issues							
Grazing	Evidence of past grazing shown by sparse ground cover and reduced species diversity in some areas, but stock not observed at time of survey.						

Wetland Name	**Kroehn's Landing**		
Feral Animals	Some selective grazing of particular plant species which may be due to feral animals.		
Acid Sulfate Soil (all information from Fitzpatrick et al 2008)	*Risk*	*Dominant Acid Sulfate Soil Material*	*Classification (Acid Sulfate Soil subtypes)*
	High to Moderate	Sulfidic	Sulfidic cracking clay soil
Drought Effects	Loss of open water habitat and submerged herbland. Colonisation of herbs, rushes and sedges onto the drying basin was sparse. Declining health of fringing reed beds, with total loss possible under continued drought conditions in areas where there is no access to fresh sub-surface water. Potential for Acid Sulfate Soils to compromise survival of colonizing vegetation and to impact on first wave of ecological production on re-wetting. Potential for acid sulfate soils to destroy eggs and resting/estivating stages of frogs, reptiles and macro-invertebrates.		
Other threatening processes	Increase in salinity on upper & lower floodplain areas without freshwater inputs. Potential for increased access by domestic stock to sensitive habitat areas not previously accessible with standing water.		
Other	Landholder pumping water from wetland. A series of low levees had been constructed in an attempt to impound water.		
Management recommendations			
	All general management recommendations apply. Additionally: • Foster support and assist with the development of a multi-property, wetland scale management plan.		

Wetland Name	**Devon Downs South**				
Date Survey	17/12/07				
In-Basin Transects surveyed	*Name*	*Coordinates*	*Length (m)*	*Orientation (◦N)*	*Number of Zones*
	DDS_01	371745 E, 6161310 N	282	350	11
Presence of surface water at time of vegetation survey	None, and reported by landholder to have been dry for at least a year.				
Habitat types, floodplain/river edge	River Red Gum and Black Box woodlands with little understorey (with the exception of the area around the connection to Devon Downs North where there is mixed native and exotic understorey), Limestone cliffs , Lignum shrublands, Samphire shrublands				
Habitat types, basin	Narrow band of fringing reed beds, open water in wet phase, exposed muds in drying phase.				
Vegetation Summary					

<table>
<tr><th>Wetland Name</th><th colspan="7">Devon Downs South</th></tr>
<tr><td rowspan="2">Vegetation Associations Documented</td><td colspan="3">2007-2008 Survey (894 m² surveyed)</td><td colspan="4">Baseline Survey (2003/04, 3,600 m² surveyed)</td></tr>
<tr><td colspan="3">• (former/ dead or dormant) Cyperus gymnocaulos closed sedgeland.
• (former/dead or dormant) Typha domingensis, Cyperus gymnocaulos very open sedgeland
• Mimulus repens open herbland
• Maireana brevifolia low very open shrubland
• Mimulus repens, *Chenopodium glaucum open herbland
• Typha domingensis, Phragmites australis sedgeland (transitional from Typha to colonizing Phragmites)
• Phragmites australis grassland
• Cyperus gymnocaulos open sedgeland</td><td colspan="4">• Muehlenbeckia florulenta Shrubland over Maireana brevifolia and Enchylaena tomentosa var. tomentosa
• Eucalyptus largiflorens and E. camaldulensis var. camaldulensis Low Woodland over Myoporum montanum and Enchylaena tomentosa var. tomentosa
• Schoenoplectus validus, Typha domingensis and Typha orientalis Sedgeland
• Phragmites australis and S. validus Grassland</td></tr>
<tr><td>Tree Health Summary</td><td colspan="7">Poor to moderate with variability potentially associated with local groundwater. Tree health not surveyed as part of original baseline survey.</td></tr>
<tr><td rowspan="3">Number of Weed and Native Species</td><td colspan="2"></td><td>2007-2008 survey</td><td colspan="4">Baseline Survey</td></tr>
<tr><td colspan="2">Native</td><td>27</td><td colspan="4">40</td></tr>
<tr><td colspan="2">Exotic</td><td>18</td><td colspan="4">20</td></tr>
<tr><td rowspan="9">Rare and Threatened flora</td><td>Baseline</td><td>07/08</td><td>Species</td><td>Common Name</td><td>AU</td><td>SA</td><td>MU</td></tr>
<tr><td>✓</td><td></td><td>Atriplex leptocarpa</td><td>Slender-fruit Saltbush</td><td></td><td></td><td>U</td></tr>
<tr><td>✓</td><td>✓</td><td>Cressa cretica</td><td>Rosinweed</td><td></td><td></td><td>U</td></tr>
<tr><td>✓</td><td></td><td>Distichlis distichophylla</td><td>Emu-grass</td><td></td><td></td><td>U</td></tr>
<tr><td></td><td>✓</td><td>Eclipta platyglossa</td><td>Yellow Twin-heads</td><td></td><td></td><td>U</td></tr>
<tr><td></td><td>✓</td><td>Persicaria lapathifolia</td><td>Pale Knotweed</td><td></td><td></td><td>U</td></tr>
<tr><td>✓</td><td></td><td>Sclerolaena brachyptera</td><td>Short-wing Bindyi</td><td></td><td></td><td>U</td></tr>
<tr><td>✓</td><td></td><td>Sclerolaena tricuspis</td><td>Three-spine Bindyi</td><td></td><td></td><td>U</td></tr>
<tr><td>✓</td><td></td><td>Senecio runcinifolius</td><td>Thistle-leaf Groundsel</td><td></td><td></td><td>U</td></tr>
</table>

Wetland Name	**Devon Downs South**						
	✓	✓	*Teucrium racemosum*	Grey Germander			U
		✓	*Lobelia anceps*	Angled Lobelia			R
	✓		*Muehlenbeckia horrida* ssp. *horrida*	Spiny Lignum		R	R
High threat weed species	Aster weed *Aster subulatus*, Boxthorn *Lycium ferocissimum*, *Paspalum* sp.						
Conservation Significance & Current Condition of Vegetation	This wetland is in poor to moderate condition due to past grazing (now removed) and salinity; the extensive samphire of the Devon Downs Swamp was in good condition. There is limited complexity of habitat. There was limited colonizing vegetation recorded from the dry basin bed.						
Summary Management Issues							
Grazing	Formerly domestic stock grazing, now native and feral species.						
Feral Animals	Goats						
Acid Sulfate Soil (all information from Fitzpatrick et al 2008)	*Risk*	*Dominant Acid Sulfate Soil Material*		*Classification (Acid Sulfate Soil subtypes)*			
	Moderate	Hyposulfidic		Cracking clay soils containing some sulfides Sulfidic soil Sulfidic cracking clay soil			
Drought Effects	Loss of open water and submerged vegetation. Declining health of fringing reed beds, with total loss possible under continued drought conditions in areas where there is no access to fresh sub-surface water.						
Other threatening processes	Further increase in salinity on upper & lower floodplain areas without freshwater inputs.						
Other							
Management recommendations							
	• All general management recommendations apply with the exception of those relating to domestic stock grazing.						

Wetland Name	**Devon Downs North**				
Date Survey	18/12/07, 19/12/07				
In-Basin Transects surveyed	*Name*	*Coordinates*	*Length (m)*	*Orientation (∘N)*	*Number of Zones*
	DDN_01	374411 E, 6161216 N	46	140	7
	DDN_02	373640 E, 6160855 N	27	0	5

Wetland Name	Devon Downs North				
	DDN_03	377281 E, 6165194 N	100	300	4
	DDN_04	375987 E, 6163920 N	100	120	7
Presence of surface water at time of vegetation survey	None in majority of wetland. Localised small pools near inlet/outlets.				
Habitat types, floodplain/river edge	Black Box and Red Gum Woodlands with moderate to good understorey in many areas. Lignum shrublands. Chenopod shrublands and herblands.				
Habitat types, basin	Reedbeds. Open water and submerged herblands in wet phase, exposed muds, diverse mat plants and diverse low and tall herblands in drying phase.				
Vegetation Summary					
Vegetation Associations Documented	*2007-2008 survey (906 m^2 surveyed)*			*Baseline Survey (2006, 675 m^2 surveyed)*	
	• (former/dead) *Graminae* sp closed grassland • **Paspalum distichum* grassland • *Phragmites australis* closed sedgeland • *Phragmites australis*, *Schoenoplectus validus* closed sedgeland • *Cyperus gymnocaulos* very open sedgeland • *Schoenoplectus pungens* very open sedgeland • (former/dead or dormant) *Schoenoplectus validus* closed sedgeland • *Schoenoplectus validus* open sedgeland • *Schoenoplectus validus* very open sedgeland • *Schoenoplectus validus* open sedgeland over *Isolepis cernua*, *Lilaeopsis polyantha*, *Crassula helmsii* very open mat plants • *Typha* sp, *Juncus aridicola* very open sedgeland • *Juncus aridicola* open sedgeland • *Juncus aridicola* sedgeland • *Juncus usitatus* open sedgeland • *Persicaria lapathifolia* shrubland over *Juncus aridicola* sedgeland • **Aster subulatus* very open herbland			• *Phragmites australis* sedgeland • *Schoenoplectus validus* sedgeland • *Typha* spp. sedgeland • *Vallisneria spiralis* submerged herbland	

Wetland Name	**Devon Downs North**						
	• **Aster subulatus* open herbland • *Persicaria lapathifolia* **Aster subulatus* over *Pseudonapthaluem luteoalbum* Open herbland • *Mimulus repens*, *Glossostigma* sp, *Limosella australis* open mat plants • *Isolepis cernua* open mat plants with emergent **Aster subulatus* • *Limosella australis*, *Isolepis cernua*, very open mat plants						
Tree Health Summary	Good to moderate, variable (very large wetland). Access to previously surveyed trees was not possible. The baseline survey noted that on average tree health was good to moderate as was found in the 2007/2008 survey. Wetland had only just lost surface water and therefore major impacts on tree health between the two surveys was unlikely to be observable yet.						
Number of Weed and Native Species		**2007-2008 survey**	**Baseline Survey**				
	Native	**51**	**48**				
	Exotic	**18**	**11**				
Rare and Threatened flora	*Baseline*	*07/08*	*Species*	*Common Name*	*AU*	*SA*	*MU*
		✓	*Triglochin hexagonum*	Six-point Arrowgrass			K
	✓		*Centipeda minima* ssp. *minima*	Spreading Sneezeweed			U
		✓	*Distichlis distichophylla*	Emu-grass			U
		✓	*Eclipta platyglossa*	Yellow Twin-heads			U
	✓		*Epaltes australis*	Spreading Nut-heads			U
		✓	*Lilaeopsis polyantha*	Australian Lilaeopsis			U
	✓	✓	*Limosella australis*	Australian Mudwort			U
	✓	✓	*Persicaria lapathifolia*	Pale Knotweed			U
		✓	*Rumex tenax*	Shiny Dock			U
		✓	*Schoenoplectus pungens*	Spiky Club-rush			U

Wetland Name	**Devon Downs North**						
		✓	*Brachyscome basaltica* var. *gracilis*	Swamp Daisy		R	R
		✓	*Epilobium hirtigerum*	Hairy Willow-herb			R
		✓	*Senecio glomeratus* ssp. *glomeratus*	Swamp Groundsel			R
High threat weed species	Aster weed *Aster subulatus*, Boxthorn *Lycium ferocissimum*, Prickly Pear *Opuntia* sp., *Paspalum* sp.						
Conservation Significance & Current Condition of Vegetation	Highly significant for conservation, large and complex wetland offering diverse habitat, with many flora species of conservation significance recorded. Healthy, diverse colonisation response to draw-down.						
Summary Management Issues							
Grazing	Low level domestic stock grazing at northern end with potential to cause degradation of the wetland ecology under drought conditions.						
Feral Animals	No major impacts noted.						
Acid Sulfate Soil (all information from Fitzpatrick et al 2008)	*Risk*	*Dominant Acid Sulfate Soil Material*		*Classification (Acid Sulfate Soil subtypes)*			
	High to Moderate	Sulfidic		Sulfidic cracking clay soil Sulfidic soil Sulfuric soil			
Drought Effects	Loss of open water and submerged vegetation. Declining health of fringing reed beds, with total loss possible under continued drought conditions in areas where there is no access to fresh sub-surface water. Potential for Acid Sulfate Soils to compromise survival of colonizing vegetation and to impact on first wave of ecological production on re-wetting. Potential for acid sulfate soils to destroy eggs and resting/estivating stages of frogs, reptiles and macro-invertebrates.						
Other threatening processes	Increase in salinity on upper & lower floodplain areas without freshwater inputs.						
Other							
Management recommendations							
	All general management recommendations apply.						

Wetland Name	**Noonawirra**				
Date Survey	23/1/08				
In-Basin Transects surveyed	*Name*	*Coordinates*	*Length (m)*	*Orientation (∘N)*	*Number of Zones*
	NOON_01	369550 E, 6182691 N	37	300	5

<table>
<tr><th>Wetland Name</th><th colspan="5">Noonawirra</th></tr>
<tr><td></td><td>NOON_02</td><td>369311 E, 6182259 N</td><td>83</td><td>290</td><td>6</td></tr>
<tr><td>Presence of surface water at time of vegetation survey</td><td colspan="5">None</td></tr>
<tr><td>Habitat types, floodplain/river</td><td colspan="5">River Red Gum Woodlands with shrub and with herb understorey, Limestone cliffs, extensive Lignum shrublands, herb and grasslands</td></tr>
<tr><td>Habitat types, basin</td><td colspan="5">Fringing reedbeds. Open water, submerged herblands, inundated grasslands in wet phase. Exposed muds, colonizing herblands in drying phase.</td></tr>
<tr><td>Vegetation Summary</td><td colspan="5"></td></tr>
<tr><td rowspan="2">Vegetation Associations Documented</td><td colspan="3">2007-2008 survey (570 m² surveyed)</td><td colspan="2">Baseline Survey (2006, 270 m² surveyed)</td></tr>
<tr><td colspan="3">• (former/dead or dormant) Juncus usitatus open sedgeland
• (former/dead or dormant) Juncus usitatus sedgeland
• *Paspalum distichum grassland with emergent Cyperus exaltatus (formerly a line of Cyperus exaltatus sedgeland)
• Cyperus gymnocaulos very open sedgeland
• *Conyza albida open herbland
• *Conyza albida tall very open herbland
• *Cirsium vulgare, *Conyza albida herbland
• (former/dead or dormant) Bolboschoenus caldwellii closed sedgeland
• (former/dead or dormant) Bolboschoenus caldwellii closed sedgeland
• Phragmites australis closed grassland</td><td colspan="2">• Typha spp. sedgeland
• Phragmites australis grassland
• Grazed riparian grassland
• Juncus usitatus sedgeland
• Vallisneria spiralis submerged herbland
• Schoenoplectus validus sedgeland</td></tr>
<tr><td>Tree Health Summary</td><td colspan="5">Good to Excellent. Individual trees from 2006 baseline survey unable to be re-located, however, both surveys recorded good to excellent health and there appears to have been no large-scale change between the two surveys.</td></tr>
<tr><td>Number of Weed and Native Species</td><td></td><td>2007-2008 survey</td><td colspan="3">Baseline Survey</td></tr>
</table>

Wetland Name	**Noonawirra**						
	Native		**33**	**34**			
	Exotic		**15**	**22**			
Rare and Threatened flora	*Baseline*	*07/08*	*Species*	*Common Name*	*AU*	*SA*	*MU*
		✓	*Centipeda minima* ssp. *minima*	Spreading Sneezeweed			U
		✓	*Distichlis distichophylla*	Emu-grass			U
		✓	*Eclipta platyglossa*	Yellow Twin-heads			U
	✓		*Haloragis aspera*	Rough Raspwort			U
	✓	✓	*Persicaria lapathifolia*	Pale Knotweed			U
		✓	*Rumex tenax*	Shiny Dock			U
		✓	*Teucrium racemosum*	Grey Germander			U
		✓	*Urtica incisa*	Scrub Nettle			U
		✓	*Brachyscome basaltica var. gracilis*	Swamp Daisy		R	R
		✓	*Calotis scapigera*	Tufted Burr-daisy		R	R
		✓	*Epilobium hirtigerum*	Hairy Willow-herb			R
		✓	*Lythrum salicaria*	Purple Loosestrife		R	R
	✓		*Myriophyllum papillosum*	Robust Milfoil		R	K
		✓	*Pratia concolor*	Poison Pratia		R	R
		✓	*Senecio glomeratus ssp. glomeratus*	Swamp Groundsel			R
High threat weed species	Fleabanes *Conyza* ssp., Golden Dodder *Cuscuta campestris*, *Paspalum* sp. Kikuyu *Pennisetum clandestinum*, Lippia *Phyla canescens*, *Pinus* sp.						
Conservation Significance & Current Condition of Vegetation	This wetland provides good diversity of habitat and is valuable as part of a much larger complex of wetlands. The native vegetation has good species diversity and structural complexity, with many species of conservation significance recorded. Heavy infestations of herbaceous exotics.						
Summary Management Issues							
Grazing	Evidence of selective heavy browsing and macropod scats observed. Domestic stock noted in past surveys.						
Feral Animals	Rabbit and fox activity.						
Acid Sulfate Soil (all information from Fitzpatrick et al 2008)	*Risk*		*Dominant Acid Sulfate Soil Material*	*Classification (Acid Sulfate Soil subtypes)*			
	Moderate to High		Sulfidic	Sulfidic cracking clay soil			

Wetland Name	Noonawirra		
		Hyposulfidic	Cracking clay soil with some sulfide minerals
Drought Effects	Loss of open water and submerged vegetation. Declining health of fringing reed beds, with total loss possible under continued drought conditions in areas where there is no access to fresh sub-surface water. Heavy colonisation of the dry basin by *Conyza* sp.		
Other threatening processes	Potential for Acid Sulfate Soils to compromise survival of colonizing vegetation and to impact on first wave of ecological production on re-wetting. Potential for acid sulfate soils to destroy eggs and resting/estivating stages of frogs, reptiles and macro-invertebrates. Camping on floodplain has lead to cleared/tracked/compacted areas.		
Other	Soil subsidence evident from drop in soil around concrete collars of piezometers.		
Management recommendations			
	All general management recommendations apply.		

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1. INTRODUCTION

The drought has resulted in a 'weir pool lowering event' in the reach of the River Murray between Lock 1 and Wellington in South Australia, which has dried many fringing wetlands and lagoons. Ecological assessment of a regionally representative sub-set of nine of these unmanaged wetlands will provide an understanding of the response of wetlands to a large-scale drawdown event. Data collected will be used to:

- Determine impact (both positive and negative) of the drought on wetlands below Lock 1.
- Identify risks / outcomes associated with long-term disconnection as well as reconnection.
- Inform decisions regarding reconnection of wetlands upon return of normal river pool levels.
- Inform future potential hydrological management of wetlands, and associated on-going monitoring needs.

All nine wetlands have been previously surveyed as part of an ecological survey program (SKM 2004, 2006; and Marsland and Nicol, 2007; Australian Water Environments, 2008). Questions addressed by the ecological survey program include:

- What is the effect of drying on vegetation composition and tree health?
- How have these vegetation parameters changed since during the course of the ecological surveys?

Previous work by CSIRO Land and Water and others in subaqueous soil (lakes and rivers) and wetland environments in the region identified various occurrences of sulfidic, sulfuric and monosulfidic black ooze materials (i.e. acid sulfate soils; see Appendix 1: Baldwin *et al*. 2007; Fitzpatrick *et al*. 2006, 2007, 2008a; Hicks and Lamontagne 2006; Lamontagne *et al*. 2004). Occurrences of these ASS materials can have serious environmental consequences relating to soil and water acidification, de-oxygenation of water, emission of foul smelling gases (H_2S, organo-S compounds) and possible release of heavy and trace metal Simpson *et al.* (2008) – especially if these wetlands evaporate slowly and experience wetting-drying cycles. Hence, characterisation of a range of both subaqueous and waterlogged or hydric soils (see Appendix 1 for definitions) in the nine unmanaged wetlands between Lock 1 and Wellington would allow:

- identification of ASS hot-spots and contaminant types, and
- development of specific management options and contingency plans.

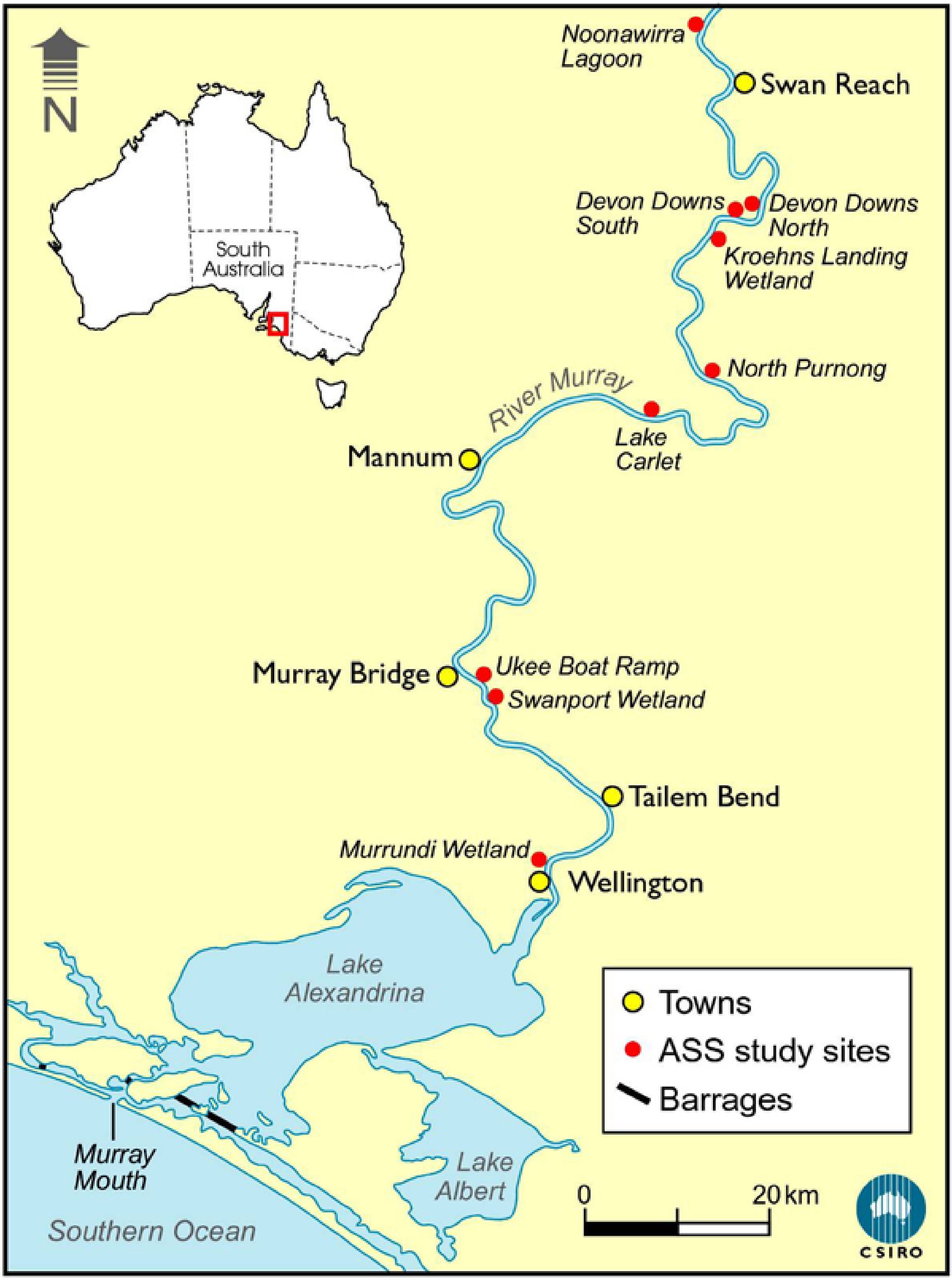


Figure 1. Locations of the nine River Murray wetlands below Lock 1 and important population centres.

1.1 Objectives

The aims of this investigation are to: (i) verify the presence (or absence) of the types of acid sulfate soil (ASS) materials (as defined in Appendix 1) in and adjacent to nine selected wetlands between Lock 1 and Wellington (Figure 1) and (ii) assess the potential risk such soil materials might pose to infrastructure and environmental assets if they are exposed by lower water levels. To achieve these aims, six objectives were identified:

- Assess the following potential impacts, due to possible presence of ASS and salt efflorescences, caused by the lowering of the water level in the River Murray:
    - Acidification (using acid-base accounting derived from chromium reducible sulfur (CRS) and carbonate content) and salinisation of inundated and progressively de-watered subaqueous soils.
    - Mineralogical and chemical composition of salt efflorescences.
    - Presence and potential mobilisation of trace elements and heavy metals (e.g. Al, As, Cd, Pb, Se, Zn).
- Identify ASS hot-spots and the range of ASS subtypes (i.e. baseline survey), and develop specific management options and contingency plans (i.e. monitoring parameters as the wetlands evaporate and refill; triggers for re-flooding; structured re-flooding program).
- Provide regular verbal and written briefings and an interim "Information paper on environmental and management issues associated with the subaqueous and wetland ASS at the Swanport wetland" (Fitzpatrick *et al.* 2007) - based primarily on field observations and screening tests (pH and peroxide tests) - **Stage 1.**
- Present detailed findings and conclusions on the properties, extent, potential severity and management of ASS materials in: (i) subaqueous soils in the River Murray (at selected sites adjacent to wetlands), (ii) waterlogged soils, which are soils that are wet or saturated long enough to produce periodically anaerobic conditions, thereby influencing the growth of plants (i.e. hydric soils with sulfidic material) and (iii) drained soils, which are de-watered subaqueous or waterlogged soils in the nine wetlands, based on field sampling, morphological descriptions and laboratory data (Appendix 2 to 5) - **Stage 2.**
- Develop and recommend a monitoring strategy, identifying key accessible monitoring sites in the nine wetlands for critical field indicators and laboratory tests; and determine key trigger values.
- Present public lectures and a field training course for wetland managers and land owners using examples from the nine wetlands covering: What are ASS?, How to recognise the 3 main types of ASS materials in the field, and Assessing risk of ASS in key wetlands in MDB – **Stage 3** (Appendix 6).

2. FIELD AND LABORATORY METHODS

2.1 Field Sampling of Soils

Soil sampling took place between July 2007 and April 2008 (see Table 1 and Figure 2). A prerequisite for ASS sampling was inclusion in the vegetation ecological surveys of Australian Water Environments (2008). Their ecological survey was conducted along transects perpendicular to the wetland shoreline, which typically traversed shoreline vegetation (i.e. the highest elevation in the transect) to the middle of the wetland (i.e. lowest elevation).

In general, the ASS surveys were guided by the location of the ecological survey transects. This allowed development of vegetation/soil relationships, and being based on toposequences (or here, *hydrosequences*, see inset diagrams in Figure 2 showing approximate placement of sites) followed valid soil survey design (McKenzie et al. 2008). However, at times during reconnaissance we chose to sample away from the transects when soils covered were considered atypical of the wetland, or to sample at locally significant sites, e.g. at groundwater discharges, in sandy profiles, or at the base of calcareous cliffs. Of the nine wetlands studied, we sampled 38 soil profiles, from which we collected and analysed 154 soil samples (Table 1).

Table 1. Survey site names, IDs, and numbers of profiles sampled and layers analysed during the survey of acid sulfate conditions in soils of nine River Murray wetlands below Lock 1.

Wetland survey Name	ID	Number of profiles sampled	Number of layers analysed
Noonawirra	NOO	3	11
Devon Downs North	DD	4	15
Devon Downs South	DDS	5	19
Kroehns Landing	KRL	4	16
North Purnong	NPU	4	18
Lake Carlet	LCA	3	12
Ukee Boat Club	UKE	6	24
Swanport	SPM	3	13
	WL	3	16
Murrundi	MUR	3	9
Total		**38**	**154**

GPS coordinates were taken for each profile location (using WGS 84 datum, zone 54 south) (see Appendix 2, Table 18). Soil sampling was conducted at dry sites predominantly from soil pits dug using a spade to approximately 0.6 m deep, and on rare occasions using a hand auger. Where soils were inundated (i.e. subaqueous soils), samples were obtained by wading and using a spade, or a hand auger (e.g. D-auger or gouge auger), again, to approximately 0.6 m depth. Irrespective of the sampling method, soil profiles were sampled on a layer-by-layer basis, and the sites and samples described according to standard methodology (McDonald *et al*. 1998; Schoeneberger *et al.* 2002).

Morphology and physical properties described included: colour (matrix and mottles), texture, structure, consistency, root abundance and nodules and concretions. Layer depth ranges were also recorded.

The following sampling procedure was followed: firstly, bulk soil samples (typically >200 g) for each layer sampled were placed in labelled plastic bags and mixed. Next, from the bag, sub-samples were taken for X-ray diffraction (XRD), X-ray fluorescence spectrometry (XRF), and chromium reducible sulfur (CRS) analyses. These samples were placed in 70 ml screw-top plastic vials, with care taken to exclude air by filling the vials to the maximum level to limit sulfur oxidation during transit and storage. Finally, further layer sub-samples were placed in one of two chip trays, with the first used to display morphologically representative aggregates for each of the sampled layers for later visual reference (e.g. during report writing and placed in the CSIRO archival soil storage system), while the second chip tray was used for ASS incubation in the laboratory (see Section 2.2.2).

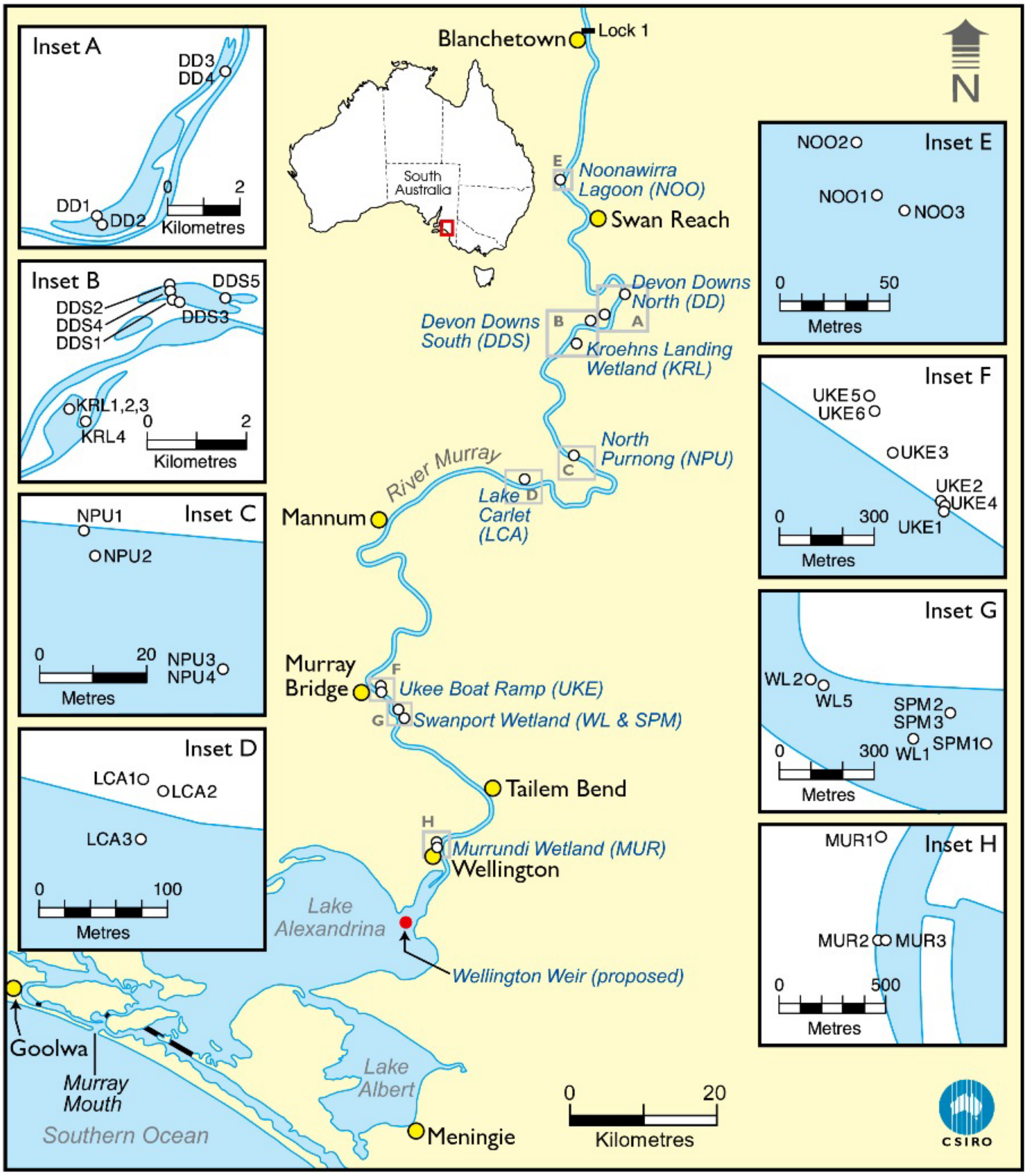


Figure 2. Locations of representative sites sampled for acid sulfate soil conditions in the unmanaged nine River Murray wetlands below Lock 1 between July 2007 and April 2008 (see Table 1 for wetland codes and Table 18 for geographic coordinates).

Physical limitations to sampling caused by the soil materials (e.g. unconsolidated coarse, sandy layers) or deeper water made recovery of deep profile samples difficult in some places, but those obtained should be adequate to characterise materials likely to be exposed as water levels decrease.

The general flowchart for soil sample collection and analysis is presented in Figure 3. On return to the laboratory the samples were kept cool at 4°C until analysed. Samples (soils and salts) for XRF and detailed sulfur analysis (CRS) were dried at 80°C. Moisture contents were recorded and bulk densities estimated. Samples for detailed sulfur analysis were sent to the Environmental Analysis Laboratory of Southern Cross University. Recorded locations and long-term storage of the oven dried samples and air dried/moist samples kept in chip trays will allow for future re-sampling and analysis, if required, and for the ageing experiments to follow the course of potential acidification and confirm ASS status (see Section 2.2.2).

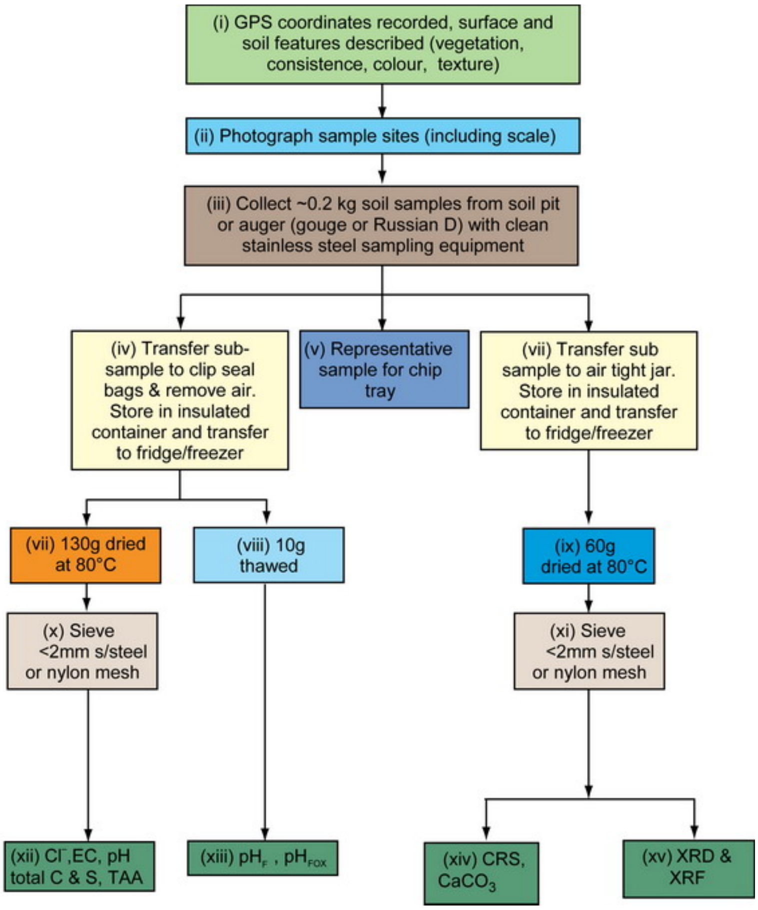


Figure 3. General flow chart for soil sampling and analysis.

2.2 Laboratory Soil Analysis Methods

2.2.1 Soil pH in Hydrogen Peroxide (pH_{FOX})

All soil samples, except for efflorescences, were selected for the following laboratory analyses: soil pH in (i) water and (ii) 30% hydrogen peroxide with pH adjusted to *ca*. pH 5. Since the soil samples were mostly wet or moist, soil to solution ratios will have varied, but approximated a soil-to-solution ratio between 1:1 and 2:1. For the peroxide pH determinations, about 7.5 to 10 ml of peroxide was carefully added until frothing and fuming ceased (Figure 4; example of effect) and the sample cooled. These variations in soil-to-solution ratios (and therefore ionic strength of the suspensions) introduces errors compared to usual laboratory pH measurements (see Rayment and Higginson, 1992) with controlled soil-to-solution ratios, but these are not thought to be significant in the context of this study. All pH measurements were made at 20^{o} C using a calibrated laboratory pH meter. Peroxide addition oxidises sulfide minerals and organic matter, the former oxidising to sulfuric acid:

Sulfidic material + hydrogen peroxide → sulfuric acid + iron sulfate minerals + heat

Figure 4. Photographs of the peroxide test in the field used to assess the presence of ASS (sulfidic material). Note the change in colour of the pH test strips indicating the drop in pH.

Comparing the water pH to the peroxide pH indicates, where the peroxide pH drops significantly below about 4, that the materials have the potential to acidify and produce an ASS due to the presence of sufficient sulfidic material that converts to sulfuric material. If the peroxide pH does not acidify significantly, the material is likely to contain enough acid neutralising capacity (ANC) to avoid sulfuric conditions. The laboratory reactions are relatively quick and may not attain a true equilibrium, thereby indicating more acidic conditions than may actually be reached by natural oxidation. However, poorly buffered sands are likely to reach the indicated pH and we have observed field pH values as low as 2.5 in clayey soils of the River Murray wetlands.

Table 2. Soil rating scale for the pH_{FOX} test. If the field pH in hydrogen peroxide (pH_{FOX}) is at least one unit below field pH (pH_w), it may indicate potential ASS. The greater the difference between the two measurements, the more indicative the value is of sulfidic material. The lower the final pH_{FOX} value is, the better the indication of a positive result.

pH_{FOX}	Indication of ASS
<3	High probability.
3–4	Probable; confirm with laboratory tests.
4–5	Sulfides may be present in small quantities or may be unreactive, or neutralising material is present. Confirm with laboratory tests.
>5	Combined with little drop from field pH, little net acid generation potential is indicated. Confirm with laboratory tests.

The final pH and reaction vigour can then be interpreted to qualitatively assess soil or sediment materials (Figure 4, Table 2).

The pH data for the nine wetland soils are presented in Appendix 2 (Table 20) and graphically in sections below for each profile, together with a photograph of the site and soil profile.

2.2.2 Incubation of Soil Material

The formal Australian Soil Classification (Isbell 1996) test for identification of sulfidic material is to:

- Incubate mineral or organic soil materials, which have a natural pH value >4, for 8 weeks (as a layer 1 cm thick under moist conditions, while maintaining contact with the air at room temperature).
- Measure the pH and observe whether there is a drop in pH of 0.5 units or more to a value of 4.0 or less within 8 weeks.
- Observe formation of jarosite mottles, which implies that the pH has dropped below 4.

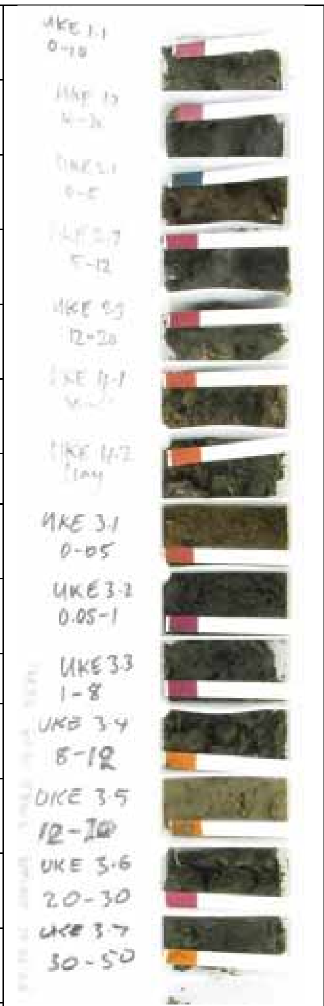
Collection and storage of moist samples in chip trays (Figure 5 and Figure 6) produces similar conditions and can similarly be used as a diagnostic test for the presence of sulfidic material. Incubation tests have the advantage of not requiring 30% hydrogen peroxide, which should only be handled by a trained operator.

Soil samples collected from the nine wetlands were placed in compartments of the chip tray as a 1 cm thick layer and kept moist. In the laboratory, the 1 cm thick layers of soil in each compartment were covered by a 1 mm thick piece of sponge (Figure 5), which allows slow oxygen diffusion into the moist soil sample and potential formation of sulfuric acid in the presence sulfidic materials, mimicking field conditions of drying soils. The sponge had been pre-leached with distilled water and its pH checked. The kind of sponge used did not alter the pH. In the chip tray, the sponge covering the soil sample was moistened and allowed to stand at room temperature (20 to 25 °C) for 8 weeks with occasional checking and re-moistening of the sponge with distilled water.

Figure 5. Field soil samples are placed in chip trays, moistened when necessary and covered with a piece of sponge. The sponge is then moistened with distilled water and the soil allowed to stand, but kept moist for eight weeks before testing with pH indicator strips.

After 8 weeks of aging, the soils were visually checked for the formation of minerals, which indicate significant acidification, for example jarosite. Since the solution in contact with the soil in the chip tray compartments is in equilibrium with the soil, a pH indicator strip (Merck item nos: pH 2.5-4.5: 1.09541.0001; pH 4.0-7.0: 1.09541.0002; pH 6.5-10.0: 1.09543.0001) was used to indicate the pH of the sample (Figure 6). A pH value of 4 or less confirms that the field soil is likely to develop sulfuric material on drying. pH values greater than this indicate that the soil materials should not acidify significantly.

UKE 1.1 0-10
UKE 1.2 10-20
UKE 2.1 0 - 5
UKE 2.2 5 - 12
UKE 2.3 12 - 20
UKE 4.1 0 - 5
UKE 4.2 5 - 10
UKE 3.1 0 – 0.05
UKE 3.2 0.05 - 1
UKE 3.3 1 - 8
UKE 3.4 8 - 12
UKE 3.5 12 – 30
UKE 3.6 20 - 30
UKE 3.7 30 50



UKE 5.1 0 – 0.05
UKE 5.2 0.05 - 10
UKE 5.3 10 - 30
UKE 6.1 0 - 5
UKE 6.2 5 - 20
UKE 6.3 20 - 40
MUR 1.1 0 - 30
MUR 1.2 30 - 40
MUR 1.3 40 - 30
MUR 2.1 0 – 5
MUR 2.3 5 - 10
MUR 2.3 10 - 45
MUR 2.4 45 - 70
MUR 3.1\ 0 - 15
MUR 3.3 15 - 30

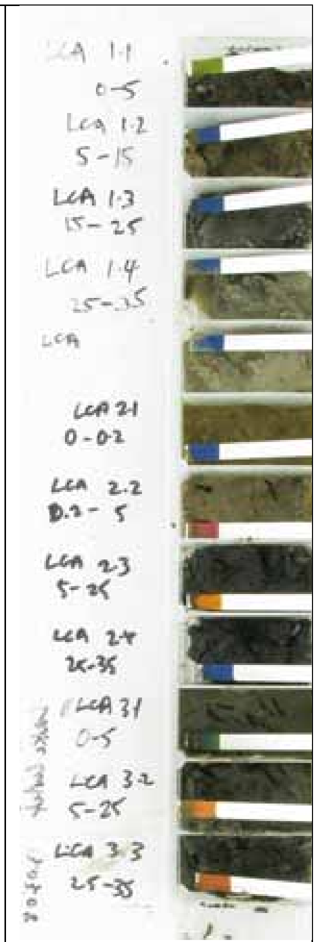


Figure 6. Left hand side: view of the whole chip tray showing samples from Ukee; Middle: top half are from Ukee (UKE 5.1. to UKE 6.3) and lower half samples are from Murrundi (North Wellington) aged for 8 weeks with pH indicator strips clearly indicating that most samples from Ukee and Murrundi are acid (red or pink colour - pH 3.9 to 4.8). Right hand side: view of samples from Lake Carlet indicating samples aged LCA 11.1 to LCA 2.1 aged for 8 weeks are alkaline (blue colour - pH 6 to 7) and LCA 2.2 is acid (red colour).

For soils sampled from Ukee (Figure 6, left hand side and middle) mostly indicated a pH less than 4 after aging for 8 weeks. These results are in agreement with the results of pH testing following peroxide treatment (Appendix 2;Table 20) and net acid generating potential analysis (Sections 2.2.3 and 3.2).

2.2.3 Sulfur and acid-base accounting

Sulfur chemistry

In sediments, total sulfur is an inexpensive, convenient measure to screen samples for ASS-potential. However, this analysis estimates the maximum potential environmental risk, so that when a trigger value is exceeded, more detailed analysis is required. Interpretation is complicated by the presence of sulfate salts (containing oxidised S) such as gypsum that do not produce acidity. Directly measuring the amount of reduced sulfur in a sample using the chromium reduction method has become the accepted standard for further investigation. Chromium reducible sulfur (commonly written as either S_{Cr} or CRS) can be directly equated with the acid generating potential (AGP) of a soil or sediment, and is one component of the net acidity - the other being the existing or actual acidity. The difference between reduced sulfur and total sulfur is the quantity of sulfate plus organic sulfur in the sample. Further analysis is required to separate the individual contributions of these components. For coastal and inland acid sulfate soils in Australia, the action criteria or trigger values for the preparation of an ASS management plan are shown in Table 3.

Table 3. Criteria indicating the need for an ASS management plan based on texture range and chromium reducible sulfur concentration and amount of soil material disturbed (Dear *et al*., 2002).

Texture range		**Existing + Potential Acidity** **TAA + S_{Cr} Equivalent sulfur (%S) (oven-dry basis)**	
		<1000 t disturbed soil	**>1000 t disturbed soil**
Coarse:	Sands to loamy sands	0.03	0.03
Medium:	Sandy loams to light clays	0.06	0.03
Fine:	Medium to heavy clays	0.10	0.03

Chromium reducible sulfur

Methods for analysing soil samples to assess acid generation potential (AGP) are given in Ahern *et al.,* (2004), which includes the chromium reducible sulfur (S_{Cr} or CRS - or RIS: Method Code 22B) and its conversion to AGP. Note that chromium reducible sulfur is also referred to as Reduced Inorganic Sulfur (RIS).

Acid-Base Accounting

Acid-base accounting is used to assess both the potential of a soil to produce acidity and also its ability to neutralise acid formed. These concepts are discussed by Ahern *et al*. 2004.

Total Actual Acidity (TAA)

Actual acidity is a measure of the existing acidity in acid sulfate soil materials that have already oxidised. The method measures acidity stored in a number of forms in the soil such as iron and aluminium oxyhydroxides and oxyhydroxysulfate precipitates (*e.g.* jarosite, schwertmannite and alunite), which dissolve to produce acidity. However, it can be applied to the acid–base budget, which uses the total of actual and potential acidity to assess the acid generation potential of a soil.

The methods for determining total actual acidity and oxidised sulfur are given by Ahern *et al.* (2004) Method Codes 23F and 23C respectively.

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 expressed in $CaCO_3$ equivalents. By definition any soil with a pH < 6.5 has a zero ANC. 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.

Acid Generation Potential (AGP)

This parameter is calculated from the concentration of reduced sulfur in the sample. Methods for analysing soil samples to assess AGP are given in Ahern *et al.* (2004), which includes the chromium reducible sulfur (CRS or S_{Cr} or RIS) (Method Code 22B) and its conversion to AGP.

Net Acid Generation Potential (NAGP)

NAGP is calculated by subtracting the ANC from the AGP and is a measure of the overall acidification risk of a soil. A positive value indicates an excess of acid and the likelihood of sulfuric materials (or an actual acid sulfate soil material) forming in the soil when it is disturbed and oxidised:

NAGP = AGP – ANC.

Net Acidity

The net acidity of a soil is where there is existing acidity and includes both NAGP and the existing or titratable actual acidity (TAA) so that:

Net Acidity = TAA + AGP – ANC

or

Net Acidity = TAA +NAGP.

Net acid generating potential (NAGP): Net acid generating potential (NAGP) was calculated by subtracting the acid neutralising capacity (ANC) from the AGP. The NAGP is conventionally expressed as the calcium carbonate equivalent to neutralise the potential acid generated (Ahern *et al.,* 2004). A positive value for NAGP indicates acid generating potential and the potential for formation of an ASS, while a negative value indicates an excess of neutralising capacity over acidity, with little likelihood of ASS formation. When converted to a lime requirement a safety factor of 1.5 is employed to account for lime purity and reactivity (fineness or particle size).

On selected soil profile samples, chromium reducible S, acid neutralising capacity (ANC, usually carbonate content) and Net Acidity was determined by the Environmental Analysis Laboratory of Southern Cross University, Lismore. Chemical analysis generally followed procedures from Ahern *et al*. (1998). Data for selected soils are presented in Appendix 3 and graphically in the results section below.

2.2.4 Geochemical analysis

Selected samples were analysed by X-ray fluorescence spectrometry (XRF) for:

1. Trace elements on pressed powder pellets. Approximately 4g of each oven dried sample (105°C) was accurately weighed with 1 g of Licowax binder and mixed using a test tube shaker. The mixtures were pressed in a 32 mm die at 12 tons pressure and the resulting pellets were analysed on a PANalytical Axios Advanced, wavelength dispersive XRF system using the in-house ProTrace calibration. These results are presented in Appendix 4.

2. Major elements on fused borate glass discs. Approximately 1g of each oven dried sample (105°C) was accurately weighed with 4g of 12-22 lithium borate flux. The mixtures were heated to 1050°C in a Pt/Au crucible for 20 minutes to completely dissolve the sample then poured into a 32mm Pt/Au mould heated to a similar temperature. The melt was cooled rapidly over a compressed air stream and the resulting glass disks were analysed on a PANalytical Axios Advanced wavelength dispersive XRF system using the in-house Silicates calibration program. The calibration was derived from a combination of 192 synthetic and certified reference materials with measured intensities corrected for drift using two highly stable monitor standards. These results are presented in Appendix 5.

2.2.5 Mineralogy

Samples were ground in an agate mortar and pestle and either back pressed into steel holders or deposited onto Si low background holders (depending on how much sample was available).

XRD patterns were recorded with a PANalytical X'Pert Pro Multi-purpose Diffractometer using Co K-alpha radiation, variable divergence slit, post diffraction graphite monochromator and fast X'Cellerator Si strip detector. The diffraction patterns were recorded in steps of 0.05° 2 theta with total counting time of 30 minutes, and logged to data files for analysis using HighScore Plus.

2.2.6 Scanning electron microscopy (SEM) analysis

Specimens were selectively sub-sampled to show the appropriate phases, often fractured to expose fresh surfaces, and then oriented and mounted onto aluminium specimen mounts using "Araldite" 5-minute epoxy resin. The samples were subsequently dried in a vacuum desiccator overnight, had the surfaces blown clean with a Nitrogen jet, and then coated with a conductive layer.

Where imaging of the composition was required, specimens were evaporatively coated with 30nm of carbon, using an EmScope SC500 coating unit, to provide electrical conductivity and maximize Backscattered Electron (BSE) phase contrast. Carbon coating also minimizes extraneous x-ray peaks from the characteristic X-ray spectrum.

Specimens were placed in a “Phillips” XL30 FEG-SEM, with an attached “EDAX” DX4 energy dispersive x-ray system. Sample examination was done using a primary electron beam energy of 20 KeV. Imaging was performed using the Secondary Electron (SE) signal where information about surface topography was required. The SE signal primarily carries information about the local topography because the signal is dependent on the angle of incidence of the primary beam. Imaging was also performed using the Backscattered Electron (BSE) signal where information about composition and phase was required. The backscattered electron signal primarily carries information about the average atomic number and the density of the sample commonly called "atomic number contrast or Z contrast". The characteristic x-ray signals were also collected at selected positions for qualitative Energy Dispersive X-ray (EDX) analysis. EDX analysis is possible within the volume over which the electron beam interacts (approximately four cubic micrometers), for all elements of atomic number greater than 6 with detection limits in the order of 0.1 to 5 wt % depending on the energy of the characteristic x-ray line.

3. ACID SULFATE SOIL CHARACTERISTICS OF WETLANDS

3.1 Introduction

This section presents a summary of the individual wetlands and assesses: (i) the current risk of occurrence of sulfuric and sulfidic materials and (ii) the acidification risk likely to take place upon drying. Between August 2007 and April 2008 we collected and analysed 154 soil samples from 38 soil profiles (i.e. subaqueous, waterlogged and drained soils) located in a selection of nine River Murray wetlands along the section below Lock 1 and above Wellington (Figure 2). The analyses performed on the samples included morphological, chemical, mineralogical and physical properties, which we used as a basis for acid sulfate soil (ASS) risk assessment for the wetlands that were drying – or dried - due to the current drought conditions.

Samples obtained in this survey provided an adequate baseline for the wide range of soil conditions (i.e. subaqueous soils within the River Murray; waterlogged or drained soils on the shores of the River Murray and in adjacent wetlands) in all nine wetlands. Recorded locations and long-term archival storage of the samples in CSIRO will allow for future re-sampling and analysis, if required. The morphological descriptions for all the 154 layers are presented in Table 19 of Appendix 2. Selected photographs of sites, including soil pits (where available), hand or spade held samples and landscape setting are provided below. Soil colour, structure, texture and consistency along with field pH are the most useful properties for soil identification and appraisal (Appendix 1; Table 19). Soil colour, texture, structure and consistency also provide practical indicators of soil redox status and existing acidity. Consequently, these field indicators were used to contribute to the development of the user-friendly soil identification key to categorise the various ASS subtypes (see Section 4 below) to assist in the Risk categorisation of all the materials.

Soil pH measurements were made in water and after peroxide treatment (pH_{Fox}). The latter measurement indicates whether a soil is likely to acidify significantly (pH < 4) on exposure to oxygen in moist conditions. The data is presented graphically here for each profile. All data are presented in tabular form in Appendix 3 (Table 20) and below. After 8 weeks of aging in chip trays (Figure 6) all the soil samples in the chip trays were tested with pH indicator strips and visually checked for the formation of minerals (Table 20).

Summary data (Table 4 to Table 12) are presented for each layer sampled showing risks for each depth in the profiles, along with the ASS classification of sulfuric ($pH_w < 4$), sulfidic (pH > 4, potential to acidify to less than pH 4 i.e. $pH_{ageing} < 4$, or pH_{Fox}), where applicable (see Appendix 1 for definitions). However, risks may also be present for soil materials, which do not form sulfuric materials but decrease in pH to between 4 to 5 and which may also have significant impacts on metal mobilisation and ecosystem response. Hence, a further classification termed "hyposulfidic" is therefore assigned to soil materials, which age to pH 4-5 (pH_{ageing}) or decrease to pH 4-5 following peroxide treatment (pH_{Fox}).

Dear *et al.* (2002) have developed a "Risk categorisation to guide management planning" to assist in "evaluating the environmental risk" posed by ASS disturbance by identifying the level of treatment required to treat all existing and potential acidity resulting from such a disturbance. They defined the following five treatment categories: Low, Medium, High, Very High and Extra High based on laboratory results and the weight of material to be disturbed or exposed to air. According to Dear *et al.* (2002), there is a general correlation between the level of treatment required and the ASS environmental risk. There are additional factors that will also influence the level of treatment required including the nature of the works to be undertaken, the staging and duration of construction, the soil characteristics (e.g. variability of sulfide concentrations, soil bulk density, physical characteristics such as texture, and self-neutralising capacity), surface and sub-surface hydrology, sensitivity of the surrounding environment, and the past history of the site.

Dear *et al.* (2002) have defined the total amount of fine agricultural lime required to neutralise the total existing plus potential acidity of a particular volume of soil, including the minimum industry safety factor of 1.5 (Table 15). Using the data presented in Table 15 and Table 21 together with interpretation from Dear *et al.* (2002), the treatment category and ASS risk class for each soil has been determined in Table 15. ASS Risk categorisation is based on a number of criteria, including mainly the five lime treatment categories (N = No treatment (no lime); L=Low level treatment; M = Medium level treatment, H = High level treatment, VH = Very high level treatment, XH = Extra High level treatment: based on data presented in Table 15). Additional criteria include the presence of MBO, peroxide pH, decrease in pH during incubation experiments.

3.2 Noonawirra

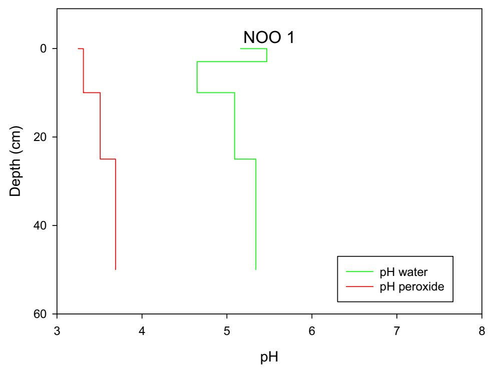
Noonawirra wetland (Figure 1), the most upstream of those surveyed, forms part of a wetland complex (Yarramundi wetland), and has been formed in a creek line (Portee Creek) (Australian Water Environments, 2008). The wetland is highly linear (approximately 1.3 km in length, and 80 m at widest). The wetland lies in a north easterly-south westerly orientation, and bound on the north-western side by a near-vertical 10 m cliff, and on the south-eastern edge by a levee bank. The outflow is at the southern end of the wetland. Sampling conducted during February 2008 was done along a 40 m tangent situated halfway along the wetland (Figure 7, Figure 8). At the time when the soil survey was conducted, the wetland was dry.

Figure 7. Noonawirra Lagoon and survey sites.

The profile NOO 1 (Figure 9) was sampled in a zone of sparse herbage approximately 7 m from the bank of the wetland. This site was characterised by peds with a self-mulching clay surface that were separated by wide (> 2 cm) cracks. The profile NOO 2 (Figure 11) was taken in the middle of the wetland, and featured a loose, crumby surface of self-mulching clay in an area of abundant carp bones, indicating this to be a locally low point in the wetland and a last refuge for carp as water level receded. The profile NOO 3 (Figure 13) was taken between the shoreline and NOO 1, and featured a surface of similar appearance to NOO 1, although with a greater density of herbage present.

Figure 8. Landscape context of Noonawirra wetland (see Figure 2).

Figure 9. Photograph of profile number NOO 1 (see Table 18 and Figure 2 for location).



.

Figure 10. Depth profiles showing pH water (green) and pH peroxide test (red) for NOO 1

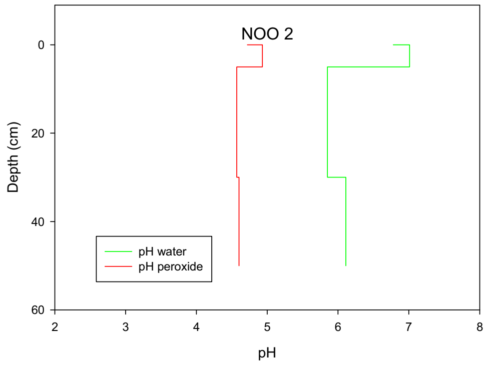


Figure 11. Photograph of profile number NOO 2 (see Table 18 and Figure 2 for location).

Figure 12. Depth profiles showing pH water (green) and pH peroxide test (red) for NOO 2

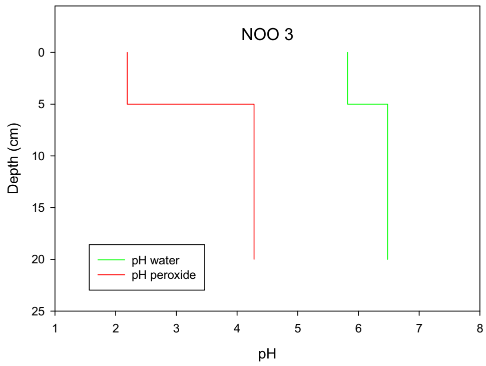


Figure 13. Photograph of area (in foreground) of where profile number NOO 3 was sampled (see Table 18 and Figure 2 for location).

Figure 14. Depth profiles showing pH water (green) and pH peroxide test (red) for NOO 3.

Table 4. Data for ASS assessment of Noonawirra wetland.

Method/ Sample	Depth	pH water	pH Fox or Peroxide	[1]ASS materials	[2]ASS classification (and [3]code)	[4]S_{cr}	[5]Lime Calculation kg $CaCO_3$ /tonne DW	[6] ASS Risk
NOO 1.1	0-0.05	5.2	3.3	Sulfidic	Sulfidic cracking clay soil (3.1)	0.013	2	H
NOO 1.2	0-3	5.5	3.3	Sulfidic		0.022	2	H
NOO 1.3	3-10	4.7	3.3	Sulfidic		0.018	3	H
NOO 1.4	10-25	5.1	3.5	Sulfidic		0.017	3	H
NOO 1.5	25-50	5.3	3.7	Sulfidic		0.027	4	H
NOO 2.1	0-0.05	6.8	4.7	Hyposulfidic	Cracking clay soil (3.4)	0.037	-3	L
NOO 2.2	0-5	7.0	4.9	Hyposulfidic		0.029	-5	L
NOO 2.3	5-30	5.9	4.6	Hyposulfidic		0.011	2	H
NOO 2.4	30-50	6.1	4.6	Hyposulfidic		0.011	2	H
NOO 2.3/4	slickensides	5.6	4.4	Hyposulfidic				
NOO 3.1	0-5	5.8	2.2	Sulfidic	Sulfidic cracking clay soil (3.1)	0.009	2	H
NOO 3.2	5-20	6.5	4.3	Hyposulfidic		0.007	1	M

[1] Sulfuric and Sulfidic (Appendix 1); Hyposulfidic (pH_{ageing} or pH_{Fox} decreases to pH 4-5)
[2] See classification in Table 15.
[3] See classification key code in Table 14.
[4] Reduced Inorganic sulfur (% chromium reducible S; S_{cr}). This measures the reduced sulfur in the sample that potentially can oxidise to sulfuric acid.
[5] Lime needed to neutralise acidity, based on net acidity/alkalinity, which includes a 1.5 times safety factor Negative values have sufficient excess ANC and should not need additional lime) and interpretation from Dear *et al.*, (2002; page 8).
[6] ASS Risk categorisation is based on a number of criteria, including mainly the five lime treatment categories (N = No treatment (no lime); L=Low level treatment; M = Medium level treatment, H = High level treatment, VH = Very high level treatment, XH = Extra High level treatment: based on data presented in Table 15). Additional criteria include the presence of MBO, peroxide pH, decrease in pH during incubation experiments.

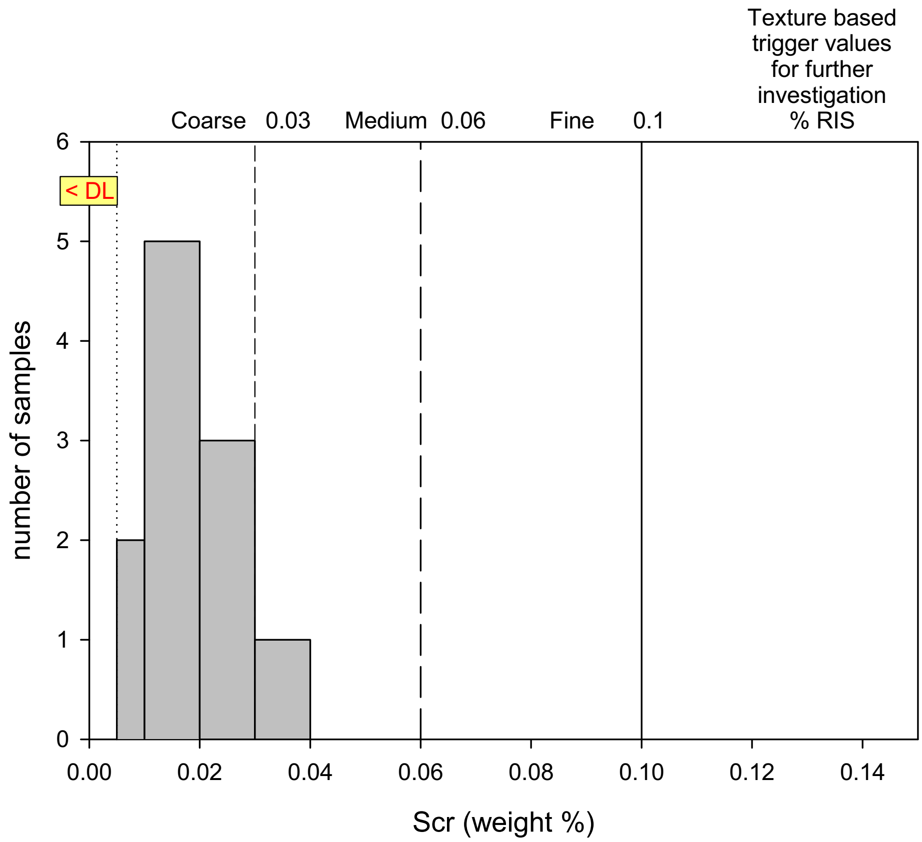


Figure 15. Chromium reducible S for Noonawirra wetland.

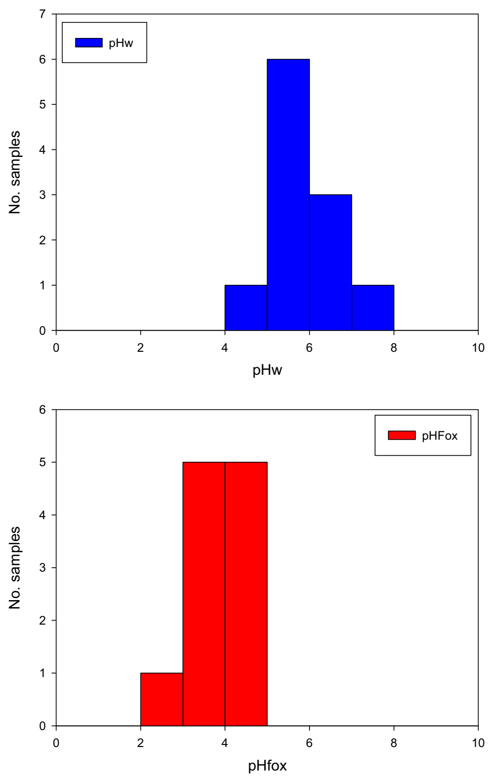


Figure 16. Number of samples at pH increments (water and peroxide) for Noonawirra.

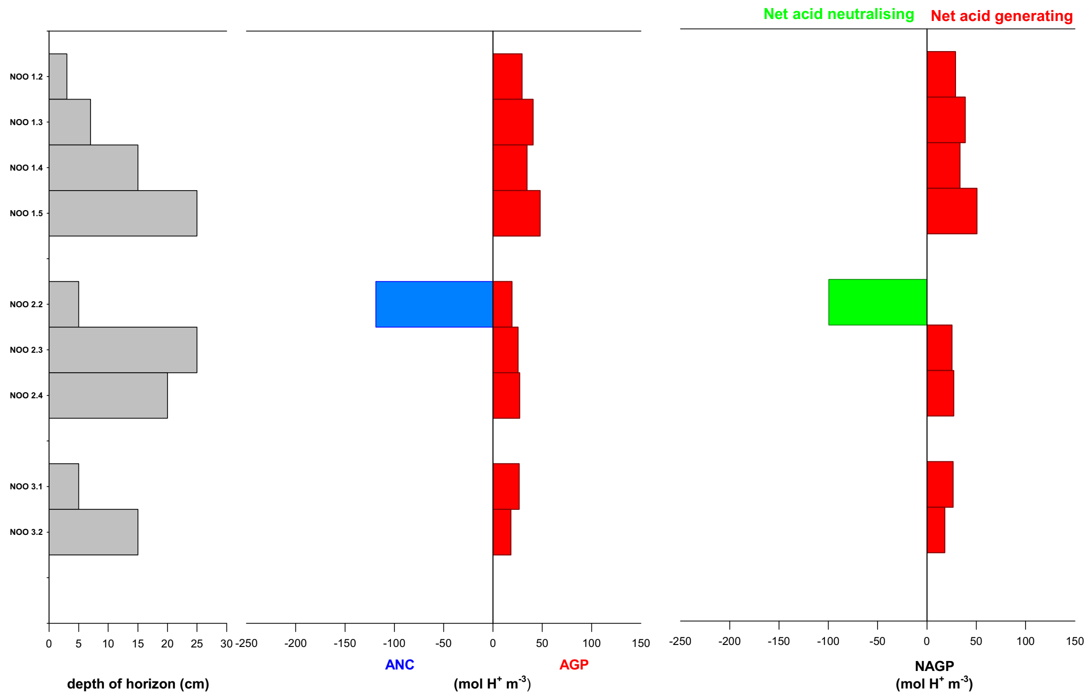


Figure 17. Net Acid Generating Potential (NAGP) for all soil layers sampled at Noonawirra. Only one of the 9 samples analysed (NOO 2.2) does not have a net acid generating potential (self neutralising).

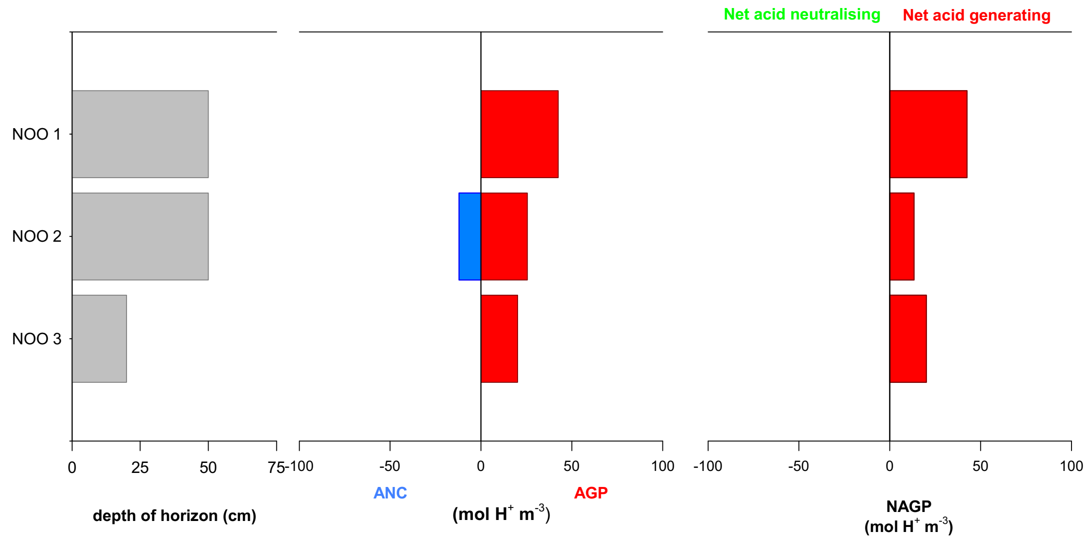


Figure 18. Acid-base accounting for sample site layers from Noonawirra. All profiles have a net acid generating potential.

Key summary findings for Noonawirra:

ASS materials:	Dominantly sulfidic material (high sulfide concentrations and potential to develop pH<4) and minor clay layers containing some sulfides (i.e. hyposulfidic material).
ASS classification:	Dominantly sulfidic cracking clay soils and minor cracking clay soils containing some sulfides (i.e. with hyposulfidic material).
ASS Risk:	**Moderate to high risk** of development of sulfuric material in ASS.

3.3 Devon Downs North

Devon Downs North (Figure 1) is a large, linear wetland that is approximately 6.5 km long, and approximately 800 m at the widest (southern end). The wetland is fringed on the river side (east) by a flood levee, and on the landward side (west), by steep gradient cliffs and low gradient footslopes and toeslopes, much of which are under agriculture. During the time of the visit (April 2008), Devon Downs North was completely dry (Figure 19), with much of the wetland surface comprising cracked clays in the south, and an almost continuous cover of *Phragmites australis* in the northern end. At the northern end of the wetland are a series of channels (now dry), and much of this area has clear evidence of salinity. Australian Water Environments (2008) present a full account of the botanic and habitat status of the wetland.

Figure 19. Landscape context of Devon Downs North wetland, taken from near the southern end, and viewed westwards (see Figure 2)

Figure 20. Devon Downs North wetland and survey sites.

The profiles DD 1 and DD 2 (Figure 20) were taken from the southern zone of the wetland from each end of a 150 m transect. DD 1 (Figure 21) was taken from a sandy beach on the fringe of a wooded promontory, and DD 2 (Figure 23) was taken adjacent to this, towards the middle of the lagoon.

The DD 3 (Figure 25) and DD4 profiles were taken from the northern end of the wetland at each end of a 50 m transect. DD 3 was taken from towards the centre of the wetland from a dry clay zone. DD 4 (Figure 27) was taken on the wetland side of a shore-fringing zone of *Phragmites australis*, which formed a continuous barrier to the shore approximately 7 m deep.

Figure 21. Photograph of profile number DD 1 (see Table 18 and Figure 2 for location).

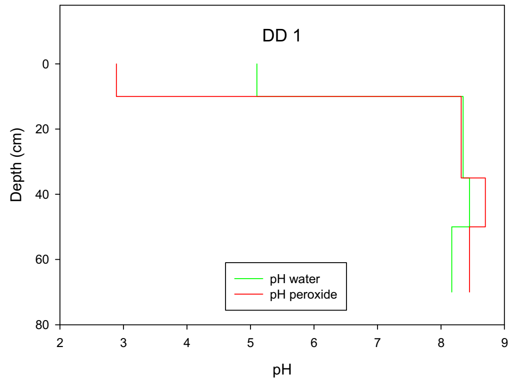


Figure 22. Depth profiles showing pH water (green) and pH peroxide test (red) for DD 1.

Figure 23. Photograph of profile number DD 2 (see Table 18 and Figure 2 for location).

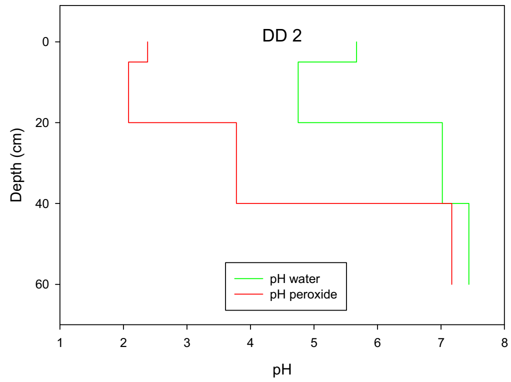


Figure 24. Depth profiles showing pH water (green) and pH peroxide test (red) for DD 2.

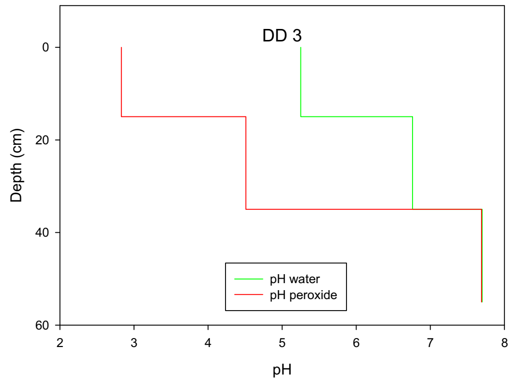


Figure 25. Photograph of profile number DD3 (see Table 18 and Figure 2 for location).

Figure 26. Depth profiles showing pH water (green) and pH peroxide test (red) for DD 3.

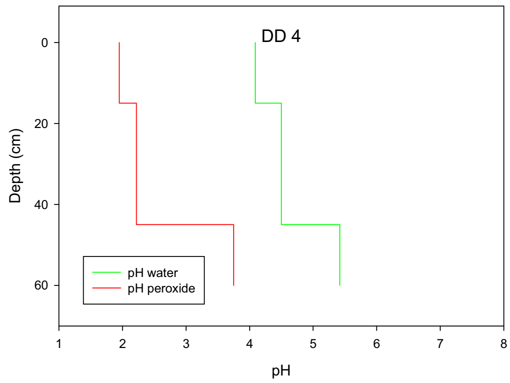


Figure 27. Photograph of profile number DD 4 (see Table 18 and Figure 2 for location).

Figure 28. Depth profiles showing pH water (green) and pH peroxide test (red) for DD 4.

Table 5. Data for ASS assessment of Devon Downs North wetland.

Method/ Sample	Depth	pH Water	pH Fox or Peroxide	[1]ASS materials	[2]ASS classification (and [3]code)	[4]S_{cr}	[5]Lime Calculation kg $CaCO_3$ /tonne DW	[6] ASS Risk
DD1.1	0-10	5.1	2.9	Sulfidic (5.2)	Sulfidic soil (5.2)	<0.005	-1	L
DD1.2	10-35	8.4	8.3	None		<0.005	-26	N
DD1.3	35-50	8.5	8.7	None		0.005	0	N
DD1.4	50-70	8.2	8.5	None		<0.005	-7	N
DD2.1	0-0.2				Sulfidic cracking clay soil (3.2)			
DD2.2	0-5	5.7	2.4	Sulfidic		0.128	7	VH
DD2.3	5-20	4.8	2.1	Sulfidic		0.210	17	VH
DD2.4	20-40	7.0	3.8	Sulfidic		0.057	-1	L
DD2.5	40-60	7.4	7.2	None		<0.005	1	M
DD3.1	0-15	5.3	2.8	Sulfidic	Sulfidic cracking clay soil (3.2)	0.006	2	M
DD3.2	15-30	6.8	4.5	Hyposulfidic		0.006	1	M
DD3.3	30-55	7.7	7.7	None		<0.005	0	L
DD4.1	0-15	4.1	2.0	Sulfuric	Sulfuric soil (4.1)	<0.005	1	M
DD4.2	15-45	4.5	2.2	Sulfidic		<0.005	2	H
DD4.3	45-60	5.4	3.8	Sulfidic		0.017	1	M

[1] Sulfuric and Sulfidic (Appendix 1); Hyposulfidic (pH_{ageing} or pH_{Fox} decreases to pH 4-5)
[2] See classification in Table 15.
[3] See classification key code in Table 14.
[4] Reduced Inorganic sulfur (% chromium reducible S; S_{cr}). This measures the reduced sulfur in the sample that potentially can oxidise to sulfuric acid.
[5] Lime needed to neutralise acidity, based on net acidity/alkalinity, which includes a 1.5 times safety factor Negative values have sufficient excess ANC and should not need additional lime) and interpretation from Dear *et al.*, (2002; page 8).
[6] ASS Risk categorisation is based on a number of criteria, including mainly the five lime treatment categories (N = No treatment (no lime); L=Low level treatment; M = Medium level treatment, H = High level treatment, VH = Very high level treatment, XH = Extra High level treatment: based on data presented in Table 15). Additional criteria include the presence of MBO, peroxide pH, decrease in pH during incubation experiments.

Key summary findings for Devon Downs North:

ASS materials: Dominantly sulfidic material (high sulfide concentrations and potential to develop pH<4); minor sulfuric materials and patches with clay layers containing some sulfides (i.e. hyposulfidic material).

ASS classification: Dominantly sulfidic cracking clay soils with minor sulfuric soil and sulfidic soils along the lagoon margins.

ASS Risk: **High to moderate risk** of further development of sulfuric material in ASS.

3.4 Devon Downs South

Devon Downs South (Figure 1) is approximately 1.6 km at longest, and 450 m at widest. To the south, the wetland is bound by a river levee (Figure 29). The north western side of the northern edge features a steep cliff (approximately 10 m) with narrow colluvial toeslope (10 m), while the north-eastern side of the northern edge is defined by a low gradient slope that is under farm management. Australian Water Environments (2008) present a full account of the botanic and habitat status of the wetland. At the time when the soil survey was conducted, the wetland was dry (Figure 30).

Figure 29. Devon Downs South with survey sites.

The sampling was based on a 260 m transect situated in the western end of the wetland, oriented south to north. The profile DDS 1 (Figure 31) was situated in a *Typha* stand on a small promontory on the southern bank of the wetland. DDS 2 (Figure 33) was taken outside the *Typha* stand, approximately the same distance for the shore. DDS 3 (Figure 35) was taken from the equidistant from both shorelines along the transect. DDS 4 (Figure 37) was taken from the shore on the northern end of the transect. Sampling locations were dominated by a steep cliff (approximately 15 m), with a narrow band of colluviated slope, with the shoreline at its base. DDS 5 (Figure 39) was taken from the eastern shore in a sandy area, which featured a cover of salt efflorescences. The sandy texture, landscape position and surface efflorescences indicated the area to be a saline discharge zone.

Figure 30. Landscape context of Devon Downs South wetland with a view near the middle of the wetland, looking west (see Figure 1).

Figure 31. Photograph of profile number DDS 1 (see Table 18 and Figure 2 for location).

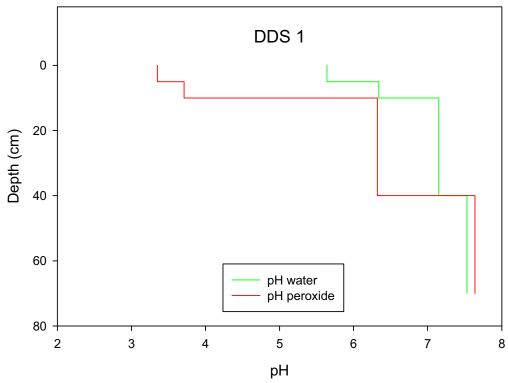


Figure 32. Depth profiles showing pH water (green) and pH peroxide test (red) for DDS 1.

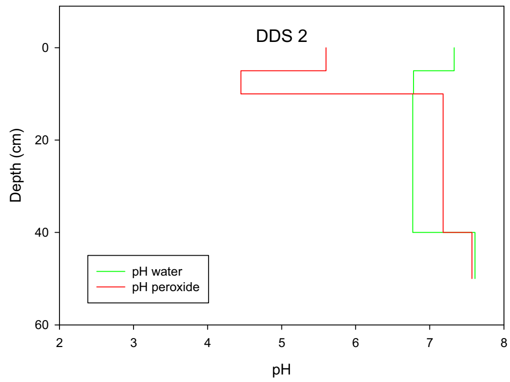


Figure 33. Photograph of profile number DDS 2 (see Table 18 and Figure 2 for location).

Figure 34. Depth profiles showing pH water (green) and pH peroxide test (red) for DDS 2.

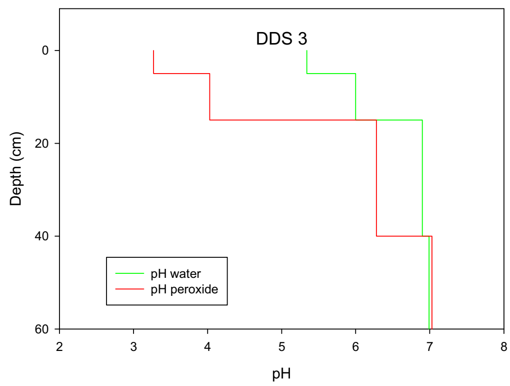


Figure 35. Photograph of profile number DDS 3 (see Table 18 and Figure 2 for location).

Figure 36. Depth profiles showing pH water (green) and pH peroxide test (red) for DDS 3.

Figure 37. Photograph of profile number DDS 4 (see Table 18 and Figure 2 for location).

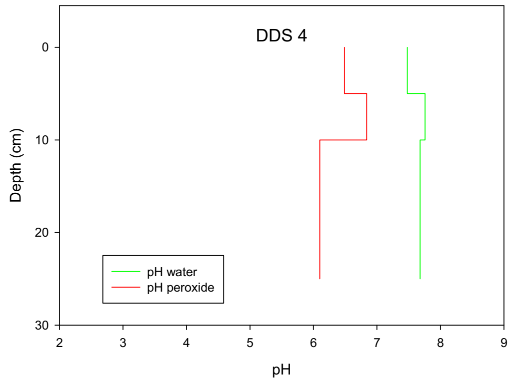


Figure 38. Depth profiles showing pH water (green) and pH peroxide test (red) for DDS 4.

Figure 39. Photograph of profile number DDS 5 (see

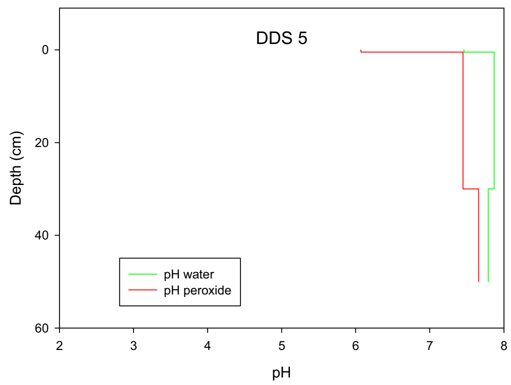


Figure 40. Depth profiles showing pH water (green)

Table 18 and Figure 2 for location). and pH peroxide test (red) for DDS 5.

Table 6. Data for ASS assessment of Devon Downs South wetland.

Method/ Sample	Depth	pH water	pH Fox or Peroxide	[1]ASS materials	[2]ASS classification (and [3]code)	[4]S_{cr}	[5]Lime Calculation kg $CaCO_3$ /tonne DW	[6] ASS Risk
DDS1.1	0-5	5.6	3.4	Sulfidic - sandy	Sulfidic soil (5.2)	0.021	7	VH
DDS1.2	5-10	6.3	3.7	Sulfidic - sandy		<0.005	0	L
DDS1.3	10-40	7.2	6.3	None		0.016	-1	N
DDS1.4	40-70	7.5	7.6	None		0.010	-1	N
DDS2.1	0-5	7.3	5.6	None	Cracking clay soil (3.4)	0.011	-1	N
DDS2.2	5-10	6.8	4.5	Hyposulfidic		0.011	0	N
DDS2.3	10-40	6.8	7.2	None		<0.005	0	H
DDS2.4	40-60	7.6	7.6	None		0.009	-1	N
DDS3.1	0-5	5.3	3.3	Sulfidic	Sulfidic cracking clay soil (3.2)	0.081	-2	N
DDS3.2	5-15	6.0	4.0	Sulfidic		0.011	1	L
DDS3.3	15-40	6.9	6.3	None		0.009	1	L
DDS3.4	40-60	7.0	7.0	None		<0.005	1	L
DDS4.1	0-5	7.5	6.5	None	Cracking clay soil (3.4)	0.020	-2	N
DDS4.2	5-10	7.8	6.8	None		0.012	-3	N
DDS4.3	10-25	7.7	6.1	None		0.024	-1	N
DDS5.1	0-0.05	7.5	6.1	None	Cracking clay soil – sandy (3.4)	0.019	0	N
DDS5.2	0.05-15	7.9	7.5	None		0.007	0	N
DDS5.3	15-30	7.9	7.5	None		<0.005	0	N
DDS5.4	30-50	7.8	7.7	None		0.013	3	L

[1] Sulfuric and Sulfidic (Appendix 1); Hyposulfidic (pH_{ageing} or pH_{Fox} decreases to pH 4-5)
[2] See classification in Table 15.
[3] See classification key code in Table 14.
[4] Reduced Inorganic sulfur (% chromium reducible S; S_{cr}). This measures the reduced sulfur in the sample that potentially can oxidise to sulfuric acid.
[5] Lime needed to neutralise acidity, based on net acidity/alkalinity, which includes a 1.5 times safety factor Negative values have sufficient excess ANC and should not need additional lime) and interpretation from Dear *et al.*, (2002; page 8).
[6] ASS Risk categorisation is based on a number of criteria, including mainly the five lime treatment categories (N = No treatment (no lime); L=Low level treatment; M = Medium level treatment, H = High level treatment, VH = Very high level treatment, XH = Extra High level treatment: based on data presented in Table 15). Additional criteria include the presence of MBO, peroxide pH, decrease in pH during incubation experiments.

Key summary findings for Devon Downs South:

ASS materials: Dominantly clays containing some sulfides (but not sulfidic material e.g. some hyposulfidic material); minor sulfidic material (high sulfide concentrations and potential to develop pH<4).

ASS classification: Dominantly cracking clay soil containing some sulfides; minor sulfidic soil and sulfidic cracking clay soil along lagoon margins.

ASS Risk: **Low to moderate risk** of development of sulfuric material in ASS.

3.5 Kroehns Landing

Kroehns Landing wetland (Figure 1) is approximately 1.1 km at longest and 600 m at widest (Figure 41). The wetland is located on the eastern bank of the river, and is separated by a levee bank. Much of the eastern shore of the wetland is dominated by a steep cliff (approximately 15 m). A small island (< 1 ha) is located towards the western shore. The wetland is fed by a northern channel and drained by a southern channel. At time of sampling the wetland was dry (Figure 42). A full account of the habitat quality is presented in Australian Water Environments (2008).

Soil sampling was conducted close to the island, with the first site (KRL 1, Figure 43) near to the shore of the island. KRL 2 (Figure 45) was taken 10 m away, almost on the shore of the island in a stand of *Phragmites*. KRL 3 (Figure 47) was taken on the eastern bank of the wetland, close to the base of the cliff, which dominates. KRL 4 (Figure 49) was taken 30 m away, in the edge of a stand of *Phragmites*.

Figure 41. Kroehns Landing and survey sites.

Figure 42. Landscape context of Kroehns Landing wetland, taken form near KRL 1, looking north (see Figure 1).

Figure 43. Photograph of profile number KRL 1 (see Table 18 and Figure 2 for location).

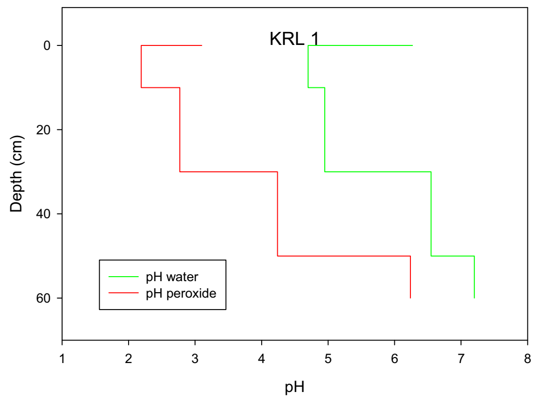


Figure 44. Depth profiles showing pH water (green) and pH peroxide test (red) for KRL 1.

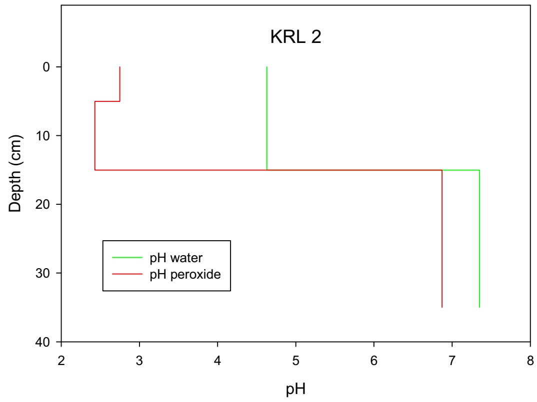


Figure 45. Photograph of profile number KRL 2 (see Table 18 and Figure 2 for location).

Figure 46. Depth profiles showing pH water (green) and pH peroxide test (red) for KRL 2.

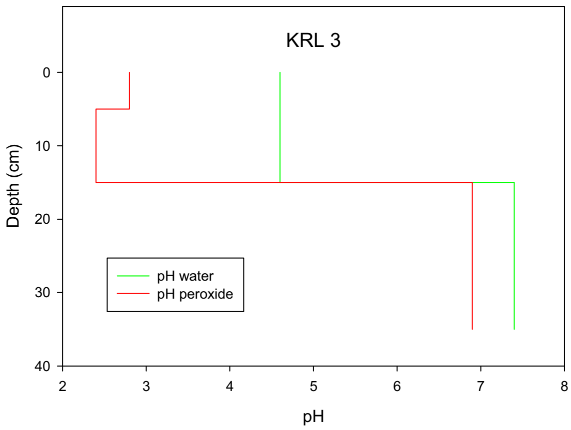


Figure 47. Photograph of profile number KRL 3 (see Table 18 and Figure 2 for location).

Figure 48 Depth profiles showing pH water (green) and pH peroxide test (red) for KRL 3

Figure 49. Photograph from near where profile numbers KRL 3 and 4 were sampled (see Table 18 and Figure 2 for location).

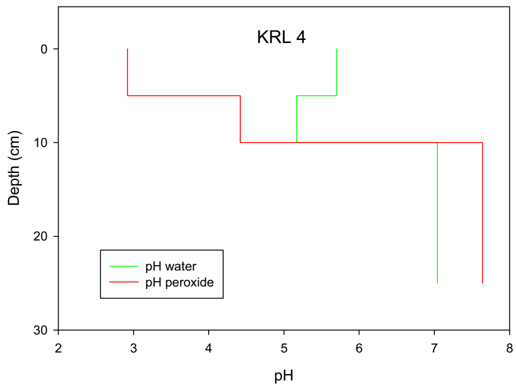


Figure 50. Depth profiles showing pH water (green) and pH peroxide test (red) for KRL 4.

Table 7. Data for ASS assessment of Kroehns Landing wetland.

Method/ Sample	Depth	pH water	pH Fox or Peroxide	[1]ASS materials	[2]ASS classification (and [3]code)	[4]S_{cr}	[5]Lime Calculation kg $CaCO_3$ /tonne DW	[6] ASS Risk
KRL 1.1	0-0.5	6.3	3.1	Sulfidic	Sulfidic cracking clay soil (3.2)	0.016	-2	N
KRL 1.2	0-10	4.7	2.2	Sulfidic		0.015	2	H
KRL 1.3	10-30	5.0	2.8	Sulfidic		0.012	1	M
KRL 1.4	30-50	6.6	4.2	Sulfidic		0.011	1	M
KRL 1.5	50-60	7.2	6.2	Hyposulfidic	Sulfidic cracking clay soil - sandy (3.2)	0.010	-6	L
KRL 2.1	0-5	4.9	2.0	Sulfidic		0.020	2	H
KRL 2.2	5-10	4.1	1.9	Sulfuric		0.028	3	H
KRL 2.3	10-45	6.3	4.0	Sulfidic		0.035	-2	L
KRL 3.1	0-5	4.6	2.8	Sulfidic	Sulfidic cracking clay soil (3.2)	0.036	3	H
KRL 3.2	5-15	4.6	2.4	Sulfidic		0.026	2	H
KRL 3.3	15-35	7.4	6.9	Sulfidic		0.025	2	H
KRL 4.1	0-5	5.7	2.9	Sulfidic	Sulfidic cracking clay soil - sandy (3.2)	0.021	2	H
KRL 4.2	5-10	5.2	4.4	Hyposulfidic		0.022	-5	N
KRL 4.3	10-25	7.0	7.6	None		0.021	-6	N

[1] Sulfuric and Sulfidic (Appendix 1); Hyposulfidic (pH_{ageing} or pH_{Fox} decreases to pH 4-5)
[2] See classification in Table 15.
[3] See classification key code in Table 14.
[4] Reduced Inorganic sulfur (% chromium reducible S; S_{cr}). This measures the reduced sulfur in the sample that potentially can oxidise to sulfuric acid.
[5] Lime needed to neutralise acidity, based on net acidity/alkalinity, which includes a 1.5 times safety factor Negative values have sufficient excess ANC and should not need additional lime) and interpretation from Dear *et al.*, (2002; page 8).
[6] ASS Risk categorisation is based on a number of criteria, including mainly the five lime treatment categories (N = No treatment (no lime); L=Low level treatment; M = Medium level treatment, H = High level treatment, VH = Very high level treatment, XH = Extra High level treatment: based on data presented in Table 15). Additional criteria include the presence of MBO, peroxide pH, decrease in pH during incubation experiments.

Key summary findings for Kroehns Landing:

ASS materials: Dominantly sulfidic material (high sulfide concentrations and potential to develop pH<4) and minor clays containing some sulfides (but not sulfidic material i.e. some hyposulfidic material).

ASS classification: Dominantly sulfidic cracking clay soil throughout with remarkably wide cracks (5 to 15cm wide).

ASS Risk: **Moderate to high risk** of development of sulfuric material in ASS.

3.6 North Purnong

North Purnong (Figure 1) is a linear wetland on the north bank of the river. The wetland is highly linear, with a length of approximately 3.5 km, and a maximum width of 450 m (Figure 51). The wetland is separated from the river by a levee bank, and contained to the north by an eroded cliff in places, and others, a steep cliff face. The cliff is approximately 20 m. The wetland contains four islands. An account of the habitat quality is presented in Australian Water Environments (2008). At the time of sampling the wetland was dry (Figure 52), and we were advised by the landholder that the drying completed during January 2008.

Of the soil profiles described, sampling was conducted on a transect from the north bank to the largest island 120 m away, on an east-southeast bearing. NPU 2 (Figure 53) was sampled near to the north shore in a sandy area. NPU 3 (Figure 55) was sampled approximately half way between the north shore and the island, in a locally low lying area – by evidence of the many carp skeletons present. NPU 4 (Figure 57) was taken from the island amongst a stand of *Typha*.

Figure 51. North Purnong wetland and survey sites.

Figure 52. Landscape context of North Purnong wetland (see Figure 1).

Figure 53. Photograph of profile number NPU 2 (see Table 18 and Figure 2 for location).

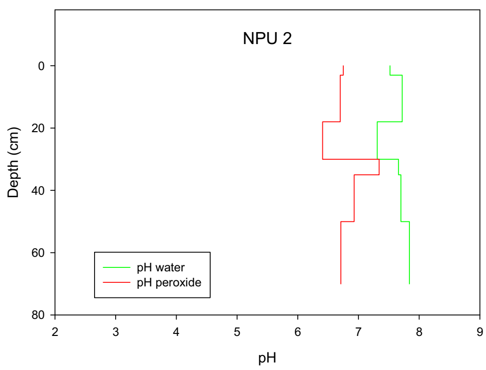


Figure 54. Depth profiles showing pH water (green) and pH peroxide test (red) for NPU 2.

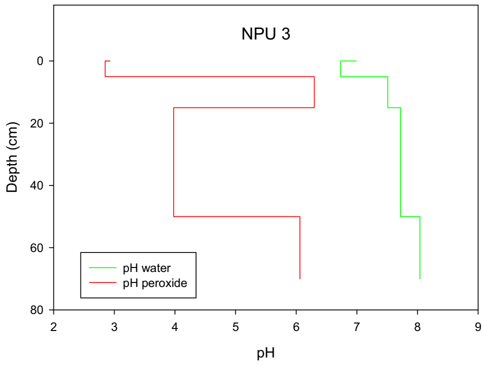


Figure 55. Photograph of profile number NPU 3 (see Table 18 and Figure 2 for location).

Figure 56. Depth profiles showing pH water (green) and pH peroxide test (red) for NPU 3.

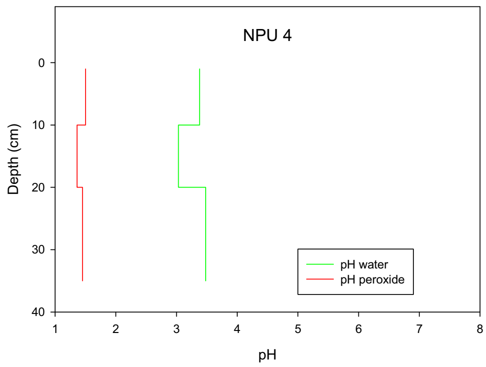


Figure 57. Photograph of profile number NPU 4 (see Table 18 and Figure 2 for location).

Figure 58. Depth profiles showing pH water (green) and pH peroxide test (red) for NPU 4.

Table 8. Data for ASS assessment of North Purnong wetland.

Method/ Sample	Depth	pH water	pH Fox or Peroxide	[1]ASS materials	[2]ASS classification (and [3]code)	[4]S_{cr}	[5]Lime Calculation kg $CaCO_3$ /tonne DW	[6] ASS Risk
NPU 2.1	0-3	7.5	6.8	None	Cracking clay soil (sandy) (3.4)	<0.005	-60	N
NPU 2.2	3-18	7.7	6.7	None		<0.005	-63	N
NPU 2.3	18-30	7.3	6.4	None		0.009	-79	N
NPU 2.4	30-35	7.7	7.3	None		0.026	-232	N
NPU 2.5	35-50	7.7	6.9	None		0.016	-161	N
NPU 2.6	50-70	7.8	6.7	None		0.023	-61	N
NPU 3.1	0-5	7.0	2.9	Sulfidic	Sulfidic cracking clay soil – sandy (3.2)	0.192	2	H
NPU 3.2	0-5	6.7	2.9	Sulfidic		0.225	-1	L
NPU 3.3	5-15	7.5	6.3	None		0.069	-19	N
NPU 3.4	15-50	7.7	4.0	Sulfidic		0.081	-4	N
NPU 3.5	50-70	8.0	6.1	None		0.031	-8	N
NPU 4.1	0-0.05			Sulfuric	Sulfuric cracking clay – sandy (3.3)	0.029	6	VH
NPU 4.2	1-10	3.4	1.5	Sulfuric				VH
NPU 4.3	10-20	3.0	1.4	Sulfuric		0.032	15	XH
NPU 4.4	20-35	3.5	1.5	Sulfuric				XH
NPU 4.5	35-50			Sulfidic		0.015	-4	L

[1] Sulfuric and Sulfidic (Appendix 1); Hyposulfidic (pH_{ageing} or pH_{Fox} decreases to pH 4-5)
[2] See classification in Table 15.
[3] See classification key code in Table 14.
[4] Reduced Inorganic sulfur (% chromium reducible S; S_{cr}). This measures the reduced sulfur in the sample that potentially can oxidise to sulfuric acid.
[5] Lime needed to neutralise acidity, based on net acidity/alkalinity, which includes a 1.5 times safety factor Negative values have sufficient excess ANC and should not need additional lime) and interpretation from Dear *et al.*, (2002; page 8).
[6] ASS Risk categorisation is based on a number of criteria, including mainly the five lime treatment categories (N = No treatment (no lime); L=Low level treatment; M = Medium level treatment, H = High level treatment, VH = Very high level treatment, XH = Extra High level treatment: based on data presented in Table 15). Additional criteria include the presence of MBO, peroxide pH, decrease in pH during incubation experiments.

Key summary findings for North Purnong:

ASS materials: Dominantly underlain by moist sulfidic material (high sulfide concentrations and potential to develop pH<4) and minor clays containing some sulfides (but not sulfidic material) and sulfuric material along the margins of islands with *Phragmites*.

ASS classification: Dominantly sulfidic cracking clay soils with wide cracks (5 to 15cm wide) and sulfuric cracking clays along margins with *Phragmites*.

ASS Risk: **Moderate to high risk** of development of sulfuric material in ASS.

3.7 Lake Carlet

Lake Carlet (Figure 1) is a large wetland on the north bank of the river. It is approximately 7.5 km long, and 1 km at widest (Figure 59). The wetland is separated from the river by a levee bank, while the north bank of the wetland is formed steep and eroded cliffs (approximately 25 m). Australian Water Environments (2008) present a full account of the habitat quality. At time of soil survey, the wetland was still flooded (Figure 60).

Soil sampling was conducted on a transect emanating from the shore of the north bank at the base of the eroded cliff, to 45 m beyond the shore. LCA 1 (Figure 61) was collected from inside a stand of *Phragmites* above the shoreline, whereas LCA 2 (Figure 63) was taken 10 m away on the shore. LCA 3 (Figure 65) was a subaqueous sample taken from a subaqueous ASS tangential from the previous samples.

Figure 59. Lake Carlet and survey sites.

Figure 60. Landscape context of Lake Carlet wetland (see Figure 1).

Figure 61. Photograph of profile LCA 1 (see Table 18 and Figure 2 for location).

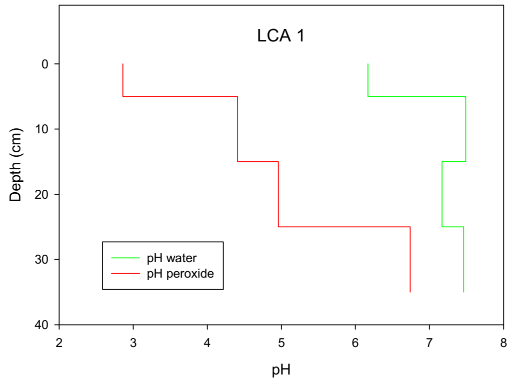


Figure 62. Depth profiles showing pH water (green) and pH peroxide test (red) for LCA 1.

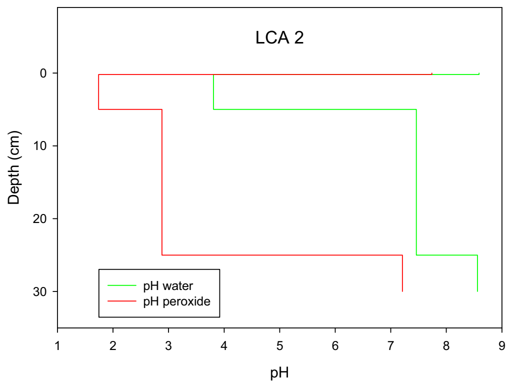


Figure 63. Photograph of profile LCA 2 (see Table 18 and Figure 2 for location).

Figure 64. Depth profiles showing pH water (green) and pH peroxide test (red) for LCA 2.

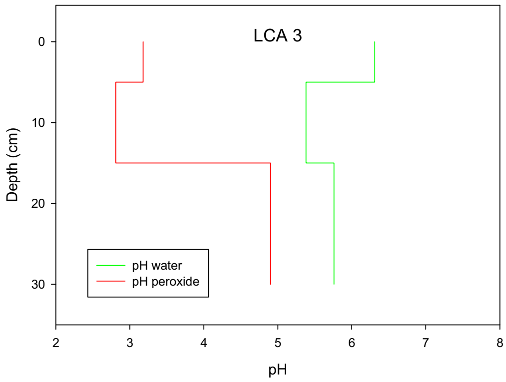


Figure 65. Photograph of person standing at the site in the lake where profile LCA 3 (see Table 18 and Figure 2 for location) was taken.

Figure 66. Depth profiles showing pH water (green) and pH peroxide test (red) for LCA 3.

Table 9. Data for ASS assessment of Lake Carlet wetland.

Method/ Sample	**Depth**	**pH_{water}**	**pH_{Fox} or Peroxide**	**[1]ASS materials**	**[2]ASS classification (and [3]code)**	**[4]S_{cr}**	**[5]Lime Calculation kg $CaCO_3$ /tonne DW**	**[6] ASS Risk**
LCA 1.1	0-5	6.2	2.9	Sulfidic	Sulfidic cracking clay soil – sandy (3.2)	0.016	2	H
LCA 1.2	5-15	7.5	4.4	**Hyposulfidic**		0.012	-6	N
LCA 1.3	15-25	7.2	5.0	**Hyposulfidic**		0.023	-8	N
LCA 1.4	25-35	7.5	6.7	**Hyposulfidic**		0.049	-16	N
LCA 2.1	0-0.02	8.6	7.7	None	Sulfidic cracking clay soil – sandy (3.2)	0.006	-9	N
LCA 2.2	2-5	3.8	1.7	Sulfidic		0.056	2	H
LCA 2.3	5-25	7.5	2.9	Sulfidic		0.237	2	H
LCA 2.4	25-40	8.6	7.2	Sulfidic		0.198	-2	N
LCA 3.1	0-5	6.3	3.2	Sulfidic	Sulfidic subaqueous clayey soil (1.2)	0.108	0	L
LCA 3.2	5-15	5.4	2.8	Sulfidic		0.479	19	VH
LCA 3.3	15-30	5.8	4.9	**Hyposulfidc**		0.367	11	VH

[1] Sulfuric and Sulfidic (Appendix 1); Hyposulfidic (pH_{ageing} or pH_{Fox} decreases to pH 4-5)
[2] See classification in Table 15.
[3] See classification key code in Table 14.
[4] Reduced Inorganic sulfur (% chromium reducible S; S_{cr}). This measures the reduced sulfur in the sample that potentially can oxidise to sulfuric acid.
[5] Lime needed to neutralise acidity, based on net acidity/alkalinity, which includes a 1.5 times safety factor Negative values have sufficient excess ANC and should not need additional lime) and interpretation from Dear *et al.*, (2002; page 8).
[6] ASS Risk categorisation is based on a number of criteria, including mainly the five lime treatment categories (N = No treatment (no lime); L=Low level treatment; M = Medium level treatment, H = High level treatment, VH = Very high level treatment, XH = Extra High level treatment: based on data presented in Table 15). Additional criteria include the presence of MBO, peroxide pH, decrease in pH during incubation experiments.

Key summary findings for Lake Carlet :	
ASS materials:	Dominantly underlain by wet (in Lagoon) and moist (banks and reeds) sulfidic material (high sulfide concentrations and potential to develop pH<4) and minor clays containing some sulfides (but not sulfidic material i.e. hyposulfidic).
ASS classification:	Dominantly sulfidic subaqueous clayey soil mostly under shallow water) and sulfidic cracking clay soils (sandy), especially along margins with *Phragmites*.
ASS Risk:	**High risk** of development of sulfuric material in ASS.

3.8 Ukee Boat Club

Ukee Boat Club (Figure 1) is an artificial wetland that is maintained behind a man-made levee, which is breached by narrow channels to maintain water levels in the wetland area behind. The wetland itself is small, being approximately 450 m at longest, and 100 m at widest (Figure 67). The wetland forms a complex of small lagoons connected by channels. Adjacent to the east the land is used for agriculture, to the north the wetland is bound by a paved road at the base of the small cliff (7 m). Willow trees line much of the river bank on the southern side of the wetland along the levee. An account of the habitat status is presented in Australian Water Environments (2008). At time of sampling the wetland was dry (Figure 68), and it was noted at the boat ramp river level gauge that the river level was -0.35 m AHD.

UKE 1 (Figure 69) was taken from the river channel, 1 m off the bank (i.e. subaqueous ASS). UKE 2 (Figure 70) was taken in close proximity, from a profile recently disturbed by land moving. UKE 3 Figure 71) was taken from the southern lagoon in a bare area that was being encroached by *Phragmites* and *Typha*. UKE 5 (Figure 73) was taken from the northern wetland, in the middle of the lagoon, while UKE 6 (Figure 74) was taken south of this. What was notable from the later two sampling sites was the large ped-size (e.g. 40 x 40 cm), and the wide (2 to 10 cm) and deep (50 cm and deeper) cracks that separated them (Figure 68).

Figure 67. Ukee Boat Club and survey sites.

Figure 68. Landscape context of Ukee Boat Club wetland (see Figure 1).

Figure 69. Photograph of profile UKE 1 sampled under water – i.e. subaqueous ASS (see Table 18 and Figure 2 for location).

Figure 70. Photograph of profile UKE 2 from disturbed material on the bank showing bright yellow jarosite mottles (pH 3.9) (see Table 18 and Figure 2 for location).

Figure 71. Photograph of profile number UKE 3 (see Table 18 and Figure 2 for location) showing bright yellow natrojarosite-rich, gypsum and hexahydrite salt efflorescences overlying sulfuric material in a cracked clayey-

organic-rich ASS profile.

Figure 72. Photograph of jarosite mottling in sandy material similar to found in UKE 4 (see Table 18 and Figure 2 for location); NOTE – carbonate nodule and carbonate coatings on peds identified in cracks near profile UKE 3 (sample UKE 3.9 and UKE 3.10). Also showing bright yellow natrojarosite-rich, gypsum and hexahydrite salt efflorescences overlying sulfuric material in a cracked clayey-organic-rich ASS profile.

Figure 73. Photograph of profile number UKE 5 (see Table 18 and Figure 2 for location).

Figure 74. Photograph of profile number UKE 6 (see Table 18 and Figure 2 for location) - showing bright yellow natrojarosite-rich, gypsum and hexahydrite salt efflorescences overlying sulfuric material in racked clayey-organic-rich ASS profile

Table 10. Data for ASS assessment of Ukee Boat Club wetland Carlet wetland.

Method/ Sample	Depth	pH water	pH Fox or Peroxide	[1]ASS materials	[2]ASS classification (and [3]code)	[4]S_{cr}	[5]Lime Calculation kg $CaCO_3$ /tonne DW	[6] ASS Risk
UKE 1.1	0-10	6.5	1.6	Sulfidic	Sulfidic subaqueous clayey soil (1.2)	0.051	4	H
UKE 1.2	10-20	5.4	1.6	Sulfidic		0.073	4	H
UKE 2.1	0-5	6.5	2.9	Sulfidic	Sulfidic cracking clay soil (3.2)	0.120	6	H
UKE 2.2	5-12	6.3	1.7	Sulfidic		0.273	14	VH
UKE 2.3	12-20			Sulfidic				
UKE 3.1	0-0.05	3.4	1.6	Sulfuric	Sulfuric cracking clay soil – sandy (3.3)	0.105	55	XH
UKE 3.2	0.5-1	2.8	1.4	Sulfuric		0.241	64	XH
UKE 3.3	1-8	2.6	1.2	Sulfuric		0.034	36	XH
UKE 3.4	8-10	3.5	1.8	Sulfuric		0.222	24	XH
UKE 3.5	12-20	4.0	2.3	Sulfuric		0.590	28	XH
UKE 3.6	20-30	3.9	1.6	Sulfuric		0.092	9	VH
UKE 3.7	30-50	5.0	2.4	Sulfidic		<0.005	1	M
UKE 4.1	-			Sulfuric	Iron coated carbonate nodules			
UKE 4.2	-			Sulfuric				
UKE 5.1	0-0.05	3.1	1.3	Sulfuric	Sulfuric cracking clay soil (3.3)	0.010	14	VH
UKE 5.2	0.5-10	3.0	1.4	Sulfuric		0.045	21	VH
UKE 5.3	10-30	6.0	3.2	Sulfidic		0.009	1	M

UKE 6.1	0-5	2.7	1.5	Sulfuric	Sulfuric cracking clay soil (3.3)	0.170	36	XH
UKE 6.2	5-20	3.0	1.4	Sulfuric		0.518	39	XH
UKE 6.3	20-40	6.9	5.0	Hyposulfidic		0.117	6	VH
UKE 6.4	0-0.5	2.5	1.5	Sulfuric				XH

[1] Sulfuric and Sulfidic (Appendix 1); Hyposulfidic (pH_{ageing} or pH_{Fox} decreases to pH 4-5)
[2] See classification in Table 15.
[3] See classification key code in Table 14.
[4] Reduced Inorganic sulfur (% chromium reducible S; S_{cr}). This measures the reduced sulfur in the sample that potentially can oxidise to sulfuric acid.
[5] Lime needed to neutralise acidity, based on net acidity/alkalinity, which includes a 1.5 times safety factor Negative values have sufficient excess ANC and should not need additional lime) and interpretation from Dear *et al.*, (2002; page 8).
[6] ASS Risk categorisation is based on a number of criteria, including mainly the five lime treatment categories (N = No treatment (no lime); L=Low level treatment; M = Medium level treatment, H = High level treatment, VH = Very high level treatment, XH = Extra High level treatment: based on data presented in Table 15). Additional criteria include the presence of MBO, peroxide pH, decrease in pH during incubation experiments.

Key summary findings for Ukee Boat Club:

ASS materials: Dominated by: (i) strongly cracked sulfuric materials (pH<4) with a thickness of 20 cm in November 2007 (shallow water table) and 50 cm in March 2008 (deeper water table) and (ii) sulfidic material (high potential to develop pH<4).

ASS classification: Dominant sulfuric clayey soil and sulfidic cracking clay soils, sulfidic subaqueous clayey soil in adjacent River Murray.

ASS Risk: **High to very high** risk from: (i) current presence of strongly cracked sulfuric material and (ii) potential for further development of sulfuric material in ASS as water levels lower**.**

3.9 Swanport

Swanport wetland (Figure 1) is a small wetland that is under community management, and is located immediately downstream of the Swanport Bridge (Figure 75). The wetland is located on the north bank of the river, and has a maximum length of 700 m and a width of 300 m. It features a complex of lagoons and reed beds (*Phragmites* and *Typha*).

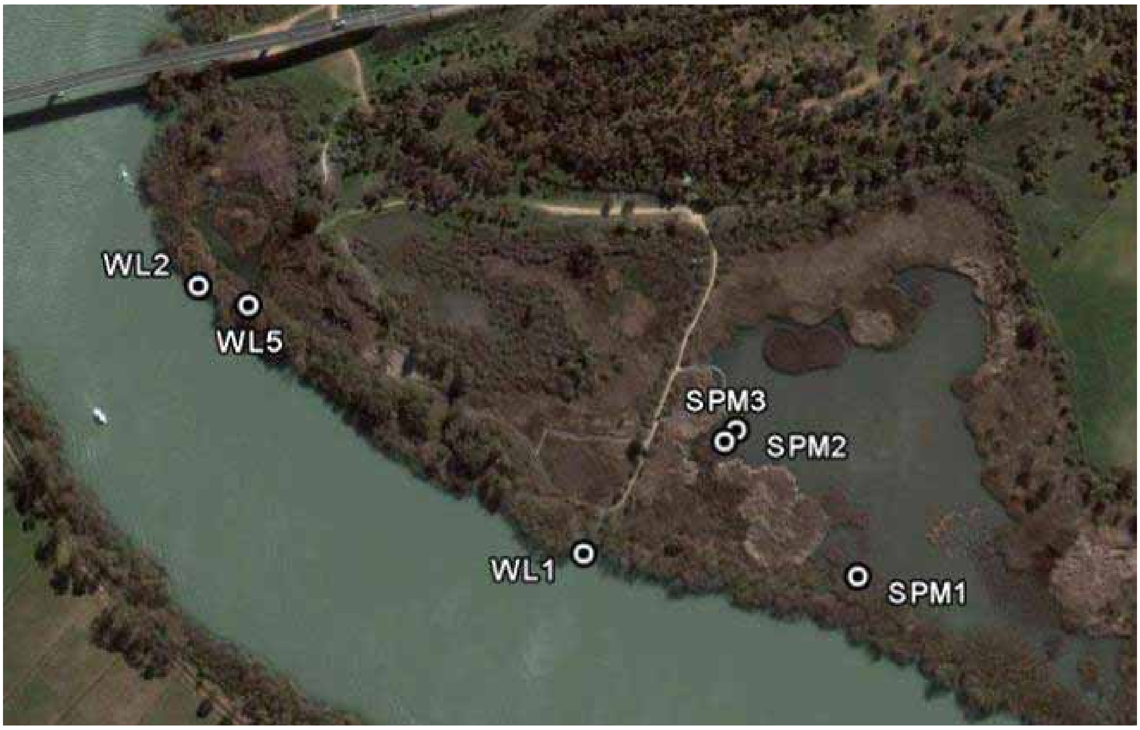


Figure 75. Swanport wetland and survey sites.

Figure 76. Landscape context of Swanport wetland (i.e. site SMP 1 in the far distance near trees: see Figure 1 and Figure 75)

Site WL1 is in the river by the willows in this picture

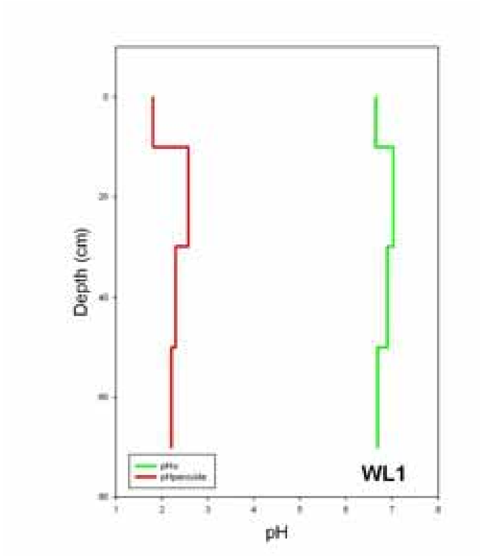


Figure 77. Depth profiles showing pH water (green) and pH peroxide test (red) for site WL1.

Site WL1 in the River Murray at the Swanport wetlands

Figure 78. Photograph showing sampling of the "Soft subaqueous sulfidic material", using a Russian D-auger at profile number WL1 (see Table 18 and Figure 2 for location).

Site WL2 on the river bank a few hundred metres N of Site WL1

Sulfidic soil materials at Site WL2

Figure 79. Photograph of profile number WL 2 (see Table 18 and Figure 2 for location) showing sampling of "Soft poorly drained **sulfidic** soil" (left) and sulfidic materials sampled from Site WL2

Figure 80. Photograph of profile number WL 5 (see Table 18 and Figure 2 for location) showing: 1: Acid Sulfate Soil with sulfuric material in drained wetlands adjacent to the River Murray (left), which shows extensive cracking and accumulation of scale-like, bright golden yellow crystals of metavoltine [$K_2Na_6Fe^{2+}Fe^{3+}_6(SO_4)_{12}O_2$ $18H_2O$] and white crystals of alunogen [$Al_2(SO_4)_3$ $17H_2O$], which have formed as a result of aqueous, acidic (pH < 2.5), sulfate bearing solutions that have percolated through the soil and attacked existing iron sulfides and layer silicates exposed in the cracks. These localised solutions were rich in ferrous and ferric iron and also contained leached potassium and sodium. Metavoltine and alunogen are presumed to be the last minerals to form. The sulfuric material, which also contains natrojarosite, hexahydrite and gypsum developed after drainage because watertable levels had dropped below 40 cm in June 2007 and below 90 cm in November 2007 - due to the severe drought conditions - exposing large sections of riverbank and wetlands that once contained high levels of un-oxidized iron sulfides (pyrite). Sulfidic material (pH>4), which contain un-oxidized pyrite, occurs below the water table shown (middle). (From Fitzpatrick *et al.* 2008a).

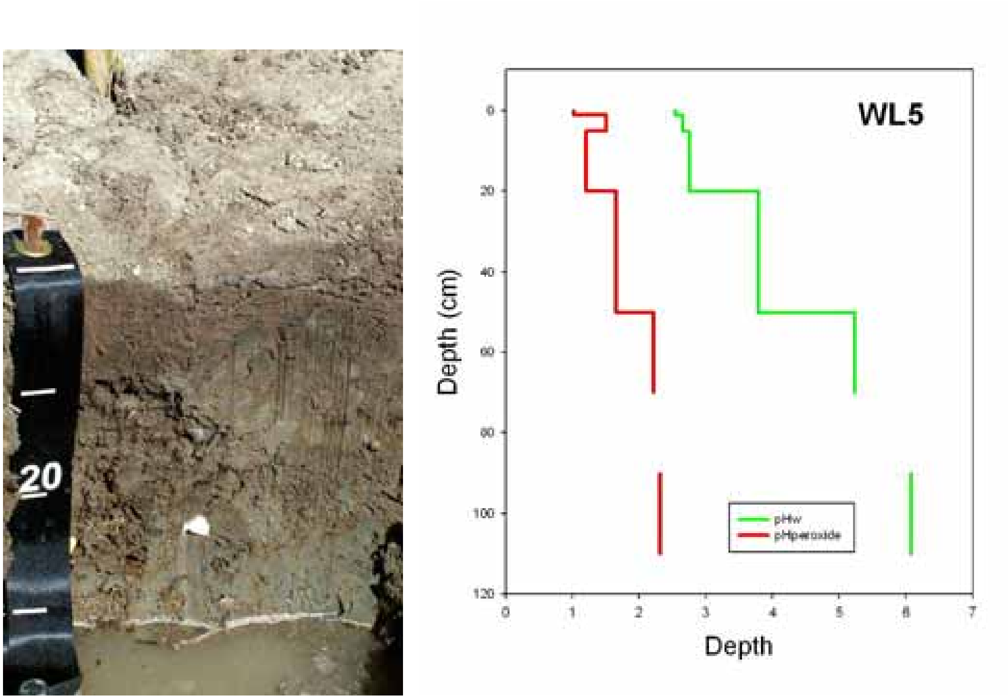


Figure 81. Photograph of profile number WL 5 (see Table 18 and Figure 2 for location) showing sulfuric material in a clayey-organic-rich ASS (cracking clay soil) profile at site WL5 in the Swanport wetland. Depth profiles showing pH water (green) and pH peroxide test (red) for site WL5. The site is about 20 m from the River Murray. The water table is at about 40 cm (July 2007).

Figure 82. Photograph of site where profile numbers SPM 2 and SPM 3 were sampled (see Table 18 and Figure 2 for location) - showing sulfuric material in a clayey-organic-rich ASS (cracking clay soil) profile within the Swanport wetland.

Figure 83. close-up photograph of profile number SPM 2 (see Table 18 and Figure 2 for location) showing bright yellow natrojarosite-rich, sideronatrite, gypsum and hexahydrite salt efflorescences overlying sulfuric material in a cracked clayey-organic-rich ASS profile within the Swanport wetland.

Table 11. Data for ASS assessment of Swanport wetland.

Method/ Sample	Depth	pH water	pH Fox or Peroxide	[1]ASS materials	[2]ASS classification (and [3]code)	[4]S_{cr}	[5]Lime Calculation kg $CaCO_3$ /tonne DW	[6] ASS Risk
SPM 1.1	0-0.02	3.1	1.2	Sulfuric	Sulfuric cracking clay soil (3.3)			XH
SPM 1.2	0-5	2.9	1.3	Sulfuric		0.076	20	VH
SPM 1.3	5-10	3.3	3.1	Sulfuric		0.052	18	VH
SPM 1.4	10-20	4.0	2.0	Sulfuric		0.015	11	VH
SPM 1.5	20-35	5.2	2.6	Sulfuric		0.022	4	H
SPM 1.6	35-50	6.2	3.2	Sulfuric		0.006	3	H
SPM 1.7	50-90	6.3	3.7			0.015	2	H
SPM 1.8	90-140	6.1	3.4			0.017	2	H
SPM 2.1	0-5			Sulfuric	Sulfuric cracking clay soil (3.3)			
SPM 2.2	5-10			Sulfuric				
SPM 2.3	10-20			Sulfuric				
SPM 3.1	0-5			Sulfuric	Sulfuric cracking clay soil (3.3)			
SPM 3.2	5-10			Sulfuric				
SPM 3.3	10-20			Sulfuric				
WL 1.1	0-10	6.7	1.8	Sulfidic	Sulfidic subaqueous clayey soil – sandy (1.2)	0.086	4	H
WL 1.2	10-30	7.0	2.6	Sulfidic		0.024	2	H
WL 1.3	30-50	6.9	2.3	Sulfidic		0.028	2	H
WL 1.4	50-70	6.7	2.2	Sulfidic		0.096	5	H
WL 2.1	0-5	7.15	2.13	Sulfidic	Sulfidic cracking clay soil (3.2)	0.046	3	H
WL 2.2	5-25	6.84	3.21	Sulfidic		0.043	2	H
WL 2.3	25-40	7.52	6.54	Sulfidic		0.047	-2	L
WL 5.1	Crust			Sulfuric	Sulfuric cracking clay soil (3.3)			
WL 5.2	Crust			Sulfuric				
WL 5.3	0-1	2.54	1.02	Sulfuric		0.069	26	XH
WL 5.4	1-5	2.65	1.51	Sulfuric		0.054	19	VH
WL 5.5	5-20	2.75	1.21	Sulfuric		0.180	24	VH
WL 5.6	20-50	3.8	1.7	Sulfuric		0.044	14	VH
WL 5.7	50-70	5.2	2.2	Sulfidic		0.043	5	VH
WL 5.8	70-90			Sulfidic		0.029	3	H
WL 5.9	90-110	6.1	2.3	Sulfidic				H

[1] Sulfuric and Sulfidic (Appendix 1); Hyposulfidic (pH_{ageing} or pH_{Fox} decreases to pH 4-5)
[2] See classification in Table 15.
[3] See classification key code in Table 14.
[4] Reduced Inorganic sulfur (% chromium reducible S; S_{cr}). This measures the reduced sulfur in the sample that potentially can oxidise to sulfuric acid.
[5] Lime needed to neutralise acidity, based on net acidity/alkalinity, which includes a 1.5 times safety factor Negative values have sufficient excess ANC and should not need additional lime) and interpretation from Dear *et al.*, (2002; page 8).
[6] ASS Risk categorisation is based on a number of criteria, including mainly the five lime treatment categories (N = No treatment (no lime); L=Low level treatment; M = Medium level treatment, H = High level treatment, VH = Very high level treatment, XH = Extra High level treatment: based on data presented in Table 15). Additional criteria include the presence of MBO, peroxide pH, decrease in pH during incubation experiments.

Key summary findings for Swanport wetland	
ASS materials:	Dominated by: (i) strongly cracked sulfuric materials (pH<4) with a thickness of 40 cm in July 2007 (shallow water table) and 90 cm in February 2008 (deeper water table) and (ii) sulfidic material (high potential to develop pH<4).
ASS classification:	Dominant sulfuric clayey soil and sulfidic cracking clay soils, sulfidic subaqueous clayey soil in adjacent River Murray.
ASS Risk:	**High to very high** risk from: (i) current presence of strongly cracked sulfuric material and (ii) potential for further development of sulfuric material in ASS as water levels lower.

3.10 Murrundi (North Wellington)

The Murrundi wetland (Figure 2) is located on the western bank of the lower River Murray, within 5 km of the river's outflow into Lake Alexandrina. This is a small wetland, being 600 m at longest and 200 m at widest (Figure 85). According to Australian Water Environments (2008), the wetland is more terrestrial than riparian in nature as it does not act as a floodplain. To the east, the river bank is generally lined with willows, and the western edge/bank of the wetland is contained by a low gradient, eroded cliff, which has been modified by quarrying and other human activity. A full account of the habitat quality of the wetland is presented by Australian Water Environments (2008).

MUR 1 (Figure 86) was taken from the northern area of the wetland, approximately 100 m from the western bank, located in an extremely dense stand of *Typha*. MUR 2 (Figure 88) was taken from the southern end of the wetland, in a stand of *Phragmites*, and MUR 3 (Figure 91), approximately 20 m away form the river. This subaqueous soil was taken from a water depth of approximately 15 cm.

Figure 84. Landscape context of Murrundi wetland showing photographs of: (i) the dense stand of *Phragmites* at site MUR 1 (Photograph on Left Hand Side) and (ii) site MUR 2 is within the degraded stand of *Typha* to the extreme left of the two people and partially hidden by the overhanging willow branches on the left of the

photograph and approximately 20 m from the river edge, and (iii) site MUR 3 is in a subaqueous soil taken from a water depth of approximately 15 cm and located 5 m to the right of the two people (see Figure 1).

Figure 85. Murrundi wetland and survey sites.

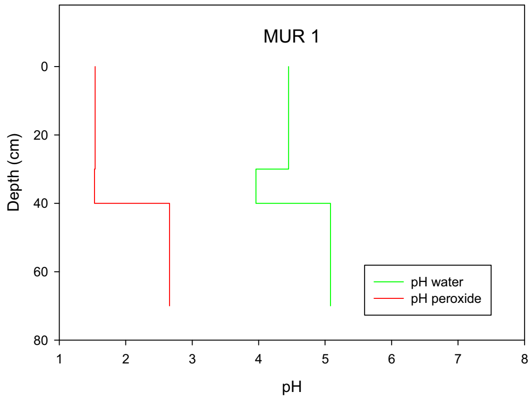


Figure 86. Photograph of profile number MUR 1 (see Table 18 and Figure 2 for location) showing organic-rich horizon

Figure 87. Depth profiles showing pH water (green) and pH peroxide test (red) for MUR 1.

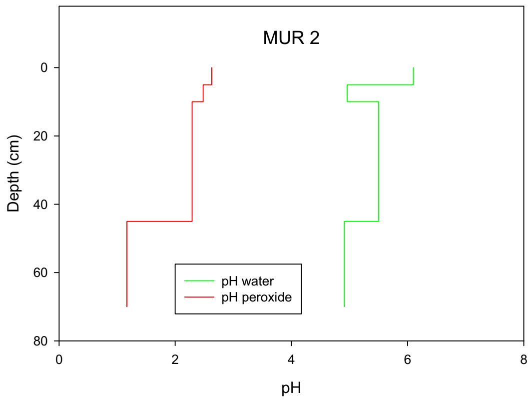


Figure 88. Photograph of profile number MUR 2 (see Table 18 and Figure 2 for location).

Figure 89. Depth profiles showing pH water (green) and pH peroxide test (red) for MUR 2.

Figure 91. Photograph of profile number MUR 3, a Sulfidic subaqueous clayey soil (see Table 18 and Figure 2 for location, and Table 19 for morphological description).

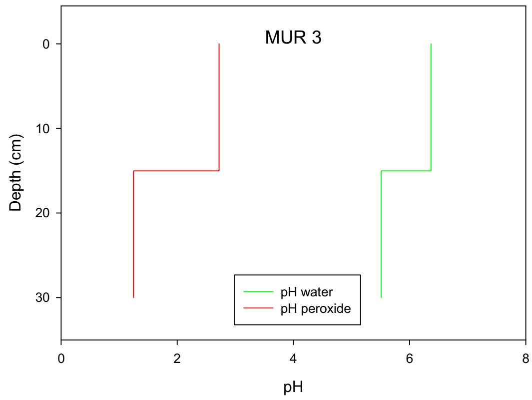


Figure 90. Figure 90. Depth profiles showing pH water (green) and pH peroxide test (red) for MUR 3.

Table 12. Data for ASS assessment of Murrundi (North Wellington) wetland.

Method/ Sample	Depth	pH Water	pH Fox or Peroxide	[1]ASS materials	[2]ASS classification (and [3]code)	[4]S_{cr}	[5]Lime Calculation kg $CaCO_3$ /tonne DW	[6]ASS Risk
MUR 1.1	0-30	4.5	1.5	Sulfuric/organic	Sulfuric organic clayey soil (2.4)	0.130	28	XH
MUR 1.2	30-40	4.0	1.5	Sulfuric		0.067	15	VH
MUR 1.3	40-70	5.1	2.7	Sulfidic		0.013	12	VH
MUR 2.1	0-5	6.1	2.6	Sulfidic	Sulfidic cracking clay soil (3.2)	0.031	6	VH
MUR 2.2	5-10	5.0	2.5	Sulfidic		0.015	3	H
MUR 2.3	10-45	5.5	2.3	Sulfidic		0.041	8	H
MUR 2.4	45-70	4.9	1.2	Sulfidic		1.373	68	XH
MUR 3.1	0-15	6.4	2.7	Sulfidic	Sulfidic subaqueous clayey soil (1.2)	0.067	5	H
MUR 3.2	15-30	5.5	1.3	Sulfidic		1.385	73	XH

[1] Sulfuric and Sulfidic (Appendix 1); Hyposulfidic (pH_{ageing} or pH_{Fox} decreases to pH 4-5)
[2] See classification in Table 15.
[3] See classification key code in Table 14.
[4] Reduced Inorganic sulfur (% chromium reducible S; S_{cr}). This measures the reduced sulfur in the sample that potentially can oxidise to sulfuric acid.
[5] Lime needed to neutralise acidity, based on net acidity/alkalinity, which includes a 1.5 times safety factor Negative values have sufficient excess ANC and should not need additional lime) and interpretation from Dear *et al.*, (2002; page 8).
[6] ASS Risk categorisation is based on a number of criteria, including mainly the five lime treatment categories (N = No treatment (no lime); L=Low level treatment; M = Medium level treatment, H = High level treatment, VH = Very high level treatment, XH = Extra High level treatment: based on data presented in Table 15). Additional criteria include the presence of MBO, peroxide pH, decrease in pH during incubation experiments.

Key summary findings for Murrundi (North Wellington)

ASS materials: Dominated by: (i) organic-rich sulfuric materials (pH<4) with *Phragmites* and (ii) sulfidic material (high potential to develop pH<4). Minor sulfidic subaqueous clayey soil in adjacent River Murray.

ASS classification: Dominant sulfuric organic soil with shallow water table and sulfidic cracking clay soils (sandy),.

ASS Risk: **High risk** from: (i) the exiting occurrences of sulfuric materials and (ii) potential for further development of sulfuric material in ASS.

3.11 Sulfate-containing salt efflorescences

The salt efflorescence or evaporite deposits sampled in the sulfuric materials at Swanport and Ukee proved to be an assemblage of sulfate-containing minerals (as detected by x-ray diffraction and by scanning electron microscopy; see Figure 92 to Figure 94). Movement and accumulation of such soluble salts is typical of drained soils under extremely acidic conditions (i.e. pH <3.5). In surface samples at Swanport and Ukee these salt efflorescences consist of salts containing:

- A yellowish brown (golden) mineral called metavoltine [$Na_6K_2FeFe_6(SO_4)_{12}O_2.18H_2O$], which forms botryoidal encrustations on edges of cracks (see Figure 80 to Figure 83) and is as an alteration product of weathered pyrite in the sulfidic material, which was first identified in the Swanport wetland (i.e. this documents only the first occurrence of metavoltine, in Australia).

- Natrojarosite [$NaFe_3(SO_4)_2(OH)_6$].
- Sideronatrite [$Na_2Fe(SO_4)_2.OH.3H_2O$].
- Tamarugite [$Na_2Al(SO_4)_2.OH.3H_2O$] (see Figure 92 to Figure 94).
- Alunogen [$Al_2(SO_4)_3$ $17H_2O$] (see Figure 92 to Figure 94).
- Gypsum ($CaSO_4.H_2O$) (see Figure 92 to Figure 94).
- Barite ($BaSO_4$),
- Hexahydrite ($MgSO_4.6H_2O$) (see Figure 92 to Figure 94).
- Konyaite [$Na_2Mg(SO_4)_25H_2O$].
- Halite (NaCl).

These minerals (especially metavoltine, natrojarosite, sideronatrite, tamarugite and alunogen) are indicators of very acidic soil conditions. Geochemical analyses of these acidic saline soil materials indicate high concentrations of iron, aluminium, sulfate, magnesium, calcium and sodium ions (see Table 22 and Table 23).

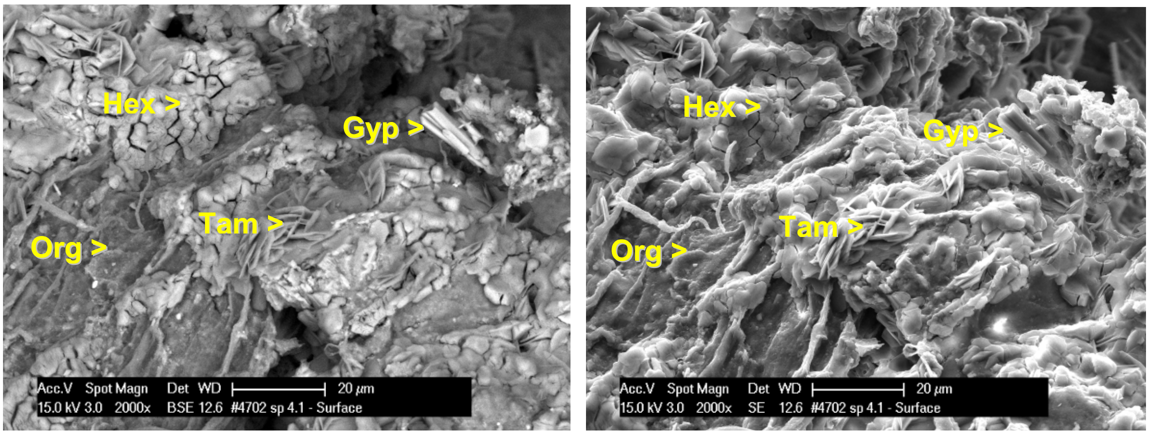


Figure 92. Scanning electron micrographs of mostly hexahydrite (Hex) ($MgSO_4.6H_2O$) (bright areas in BSE mode), organic matter (Org), single isolated bunch of elongated / needle-like crystals of gypsum (Gyp) ($CaSO_4$ $2H_2O$) and platy crystals of mostly tamarugite (Tam) with alunogen. Imaging was performed using Backscattered Electron (BSE) and Secondary Electron (SE) modes.

We interpret the subsurface zones of soluble salts to represent changing water tables linked to the lowering of water levels in the River Murray where capillary action, combined with subsurface evaporation, has concentrated Fe-Al-Na-Mg sulfates, especially in summer or during dry periods. These salt efflorescences are caused by the somewhat unique geochemistry of the combined groundwater, drainage water and drained soils in these wetlands. Sulfides produced in the underlying/original sulfidic materials react with the oxygen in the air to form sulfuric acid. The acid either drains into the River Murray or reacts with other minerals in the soils to form sulfates – liberating dissolved iron, calcium, magnesium, sodium and other elements such as manganese (Mn). The components (Fe, Al, Na, Ca, Mg and SO_4) of the evaporite minerals were derived by leaching of oxidized iron sulfides and then precipitated as specific minerals (e.g. hexahydrite, tamarugite and gypsum) at various stages during the drying/evaporation of the drained soils.

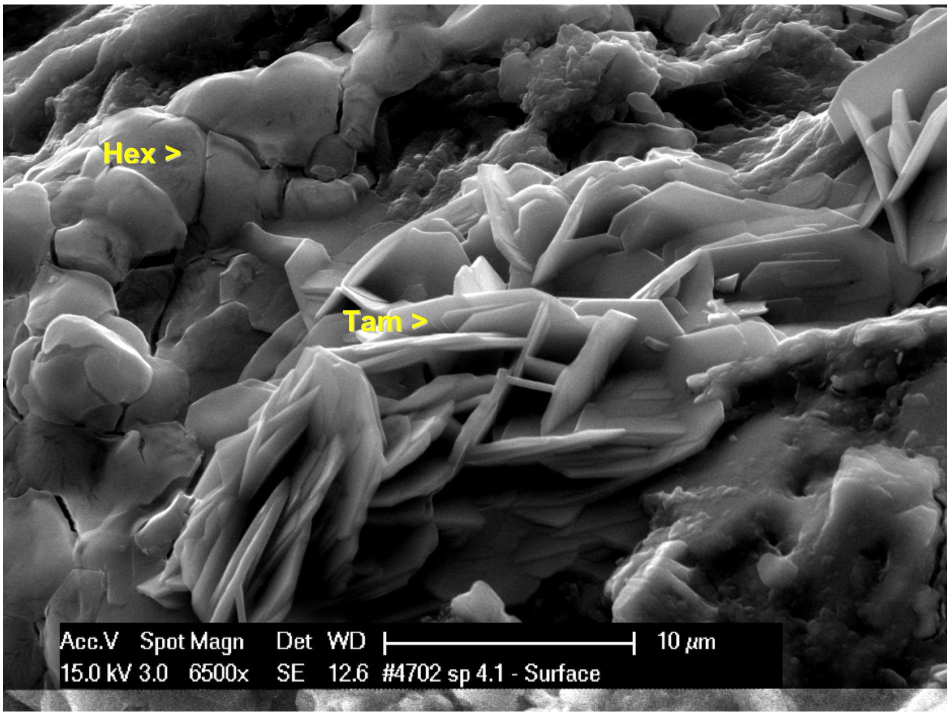


Figure 93. Scanning electron micrographs of mostly hexahydrite (Hex) and platy crystals of Tamarugite (Tam) with alunogen. Imaging was performed using Secondary Electron (SE) mode.

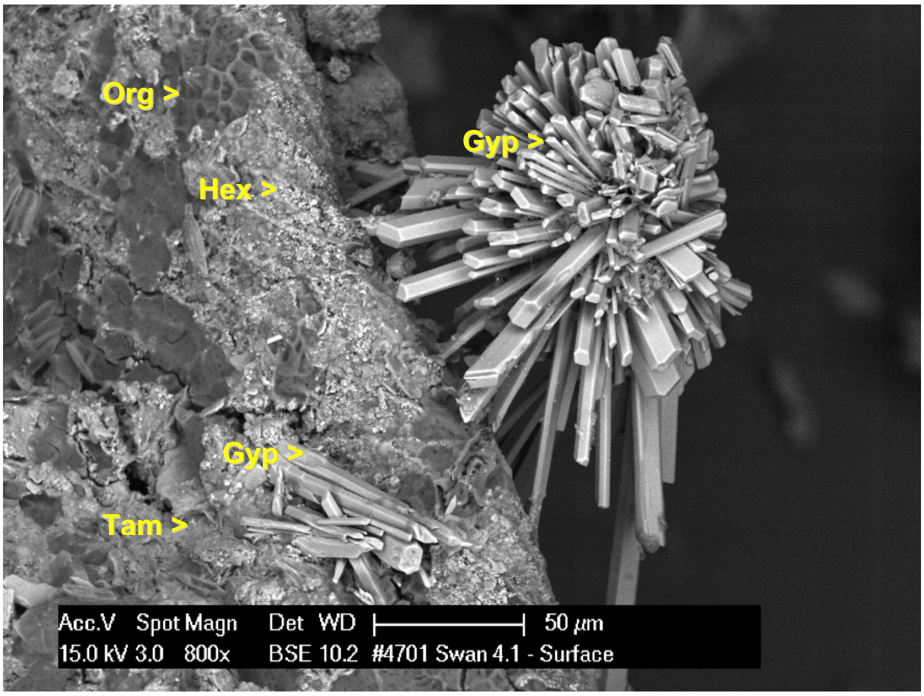


Figure 94. Scanning electron micrographs of mostly hexahydrite (Hex) (bright areas), organic matter showing cell structures (Org), two large single isolated bunches of elongated / needle-like crystals of gypsum (Gyp) ($CaSO_4$ $2H_2O$) and platy crystals of tamarugite (Tam) with alunogen. Imaging was performed using Backscattered Electron (BSE) mode.

The data we have gained indicates that these salts are seasonal or wet/dry period pedogenic products and result from the evaporation of saline sulfatic drainage water produced from the oxidation of sulfidic material at depth (i.e. sulfidic subaqueous clayey or organic soil). More work should be undertaken to confirm seasonal/wet-dry period changes in mineralogical composition. Similar observations have been made of salt efflorescences in the Great Konya Basin in Turkey by Driessen and Schrool (1973) who also identified halite with gypsum and other sulfate minerals (e.g. thenardite). Gumuzzio *et al*. (1982) have identified mixtures of thenardite and mirabilite in salt efflorescences of

Spanish soils (i.e. in winter rainfall areas). They reported that the mineralogical composition varied with the winter type being characterised by mirabilite-thenardite-epsomite and a summer type constituted thenardite-bloedite. More recently, a remarkably similar assemblage of sulfate minerals (eugsterite, thenardite, bloedite, gypsum and halite) were identified in salt efflorescences at Lake Bonney (Fitzpatrick *et al.* 2008d), Tareena Billabong (Fitzpatrick *et al.* 2008b) and in Iraq by Fitzpatrick (2004).

During winter rainfall events these soluble sulfate-containing minerals play important roles in the transient storage of components (Fe, Al, Na, Ca, Mg, Cl, Sr and SO_4), which will dissolve to form the saline monosulfidic black ooze (MBO) in the wetlands.

These salts are likely to form if water levels decrease and have the potential to become a problem during reflooding if not managed properly.

Salt efflorescences also have potential for aerial transport and to be dissolved in water. There is a need to prevent stock from ingesting these salts (similar to Epsom salts) because this is likely to lead to scouring in sheep and cattle. Magnesium salts are toxic when ingested in high levels.

Key Findings:

The significance of the minerals found in these salt efflorescences is that they appear each summer or in a dry period and are environmental indicators. A change in the minerals found will indicate a change in the nature of the salts entering the system from surface or ground waters. Hence, more monitoring work should be undertaken to confirm seasonal/wet-dry period changes in mineralogical composition.

This study documents the first recorded occurrence of metavoltine in Australia. We interpret the occurrence of these soluble salts to represent changing surface and ground water tables, which are linked to the lowering of water levels in the River Murray where capillary action, combined with subsurface evaporation, has concentrated Fe-Al-Na-Mg sulfates, especially in summer or during dry periods.

3.12 Major and minor elements in soils

Trace element concentrations were determined quantitatively using X-ray fluorescence spectroscopy (XRF) on pressed powder pellets (Table 22 and Table 23). Major elements analysed by Simpson *et al*. (2008) provide corrections for matrix effects. The major element data presented are qualitative but are provided as a guide to the bulk chemistry and help to differentiate soil types (e.g. high Al indicates the likelihood of clay minerals). The concentrations of the major elements are expressed in % and the minor elements as ppm (or mg kg^{-1}).

All total analyses of the wetland soils were found to be less than or close to the normal median values reported for soil materials (Bowen 1979). The soils of these wetlands are typically clayey and this is reflected in relatively high Al concentrations. Higher Al and Fe and some of the trace elements (e.g. Mn, Ni, and Zn) are associated with more clay-rich sites but also typically increase with depth in the profiles (Table 22 and Table 23). A number of trace elements were present at detectable concentrations, although they were within the range of uncontaminated soil from around the world (Bowen, 1979; Essington, 2004). Several elements, notably mercury (Hg), cadmium (Cd) and selenium (Se), were present at concentrations below the lower limits of detection for the XRF method used.

In general, the concentration of trace metals were low and below the ANZECC/ARMCANZ (2000) guideline concentrations for sediment and soil quality in waterways. The majority of trace elements correlated well with Fe, hence are likely to be largely present in the finer grained soil fractions (Simpson *et al*., 2008). Profiles on selected soils show the close correlation between the major element Al and the trace elements Fe, Ni and Zn; similar correlations are observed for Ba, Co, Cu, Ga, Nb, Rb, Ti, V, Y and the rare earth elements (see Appendix in Simpson *et al*., 2008).

Manganese concentrations are generally high (> 200 ppm) and in many profiles exceed 500 ppm. Although the concentrations of most trace elements are not unusual, their mobility and bioavailability in most of these wetlands are not known and will depend on the degree to which they are incorporated into different minerals or adsorbed onto mineral surfaces.

3.13 Metal mobilisation following rewetting of acid sulfate soils

The potential for the mobilisation of acid and metals following the rewetting of a wide range of dried ASS subtypes in the lower River Murray and Lakes region was assessed by Simpson *et al.* (2008) in a concurrent project. That project generated data suitable for a screening level risk assessment of ASS from Murrundi, Swanport and Ukee; also undertaken concurrently (Stauber *et al.,* 2008).

The study by Simpson *et al.* (2008) found that upon wetting of the soils with River Murray water using a rapid laboratory testing method, the water was effectively buffered to the pH of the soil. The metal release from the soils was rapid and varied over several orders of magnitude for different soil types. There were exceedances of the water quality guidelines (WQGs) for all metals for which WQGs exist. The metals that most often exceeded the WQGs were Cu (87% of 47 samples), Zn (68%), Ni (64%), Co (60%), Cd (51%), Mn (51%) and Al (>49%). For Al, Cu, and Zn, concentrations were often greater than 100×WQGs. The release of Al, Fe, Cr Cu, V and Zn increased as pH decreased and was adequately modelled using power functions. The mixing of acidic metal-rich waters (mobilised from soils) with River Murray water (pH 7, 40 mg/L $CaCO_3$ alkalinity) was demonstrated to result in the co-precipitation and adsorption of trace metals through freshly forming Al, Fe and Mn oxyhydroxide phases. The soil re-wetting experiments and relationships between pH and metal release indicated that exceedances of WQGs in the River Murray system are likely if the mixed waters have pH 5, but possible at pH 6 if attenuation processes are inadequate.

The screening level risk assessment identified the major metals for which there is a potential risk of acute or chronic ecotoxicological effects to aquatic biota in the Murray system from rewetted sulfuric materials in Ukee and Swanport wetlands (Simpson *et al*., 2008; Stauber *et al*., 2008). Aluminium was the foremost element of concern in these two wetlands. In addition, high concentrations of other metals were also released from rewetted sulfuric materials in the Ukee and Swanport wetlands, leading to high hazard quotients (HQ). HQs were observed for acute exposures for 9 of the 13 metals measured, including Cd, Co, Cr (assuming all Cr is present as Cr(VI)), Cu, Mn, Ni, V, Zn and Al. Dilutions of 100 fold reduced the risk (HQ<1) for all these metals except cobalt and aluminium. Even a 1:1000 dilution was insufficient to reduce the potential risk of aluminium toxicity (assuming bioavailability), with a HQ of 39 for Ukee and 14 for Swanport. Large amounts of iron were also released in the ASS metal mobilisation studies (mean of 85 mg/L for Ukee and 17 mg/L for Swanport) potentially leading to indirect effects from iron flocculation and precipitation. The co-precipitation and adsorption of trace metals with through to freshly forming Al, Fe and Mn oxyhydroxide phases that occurs during mixing was also a concern (Simpson *et al*., 2008). Although trace metals may be removed from the dissolved phase, the flocculation of aluminium may cause toxicity to a range of aquatic fish, and the trace metal-enriched precipitates may be toxic to a variety of filter feeding or benthic organisms.

Key Findings:

Large amounts of aluminium, iron and some trace metals were released in the ASS metal mobilisation studies conducted by Simpson *et al.* (2008), which may potentially cause direct acute toxicity from aluminium and some trace metals or indirect effects from precipitation and particulate iron and aluminium.

For the chronic exposure scenario (1:1000 dilution in the River Murray), cobalt and aluminium represented a potential risk to aquatic biota due to metal release from rewetted ASS in Ukee and Swanport. Trace metal-enriched precipitates may form and may cause chronic toxicity to a variety of filter feeding or benthic organisms.

4. MANAGEMENT PLANNING FOR ACID SULFATE SOILS

It is only during the past couple years that the extent of inland acid sulfate soils has been established and more recently that they are common features within the Murray Darling Basin. This has partly been due to the current drought conditions and low weir pool levels that have exposed sulfidic materials, which have subsequently formed sulfuric material. Case studies in the Lower Lakes and in the channel and adjacent wetlands below Lock 1 (Fitzpatrick *et al*. 2008a) have shown that there are considerable risks of soil acidification due to oxidation of previously unknown ASS.

4.1 Soil identification key

To assist users to identify types and subtypes of soils, a user-friendly soil identification key (Table 13, Table 14) was developed to more readily define and identify the various types and subtypes of ASS and non-ASS. The key is designed for people who are not experts in soil classification systems such as the Australian Soil Classification (Isbell 1996). Hence it has the potential to deliver soil-specific land development and soil management packages to advisors, planners and engineers working in the MDBC.

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

The key consists of a systematic arrangement of soils into 5 broad ASS types, each of which can be divided into up to 4 soil subtypes. The key layout is bifurcating, being based on the presence or absence of particular soil profile features (i.e. using a series of questions set out in a key). A soil is allocated to the first type whose diagnostic features it matches, even though it may also match diagnostic features further down the key. The soil types and subtypes in the Soil Identification Key are largely in the same order as occurs in the Australian Soil Classification (Isbell 1996) and Keys to Soil Taxonomy (Soil Survey Staff 2003). A collection of plain language soil type and subtype names was developed. The 5 ASS types in the Key are: (i) Subaqueous Soils, (ii) Organic Soils, (iii) Cracking Clay Soils, (iv) Sulfuric Soils and (v) Sulfidic Soils (Table 13). These are further sub-divided into 16 subtypes based on occurrence of monosulfidic black ooze material (MBO), sulfidic material, sulfuric material and clayey or sandy layers (Table 14). The key permits easy identification of ASS types and subtypes, and describes practical, surrogate methods to assist uses to estimate treatment categories and risk classes (High, medium, low and very low such as in Table 16).

Table 13. Summary soil identification key for ASS types in the Murray-Darling basin and Lower Lakes. After finding the soil type use Table 14 to find the soil subtype.

Diagnostic features for Soil Type	**Soil Type**	
Does the soil occur in shallow permanent flooded environments (typically not greater then 2.5 m)? No ↓ Yes →	**Subaqueous soil** 	**1**
Does the upper 80cm of soil consist of more than 40 cm of organic material (peat)? No ↓ Yes →	**Organic soil** 	**2**
Does the soil develop cracks at the surface OR in a clay layer within 100 cm of the soil surface OR have slickensides (polished and grooved surfaces between soil aggregates), **AND** is the subsoil uniformly grey coloured (poorly drained or very poorly drained)? No ↓ Yes →	**Cracking clay soil** 	**3**
Does a sulfuric layer (pH<4) occur within 150 cm of the soil surface, **AND** is the subsoil uniformly grey coloured (poorly drained)? No ↓ Yes →	**Sulfuric soil** 	**4**
Does sulfidic material (pH>4 which changes on ageing to pH<4) occur within 100 cm of the soil surface, **AND** is the subsoil uniformly grey coloured (poorly drained)? No ↓ Yes →	**Sulfidic soil** 	**5**
Other soils	**Other soils**	**6**

Where: Subaqueous soil is defined in Appendix 1; Cracking clay is confirmed by field observation, cracks, texture (Appendix 1). Organic material is confirmed by field observation and laboratory data (organic carbon, clay); Sulfuric material is confirmed by field observation (pH measurement using pH strips or meter). Sulfidic material is initially inferred from field observations (e.g. peroxide pH) and confirmed by sampling and incubation for 8 weeks (Isbell 1996; Appendix 1).

Table 14. Soil identification key for ASS and other subtypes at the nine wetlands.

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

Soil Type	Diagnostic features for Soil Subtype		Soil Subtype	
[1]**Cracking clay soil** No ↓ Yes →	Does **sulfidic** material occur within 100 cm of the soil surface? **AND** Does a clayey layer with slickensides occur within 100 cm of the soil surface? No ↓ Yes →	Does a monosulfidic black ooze (**MBO**) material layer >10 cm thick occur within 50 cm of the soil surface? No ↓ Yes →	**Sulfidic cracking clay soil with MBO**	**3.1**
		→	**Sulfidic cracking clay soil**	**3.2**
	Does **sulfuric** material occur within 100 cm of the soil surface? **AND** Does a clayey layer with slickensides occur within 100 cm of the soil surface? No ↓ Yes →		**Sulfuric cracking clay soil**	**3.3**
			Cracking clay soils	**3.4**
Sulfuric soil No ↓ Yes →	Does **sulfuric** material occur within 100 cm of the soil surface? No ↓ Yes →		**Sulfuric soil**	**4.1**
Sulfidic soil No ↓ Yes →	Does a sandy to loamy layer occur within 100 cm of the soil surface?	Does a monosulfidic black ooze (MBO) material layer >10 cm thick occur within 50 cm of the soil surface? No ↓ Yes →	**Sulfidic soil with MBO**	**5.1**
		No ↓ Yes →	**Sulfidic soil**	**5.2**
Other soils			**Hydrosol - sandy or loamy**	**6.1**

[1]"Cracking clay soil" is equivalent to "Vertosol" (Isbell 1996) e.g. Sulfuric cracking clay soil is similar to: "Sulfuric Vertosol. The latter terminology is used in the Legend of the "Atlas for Australian Acid Sulfate Soils" by Fitzpatrick, Marvanek and Powell (2008) and in the ASS maps of the Lower Lakes and River Murray below Lock 1 because it of necessity saves space on Legends displayed on ASS maps (Fitzpatrick *et al*. 2008a).

4.2 Risk categorisation of soil subtypes for management planning

We used the Soil Identification Key to classify the wide range of subtypes of ASS and non-ASS in the nine River Murray wetlands below Lock 1 (Table 15). The method developed by Dear *et al.* (2002) was used to determine the environmental risk" posed by

ASS disturbance with treatment categories: Low, Medium, High, Very High and Extra High. Sulfuric material was generally assigned a risk rating of "Extra High" ((Table 15).

Table 15. Acid sulfate soil subtype, lime treatment categories and risk class for nine wetlands below Lock 1.

Site Code	**Depth, cm**	**Soil subtype**	**Treatment category**	**Risk class[1]**
NOO 1.1	0-0.05	Sulfidic cracking clay soil	H	H
NOO 1.2	0-3		H	H
NOO 1.3	3-10		H	H
NOO 1.4	10-25		H	H
NOO 1.5	25-50		H	H
NOO 2.1	0-0.05	Cracking clay soil	L	L
NOO 2.2	0-5		L	L
NOO 2.3	5-30		H	H
NOO 2.4	30-50		H	H
NOO 3.1	0-5	Sulfidic cracking clay soil		
NOO 3.2	5-20		H	H
DD1.1	0-10	Sulfidic soil	L	L
DD1.2	10-35		N	N
DD1.3	35-50		N	N
DD1.4	50-70		N	N
DD2.1	0-0.2	Sulfidic cracking clay soil		
DD2.2	0-5		VH	VH
DD2.3	5-20		VH	VH
DD2.4	20-40		L	L
DD2.5	40-60		M	M
DD3.1	0-15	Sulfidic cracking clay soil	M	M
DD3.2	15-30		M	M
DD3.3	30-55		L	L
DD4.1	0-15	**Sulfuric** soil	L	H
DD4.2	15-45		H	H
DD4.3	45-60		M	M
DDS1.1	0-5	Sulfidic soil	VH	VH
DDS1.2	5-10		L	L
DDS1.3	10-40		N	N
DDS1.4	40-70		N	N
DDS2.1	0-5	Cracking clay soil	N	N
DDS2.2	5-10		N	N
DDS2.3	10-40		H	H
DDS2.4	40-60		N	N
DDS3.1	0-5	Sulfidic cracking clay soil	N	N
DDS3.2	5-15		L	L
DDS3.3	15-40		L	L
DDS3.4	40-60		L	L
DDS4.1	0-5	Cracking clay soil	N	N
DDS4.2	5-10		N	N
DDS4.3	10-25		N	N
DDS5.1	0-0.05	Cracking clay soil (sandy)	N	N

Site Code	Depth, cm	Soil subtype	Treatment category	Risk class[1]
DDS5.2	0.05-15		N	N
DDS5.3	15-30		N	N
DDS5.4	30-50		L	L
KRL 1.1	0-0.5	Sulfidic cracking clay soil	N	L
KRL 1.2	0-10		H	H
KRL 1.3	10-30		M	M
KRL 1.4	30-50		M	M
KRL 1.5	50-60		L	L
KRL 2.1	0-5	Sulfidic cracking clay soil (sandy)	H	H
KRL 2.2	5-10		H	H
KRL 2.3	10-45		L	L
KRL 3.1	0-5	Sulfidic cracking clay soil	H	H
KRL 3.2	5-15		H	H
KRL 3.3	15-35		H	H
KRL 4.1	0-5	Sulfidic cracking clay soil (sandy)	H	H
KRL 4.2	5-10		N	N
KRL 4.3	10-25		N	N
NPU 1.1	0-0.5	Cracking clay soil (sandy)		N
NPU 1.2	0-0.05	Cracking clay soil (sandy)		N
NPU 2.1	0-3		N	N
NPU 2.2	3-18		N	N
NPU 2.3	18-30		N	N
NPU 2.4	30-35		N	N
NPU 2.5	35-50		N	N
NPU 2.6	50-70		N	N
NPU 3.1	0-5	Sulfidic cracking clay soil (sandy)	H	H
NPU 3.2	0-5		L	L
NPU 3.3	5-15		N	N
NPU 3.4	15-50		N	N
NPU 3.5	50-70		N	N
NPU 4.1	0-0.05	**Sulfuric** cracking clay soil (sandy)	VH	XH
NPU 4.2	1-10		VH	VH
NPU 4.3	10-20		XH	XH
NPU 4.4	20-35		XH	XH
NPU 4.5	35-50		L	L
LCA 1.1	0-5	Sulfidic cracking clay soil (sandy)	H	H
LCA 1.2	5-15		N	N
LCA 1.3	15-25		N	N
LCA 1.4	25-35		N	N
LCA 1.5	+ 35-			
LCA 2.1	0-0.02	Sulfidic cracking clay soil (sandy)	N	N
LCA 2.2	2-5		H	H
LCA 2.3	5-25		H	H
LCA 2.4	25-40			
LCA 3.1	0-5	Sulfidic subaqueous clayey soil	L	L
LCA 3.2	5-15		VH	VH
LCA 3.3	15-30		VH	VH

Site Code	Depth, cm	Soil subtype	Treatment category	Risk class[1]
UKE 1.1	0-10	Sulfidic subaqueous clayey soil	H	H
UKE 1.2	10-20		H	H
UKE 2.1	0-5	Sulfidic cracking clay soil	H	H
UKE 2.2	5-12		VH	VH
UKE 2.3	12-20			
UKE 4.1	-		XH	XH
UKE 4.2	-		XH	XH
UKE 3.1	0-0.05	**Sulfuric** cracking clay soil (sandy)	XH	XH
UKE 3.2	0.5-1		XH	XH
UKE 3.3	1-8		XH	XH
UKE 3.4	8-10		VH	VH
UKE 3.5	12-20		M	M
UKE 3.6	20-30		M	M
UKE 3.7	30-50		M	M
UKE 5.1	0-0.05	**Sulfuric** cracking clay soil	VH	XH
UKE 5.2	0.5-10		VH	XH
UKE 5.3	10-30		M	M
UKE 6.1	0-5	**Sulfuric** cracking clay soil	XH	XH
UKE 6.2	5-20		XH	XH
UKE 6.3	20-40		VH	VH
UKE 6.4	0-0.5			
SPM 1.1	0-0.02	**Sulfuric** cracking clay soil	XL	XL
SPM 1.2	0-5		VH	XH
SPM 1.3	5-10		VH	VH
SPM 1.4	10-20		VH	VH
SPM 1.5	20-35		H	H
SPM 1.6	35-50		H	H
SPM 1.7	50-90		H	H
SPM 1.8	90-140		H	XH
SPM 2.1	0-5	**Sulfuric** cracking clay soil		
SPM 2.2	5-10			
SPM 2.3	10-20			
SPM 3.1	0-5			
SPM 3.2	5-10			
SPM 3.1.13	10-20			
WL 1.1	0-10	Sulfidic subaqueous clayey soil (sandy)	H	H
WL 1.2	10-30		H	H
WL 1.3	30-50		H	H
WL 1.4	50-70		H	H
WL 2.1	0-5	Sulfidic cracking clay soil	H	H
WL 2.2	5-25		H	H
WL 2.3	25-40		L	L
WL 5.1	Crust	**Sulfuric** cracking clay		
WL 5.2	Crust			
WL 5.3	0-1		XH	XH
WL 5.4	1-5		VH	VH
WL 5.5	5-20		VH	VH

Site Code	Depth, cm	Soil subtype	Treatment category	Risk class[1]
WL 5.6	20-50		VH	VH
WL 5.7	50-70		VH	VH
WL 5.8	70-90		H	H
WL 5.9	90-110		H	H
MUR 1.1	0-30	**Sulfuric** organic clayey soil	XH	XH
MUR 1.2	30-40		VH	XH
MUR 1.3	40-70		VH	VH
MUR 2.1	0-5	Sulfidic cracking clay soil (sandy)	VH	VH
MUR 2.2	5-10		H	H
MUR 2.3	10-45		VH	H
MUR 2.4	45-70		XH	XH
MUR 3.1	0-15	Sulfidic subaqueous clayey soil	VH	XH
MUR 3.2	15-30		XH	XH

[1] ASS risk characterisation categorisation is based on a number of criteria, including mainly the five lime treatment categories: N = No treatment (no lime); L=Low level treatment; M = Medium level treatment, H = High level treatment, VH = Very high level treatment, XH = Extra High level treatment: based on data presented in Table 21 Additional criteria include the presence of MBO, peroxide pH, decrease in pH during incubation experiments. Lime needed to neutralise acidity, based on net acidity/alkalinity, which includes a 1.5 times safety factor. Negative values have sufficient excess ANC and should not need additional lime) and i

5. SUMMARY AND CONCLUSIONS

From the 154 soil samples, the following kinds of soil materials were identified in the range of ASS subtypes: 29 sulfuric materials, 73 sulfidic materials, 2 MBO materials, 13 sulfide-rich clays, 32 sulfide-rich sands and sulfide-rich organic materials. These diagnostic materials and the soil identification key (Fitzpatrick *et al*., 2008a,b) were used to classify the full spectrum of ASS and non-ASS subtypes (Table 16). The individual wetlands have been classified according to risk into the following five categories (Table 16).

Table 16. Risk assessment of the nine wetlands based on a combination of the ASS tests and application of the ASS Identification key

[1]ASS Risk	Wetland	[1]Dominant Acid Sulfate Soil (ASS)	
		Material	[1]Classification (ASS subtypes)
Extremely High	**Ukee and Swanport**	**Sulfuric**	**[2]Sulfuric cracking clay soil**
High	Murrundi (North Wellington) Lake Carlet	Sulfidic	[2]Sulfuric organic soil [3]Sulfidic subaqueous clayey soil
High to Moderate	Kroehns Landing, Devon Downs North	Sulfidic	[4]Sulfidic cracking clay soils
Moderate to High	Noonawirra North Purnong	Sulfidic	[4]Sulfidic cracking clay soils
Moderate	Devon Downs South	Hypo-Sulfidic	[5]Cracking clay soil containing some sulfides

[1]The ASS risk and occurrence of various other subtypes of ASS within individual wetlands is variable. [2]Sulfuric clayey or organic soils are currently extremely acidic with Extremely High ASS Risk and will require high to extremely high levels of lime treatment. [3]Sulfidic subaqueous clayey soils will only become acidic when exposed to air, hence they are "potentially High ASS Risk" and will only require high to moderate levels of lime treatment when drained. [4]Sulfidic cracking clay soils are either dried, partly dried or saturated and will progressively become acidic when they are continually exposed to air, hence they are "potentially High to Moderate ASS Risk" and will require high to moderate levels of lime treatment, (iii) [5]Cracking clay soil containing some sulfides are "potentially Moderate ASS Risk" and will require moderate levels of lime treatment.

5.1 Generalised schematic cross section models illustrating the multi-process formation of ASS materials under pre-European, European and extreme drought conditions

The current drought has accelerated the decline in river health. In the Living Murray Icon Site Environmental Management Plan (MDBC, 2006a,b), six factors were identified as the primary determinants of the lakes' ecological character: salinity, turbidity and sedimentation, water levels, keystone aquatic plants, habitat availability and flows. However, the problem of ASS was not recognised, nor even mentioned, in this 2006-2007 management plan. The SA EPA, SA Water and the SA Murray-Darling Basin Natural Resource Management Board (SAMDBNRMB) recently undertook a qualitative risk assessment for water quality in the River Murray and Lower Lakes catchment to prioritise actions to best mitigate water quality risks (EPA, 2007). The River Murray system in SA was split into 8 regions, of which 4 regions: Mid Murray-Blanchetown, Mannum to Wellington, Goolwa to Wellington and Coorong (encompassing the Lower Lakes) overlap with the current study. This risk assessment focused largely on point sources, rather than more general risk from drought, climate change, reduced flows etc. Risks from ASS were not mentioned in this report. We have conducted detailed field and laboratory investigations to assess the acid sulfate properties, risk and management options with respect to the soils and subaqueous soil materials of nine representative wetlands below Lock 1 and above the lower lakes of the South Australian River Murray. The wetlands studied are currently undergoing unprecedented (at least in recent history) drying during the current, extreme low-flows affecting the lower-Murray.

Based on these investigations, we have developed a series of eight generalised conceptual models presented below that illustrate how subaqueous soil conditions have sequentially changed – and will change - across a theoretical cross-section of the river channel, banks and fringing wetlands since the 1880s (i.e. when the river was first managed using locks) to present day. Furthermore, we present conceptual models of the likely outcomes of management scenarios for the river cross-sections. As presented in Figure 95 (upper panel), before the 1880s the lower River Murray cycled between natural wetting and flushing, and partial drying conditions in response to seasonal (i.e. winter/summer) and climatic (e.g. drought/wet) cycles occurring in the upper Murray-Darling River basin (MDRB).

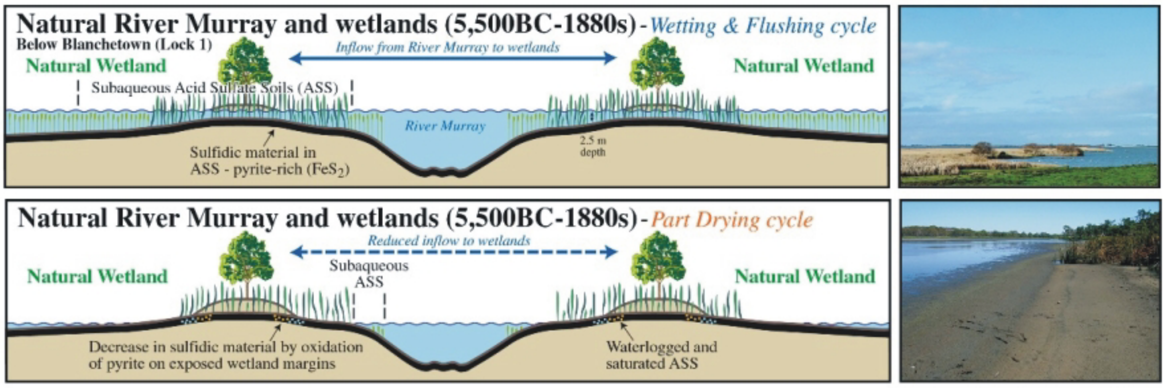


Figure 95. Generalised schematic cross section models for the lower- River Murray banks and wetlands; illustrating natural wetting and flushing (upper panel), and partial drying (lower panel) cycle conditions during pre-colonial times (5,000 BC - 1880s).

During wetter periods the river banks and fringing wetlands underwent regular wetting and flushing cycles. Waters received by the wetlands were transferred via channels, over-bank floods, and by infiltration. Wetlands received and accumulated sulfidic materials from upstream and groundwaters. However, during dry periods (Figure 95 - lower panel) when river flows were lower, banks and fringing wetlands dried, causing oxidation sulfidic materials on the now-dry margins. Sulfidic materials were converted to sulfuric materials – with attendant acidification. In wetter times and floods, sulfuric materials were dissipated into the water column, redistributed, and reformed as sulfidic material. The build-up of sulfuric/sulfidic materials in the river system (wetlands and river banks) was regularly checked by scouring floods.

Since the 1880s, European colonists moderated the flows of the lower River Murray by locks to ensure reliable navigation and irrigation. During the 1880 – 1930 period, many of the wetlands were managed for irrigation (dairy and other flood irrigation) by the installation of sluice gates in the levee banks and inflow channels. However, many other wetlands in the lower river system remained unmanaged, and continued to operate as before, albeit moderated by the locks.

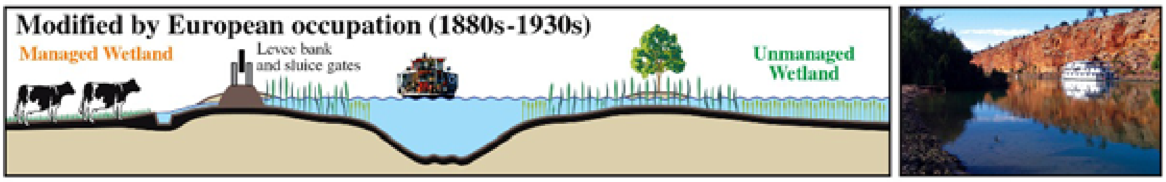


Figure 96. Generalised schematic cross section model for the lower-River Murray banks and wetlands; illustrating modification of water flows by European occupation (1880s- 1930s).

During this period (1880s – 2006) (Figure 97), the lack of scouring, flushing floods, along with evaporative concentration, allowed considerable build-up sulfidic material from upstream and groundwater sources in the unmanaged wetlands, the river banks, and in the river channel (subaqueous sulfidic materials). Along the fringes of the irrigated managed wetlands, there was much accumulation of ultra-fine monosulfidic black ooze (MBO) material - particularly in low-flow backwaters.

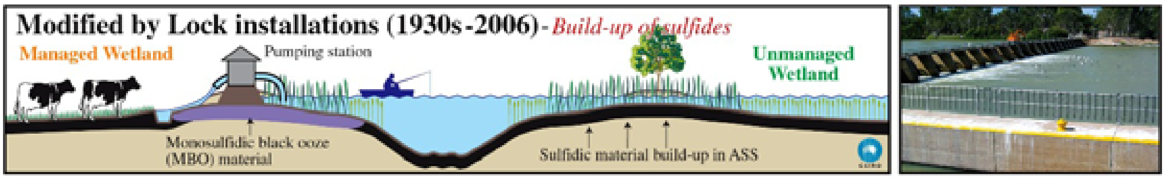


Figure 97. Generalised schematic cross section model for the lower-River Murray banks and wetlands; illustrating modification of water flows by lock installations causing the build up of sulfides under continues subaqueous ASS conditions from 1930s-2006.

As the present drought continued into 2006 and 2007 (Figure 98) and the river channel levels continued to drop, wetlands perched above the river level started to dry. Many wetlands with deep connecting channels to the river were blocked off from the river to preserve river channel water volumes for critical downstream needs. Consequently, these lower-level wetlands also started to dry as watertables receded. With drying, locally elevated (levee banks) and fringing wetland areas experienced vegetation stress and die-back. Areas with MBO also continued to dry out, causing desiccation cracks to develop in the fine textured material.

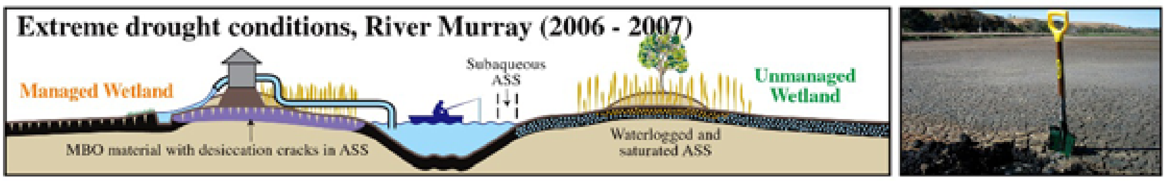


Figure 98. Generalised schematic cross section model for the lower-River Murray banks and wetlands; illustrating extreme drought conditions in 2006 – 2007 where subaqueous ASS transform to waterlogged ASS (i.e. ASS that are wet or saturated long enough to produce periodically anaerobic conditions, thereby influencing the growth of plants: e.g. hydric soils with sulfidic material).

As the current drought has persisted (2007 – 2008) (Figure 99), the river level continued to lower, and most wetlands have effectively become hydraulically disconnected from the river channel. This resulted in the formation of sulfuric material (> 30cm) and deepening of desiccation cracks (> 50cm), especially in wetlands that are organic-rich (>10 % organic carbon) and clayey (>35 % clay). This has also resulted in extreme acidic conditions (pH less than 4, in places pH less than 2) in several wetlands (e.g. Swanport and Ukee).

Under such low pH conditions, acid dissolution of the layer silicate soil minerals has caused the release of high levels of Fe, Al, Mg, Si (and others) and the formation of sulfate-rich salt efflorescences in and near soil surfaces. The lowered river water levels have caused the curtailment of much irrigation pumping activity due to prescribed controls, and because water intakes are no longer submerged and viable (Figure 99). The continued drying of the wetlands has caused further desiccation, and the precipitation of sulfate-rich salt efflorescences in the desiccation cracks (Figure 99).

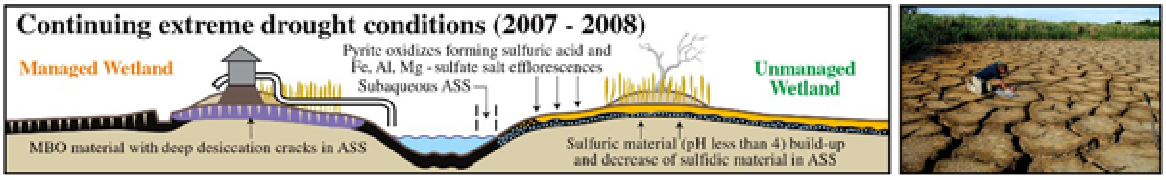


Figure 99. Generalised schematic cross section model for the lower-River Murray banks and wetlands; illustrating the formation of: (i) sulfuric material (pH <4) by oxidation of sulfides in sulfidic material, (ii) sulfate-rich salt efflorescences and (iii) deep desiccation cracks; due to continued lowering of water levels under persistent extreme drought conditions during 2007 – 2008.

5.2 Possible management options

Several management options are currently being considered (Table 17) for mitigating the effects of sulfuric and exposed MBO materials that have already formed in several of the nine wetlands because of the extreme drought conditions (Figure 95 to Figure 99). For example, in the upper and lower panels of Figure 100 we present management scenarios, and the likely outcomes for the wetlands, river banks and river channel.

The scenarios presented are based on availability of sufficient water for ASS management in the wetlands (Table 17). Under the first scenario presented (upper panel, Figure 100), the river is maintained at before-current drought levels (e.g. Figure 97) in which the unmanaged wetlands and managed wetlands are once again sustained by sufficient water to maintain moderated flood and irrigation regimes. Under these conditions in the unmanaged wetland, sulfuric materials (including MBO) and sulfate salt efflorescences become diluted, mobilised, and once appropriate wetland/redox conditions resume, sulfidic materials reform, while metal salts bioaccumulate, or accumulate in sediments. However, under this management scenario, there is little control of the distribution and eventual fate of sulfates, MBO and salts, and the fates of which are controlled by natural – but moderated – river water flows and floods.

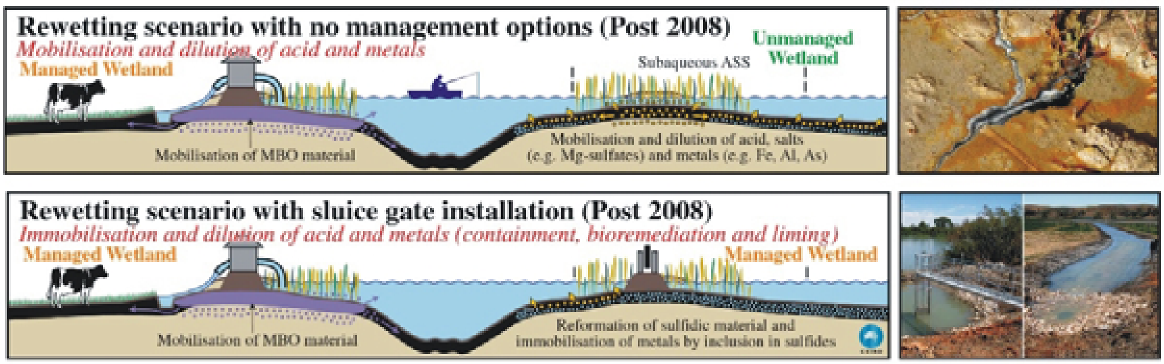


Figure 100. Generic conceptual model for lower-River Murray banks and wetlands; re-wetting management post-2008: no management scenario (upper panel) and management by sluice gates scenario (lower panel).

To address the fate of these materials on the river system, the second management scenario shown in the lower panel of Figure 100 involves the construction of sluice gates at the river inflows of the unmanaged wetlands. Management of these now unmanaged wetlands will involve carefully maintaining water level by controlling in- and out-flows. Under this management scenario, sulfuric materials and metal salts will be contained in the wetland, thus allowing targeted and controlled management to occur to re-instigate and maintain wetland quality. Such management options include bioremediation (such as organic mulching to reform pyrite) and/or liming (to neutralise acidity). However, clearly, such targeted management would not be possible on river banks, which would experience mobilisation of sulfuric materials (including MBO) – although the volume of water in the river channel would effect considerable dilution to such materials.

5.3 Generalised conceptual model illustrating sequential transformation of ASS materials under drought conditions

ASS form naturally in both coastal and freshwater environments where sulfate is present in the surface or groundwater, along with large amounts of organic matter such as decaying vegetation in waterlogged areas. Under normal or natural wetting and drying cycles, build up of ASS is minimised. However, since the completion of locks, weirs and barrages as a result of river regulation, sulfide minerals, e.g. pyrite, is likely to have accumulated in subaqueous or submerged soils. Current drought conditions have led to a considerable drop in water levels below Lock 1, resulting in the progressive exposure of sulfidic material along the river bank and wetlands in waterlogged soils, which in turn leads to the formation of sulfuric material (pH <4) in ASS (Figure 101).

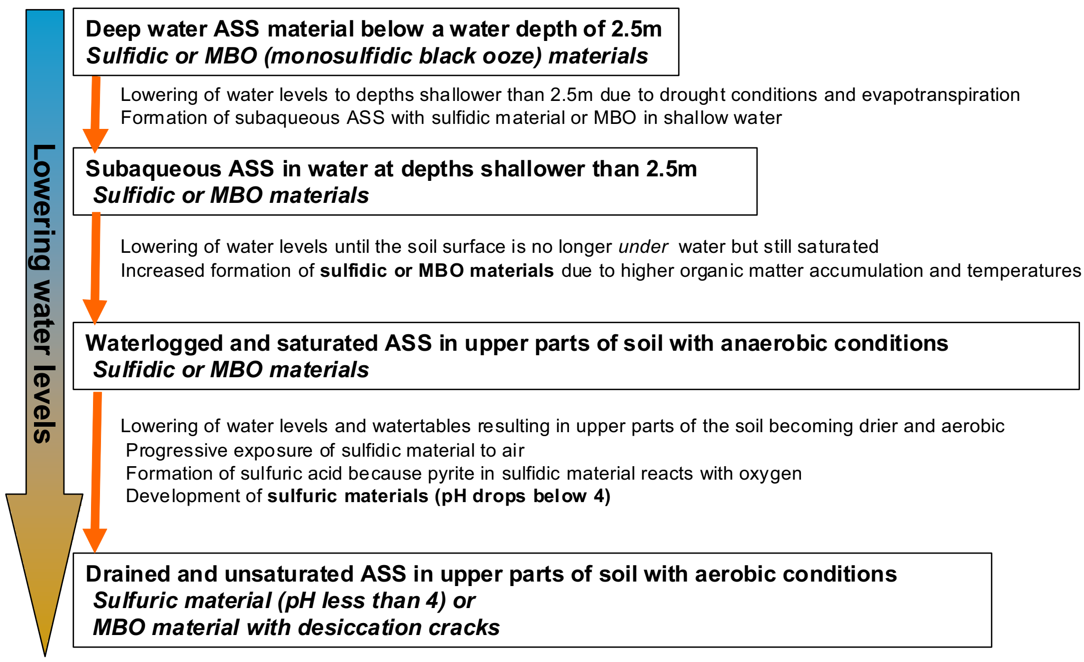


Figure 101. Generalised conceptual model showing the sequential transformation of four Classes of ASS due to lowering of water levels from “Deep-water ASS” → “Subaqueous ASS” → “Waterlogged and saturated

ASS" (all containing sulfidic material with high sulfide concentrations and pH>4) to → "Drained and unsaturated ASS" containing sulfuric material (pH<4) in the upper soil layers (from Fitzpatrick *et al*. 2008a).

5.4 Management options and monitoring

Several management options for mitigating the effects of sulfuric and MBO materials in ASS, which have formed because of the extreme drought conditions in the Lower Murray are currently being considered. These include:

- Closing off selected wetlands with sluice gates to exclude or regulate water flow in wetlands from the main river channel to: (i) reduce evaporation losses and (ii) reduce the risk of saline, nutrient-laden and acidic-metal-rich water draining back into the river as river levels fall and/or rise (Figure 100).

- Reflooding wetlands where there is a need for a wetland re-wetting strategy. All nine wetlands investigated in this study are open to the river and will require installation of structures (sluice gates) to manage the flux of water movement, presuming the wetlands are not 'leaky'. Hence, refilling or flooding of these wetlands could potentially contribute polluted water to the River Murray. Some irrigation drainage water and stormwater enters these wetlands and the capture area of the wetlands is greater than the immediate catchment. A rigorous monitoring program should be developed to document the outcomes of the use of the water in all nine wetlands. Key components for ASS monitoring are:

    a. Acid Sulfate Soils (e.g. S suite, peroxide pH and efflorescence mineral indicators along current transects).

    b. Surface water levels and quality (pH, SEC, Eh, alkalinity and a range of major and trace elements).

    c. Groundwater levels and quality (pH, SEC, Eh, alkalinity and a range of major and trace elements).

    An assessment of ASS should be undertaken in all wetlands after water has been introduced, to determine the effectiveness of applying water as a control technique. Control techniques e.g. sluice gate installation should be trialled.

- Liming (see Table 21 for amounts of lime needed to neutralise acidity, based on net acidity/alkalinity) for acidic, sulfuric materials could be trialled in ASS.

- Other localised treatments such as bioremediation for sulfuric materials should also be trialled and tested.

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APPENDIX 1: DEFINITIONS AND MANAGEMENT OPTIONS

What are Subaqueous soils?

In the last decade, the United States Department of Agriculture's (USDA) definition of soils has completely changed to include environments that are permanently submerged (Soil Survey Staff 1999). Subaqueous soils form in sediments found in shallow permanently flooded environments. Excluded from the definition of subaqueous soils are any areas "permanently covered by water too deep (typically greater than 2.5m) for the growth of rooted plants" (Stolt 2006). Soil scientists (mainly pedologists) have been studying these subaqueous soils in shallow sub-tidal lagoons and described them from a pedological perspective. The pedological approach involves characterising the morphological (colour, structure), physical (texture, compressibility), chemical (pH, salinity), mineralogical (layer silicates, iron oxides) and biological (roots, plants) properties of the benthic substrates and describing them using the terminology commonly used for soils. Once the benthic materials and underlying sediments are described as soils, investigators can easily identify the relationship between the soils and their position on the landscape (e.g. Bradley and Stolt 2002, 2003). An understanding of these relationships enables land managers to identify the best location for specific land uses and to better predict the potential impact of proposed changes (e.g. dredging or drainage) on subaqueous soils and ecosystems they support.

What are waterlogged and hydric soils?

Waterlogged soils are a general term used to describe soils that are saturated or soaked with water long enough during the growing season to develop anaerobic conditions in the upper part to produce swampy or spongy conditions in wetlands.

Hydric soils equate to "waterlogged soils" because they are normally associated with wetlands and hydrophilic vegetation. According to Mausbach and Parker (2001) the term "hydric soil" was defined by observing: (i) the connection between the vegetation in classic wetlands and the soils that help support them, (ii) wetness or saturation during the growing season of plants and (iii) anaerobic conditions in the root zone of plants. *Definition of hydric soil*: A hydric soil is a soil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part (National Technical Committee for Hydric Soils, 1987; Environmental Laboratory, 1987).

What are Acid Sulfate Soils?

Acid sulfate soils (ASS) are all those soils with soil materials affected by iron sulfide minerals. These soils may either contain sulfuric acid or have the potential to form sulfuric acid or cause deoxygenation or release contaminants when the sulfide minerals are exposed to oxygen. This general definition includes: (i) potential and actual (or active) ASS, two broad genetic soil types originally defined by Pons (1973), (ii) post-active ASS, which have a lasting effect on main soil characteristics, recognised by Fanning (2002) and

(iii) ASS with monosulfidic black ooze (MBO) material, which is a subaqueous or waterlogged organic rich material that contains high appreciable concentrations of monosulfides to cause deoxygenation (Sullivan et al. 2002). ASS form in coastal, estuarine, mangrove swamp, coastal back swamp/marsh environments and in inland saline wetlands (e.g. Fitzpatrick 1996) because these waterlogged or highly reducing environments are ideal for the formation of sulfide minerals, predominantly iron pyrite (FeS_2). Iron sulfide minerals are one of the end products that form as part of the process of sulfate reduction (i.e. the use of SO_4^{2-} instead of O_2 during microbial respiration). Sulfate reduction is a natural process that occurs virtually in all subaqueous soils in oceans, estuaries, lakes, rivers and wetlands. However, the quantities of sulfidic material that will accumulate in a given environment are a function of many factors. The key requirements for high rates of sulfate reduction and sulfide accumulation are:

i) high concentrations of sulfate in surface or groundwater,

ii) saturation of soils and sediments for periods long enough to favour anaerobic conditions,

iii) availability of labile carbon to fuel microbial activity and

iv) availability of iron minerals (Figure 102).

To form sulfidic materials, the bicarbonate produced by the reduction reactions must be flushed from the sediment, for example by tides or seiches (standing waves) caused by wind in lakes and rivers.

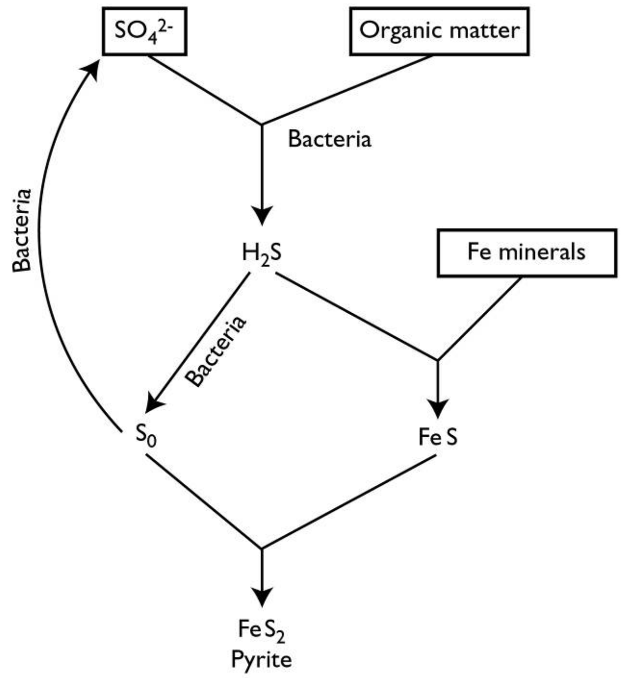


Figure 102. Schematic diagram for the formation of pyrite in anoxic sediments (after Berner 1984)

Soil horizons that contain sulfides are called sulfidic materials (Isbell 1996; Soil Survey Staff 2003) and can be environmentally damaging if exposed to air by disturbance.

In summary, sulfidic materials contain oxidisable sulfur compounds. They may be mineral or organic soil materials, have a natural pH value >4, and when incubated as a layer 1 cm thick under moist conditions, while maintaining contact with the air at room temperature, they show a drop in pH of 0.5 units or more to a value of 4.0 or less within 8 weeks (Soil Survey Staff 2003).

Exposure of sulfidic material results in the oxidation of pyrite, with each mole of pyrite yielding 4 moles of protons (i.e. 2 moles of sulfuric acid). This process transforms sulfidic material to sulfuric material when, on oxidation, the material develops a pH of 4 or less (Isbell 1996); note that a sulfuric horizon has a pH of 3.5 or less according to Soil Survey Staff (2003). If disturbed, the time required for the transition from sulfidic materials to sulfuric material ranges from weeks to years.

Monosulfidic black ooze (MBO) material is a subaqueous or waterlogged mineral or organic material that contains mainly oxidisable monosulfides that have a field pH of 4 or more but which may not become extremely acid (pH <4) when drained.

The recognition of the occurrence and importance of monosulfides in soil materials led in 2005 to the inclusion of monosulfidic materials as a distinguishing property within mapping units of the Australian National Atlas of Acid Sulfate Soils (Fitzpatrick *et al*. 2006, 2008c). High nutrient environments together with the activity of algae and micro-organisms generate redoximorphic conditions, which result in the formation of black, smelly, iron monosulfides. When subaqueous materials rich in monosulfides are resuspended, for example during the flushing of drains by high runoff events, they rapidly oxidise to elemental sulfur and ferrous iron, potentially removing most of the oxygen from the water column (Sullivan et al. 2002; Burton et al 2006). The elemental sulfur so formed can further oxidise to sulfate causing severe acidification of water bodies after several days (Sullivan et al. 2002; Burton et al 2006). This can lead to fish kills, especially in enclosed areas such as aquaculture ponds or estuaries. Hence, MBO is reactive if exposed to oxygen but is harmless if left undisturbed.

Monosulfidic soil materials have the ability to favourably affect surrounding environments by immobilizing potential metal pollutants (e.g. Simpson et al. 1998). This beneficial effect of monosulfides accumulating metal contaminants will continue until the monosulfidic materials are mobilised into oxygenated water bodies by, for example, increased local water flows. When this happens the metal pollutants trapped within monosulfides can be rapidly and effectively mobilised back into the surrounding environments causing acute pollution (Burton et al. 2006). When a drain is cleaned, iron and alumino-sulfate salts (e.g. jarosite and alunite), iron oxyhydroxy-sulfate salts (e.g. schwertmannite) precipitate on the soil surface along the drain edges. These soluble salts dissolve during rain events and contribute to MBO formation, acidity and metal content in drainage waters.

Soil Cracks, Slickensides and Cracking Clay Soils

Soil cracks are features that are difficult to observe because they occur mostly at the soil surface only when the soil is dry and often in soil layers below the surface. Knowledge about soil behaviour during seasonal changes is required to determine if these features exist.

Slickensides: are polished and grooved surfaces that are produced when one soil mass slides past another (Isbell 1996; Soil Survey Staff 2003). Slickensides result directly from the swelling of clay minerals and shear failure. They are common in swelling clays that undergo marked changes in moisture content. All cracking clay soils contain slickensides and crack when dry. In many landscapes across Australia, this group of soil material contains both acid sulfate materials and non–acid sulfate members. Cracking clay soils are characterised by swelling on wetting and shrinking on drying with consequent crack formation. This behaviour is caused by the presence of inter-layered clay minerals such as smectite.

n Value

n Value: characterises the relation between the percentage of water in a soil under field conditions and its percentages of inorganic clay and humus. It is used to predict whether a soil can support loads and what degree of subsidence would occur after drainage. It is defined as $(A - 0.2R)/(L + 3H)$, where A is the percentage field water content, R the percentage of silt plus sand, L the percentage clay and H the percentage of organic matter (or organic carbon × 1.724).

A value of 0.7 or greater indicates that the soil is soft and would subside under a load.

Acid sulfate soil management: Summary of principles

The environmental risk is present because draining river or wetland systems involves the disturbance of material that was not previously in contact with the oxygen in the atmosphere. During the lowering of the watertable or drying of subaqueous soils, sulfidic materials may be exposed and sulfides within the subaqueous soil horizons will begin to oxidise because they are exposed to air. This will produce sulfuric acid and potentially release toxic quantities of iron, aluminium and heavy metals if the soils do not contain sufficient acid neutralising capacity to maintain a sufficiently high pH (above about 5). The acid, aluminium and heavy metals can leach into waterways, kill fish, other aquatic organisms and vegetation, and can even degrade concrete and steel pipes and structures to the point of failure. However, appropriate management of ASS during development can improve discharge water quality, increase agricultural productivity and protect infrastructure and the environment.

Identification and avoidance of ASS materials

Slowing or stopping the rate and extent of pyrite oxidation. This can be achieved either by keeping sulfidic material anaerobic under saturated conditions or by rapid drying of sulfidic material to slow the biological process, which are responsible for the formation of acid.

However, some projects may occur where avoidance is not possible, as such the following management options, in order of preference, include:

1. minimisation of disturbance;

2. prevention of oxidation through strategic reburial (on- and off-site);

3. neutralization; and

4. disposal off-site.

We emphasise that within the above management strategies there is still a degree of risk associated with these techniques, and that some strategies may not be suitable to a particular site. Management strategies other than those listed may be considered provided sufficient information regarding their successful implementation and scientific merit is provided.

In managing risk and selecting preferred management strategies in situations where all relevant approvals have been obtained, it is still the responsibility of the developer/proponent to satisfy that the project be conducted in a manner that will not result in environmental damage.

Retaining existing acidity within the ASS landscape

Acidity and oxidation products that cannot be retained on-site may be managed by other techniques such as acidity barriers or wetlands that intercept and treat contaminated water before it is finally discharged into rivers or estuaries.

Minimisation of disturbance

The amount of ASS requiring excavation and/or dewatering can be minimized through reconsideration of the design for the proposed development. This consideration will relate to an understanding of where exactly, in terms of lateral and depth occurrences, ASS is positioned on the site. Dewatering impacts can more easily be minimized through installation of hydraulic impediments to dewatering such as engineered 'curtains (e.g. shoring), re-injection wells and galleries, infiltration basins, and wet excavations etc.

Strategic reburial

Strategic reburial strategies should be detailed as part of any ASS management plan where this methodology is proposed (whether for on-site or off-site reburial). Further detail is presented in Dear et al. (2002). Essentially, there are two forms of strategic reburial: below the permanent water-table at the floor of a permanent open water body; and buried below the permanent water-table beneath a cap of ASS. A feature of the reburial strategy is that monitoring will be required to ensure that the ASS sediments remain saturated, and water-table levels remain elevated, following ASS placement.

Neutralisation

The most common method of neutralising acidic sediments is the mixing of agricultural lime ($CaCO_3$) with the targeted material. The neutralising requirements of ASS are based on the actual acid produced (total actual acidity or TAA), potential for further production of acid (net acid generation potential or NAGP), and the effective neutralising value of the neutralising agent to be used.

According to ASSMAC (1998), liming rates are calculated based on a 'safety factor' of 1.5 (kg of lime per tonne of soil), which allows for inefficient mixing and the slow reaction rate of agricultural lime. The safety factor of 1.5 is determined through calculating the neutralising value (NV) and effective neutralising value (ENV) of the liming material used. Table 2 of Dear et al. (2002) allows for accurate determination of the liming requirement (LR) of ASS, based on detailed laboratory assessment. Table 1 of Dear et al. (2002) is provided as a lime requirement guide based on soil texture.

In the event that large volumes of ASS are to be disturbed (i.e. Significant or High risk rating), the estimation of liming requirement needs to be calibrated through an Accelerated Weathering Trial. The aim of such trials are to ensure that the liming rate proposed is sufficient to account for variability in S levels in the excavated soil, and variability's in soil reaction rates.

Summary

Selection of management options will depend on the ASS subtype, and their position in the landscape (Table 17). This is why reliable ASS risk maps, at appropriate scales, and characterising ASS landscapes are so important. All management options recommended in this report comply with the above principles.

Table 17. Subtypes of acid sulfate soils and general management options

Soil Type	Soil Subtype	Management options
Subaqueous soils	**Sulfidic** subaqueous clayey soil with MBO **Sulfidic** subaqueous clayey soil **Sulfidic** subaqueous soil	**1&2** Avoid/minimise disturbance
Cracking clay soils	**Sulfidic** cracking clay soil **Sulfidic** cracking clay soil with MBO	**1 & 2** Avoid/minimise disturbance **3** Treat by rapid drying
Sulfidic soils	**Sulfidic** soil **Sulfidic** soil with MBO	**1 & 2** Avoid/minimise disturbance **3** Treat by rapid drying
[1]Sulfuric soils	**Sulfuric** soil **Sulfuric** cracking clay soil	**4** Treat disturbed areas / Minimise further disturbance.

[1] Predicted ASS subtypes when the current Subaqueous, Cracking clay and Sulfidic soil subtypes were drained or disturbed (i.e. when water levels drop in the wetlands).

1. **Avoid** disturbance where tests show **high levels** of **sulfidic** material (This includes avoiding drainage and drying).
2. **Minimise** disturbance where tests show **low levels** of **sulfidic** material (Broad, shallow drains; minimise drying by controlling water table: e.g. flood gate control).
3. **Treat** disturbed or drained area where field observations and laboratory tests show it is possible to dry **sulfidic material** rapidly to slow-down the biological process.
4. **Treat** disturbed area where tests show **sulfuric** material or acid water (Neutralise current/historical disturbance; contain acid; reverse disturbance)

APPENDIX 2: LOCATION AND DESCRIPTION OF SOIL SAMPLES

Table 18. Location of River Murray soil sampling sites downstream of Lock 1 (WGS 84, zone 54 south).

Site Code	GPS Location (Easting, Northing)	
NOO 1.1	369298	6182268
NOO 1.2	369298	6182268
NOO 1.3	369298	6182268
NOO 1.4	369298	6182268
NOO 1.5	369298	6182268
NOO 2.1	369289	6182292
NOO 2.2	369289	6182292
NOO 2.3	369289	6182292
NOO 2.4	369289	6182292
NOO 3.1	369311	6182261
NOO 3.2	369311	6182261
DD1.1	374408	6161194
DD1.2	374408	6161194
DD1.3	374408	6161194
DD1.4	374408	6161194
DD2.1	374458	6161051
DD2.2	374458	6161051
DD2.3	374458	6161051
DD2.4	374458	6161051
DD2.5	374458	6161051
DD3.1	377227	6165219
DD3.2	377227	6165219
DD3.3	377227	6165219
DD4.1	377262	6165200
DD4.2	377262	6165200
DD4.3	377262	6165200
DDS1.1	371758	6161325
DDS1.2	371758	6161325
DDS1.3	371758	6161325
DDS1.4	371758	6161325
DDS2.1	371728	6161336
DDS2.2	371728	6161336
DDS2.3	371728	6161336
DDS2.4	371728	6161336
DDS3.1	371723	6161442

Site Code	GPS Location (Easting, Northing)	
DDS3.2	371723	6161442
DDS3.3	371723	6161442
DDS3.4	371723	6161442
DDS4.1	371697	6161574
DDS4.2	371697	6161574
DDS4.3	371697	6161574
DDS5.1	372574	6161354
DDS5.2	372574	6161354
DDS5.3	372574	6161354
DDS5.4	372574	6161354
KRL 1.1	370068	6159133
KRL 1.2	370068	6159133
KRL 1.3	370068	6159133
KRL 1.4	370068	6159133
KRL 1.5	370068	6159133
KRL 2.1	370073	6159129
KRL 2.2	370073	6159129
KRL 2.3	370073	6159129
KRL 3.1	370344	6158897
KRL 3.2	370344	6158897
KRL 3.3	370344	6158897
KRL 4.1	370363	6158879
KRL 4.2	370363	6158879
KRL 4.3	370363	6158879
KRL 4.4	370363	6158879
KRL 4.5	370363	6158879
NPU 1.1	370419	6144384
NPU 1.2	370419	6144384
NPU 2.1	370421	6144379
NPU 2.2	370421	6144379
NPU 2.3	370421	6144379
NPU 2.4	370421	6144379
NPU 2.5	370421	6144379
NPU 2.6	370421	6144379
NPU 3.1	370441	6144358

Site Code	GPS Location (Easting, Northing)	
NPU 3.2	370441	6144358
NPU 3.3	370441	6144358
NPU 3.4	370441	6144358
NPU 3.5	370441	6144358
NPU 4.1	370441	6144358
NPU 4.2	370441	6144358
NPU 4.3	370441	6144358
NPU 4.4	370441	6144358
NPU 4.5	370441	6144358
LCA 1.1	362267	6140437
LCA 1.2	362267	6140437
LCA 1.3	362267	6140437
LCA 1.4	362267	6140437
LCA 1.5	362267	6140437
LCA 2.1	362280	6140428
LCA 2.2	362280	6140428
LCA 2.3	362280	6140428
LCA 2.4	362280	6140428
LCA 3.1	362266	6140391
LCA 3.2	362266	6140391
LCA 3.3	362266	6140391
UKE 1.1	344545	6111773
UKE 1.2	344545	6111773
UKE 2.1	344544	6111775
UKE 2.2	344544	6111775
UKE 2.3	344544	6111775
UKE 4.1	344540	6111781
UKE 4.2	344540	6111781
UKE 3.1	344455	6111878
UKE 3.2	344455	6111878
UKE 3.3	344455	6111878
UKE 3.4	344455	6111878
UKE 3.5	344455	6111878
UKE 3.6	344455	6111878
UKE 3.7	344455	6111878
UKE 3.8	344455	6111878
UKE 3.9	344455	6111878
UKE 3.10	344455	6111878
UKE 5.1	344415	6111993

Site Code	GPS Location (Easting, Northing)	
UKE 5.2	344415	6111993
UKE 5.3	344415	6111993
UKE 6.1	344424	6111962
UKE 6.2	344424	6111962
UKE 6.3	344424	6111962
UKE 6.4	344424	6111962
SPM 1.1	346521	6109005
SPM 1.2	346521	6109005
SPM 1.3	346521	6109005
SPM 1.4	346521	6109005
SPM 1.5	346521	6109005
SPM 1.6	346521	6109005
SPM 1.7	346521	6109005
SPM 1.8	346521	6109005
SPM 2.1	346436	6109102
SPM 2.2	346436	6109102
SPM 2.3	346428	6109094
SPM 3.1	346428	6109094
SPM 3.2	346428	6109094
SPM 3.3	346428	6109094
WL 1.1	346334	6109016
WL 1.2	346334	6109016
WL 1.3	346334	6109016
WL 1.4	346334	6109016
WL 2.1	346070	6109189
WL 2.2	346070	6109189
WL 2.3	346070	6109189
WL 5.1	346104	6109177
WL 5.2	346104	6109177
WL 5.3	346104	6109177
WL 5.4	346104	6109177
WL 5.5	346104	6109177
WL 5.6	346104	6109177
WL 5.7	346104	6109177
WL 5.8	346104	6109177
WL 5.9	346104	6109177
MUR 1.1	352568	6091006
MUR 1.2	352568	6091006
MUR 1.3	352568	6091006

Site Code	GPS Location (Easting, Northing)	
MUR 2.1	352564	6090525
MUR 2.2	352564	6090525
MUR 2.3	352564	6090525
MUR 2.4	352564	6090525
MUR 3.1	352581	6090527
MUR 3.2	352581	6090527

Table 19. Acid sulfate soil and associated materials collected from River Murray wetlands and lagoons downstream of Lock 1.

Site Code	Depth, cm	ASS material, soil texture and organic matter	Description
NOO 1.1	0-0.05	Sulfidic clayey	White salt coating algal mat.
NOO 1.2	0-3	Sulfidic clayey	Dark grey, self-mulching heavy clay.
NOO 1.3	3-10	Sulfidic clayey	Hard heavy clay with orange coatings in many pores.
NOO 1.4	10-25	Sulfidic clayey	As above, with orange coatings in pores; very hard; dark grey.
NOO 1.5	25-50	Sulfidic clayey	Soft heavy clay. Orange Schwertmannite and some goethite. pH 4.8 - 5. Slickensides.
NOO 2.1	0-0.05	Hyposulfidic clayey	Dark brown mulch/self-mulching clay/MBO material. Crumbs (0.1 - 2 cm). Most have dark brown coatings on surface, but dark grey undersides. Heavy clay. pH 5-6.
NOO 2.2	0-5	Hyposulfidic clayey	Dark grey hard peds. Heavy clay with slickensides. pH 5 - 6.
NOO 2.3	5-30	Hyposulfidic clayey	Dark grey hard peds with slickensides and pores with yellow (goethite) coatings. pH > 6.
NOO 2.4	30-50	Hyposulfidic clayey	Black to very dark grey/olive. Soft with many prominent slickensides.
NOO 3.1	0-5	Hyposulfidic clayey	Dark grey to dark brown, self-mulching, heavy clay. Crumbs are large (1 cm). pH 5 - 5.3 - 6.
NOO 3.2	5-20	Hyposulfidic clayey	Dark grey to black heavy clay, hard with fine pores with mostly yellow (goethite) and some orange. Many slickensides. pH 6.
DD1.1	0-10	Sulfidic sandy	Pale yellowish grey fine sand with 5% orange mottles towards base; slightly loose but firm where mottled; dry; few fine roots; field pH 4.7; irregular sharp boundary to
DD1.2	10-35	None sandy	Grey sandy clay (LC or MC) with 10% orange mottle around root channels; coarse prismatic structure; vertical void planes with sand and orange mottles; moist; field pH 5.8; clear to gradual to
DD1.3	35-50	None sandy	Pale olive grey loamy sand with coarse, diffuse orange mottles; moist; field pH 5.3; continues
DD1.4	50-70	None sandy	As above; field pH 5.0; continues
DD2.1	0-0.2		Surface crust; platy with red oxide upper surface
DD2.2	0-5	Sulfidic clayey	Grey to pale grey (dry) heavy clay; coarse columnar structure breaking to blocky and then to fine polyhedral peds; fine salt crystals on upper parts of vertical ped faces
DD2.3	5-20	Sulfidic clayey	Pale grey heavy clay; common orange mottles on vertical faces of base of columns; damp; abrupt to clear, even change to
DD2.4	20-40	Sulfidic clayey	Black heavy clay; fine granular to polyhedral peds; friable; moist; inclusions of patches of grey heavy clay which is moister, lenticular and have slickensides; abrupt wavy boundary to
DD2.5	40-60	None clayey	Grey heavy clay; lenticular peds with slickensides; moist to wet; continues
DD3.1	0-15	Sulfidic clayey	Pale yellowish grey heavy clay with orange mottles common around root channels; thin, fine sandy surface crust in places; coarse prismatic to columnar structure; very dry and hard; gradual to
DD3.2	15-30	Hyposulfidic clayey	Dark grey heavy clay; orange mottles and fine salt crystals on vertical ped faces changing to pale yellow mottles along root channels below about 20

Site Code	Depth, cm	ASS material, soil texture and organic matter	Description
			cm; coarse prismatic structure.
DD3.3	30-55	None clayey	Dark olive to dark grey heavy clay; black charcoal and dark brownish organic matter concentrations; common soft calcium carbonate in concentrations 3 to 8 mm across; fine polyhedral structure, lenticular in part with slickensides; continues
DD4.1	0-15	Sulfuric sandy	Pale grey fine sand; loose but slightly damp; fine roots with orange mottling; clear to
DD4.2	15-45	Sulfidic sandy	Grey to yellowish grey fine sandy loam or sandy clay loam with coarse, distinct orange mottles; brown mottles along root channels; fine pores; sharp to
DD4.3	45-60	Sulfidic clayey	Dark grey heavy clay with orange to orange red mottles around common root channels; coarse prismatic structure; organic matter accumulations; damp; continues
DDS1.1	0-5	Sulfidic - sandy	Thin +/- 1 cm organic mat, many fine roots; abrupt light grey; light clay; medium blocky; dry and hard; very few fine roots.
DDS1.2	5-10	Sulfidic - sandy	Light to dark grey; medium clay; few fine roots; dry and hard.
DDS1.3	10-40	None clayey	Dark grey; heavy clay; massive with very prominent abrupt slickensides; very few medium roots along slickensides; few soft carbonate zones; moist and hard.
DDS1.4	40-70	None clayey	Black with few greyish olive mottles; heavy clay; prominent, very abundant slickensides; very few medium roots; pockets/zones of carbonate (light brown); moist and slightly sticky.
DDS2.1	0-5	None clayey	Light grey with increasing yellow (10 YR) prominent/discrete mottles; light clay; fine crumbly peds (0.5 - 1 cm diameter.); few fine roots (no medium roots - see paired site); friable to hard, and dry; some salt efflorescence along fine cracks.
DDS2.2	5-10	Hyposulfidic clayey	Black; intermixed with few zones with black matrix with prominent yellow mottles; heavy clay; medium blocky; moist; slightly sticky and pliable.
DDS2.3	10-40	None clayey	Black; heavy clay; prominent large slickensides; few zones of carbonate (brownish); few roots.
DDS2.4	40-60	None clayey	Black matrix with gleyed grey mottles and many carbonate-rich zones; heavy clay; many smaller prominent slickensides; very few fine roots
DDS3.1	0-5	Sulfidic clayey	Very light grey; light to medium clay; self mulching layer that is soft comprising fine and coarse (0.5 - < 2 mm) angular aggregates with white salt efflorescence on ped faces; aggregates hard and dry; no roots.
DDS3.2	5-15	Sulfidic clayey	Dark grey matrix with few dark brownish-red coatings on ped faces (ferrihydrite-rich); heavy clay; very few slickensides (diffuse, not prominent); moist and slightly sticky; no roots (few fossil root holes); few patches of fine carbonate (light brownish).
DDS3.3	15-40	None clayey	Dark greyish-green; heavy clay; massive with few to many slickensides; moderate amount of carbonate pods/patches (light-brown to olive); moist to sticky.
DDS3.4	40-60	None clayey	Dark greyish-green with grey/olive mottle; heavy clay; prominent/distinct slickensides; moderate amounts of carbonate patches (light brown); moist

Site Code	Depth, cm	ASS material, soil texture and organic matter	Description
			and very sticky; no roots.
DDS4.1	0-5	None clayey	Light yellowish-brown; sand; few dead mussels; damp surface weak crust; very loose.
DDS4.2	5-10	None clayey	Greenish-brown matrix with fine distinct orange/yellow streaks along root channels; sand; coherent; moist; many fine roots.
DDS4.3	10-25	None clayey	Black matrix with many very fine orange/brown-reddish streaks along many fossil root pores; many roots (medium and fine) and some large *Phragmites* roots at 25 cm; many shells (whole and fragments).
DDS5.1	0-0.05	None sandy	Dark brownish-black crust; salt efflorescent gypsum; sandy; friable; no roots.
DDS5.2	0.05-15	None sandy	Yellowish-brown with orange/yellow mottles; fine sand; no roots.
DDS5.3	15-30	None sandy	Dark greyish-olive with patches of grey-green; clayey sand to sandy clay loam with few pockets of large clay lenses; moist to wet, and quite sticky.
DDS5.4	30-50	None clayey	Very dark grey with olive mottles; abundant slickensides and "parallelepipeds"; heavy clay; no roots; few patches of carbonate (light brown).
KRL 1.1	0-0.5	Sulfidic clayey	Friable greenish-light grey clay with salts (few) maybe jarosite. pH 4.8.
KRL 1.2	0-10	Sulfidic clayey	Light grey clay, friable with some orange mottles. pH 4.5.
KRL 1.3	10-30	Sulfidic clayey	Light to dark grey with yellow mottles in root channels. pH 4.5.
KRL 1.4	30-50	Sulfidic clayey	Black, hard, heavy clay with bright yellow mottles/streaks. pH 4.8.
KRL 1.5	50-60	Hyposulfidic clayey	Black heavy clay; moist, not quite sticky. Very few yellow mottles/streaks. pH 4.8.
KRL 2.1	0-5	Sulfidic sandy	Sandy with bright orange mottles (Schwertmannite). Dark grey with abundant roots and orange mottles/pores. pH 4.7.
KRL 2.2	5-10	Sulfuric sandy	Light grey with bright orange mottles/pores, sandy. pH 4.4.
KRL 2.3	10-45	Sulfidic clayey	Black with bright orange mottles in pores of roots, mainly Schwertmannite. Abrupt transition. Heavy clay. Dry. pH 4.7.
KRL 3.1	0-5	Sulfidic clayey	Light grey, heavy clay with orange mottles. pH 4.7.
KRL 3.2	5-15	Sulfidic clayey	Light grey, heavy clay with orange mottles in pores. pH 4.7.
KRL 3.3	15-35	Sulfidic clayey	Black matrix with grey mottles and yellowish, many holes from roots. Orange/yellow mottles. pH 5.6.
KRL 4.1	0-5	Sulfidic sandy	Sand, pH 4.7.
KRL 4.2	5-10	Hyposulfidic clayey	Black heavy clay with bright orange coating on pores/mottles. Very hard. pH 5.0.
KRL 4.3	10-25	None clayey	Black heavy clay with very few orange coatings in pores. pH > 6.
KRL 4.4	-	Burnt clay	Burnt (?) clay material scattered on surface.
KRL 4.5	-	Burnt clay	Burnt clay fragment on surface.
NPU 1.1	0-0.5	None sandy	White algal crust; soft friable flakes in places.
NPU 1.2	0-0.05	None sandy	Organic-rich algal mat with white precipitate impregnating on surface.
NPU 2.1	0-3	None sandy	Yellowish sand (fine), crusty with very few fresh white shells (remnant). Many reddish-brown mottles (medium).

Site Code	Depth, cm	ASS material, soil texture and organic matter	Description
NPU 2.2	3-18	None sandy	Yellowish sand (fine) with 40% clay lenses (light clay); dark grey.
NPU 2.3	18-30	None clayey	Dark brown light clay matrix with black sulfidic mottles.
NPU 2.4	30-35	None clayey	Grit layer with blackish-grey mottled clay; carbonate nodules.
NPU 2.5	35-50	None sandy mixed clayey	Blackish/dark grey light clay with few sand lenses. Hard surface layer with brownish clay.
NPU 2.6	50-70	None clayey	Black, sulfidic; light medium clay.
NPU 3.1	0-5	Sulfidic clayey	Flocculated powdery clay filling up large cracks.
NPU 3.2	0-5	Sulfidic clayey	Very hard peds. Light grey with cracks.
NPU 3.3	5-15	None sandy	Soft friable, weakly moist with very fine sand and intermixed with gypsum and carbonate(?). Many relict roots.
NPU 3.4	15-50	Sulfidic clayey	Black heavy clay, sticky, few slickensides.
NPU 3.5	50-70	None clayey	Black, heavy clay, sticky, many slickensides with blue-grey mottles.
NPU 4.1	0-0.05	Sulfuric organic	O horizon with white salt efflorescent; gypsum crystals.
NPU 4.2	1-10	**Sulfuric organic**	O horizon, decomposed/undecomposed leaf matter.
NPU 4.3	10-20	Sulfuric organic and sandy	Organic-rich sandy clay. Very dark brown with decomposed OM.
NPU 4.4	20-35	Sulfuric sandy	Sandy, very fine silty, pH 3.9. Sulfidic horizon/material with few black mottles.
NPU 4.5	35-50	Sulfidic clayey	Black heavy clay, sticky. Also some peds are hard. Sulfidic material.
LCA 1.1	0-5	Sulfidic organic and sandy	Organic-rich, very dark brown. Sandy with 5% black clay lumps.
LCA 1.2	5-15	Hyposulfidic sandy	Sandy yellowish-dark grey with yellow mottles. pH 6.5. Large carbonate?/Fe-stained nodules.
LCA 1.3	15-25	Hyposulfidic clayey	Black heavy clay; very sticky. Sulfidic.
LCA 1.4	25-35	Hyposulfidic clayey	Grey gleyed, heavy clay. Some carbonate (fine). Heavy clay, sticky. pH > 7 - 8.
LCA 1.5	+ 35-	None clayey	Clay, light many abundant nodules and fine. Light grey and gleyed.
LCA 2.1	0-0.02	None clayey	Sandy, dark to light grey with orange mottling. pH 7.
LCA 2.2	2-5	Sulfidic sandy	Very dark grey with orange/yellow/red mottles. Sandy with SCL layer, thin 0.5 cm.
LCA 2.3	5-25	Sulfidic clayey	Black, heavy clay with dark brown patches.
LCA 2.4	25-40	Sulfidic clayey	Black, heavy clay with prominent slickensides. Also blue specs of carbonate (?).
LCA 3.1	0-5	Sulfidic clayey	Brownish gel with some black streaks. N > 3. Sulfidic. Clay with silt feel.
LCA 3.2	5-15	Sulfidic clayey	Black to dark brownish mud/MBO; some dark grey mottles. Heavy clay.
LCA 3.3	15-30	Hyposulfidic clayey	Black, heavy clay with some slickensides. Sulfidic. Also patches of greenish-grey clay. Nodules of carbonate (?).
UKE 1.1	0-10	Sulfidic clayey	Light grey clay (heavy clay), sticky, sulfidic with 20% *Phragmites* roots (fossil); few sandy lenses.
UKE 1.2	10-20	Sulfidic clayey	Dark grey clay (heavy) with n > 2. Sulfidic with 20% of relict *Phragmites*.
UKE 2.1	0-5	Sulfidic clayey organic-rich	Organic, with live roots plus 30% sapric (brown-olive colour). Rest is dark brown. Matrix mostly sandy.
UKE 2.2	5-12	Sulfidic clayey organic-rich	Very dark grey heavy clay with few black sulfidic

Site Code	Depth, cm	ASS material, soil texture and organic matter	Description
			mottles. N > 2. 10 - 15% relict *Phragmites* roots. Sticky.
UKE 2.3	12-20	Sulfidic clayey	Dark grey olive, heavy clay.
UKE 3.1	0-0.05	Sulfuric clayey	Salt efflorescence. pH 3.2.Bright yellow salts on upper edge of ped face. Bright yellow salts in middle of upper ped face. White salts at base of cracks between peds.
UKE 3.2	0.5-1	Sulfuric clayey organic-rich	Black moist plus hard areas; heavy clay. Massive. Very few orange mottles.
UKE 3.3	1-8	Sulfuric clayey organic-rich	Light grey; very hard and dry, heavy clay; massive, very few orange mottles.
UKE 3.4	8-10	Sulfuric clayey organic-rich	Light grey heavy clay (cracked to 1 - 2 cm), with many mottles of orange colour in crack and root pores.
UKE 3.5	12-20	Sulfuric sandy	Sand. Abrupt transition. Moist.
UKE 3.6	20-30	Sulfuric organic-rich	Dark greyish-black light clay with 20% fossil organic matter (peaty) with orange and yellow (jarosite) mottles in root pores.
UKE 3.7	30-50	Sulfuric clayey	Greyish-olive light clay with few mottles. Some bright yellow Na- jarosite mottles in few large root pores at 40 cm.
UKE 3.8	-	Sulfuric clayey organic-rich	Salt efflorescence (white) on sides and bottom of crack. Very thin layer.
UKE 3.9	-	Sulfuric clayey organic-rich	Thin patina / washing of carbonate and Fe-oxide in soil.
UKE 3.10	-	Sulfuric clayey organic-rich	Calcrete nodule in sulfidic horizon (0 - 5) in side of crack.
UKE 4.1	-	Sulfuric sandy	Sand with jarosite mottles.
UKE 4.2	-	Sulfuric clayey	Clay, heavy. Dry and very hard with pores of bright orange / yellow mottles.
UKE 5.1	0-0.05	Sulfuric clayey	Whitish - bright yellow salt efflorescent flakes and salts. Jarosite pH 3.9 - 4.2.
UKE 5.2	0.5-10	Sulfuric clayey	Organic-rich. Light grey peaty / clay with abundant root / plant material (fossil and remnant), much fibric material.
UKE 5.3	10-30	Sulfidic clayey	Black heavy clay. Abrupt transition. At interface abundant orange mottling (Schwertmannite) in pores and fractures especially in pores at depth to 50 cm.
UKE 6.1	0-5	Sulfuric clayey organic-rich	Very hard, dry cracks with bright yellow salt efflorescence. pH 3.6 - 3.9.
UKE 6.2	5-20	Sulfuric clayey	Black heavy clay with very few orange mottles.
UKE 6.3	20-40	Sulfuric clayey	Black heavy clay with many orange mottles in pores/cracks.
UKE 6.4	0-0.5	Sulfuric clayey organic-rich	Salt efflorescence, whitish-yellow, jarosite and gypsum.
SPM 1.1	0-0.02	Sulfuric clayey organic-rich	Yellow-white salt efflorescence. Very thin crust, which flakes. Mostly in centre of pad.
SPM 1.2	0-5	Sulfuric clayey organic-rich	Hard to friable; greyish-yellow with yellow mottles. Surface horizon. Sandy/silty clay loam.
SPM 1.3	5-10	Sulfuric clayey organic-rich	Sandy/silty loam. Hard to friable brownish with grey mottles and reddish-brown streaks. Massive. Very porous when dry. Many fine roots and decomposed organic matter.
SPM 1.4	10-20	Sulfuric clayey organic-rich	Very heavy clay/silty. Moist but friable. Dark brownish with few grey mottles; abundant reddish-brown streaks. 20% decomposed organic matter.
SPM 1.5	20-35	Sulfuric clayey	Dark brown with many reddish-orange mottles and streaks along decomposed root holes. 20%

Site Code	Depth, cm	ASS material, soil texture and organic matter	Description
			decomposed organic matter. Heavy clay.
SPM 1.6	35-50	Sulfuric clayey	Black with brown mottles. Heavy clay, few organic and roots.
SPM 1.7	50-90	Sulfuric clayey	Black with very fine greyish-white mottles. Very few roots and decomposed organic matter fragments. Heavy clay.
SPM 1.8	90-140	Sulfuric clayey	Black with bluish-green mottles. Pockets of fossil *Phragmites* remnant roots (many). Heavy clay. EC > 2 dS/m in water at 120 - 140 cm. Very sticky, n > 2.1.
SPM 2.1	0-5	Sulfuric clayey organic-rich	Dark grey, heavy organic clay. White salts on crack face.
SPM 2.2	5-10	Sulfuric clayey organic-rich	Dark grey, heavy clay. Massive, very hard. Abundant orange mottles along root voids. Fibrous vegetation matter present.
SPM 2.3	10-20	Sulfuric clayey	Dark grey heavy clay, massive, orange mottles on faces.
SPM 3.1	0-5	Sulfuric clayey organic-rich	Peaty clay, white salts present
SPM 3.2	5-10	Sulfuric clayey organic-rich	Dark grey heavy clay, grey orange mottles along root voids, few. Lower bulk density than SMP 2. Few fine roots.
SPM 3.3	10-20	Sulfuric clayey	Dark grey heavy clay, grey orange mottles along root voids, few. Lower bulk density than SMP 2. Few fine roots, decomposing vegetation present.
WL 1.1	0-10	Sulfidic sandy	Grey sandy clay, soft, abrupt to
WL 1.2	10-30	Sulfidic clayey	Grey clay, small black mottles.
WL 1.3	30-50	Sulfidic clayey	As above but with thin sandy layers; many fine, decomposing roots (reeds).
WL 1.4	50-70	Sulfidic clayey	as above; many decomposing reed roots.
WL 2.1	0-5	Sulfidic sandy	Grey sandy clay; top 1 cm algal mat; small fragments of calcrete; abrupt to
WL 2.2	5-25	Sulfidic clayey	Very dark grey heavy clay, black mottles; highly organic; orange mottles along old root channels; polyhedral structure (1 - 2 cm); probable old cracks filled with pale grey sand.
WL 2.3	25-40	Sulfidic clayey	Dark bluish grey heavy clay.
WL 5.1	Crust	Sulfuric clayey organic-rich	Efflorescence, see chip tray.
WL 5.2	Crust	Sulfuric clayey organic-rich	Efflorescence, see chip tray.
WL 5.3	0-1	Sulfuric clayey organic-rich	Crust containing efflorescence and organic material.
WL 5.4	1-5	Sulfuric clayey organic-rich	Brown organic loam, sapric, charcoal(?), common fine roots.
WL 5.5	5-20	Sulfuric clayey organic-rich	Very dark brownish grey silty loam; pockets of sapric organic matter; mottled in top 5 cm.
WL 5.6	20-50	Sulfidic clayey	At water table; probably heavy clay, but saturated and soft; vertical cracks coated with orange brown sapric organic matter.
WL 5.7	50-70	Sulfidic clayey	Light grey heavy clay; vertical crack faces coated with organic matter and roots; also similar horizontal surfaces; very organic patches about 3 to 5 cm across.
WL 5.8	70-90	Sulfidic clayey	Grey heavy clay; root channels (5 mm) mottled orange brown throughout; some black mottles
WL 5.9	90-110	Sulfidic clayey	Black heavy clay; sulfidic (strong0; much decomposing reed roots.
MUR 1.1	0-30	Sulfuric organic	100% organic (fibric) with some localised areas of sapric material.
MUR 1.2	30-40	Sulfidic clayey and organic	Very dark brown with 50% organic intermixed with

Site Code	Depth, cm	ASS material, soil texture and organic matter	Description
			50% heavy clay, strongly mixed with many live roots and fossil.
MUR 1.3	40-70	Sulfuric organic	Black to very dark brown heavy clay with few slickensides. Also in places along fractures and organic-rich zones are thin coatings of reddish-brown ferrihydrite; very distinct and prominent in black matrix.
MUR 2.1	0-5	Sulfuric organic and sandy	pH 4.7. Organic light grey (when dry) with sand.
MUR 2.2	5-10	Sulfidic clayey	Black heavy clay, very dense clay; moist almost dry, crumbly in places. With sand.
MUR 2.3	10-45	Sulfidic clayey	Black very heavy clay, very dense, moist, n > 0.8.
MUR 2.4	45-70	Sulfidic organic	Very dark brown to blackish sulfidic with relict *Typha* and *Phragmites* roots and organic (sapric, black zone). 30% sapric material, strongly decomposed organic matter.
MUR 3.1	0-15	Sulfidic clayey	Black heavy clay, very sticky, n > 2. Approx 10% fossil reed root material.
MUR 3.2	15-30	Sulfidic organic	Olive greenish sulfidic organic-rich clay (30%) with abundant fossil reed roots (*Phragmites* and *Typha*).

APPENDIX 3: PH IN WATER, PH IN HYDROGEN PREOXIDE, PH AFTER AGEINING FOR 8 WEEKS AND SELECTED SULFUR–BASED ACIDITY AND ACID NEUTRALISING CAPACITY ANALYSES

Table 20. pH of soil samples from nine wetlands measured in water, hydrogen peroxide and after ageing for 8 weeks

Sample No	Upper Depth	Lower Depth	pH water	pH $_{Fox\ or\ peroxide}$	pH Ageing
NOO 1.1			5.2	3.3	5
NOO 1.2	0	3	5.5	3.3	4.4
NOO 1.3	3	10	4.7	3.3	4.4
NOO 1.4	10	25	5.1	3.5	4.7
NOO 1.5	25	50	5.3	3.7	4.7
NOO 2.1	0	0.1	6.8	4.7	5.8
NOO 2.2	0	5	7.0	4.9	5.8
NOO 2.3	5	30	5.9	4.6	4.7
NOO 2.4	30	50	6.1	4.6	4.7
NOO 2.3/4		Slickensides	5.6	4.4	4.7
NOO 3.1	0	5	5.8	2.2	4.7
NOO 3.2	5	20	6.5	4.3	5.8
DD 1.1	0	10	5.1	2.9	7
DD 1.2	10	35	8.4	8.3	8
DD 1.3	35	50	8.5	8.7	8
DD 1.4	50	70	8.2	8.5	8
DD 2.1					5.5
DD 2.2	0	5	5.7	2.4	4.4
DD 2.3	5	20	4.8	2.1	2.5
DD 2.4	20	40	7.0	3.8	4.7
DD 2.5	40	60	7.4	7.2	4.7
DD 3.1	0	15	5.3	2.8	4.4
DD 3.2	15	35	6.8	4.5	4.7
DD 3.3	35	55	7.7	7.7	6.1
DD 4.1	0	15	4.1	2.0	4.2
DD 4.2	15	45	4.5	2.2	4.2
DD 4.3	45	60	5.4	3.8	4.7
DDS 1.1	0	5	5.6	3.4	8
DDS 1.2	5	10	6.3	3.7	4.7
DDS 1.3	10	40	7.2	6.3	4.7
DDS 1.4	40	70	7.5	7.6	5
DDS 2.1	0	5	7.3	5.6	6
DDS 2.2	5	10	6.8	4.5	4.7
DDS 2.3	10	40	6.8	7.2	6.1
DDS 2.4	40	50	7.6	7.6	7

Sample No	Upper Depth	Lower Depth	pH water	pH Fox or peroxide	pH Ageing
DDS 3.1	0	5	5.3	3.3	7
DDS 3.2	5	15	6.0	4.0	4.7
DDS 3.3	15	40	6.9	6.3	5
DDS 3.4	40	60	7.0	7.0	5
DDS 4.1	0	5	7.5	6.5	7
DDS 4.2	5	10	7.8	6.8	7
DDS 4.3	10	25	7.7	6.1	7
DDS 5.1	0	0.5	7.5	6.1	7
DDS 5.2	0.5	15	7.9	7.5	7
DDS 5.3	15	30	7.9	7.5	7
DDS 5.4	30	50	7.8	7.7	7
KRL 1.1	0	0.5	6.3	3.1	5
KRL 1.2	0	10	4.7	2.2	4.2
KRL 1.3	10	30	5.0	2.8	4.7
KRL 1.4	30	50	6.6	4.2	4.7
KRL 1.5	50	60	7.2	6.2	4.7
KRL 2.1	0	5	4.9	2.0	4.4
KRL 2.2	5	10	4.1	1.9	3.9
KRL 2.3	10	45	6.3	4.0	4.7
KRL 3.1	0	5	4.6	2.8	4.4
KRL 3.2	5	15	4.6	2.4	3.9
KRL 3.3	15	35	7.4	6.9	4.7
KRL 4.1	0	0.5	5.7	2.9	4.4
KRL 4.2	5	10	5.2	4.4	4.7
KRL 4.3	10	25	7.0	7.6	4.7
LCA 1.1	0	5	6.2	2.9	4.7
LCA 1.2	5	15	7.5	4.4	5.5
LCA 1.3	15	25	7.2	5.0	6.1
LCA 1.4	25	35	7.5	6.7	7
LCA 2.1	0	0.2	8.6	7.7	7
LCA 2.2	0.2	5	3.8	1.7	2.5
LCA 2.3	5	25	7.5	2.9	3.9
LCA 2.4	25	30	8.6	7.2	7
LCA 3.1	0	5	6.3	3.2	4.4
LCA 3.2	5	15	5.4	2.8	3.6
LCA 3.3	15	30	5.8	4.9	3.9
NPU 2.1	0	3	7.5	6.8	7
NPU 2.2	3	18	7.7	6.7	7
NPU 2.3	18	30	7.3	6.4	7
NPU 2.4	30	35	7.7	7.3	6.5
NPU 2.5	35	50	7.7	6.9	6.5
NPU 2.6	50		7.8	6.7	6.5
NPU 3.1	0	5	7.0	2.9	6.5
NPU 3.2			6.7	2.9	6.5
NPU 3.3	5	15	7.5	6.3	6.5
NPU 3.4	15	50	7.7	4.0	5
NPU 3.5	50	70	8.0	6.1	6
NPU 4.1					3.9

Sample No	Upper Depth	Lower Depth	pH water	pH Fox or peroxide	pH Ageing
NPU 4.2		10	3.4	1.5	3.9
NPU 4.3	10	20	3.0	1.4	2.5
NPU 4.4	20	35	3.5	1.5	2.5
UKE 1.1	0	10	6.5	1.6	2.5
UKE 1.2	10	20	5.4	1.6	2.5
UKE 2.1	0	5	6.5	2.9	4.7
UKE 2.2	5	12	6.3	1.7	<2.5
UKE 3.1	0	0.5	3.4	1.6	3
UKE 3.2	0.5	1	2.8	1.4	<2.5
UKE 3.3	1	8	2.6	1.2	<2.5
UKE 3.4	8	12	3.5	1.8	3.3
UKE 3.5	12	20	4.0	2.3	3.9
UKE 3.6	20	30	3.9	1.6	<2.5
UKE 3.7	30	50	5.0	2.4	4.2
UKE 5.1	0	0.5	3.1	1.3	<2.5
UKE 5.2	0.5	10	3.0	1.4	<2.5
UKE 5.3	10	30	6.0	3.2	4.5
UKE 6.1	0	5	2.7	1.5	<2.5
UKE 6.2	5	20	3.0	1.4	<2.5
UKE 6.3	20	40	6.9	5.0	5
SPM 1.1	0		3.1	12	<2.5
SPM 1.2	0	5	2.9	1.3	<2.5
SPM 1.3	5	10	3.3	1.3	<2.5
SPM 1.4	10	20	4.0	2.0	<2.5
SPM 2.1	0	5			<2.5
SPM 2.2	5	10			<2.5
SPM 2.3	10	20			<2.5
SPM 3.1	0	5			<2.5
SPM 3.2	5	10			<2.5
SPM 3.3	10	20			<2.5
WL 1.1	0	10	6.7	1.8	
WL 1.2	10	30	7.0	2.6	
WL 1.3	30	50	6.9	2.3	
WL 1.4	50	70	6.7	2.2	
WL 2.1	0	5	7.15	2.13	
WL 2.2	5	25	6.84	3.21	
WL 2.3	25	40	7.52	6.54	
WL 5.3	0	1	2.54	1.02	
WL 5.4	1	5	2.65	1.51	
WL 5.5	5	20	2.75	1.21	
WL 5.6	20	50	3.8	1.7	
WL 5.7	50	70	5.2	2.2	
WL 5.9	90	110	6.1	2.3	
MUR 1.1	0	30	4.5		4.5
MUR 1.2	30	40	4.0	1.5	3.6
MUR 1.3	40	70	5.1	1.5	4.2
MUR 2.1	0	5	6.1	2.7	4.5
MUR 2.2	5	10	5.0	2.6	3

Sample No	Upper Depth	Lower Depth	pH water	pH Fox or peroxide	pH Ageing
MUR 2.3	10	45	5.5	2.5	3.9
MUR 2.4	45	70	4.9	2.3	4.5
MUR 3.1	0	15	6.4	1.2	4.2
MUR 3.2	15	30	5.5	2.7	<2.5

Table 21. Selected sulfur–based acidity and acid neutralising capacity analyses and calculations. See footnotes for explanations. Analyses provided by Environment Analysis Laboratory, Southern Cross University.

Sample No	Texture Class [a]	pH_{kcl} [b]	S_{cr} [c]	$CaCO_3$ [d]	Net Acidity mole H^+/tonne [e]	Lime Calculation [f] kg $CaCO_3$ /tonne DW
NOO 1.1	Medium	4.82	0.013	0.00	31	2
NOO 1.2	Fine	4.95	0.022	0.00	29	2
NOO 1.3	Fine	4.45	0.018	0.00	41	3
NOO 1.4	Fine	4.71	0.017	0.00	34	3
NOO 1.5	Fine	4.53	0.027	0.00	48	4
NOO 2.1	Fine	5.65	0.037	0.56	-45	-3
NOO 2.2	Fine	6.18	0.029	0.62	-63	-5
NOO 2.3	Fine	4.83	0.011	0.00	28	2
NOO 2.4	Fine	4.81	0.011	0.00	26	2
NOO 3.1	Fine	4.86	0.009	0.00	25	2
NOO 3.2	Fine	5.2	0.007	0.00	18	1
DD1.1	Coarse	6.12	<0.005	0.09	-11	-1
DD1.2	Medium	8.11	<0.005	2.59	-345	-26
DD1.3	Medium	8.51	0.005	0.05	-4	0
DD1.4	Medium	8.48	<0.005	0.66	-87	-7
DD2.1						
DD2.2	Fine	5.69	0.128	0.00	92	7
DD2.3	Fine	4.38	0.210	0.00	229	17
DD2.4	Fine	5.68	0.057	0.48	-17	-1
DD2.5	Fine	5.77	<0.005	0.00	10	1
DD3.1	Fine	4.98	0.006	0.00	21	2
DD3.2	Medium	5.90	0.006	0.00	9	1
DD3.3	Medium	6.26	<0.005	0.00	2	0
DD4.1	Coarse	4.63	<0.005	0.00	9	1
DD4.2	Medium	4.12	<0.005	0.00	32	2
DD4.3	Fine	6.27	0.017	0.00	12	1
DDS1.1	Medium	4.83	0.021	0.13	12.78	0.96
DDS1.2	Medium	5.86	<0.005	0.61	-75.25	-5.65
DDS1.3	Fine	6.05	0.016	0.71	-84.59	-6.35
DDS1.4	Fine	6.74	0.010	0.96	-121.64	-9.13
DDS2.1	Medium	7.18	0.011	1.12	-142.32	-10.68
DDS2.2	Fine	6.03	0.011	0.60	-72.06	-5.41
DDS2.3	Fine	5.90	<0.005	0.75	-96.90	-7.27
DDS2.4	Fine	6.33	0.009	0.99	-126.25	-9.48
DDS3.1	Coarse	7.37	0.081	2.87	-331.76	-24.91
DDS3.2	Fine	5.85	0.011	0.60	-68.06	-5.11
DDS3.3	Fine	5.98	0.009	0.60	-71.31	-5.35
DDS3.4	Medium	5.97	<0.005	0.67	-86.24	-6.47
DDS4.1	Coarse	8.23	0.020	22.33	-2961.88	-222.36
DDS4.2	Coarse	8.28	0.012	25.98	-3453.05	-259.24
DDS4.3	Medium	7.55	0.024	10.68	-1407.61	-105.68
DDS5.1	Coarse	7.96	0.019	0.66	-76.06	-5.71
DDS5.2	Medium	7.17	0.007	0.20	-22.27	-1.67
DDS5.3	Medium	6.88	<0.005	0.24	-31.97	-2.40
DDS5.4	Medium	6.43	0.013	0.44	-41.50	-3.12
KRL 1.1	Medium	5.84	0.016	0.34	-29	-2
KRL 1.2	Medium	4.67	0.015	0.00	26	2
KRL 1.3	Medium	5.41	0.012	0.00	19	1
KRL 1.4	Fine	5.89	0.011	0.00	14	1

Sample No	Texture Class [a]	pH_{kcl} [b]	S_{cr} [c]	$CaCO_3$ [d]	Net Acidity mole H^+/tonne [e]	Lime Calculation [f] kg $CaCO_3$ /tonne DW
KRL 1.5	Fine	6.03	0.010	0.70	-82	-6
KRL 2.1	Medium	5.09	0.020	0.00	24	2
KRL 2.2	Medium	4.49	0.028	0.00	37	3
KRL 2.3	Fine	5.61	0.035	0.41	-23	-2
KRL 3.1	Medium	4.70	0.036	0.00	44	3
KRL 3.2	Medium	4.72	0.026	0.00	33	2
KRL 3.3	Medium	5.99	0.025	0.00	20	2
KRL 4.1	Medium	5.08	0.021	0.00	20	2
KRL 4.2	Medium	5.46	0.022	0.69	-71	-5
KRL 4.3	Medium	5.58	0.021	0.72	-75	-6
NPU 1.1						
NPU 1.2						
NPU 2.1	Medium	8.63	<0.005	6.03	-803	-60
NPU 2.2	Medium	8.58	<0.005	6.33	-843	-63
NPU 2.3	Medium	8.32	0.009	7.94	-1052	-79
NPU 2.4	Medium	8.62	0.026	23.31	-3089	-232
NPU 2.5	Fine	8.50	0.016	16.14	-2140	-161
NPU 2.6	Fine	8.20	0.023	6.24	-817	-61
NPU 3.1	Medium	7.16	0.192	0.69	28	2
NPU 3.2	Coarse	7.21	0.225	1.11	-8	-1
NPU 3.3	Medium	8.16	0.069	2.25	-257	-19
NPU 3.4	Fine	6.66	0.081	0.74	-48	-4
NPU 3.5	Fine	6.81	0.031	0.91	-102	-8
NPU 4.1	Medium	3.85	0.029	0.00	75	6
NPU 4.2						
NPU 4.3	Fine	3.38	0.032	0.00	204	15
NPU 4.4						
NPU 4.5	Fine	5.64	0.015	0.51	-49	-4
LCA 1.1	Fine	5.22	0.016	0.00	22	2
LCA 1.2	Medium	8.58	0.012	0.68	-83	-6
LCA 1.3	Fine	7.74	0.023	0.89	-104	-8
LCA 1.4	Fine	8.46	0.049	1.87	-219	-16
LCA 1.5						
LCA 2.1	Medium	9.13	0.006	0.94	-121	-9
LCA 2.2	Medium	5.59	0.056	0.05	30	2
LCA 2.3	Fine	6.59	0.237	0.95	21	2
LCA 2.4	Fine	7.14	0.198	1.16	-31	-2
LCA 3.1	Fine	6.05	0.108	0.50	4	0
LCA 3.2	Fine	5.73	0.479	0.45	247	19
LCA 3.3	Fine	6.22	0.367	0.62	148	11
UKE 1.1		4.64	0.051	<0.05	59	4
UKE 1.2		5.32	0.073	<0.05	59	4
UKE 2.1		5.63	0.120	<0.05	83	6
UKE 2.2		5.25	0.273	<0.05	188	14
UKE 2.3						
UKE 3.1		3.71	0.105	<0.05	736	55
UKE 3.2		3.11	0.241	<0.05	852	64
UKE 3.3		2.76	0.034	<0.05	473	36
UKE 3.4		3.46	0.222	<0.05	321	24
UKE 3.5		4.61	0.590	<0.05	379	28
UKE 3.6		4.57	0.092	<0.05	114	9
UKE 3.7		5.42	<0.005	<0.05	7	1
UKE 3.8						

Sample No	Texture Class [a]	pH_{kcl} [b]	S_{cr} [c]	$CaCO_3$ [d]	Net Acidity mole H^+/tonne [e]	Lime Calculation [f] kg $CaCO_3$ /tonne DW
UKE 3.9						
UKE 3.10						
UKE 4.1						
UKE 4.2						
UKE 5.1		3.33	0.010	<0.05	189	14
UKE 5.2		3.11	0.045	<0.05	281	21
UKE 5.3		5.56	0.009	<0.05	19	1
UKE 6.1		3.02	0.170	<0.05	481	36
UKE 6.2		3.52	0.518	<0.05	525	39
UKE 6.3		5.62	0.117	<0.05	81	6
UKE 6.4						
SPM 1.1						
SPM 1.2		3.35	0.076	<0.05	270	20
SPM 1.3		3.29	0.052	<0.05	243	18
SPM 1.4		3.63	0.015	<0.05	151	11
SPM 1.5		4.63	0.022	<0.05	49	4
SPM 1.6		4.93	0.006	<0.05	35	3
SPM 1.7		5.16	0.015	<0.05	25	2
SPM 1.8		5.30	0.017	<0.05	26	2
SPM 2.1						
SPM 2.2						
SPM 2.3						
SPM 3.1						
SPM 3.2						
SPM 3.13						
WL 1.1	Medium	5.52	0.086	0.00	59	4
WL 1.2	Medium	5.19	0.024	0.00	28	2
WL 1.3	Coarse	5.63	0.028	0.00	24	2
WL 1.4	Medium	5.39	0.096	0.00	68	5
WL 2.1	Coarse	5.65	0.046		34	3
WL 2.2	Fine	6.50	0.043	0.01	25	2
WL 2.3	Medium	7.41	0.047	0.40	-24	-2
WL 5.1						
WL 5.2						
WL 5.3	Medium	3.24	0.069	0.00	352	26
WL 5.4	Medium	3.24	0.054	0.00	254	19
WL 5.5	Medium	3.33	0.180	0.00	324	24
WL 5.6	Medium	3.80	0.044	0.00	181	14
WL 5.7	Fine	4.56	0.043	0.00	64	5
WL 5.8	Fine	5.02	0.029	0.00	40	3
WL 5.9						
MUR 1.1		4.49	0.130	<0.05	374	28
MUR 1.2		4.21	0.067	<0.05	201	15
MUR 1.3		4.77	0.013	<0.05	164	12
MUR 2.1		5.12	0.031	<0.05	83	6
MUR 2.2		4.23	0.015	<0.05	40	3
MUR 2.3		5.24	0.041	<0.05	106	8
MUR 2.4		5.07	1.373	<0.05	905	68
MUR 3.1		5.58	0.067	<0.05	63	5
MUR 3.2		4.38	1.385	<0.05	975	73

[a] Texture Class: coarse = sands to loamy sands; medium = sandy loams to light clays; fine = medium to heavy clays and silty clay

[b] pH_{kcl} : pH measured in 1M KCl. Samples with pH values greater then 6.5 have no residual acidity.

[c] Reduced Inorganic sulfur (% chromium reducible S; S_{cr}). This measures the reduced sulfur in the sample that potentially can oxidise to sulfuric acid. Classification is as potential acid sulfate material if: coarse $S_{cr} \geq 0.03\%$ or 19 mole H^+/t; medium $S_{cr} \geq 0.06\%$S or 37 mole H^+/t; fine $S_{cr} \geq 0.1\%$S or 62 mole H^+/t).

[d] % ANC: This is termed acid neutralising capacity (ANC) and is presented as $CaCO_3$ equivalents.

[e] This is based on potential acidity derived from % S_{cr}.

[f] Lime needed to neutralise acidity, based on net acidity/alkalinity. Includes a 1.5 times safety factor. Negative values have sufficient excess ANC and should not need additional lime.

APPENDIX 4: CONCENTRATIONS OF MINOR ELEMENTS

Table 22. Concentrations of minor elements in samples from nine wetlands – elements Ag to Nd. Detection limits vary with sample and counting time.

Element	Ag	As	Ba	Bi	Br	Cd	Ce	Co	Cr	Cs	Cu	Ga	Ge	Hf	Hg	I	La	Mn	Mo	Nb	Nd
	Concentration (ppm)																				
Lower detection limit (ppm)	**2**	**1**	**12**	**3**	**1**	**3**	**15**	**5**	**3**	**7**	**1**	**1**	**1**	**7**	**11**	**6**	**13**	**7**	**1**	**1**	**9**
NOO1.1	<2	11	353	<3	8	<3	60	17	70	10	34	21	3	<7	<11	11	28	672	<1	17	37
NOO1.2	<2	10	330	3	<1	<3	60	20	71	14	32	21	4	<7	<11	<6	33	405	<1	16	35
NOO1.3	<2	11	340	<3	3	<3	67	25	74	12	33	20	3	<7	<11	6	34	490	1	17	33
NOO1.4	<2	11	360	4	<1	<3	60	15	79	12	39	23	3	<7	<11	<6	28	516	1	17	33
NOO1.5	<2	10	348	4	1	<3	75	20	74	16	37	20	3	<7	<11	6	38	425	<1	16	35
NOO2.1	<2	9	326	<3	1	<3	58	17	71	11	36	19	3	<7	<11	<6	27	415	<1	15	32
NOO2.2	<2	10	331	3	2	<3	67	17	73	17	35	19	3	7	<11	<6	28	421	<1	15	33
NOO2.3	<2	8	363	<3	<1	<3	72	20	78	15	39	23	4	9	<11	<6	24	515	<1	16	41
NOO2.4	<2	11	348	3	<1	<3	75	14	74	10	39	20	3	8	<11	<6	35	422	<1	15	38
NOO3.1	<2	10	350	3	7	<3	58	18	72	8	34	20	3	<7	<11	6	24	369	<1	16	31
NOO3.2	<2	8	321	<3	1	<3	62	17	76	12	35	21	3	8	<11	<6	34	363	1	16	37
DD 1.1	<3	4	289	2	0	1	17	8	13	7	2	4	2	3	25	4	11	77	<1	5	6
DD 1.2	<3	5	349	1	1	1	36	11	39	20	8	7	2	9	24	3	27	240	0	9	19
DD 1.3	<3	7	339	<3	<1	0	39	20	22	11	3	7	3	12	23	6	2	159	<1	7	14
DD 1.4	<3	10	329	0	<1	3	31	31	21	4	4	6	3	9	41	9	21	151	<1	7	16
DD 2.2	<3	10	322	2	10	0	68	18	61	10	27	15	3	7	26	7	34	297	0	16	29
DD 2.3	<3	9	291	1	13	<3	62	17	61	8	28	18	3	6	26	2	37	388	0	15	38
DD 2.4	<3	15	299	2	10	1	69	20	66	8	32	19	3	6	24	5	38	298	1	15	31
DD 2.5	<3	7	282	<3	6	2	56	13	67	8	33	20	2	4	27	2	34	256	<1	12	22
DD 3.1	<3	8	340	1	7	2	68	17	50	13	18	12	3	10	25	10	25	267	0	15	30
DD 3.2	<3	9	388	<3	8	1	62	27	64	11	31	17	3	8	20	7	35	590	0	16	30
DD 3.3	<3	8	430	1	9	1	64	33	63	16	30	18	4	6	28	9	39	1078	<1	17	30

Element	Ag	As	Ba	Bi	Br	Cd	Ce	Co	Cr	Cs	Cu	Ga	Ge	Hf	Hg	I	La	Mn	Mo	Nb	Nd
	Concentration (ppm)																				
Lower detection limit (ppm)	**2**	**1**	**12**	**3**	**1**	**3**	**15**	**5**	**3**	**7**	**1**	**1**	**1**	**7**	**11**	**6**	**13**	**7**	**1**	**1**	**9**
DD 4.1	<3	5	291	2	13	2	37	16	24	5	6	7	4	11	32	6	19	144	1	10	13
DD 4.2	<3	6	330	1	8	1	42	15	36	16	10	8	2	9	19	8	24	172	1	12	14
DD 4.3	<3	6	323	2	12	<3	75	19	59	16	37	15	2	9	27	0	22	351	0	17	35
DDS 1.1	<3	12	308	2	79	0	57	16	51	10	23	14	4	9	31	31	27	282	0	14	24
DDS 1.2	<3	6	328	<3	38	2	52	13	51	12	19	12	2	10	18	5	19	251	<1	14	27
DDS 1.3	<3	11	356	1	29	3	68	24	71	4	34	22	3	6	19	8	34	850	0	15	31
DDS 1.4	<3	11	485	3	35	2	68	25	73	12	34	20	2	7	21	24	37	1670	1	16	34
DDS 2.1	<3	8	338	1	23	1	59	11	49	5	20	13	2	8	21	7	31	361	0	14	25
DDS 2.2	<3	10	342	1	26	<3	52	15	60	10	25	17	3	10	20	<7	27	343	<1	15	30
DDS 2.3	<3	12	313	2	21	1	73	22	69	14	34	17	3	7	21	10	33	803	0	14	36
DDS 2.4	<3	9	344	0	24	1	80	17	73	11	29	23	4	10	31	18	36	805	0	17	35
DDS 3.1	<3	11	343	3	18	3	67	23	59	10	24	16	3	6	18	15	34	740	<1	15	31
DDS 3.2	<3	8	346	3	35	<3	60	19	64	13	28	18	3	6	24	10	29	347	0	15	34
DDS 3.3	<3	9	311	1	26	<3	54	18	67	12	31	17	3	8	19	5	20	337	1	14	32
DDS 3.4	<3	10	304	<3	31	1	59	31	66	16	32	20	4	8	24	15	32	949	2	15	31
DDS 4.1	<3	8	144	0	10	1	26	37	15	14	2	1	1	6	21	8	6	164	<1	6	11
DDS 4.2	<3	8	157	<3	8	<3	27	28	15	12	1	2	2	1	27	<7	12	139	<1	4	9
DDS 4.3	<3	7	263	1	20	1	50	12	49	12	18	10	3	7	27	9	33	225	<1	9	26
DDS 5.1	<3	5	200	<3	209	<3	15	14	15	6	4	3	2	8	20	4	7	128	<1	7	6
DDS 5.2	<3	4	284	2	32	1	27	21	20	12	2	5	2	8	24	3	11	74	1	7	14
DDS 5.3	<3	4	256	1	8	1	28	14	29	14	5	6	3	8	19	9	22	103	1	8	13
DDS 5.4	<3	6	242	2	12	2	41	19	42	7	17	11	3	4	25	34	16	150	<1	10	18
KRL1.1	<2	8	333	5	6	<2	50	23	42	15	16	8	2	9	19	5	32	264	1	15	27
KRL1.2	<2	8	347	2	10	1	55	13	42	11	19	10	2	13	14	7	30	307	0	14	21
KRL1.3	<2	8	348	3	8	<2	56	19	53	12	23	13	3	7	19	7	22	316	0	16	29
KRL1.4	<2	7	334	2	10	0	70	13	63	14	27	15	2	6	18	4	27	258	<1	15	35
KRL1.5	<2	9	301	3	18	0	56	18	65	13	33	18	3	6	28	8	29	291	<1	15	31

Element	Ag	As	Ba	Bi	Br	Cd	Ce	Co	Cr	Cs	Cu	Ga	Ge	Hf	Hg	I	La	Mn	Mo	Nb	Nd
	Concentration (ppm)																				
Lower detection limit (ppm)	**2**	**1**	**12**	**3**	**1**	**3**	**15**	**5**	**3**	**7**	**1**	**1**	**1**	**7**	**11**	**6**	**13**	**7**	**1**	**1**	**9**
KRL2.1	<2	7	318	2	13	1	42	25	27	4	11	6	2	11	18	12	23	253	1	9	19
KRL2.2	<2	7	330	0	10	0	38	44	19	11	11	5	3	7	23	6	19	160	1	8	19
KRL2.3	<2	8	309	2	13	1	69	15	56	16	26	14	2	8	17	1	24	213	<1	15	32
KRL3.1	<2	8	336	2	14	<2	56	17	46	10	17	11	2	12	16	8	39	283	2	15	27
KRL3.2	<2	7	347	3	6	2	63	16	42	5	14	10	3	9	18	3	30	249	<1	14	31
KRL3.3	<2	7	353	2	10	<2	54	23	61	12	28	16	2	11	18	6	25	313	0	15	30
KRL4.1	<2	6	294	1	3	1	46	35	28	3	6	7	3	9	27	6	33	160	2	9	19
KRL4.2	<2	10	446	5	12	<2	61	25	68	13	38	20	3	5	26	19	33	642	0	17	36
KRL4.3	<2	9	383	3	8	<2	61	15	73	16	33	20	3	6	18	15	22	761	0	18	39
NPU2.1	<2	17	203	3	9	<2	14	25	12	2	3	3	2	3	20	7	3	108	<1	5	9
NPU2.2	<2	20	233	2	5	1	21	20	14	4	4	5	3	4	22	2	12	143	<1	6	10
NPU2.3	<2	26	246	1	10	0	17	11	27	8	8	6	2	4	24	10	9	271	<1	7	14
NPU2.4	<2	20	168	3	13	<2	24	8	22	8	4	3	2	7	25	12	21	352	<1	5	16
NPU2.5	<2	19	240	3	13	<2	29	6	31	9	8	5	2	5	23	9	14	393	<1	6	8
NPU2.6	<2	17	309	2	18	<2	44	14	38	7	12	7	2	6	23	8	17	249	0	10	21
NPU3.1	<2	15	326	1	87	<2	47	16	43	13	17	11	3	6	23	13	22	281	<1	11	26
NPU3.2	<2	16	319	2	86	0	63	17	54	8	22	13	3	8	28	14	39	313	<1	14	29
NPU3.3	<2	8	307	1	17	<2	39	9	37	7	10	8	3	8	20	5	15	255	<1	8	15
NPU3.4	<2	13	329	1	35	0	60	16	62	16	27	18	3	8	19	9	29	291	0	15	29
NPU3.5	<2	9	324	3	29	3	45	14	64	8	29	17	3	7	20	6	36	243	<1	15	22
NPU4.1	<2	8	311	1	15	0	31	10	26	5	9	6	2	5	23	6	21	84	1	9	18
NPU4.3	<2	11	295	2	46	<2	41	14	39	6	19	9	3	6	24	21	28	119	0	10	18
NPU4.5	<2	12	369	1	28	<2	45	13	49	10	21	14	4	7	24	6	29	289	0	14	24
LCA1.1	<2	9	261	1	111	<2	52	9	31	12	14	8	3	7	22	16	18	142	1	9	23
LCA1.2	<2	10	243	2	20	0	21	29	22	6	3	4	2	8	23	9	20	140	<1	7	13
LCA1.3	<2	12	283	2	21	2	59	13	55	11	14	14	2	8	20	5	19	185	0	12	25
LCA1.4	<2	9	264	3	6	1	46	16	34	6	8	8	3	8	22	6	19	119	0	8	15

Element	Ag	As	Ba	Bi	Br	Cd	Ce	Co	Cr	Cs	Cu	Ga	Ge	Hf	Hg	I	La	Mn	Mo	Nb	Nd
	Concentration (ppm)																				
Lower detection limit (ppm)	**2**	**1**	**12**	**3**	**1**	**3**	**15**	**5**	**3**	**7**	**1**	**1**	**1**	**7**	**11**	**6**	**13**	**7**	**1**	**1**	**9**
LCA 2.1	<2	5	219	0	25	<2	4	12	9	6	1	4	3	5	29	5	19	154	0	3	7
LCA2.2	<2	7	235	4	2	<2	33	32	19	8	2	3	3	9	22	2	18	60	1	7	14
LCA2.3	<2	13	402	2	19	<2	50	20	67	16	32	18	3	6	21	8	19	410	<1	13	26
LCA2.4	<2	14	333	3	13	0	73	19	73	11	39	21	3	4	21	10	45	267	<1	14	32
LCA3.1	<2	16	340	3	13	<2	53	20	58	19	26	15	3	7	26	16	37	374	0	13	27
LCA3.2	<2	21	330	2	12	1	61	25	67	7	30	19	3	6	27	5	44	483	0	13	27
LCA3.3	<2	15	322	4	9	<2	58	20	68	11	33	21	3	6	27	9	33	563	0	14	26
UKE1.1	<2	7	297	3	2	<2	46	10	43	6	13	13	3	10	24	<6	30	168	1	15	24
UKE1.2	<2	8	277	<3	5	<2	51	11	47	6	18	14	3	8	22	<6	20	181	<1	15	29
UKE2.1	<2	7	290	<3	27	2	41	4	36	7	13	8	2	<7	22	12	30	113	2	10	21
UKE2.2	<2	7	300	<3	3	<2	52	9	52	9	15	12	3	10	21	<6	30	191	2	16	23
UKE3.1	<2	8	128	3	29	<2	112	52	19	12	21	4	2	<7	25	15	53	944	<1	5	54
UKE3.2	<2	7	217	<3	38	3	72	46	34	11	38	6	1	<7	24	18	35	609	<1	8	41
UKE3.3	<2	9	281	3	35	<2	55	17	47	12	29	10	2	<7	18	14	30	168	<1	11	25
UKE3.4	<2	11	298	<3	23	<2	53	14	57	15	27	17	3	11	26	17	32	212	1	13	32
UKE3.5	<2	5	230	<3	<1	<2	15	2	10	9	2	3	2	<7	26	<6	<13	44	1	4	9
UKE3.6	<2	14	280	<3	28	<2	54	17	60	11	25	16	3	<7	27	14	18	276	1	14	24
UKE3.7	<2	8	363	4	7	<2	58	10	51	14	15	12	3	8	18	<6	28	179	<1	14	27
UKE5.1	<2	8	297	<3	33	<2	52	13	34	8	42	7	2	9	17	10	15	120	<1	9	29
UKE5.2	<2	9	311	<3	48	<2	40	11	42	13	30	11	3	8	20	10	22	197	<1	12	17
UKE5.3	<2	9	392	<3	23	<2	61	17	63	9	27	17	4	11	30	10	27	393	<1	16	33
UKE6.1	<2	8	280	<3	31	2	48	18	45	11	31	10	2	7	17	12	23	205	<1	12	27
UKE6.2	<2	12	308	<3	31	2	56	18	59	9	32	15	3	7	20	18	40	199	<1	14	27
UKE6.3	<2	12	404	3	11	<2	67	19	73	16	31	20	3	<7	27	<6	27	178	<1	16	34
SPM1.2	<2	12	308	<3	21	<2	43	15	42	5	34	9	2	6	7	9	13	150	0	11	22
SPM1.3	<2	14	312	<3	21	1	43	15	47	7	35	12	2	10	4	13	22	132	0	12	22
SPM1.4	<2	10	378	1	8	2	74	19	68	15	29	18	2	7	5	6	31	207	<1	16	35
SPM1.5	<2	9	384	1	6	2	68	19	66	11	27	18	3	4	8	3	30	277	1	16	35

Element	Ag	As	Ba	Bi	Br	Cd	Ce	Co	Cr	Cs	Cu	Ga	Ge	Hf	Hg	I	La	Mn	Mo	Nb	Nd
	Concentration (ppm)																				
Lower detection limit (ppm)	**2**	**1**	**12**	**3**	**1**	**3**	**15**	**5**	**3**	**7**	**1**	**1**	**1**	**7**	**11**	**6**	**13**	**7**	**1**	**1**	**9**
SPM1.6	<2	9	381	0	6	1	67	17	63	4	26	17	2	5	7	6	37	256	1	17	31
SPM1.7	<2	10	361	<3	5	<2	60	13	73	7	28	22	4	7	10	<6	27	188	<1	16	34
SPM1.8	<2	8	373	<3	4	0	71	14	74	14	28	23	4	7	14	3	44	177	0	18	35
MUR1.1	<2	11	109	<3	152	2	4	7	8	3	7	3	1	3	18	24	15	87	<1	2	5
MUR1.2	<2	12	323	2	34	0	50	14	66	11	29	18	2	5	21	8	24	153	0	12	28
MUR1.3	<2	11	281	3	24	2	57	13	64	14	29	18	2	5	21	7	23	166	0	11	25
MUR2.1	<2	6	241	2	52	0	40	9	32	7	18	8	1	5	14	15	24	209	1	8	20
MUR2.2	<2	9	332	4	12	2	44	11	57	9	24	15	3	7	24	0	22	136	0	14	26
MUR2.3	<2	7	360	4	5	<2	87	8	68	19	24	17	3	4	21	6	46	170	0	19	42
MUR2.4	<2	14	267	2	26	<2	48	17	62	13	32	18	3	6	25	7	25	146	1	14	26
MUR3.1	<2	8	346	4	10	<2	88	7	61	13	26	17	3	5	24	2	42	163	1	18	44
MUR3.2	<2	23	156	3	27	1	26	20	48	11	27	14	2	4	23	5	24	109	3	9	15

Table 23. Concentrations of minor elements in samples from nine wetlands – elements Ni to Zr. Detection limits vary with sample and counting time.

Element	Ni	Pb	Rb	Sb	Sc	Se	Sm	Sn	Sr	Ta	Th	Tl	U	V	Y	Yb	Zn	Zr
	Concentration (ppm)																	
Lower detection limit (ppm)	**2**	**2**	**2**	**6**	**3**	**1**	**9**	**2**	**1**	**6**	**3**	**2**	**2**	**6**	**2**	**9**	**2**	**1**
NOO1.1	33	15	123	<6	17	2	12	<2	103	<6	17	13	4	127	32	<9	88	195
NOO1.2	33	12	124	<6	17	1	13	5	97	<6	18	9	4	130	30	<9	84	182
NOO1.3	39	15	128	<6	17	1	<9	<2	95	<6	19	12	6	138	32	<9	86	181
NOO1.4	35	13	130	<6	19	1	<9	<2	97	<6	19	11	4	143	33	<9	90	161
NOO1.5	40	14	131	<6	15	1	<9	<2	94	<6	17	12	5	147	31	<9	91	157
NOO2.1	36	15	119	<6	15	1	11	<2	92	<6	18	13	6	128	29	<9	87	153
NOO2.2	37	14	122	<6	15	2	<9	<2	91	<6	17	12	5	140	29	<9	92	153
NOO2.3	38	14	124	<6	18	1	<9	4	97	<6	17	10	5	145	30	<9	93	157
NOO2.4	38	14	114	<6	16	2	9	<2	92	<6	17	13	7	141	30	<9	87	146
NOO3.1	35	13	121	<6	17	1	10	<2	107	<6	18	10	5	128	32	<9	82	187
NOO3.2	37	15	126	<6	18	2	13	3	102	<6	18	14	7	139	32	<9	88	159
DD 1.1	3	1	50	<7	2	1	<9	<2	57	<5	6	8	2	17	12	<8	5	207
DD 1.2	9	5	72	<7	6	1	<9	<2	92	<5	9	9	5	47	20	0	18	284
DD 1.3	8	3	65	0	7	1	1	<2	62	<5	8	8	4	38	15	5	12	293
DD 1.4	6	4	65	<7	2	2	6	<2	59	<5	10	9	3	39	16	<8	12	319
DD 2.2	30	12	114	<7	14	2	10	<2	94	<5	16	10	5	101	31	1	68	251
DD 2.3	38	11	119	<7	14	1	3	<2	93	3	15	7	5	113	31	1	77	203
DD 2.4	42	14	122	1	14	2	1	<2	101	1	15	12	7	117	30	1	89	173
DD 2.5	38	13	119	<7	14	2	12	<2	97	3	13	10	7	123	24	8	92	140
DD 3.1	18	11	100	<7	12	2	5	<2	87	<5	15	9	6	74	31	3	46	346
DD 3.2	39	11	122	<7	14	1	8	<2	106	<5	15	8	2	116	31	<8	74	230
DD 3.3	45	15	122	<7	15	2	8	<2	120	1	16	9	5	114	43	<8	72	243
DD 4.1	9	3	63	<7	5	2	12	<2	68	<5	13	10	3	29	21	1	12	414
DD 4.2	14	7	81	<7	8	2	10	<2	76	1	12	9	5	53	25	<8	27	347

Element	Ni	Pb	Rb	Sb	Sc	Se	Sm	Sn	Sr	Ta	Th	Tl	U	V	Y	Yb	Zn	Zr
	Concentration (ppm)																	
Lower detection limit (ppm)	**2**	**2**	**2**	**6**	**3**	**1**	**9**	**2**	**1**	**6**	**3**	**2**	**2**	**6**	**2**	**9**	**2**	**1**
DD 4.3	35	15	121	<7	13	2	8	<2	106	1	18	10	6	105	33	2	67	273
DDS 1.1	24	11	95	<7	10	2	11	<2	125	<6	15	8	6	94	28	<8	56	254
DDS 1.2	19	9	94	<7	10	1	10	<2	99	<6	13	9	4	81	29	0	49	301
DDS 1.3	40	14	120	<7	16	2	15	<2	113	<6	15	10	4	138	31	<8	69	172
DDS 1.4	46	14	127	0	15	2	3	1	138	<6	18	10	4	135	36	2	68	152
DDS 2.1	24	9	95	<7	9	1	7	<2	108	7	14	10	4	80	28	5	51	299
DDS 2.2	29	12	107	<7	13	2	5	<2	102	0	16	9	6	101	30	<8	61	232
DDS 2.3	41	12	119	<7	16	2	15	<2	107	2	14	8	4	133	31	4	69	177
DDS 2.4	37	16	126	<7	20	1	12	0	125	1	18	10	7	150	34	4	70	174
DDS 3.1	28	12	110	<7	12	2	8	<2	145	1	15	12	5	95	30	2	69	233
DDS 3.2	32	13	119	1	13	2	10	<2	103	<6	16	10	6	105	30	4	73	201
DDS 3.3	38	13	117	<7	16	1	1	1	97	2	14	10	7	122	28	<8	77	182
DDS 3.4	44	13	119	1	13	1	7	<2	96	1	15	8	5	129	29	<8	80	164
DDS 4.1	3	<2	24	<7	<3	1	1	<2	121	1	7	8	2	17	11	1	7	252
DDS 4.2	2	<2	25	<7	<3	1	4	<2	137	<6	7	12	3	19	9	1	7	120
DDS 4.3	21	6	73	<7	9	1	6	<2	113	<6	11	9	5	81	22	1	41	189
DDS 5.1	5	0	44	0	1	2	9	<2	204	<6	12	11	4	19	14	<8	11	261
DDS 5.2	3	2	55	<7	4	2	6	<2	57	<6	11	9	3	21	17	1	7	295
DDS 5.3	8	2	60	<7	8	2	<9	<2	55	1	10	10	0	41	18	2	16	308
DDS 5.4	17	6	82	<7	10	2	5	<2	77	<6	12	9	1	69	20	2	35	191
KRL1.1	19	7	85	<6	9	1	3	<2	95	1	15	12	2	55	30	3	37	374
KRL1.2	17	7	87	<6	8	1	7	<2	88	<6	15	11	3	64	28	<8	39	325
KRL1.3	25	10	107	<6	11	1	3	<2	93	2	18	13	6	82	31	0	54	294
KRL1.4	32	10	114	<6	14	1	4	<2	100	3	15	13	4	101	29	5	64	250
KRL1.5	37	12	117	<6	15	1	3	<2	106	3	16	13	4	122	29	1	77	209
KRL2.1	15	4	63	<6	7	1	<9	<2	81	<6	12	12	2	41	24	1	18	361

Element	Ni	Pb	Rb	Sb	Sc	Se	Sm	Sn	Sr	Ta	Th	Tl	U	V	Y	Yb	Zn	Zr
	Concentration (ppm)																	
Lower detection limit (ppm)	**2**	**2**	**2**	**6**	**3**	**1**	**9**	**2**	**1**	**6**	**3**	**2**	**2**	**6**	**2**	**9**	**2**	**1**
KRL2.2	16	4	60	2	5	1	<9	<2	70	<6	12	11	2	30	23	8	17	340
KRL2.3	30	8	107	1	15	2	3	<2	101	1	16	12	2	95	31	2	58	294
KRL3.1	19	8	90	<6	10	1	11	0	85	4	17	11	3	72	31	3	43	442
KRL3.2	17	8	88	1	11	1	<9	<2	82	5	16	14	6	67	29	5	35	446
KRL3.3	35	12	106	<6	13	1	7	<2	101	3	17	13	8	107	28	0	64	307
KRL4.1	8	4	55	<6	9	1	4	<2	58	<6	15	13	4	34	23	1	16	454
KRL4.2	45	14	126	3	17	1	10	1	132	1	20	13	6	131	35	3	67	195
KRL4.3	37	14	126	<6	17	2	<9	<2	121	<6	18	14	5	124	31	<8	72	191
NPU2.1	5	1	37	0	3	1	8	<2	71	<6	6	14	1	32	7	4	9	73
NPU2.2	7	1	43	<6	3	1	2	<2	82	<6	9	13	2	36	9	0	13	107
NPU2.3	11	1	51	3	3	1	8	<2	142	<6	8	9	2	56	13	1	21	147
NPU2.4	3	<2	31	2	<3	0	8	<2	214	<6	8	10	3	57	9	0	12	106
NPU2.5	10	3	53	2	2	1	4	<2	171	1	7	12	3	66	12	0	21	127
NPU2.6	14	7	71	<6	7	1	9	0	128	<6	13	12	6	71	19	<8	33	227
NPU3.1	20	7	82	<6	7	1	16	<2	148	2	12	11	2	67	22	1	43	232
NPU3.2	26	11	96	<6	9	1	13	<2	106	<6	15	11	3	91	26	4	58	232
NPU3.3	13	6	68	<6	6	2	10	<2	86	<6	10	14	1	60	15	<8	27	160
NPU3.4	34	9	115	<6	13	1	7	<2	108	2	16	11	6	103	26	2	74	192
NPU3.5	34	11	121	<6	14	1	9	<2	105	<6	15	13	5	118	27	1	81	196
NPU4.1	13	3	71	<6	5	1	7	<2	66	3	11	11	2	48	16	1	20	243
NPU4.3	19	8	78	<6	8	2	5	<2	69	1	12	12	2	94	18	3	40	206
NPU4.5	26	8	100	<6	12	1	13	0	112	<6	15	11	3	85	24	<8	48	208
LCA1.1	15	3	61	<6	9	1	2	<2	142	2	11	10	4	62	17	1	32	308
LCA1.2	9	<2	38	<6	0	1	10	<2	128	<6	11	13	0	25	13	3	7	343
LCA1.3	21	5	89	<6	12	0	<9	<2	144	1	14	10	2	88	21	3	40	251
LCA1.4	11	2	59	<6	7	1	2	<2	116	<6	10	12	3	58	16	<8	20	316

Element	Ni	Pb	Rb	Sb	Sc	Se	Sm	Sn	Sr	Ta	Th	Tl	U	V	Y	Yb	Zn	Zr
	Concentration (ppm)																	
Lower detection limit (ppm)	**2**	**2**	**2**	**6**	**3**	**1**	**9**	**2**	**1**	**6**	**3**	**2**	**2**	**6**	**2**	**9**	**2**	**1**
LCA 2.1	3	<2	30	<6	3	0	<9	<2	105	<6	4	10	2	12	4	3	1	70
LCA2.2	4	<2	37	<6	3	1	3	<2	43	<6	10	11	0	18	13	2	5	418
LCA2.3	39	7	104	<6	14	1	6	<2	159	<6	15	12	2	110	25	2	69	179
LCA2.4	44	9	115	<6	14	1	15	<2	193	0	15	12	2	125	28	<8	79	164
LCA3.1	32	11	93	1	12	1	8	<2	103	<6	16	11	6	98	28	7	62	254
LCA3.2	40	9	107	<6	16	1	2	<2	116	1	15	12	4	123	26	6	76	174
LCA3.3	41	12	119	<6	15	1	7	0	133	<6	17	15	4	138	27	<8	82	152
UKE1.1	15	7	92	<6	9	1	<9	<2	77	<6	16	10	5	80	26	<8	34	306
UKE1.2	21	8	96	<6	8	<1	<9	<2	81	<6	16	11	5	82	31	<8	42	330
UKE2.1	14	11	67	<6	7	1	13	<2	93	<6	12	10	4	67	18	<8	27	236
UKE2.2	16	9	99	<6	10	1	9	<2	86	<6	18	11	6	87	32	<8	42	303
UKE3.1	70	7	32	<6	<3	1	11	<2	900	<6	9	11	12	64	65	<8	147	68
UKE3.2	66	24	51	<6	5	2	14	<2	260	<6	12	10	9	86	52	<8	159	135
UKE3.3	24	15	77	<6	8	2	<9	<2	79	<6	14	11	5	82	23	<8	61	241
UKE3.4	29	17	101	<6	12	1	<9	<2	87	<6	15	10	7	102	25	<8	82	171
UKE3.5	2	<2	45	<6	8	1	<9	<2	42	<6	6	12	<2	21	7	<8	7	80
UKE3.6	31	14	98	<6	15	2	<9	<2	95	<6	15	12	5	105	24	<8	79	160
UKE3.7	20	9	106	<6	12	2	<9	<2	80	<6	14	12	2	81	25	<8	42	249
UKE5.1	16	19	62	<6	5	1	12	<2	350	<6	12	11	6	64	27	<8	31	211
UKE5.2	19	13	83	<6	10	1	<9	<2	101	<6	15	11	6	77	20	<8	53	243
UKE5.3	36	13	125	<6	12	1	10	<2	103	<6	17	11	4	103	30	<8	77	217
UKE6.1	29	12	76	<6	8	2	<9	<2	89	<6	14	10	5	69	26	<8	62	241
UKE6.2	31	16	103	<6	11	2	<9	<2	92	<6	16	11	6	100	29	<8	82	192
UKE6.3	40	13	124	<6	16	1	<9	<2	97	<6	17	15	5	125	29	<8	69	157
SPM1.2	24	12	71	<6	7	1	9	<2	94	2	16	3	6	63	27	<8	39	297
SPM1.3	20	16	83	<6	10	1	6	<2	81	0	15	7	4	83	26	<8	48	280

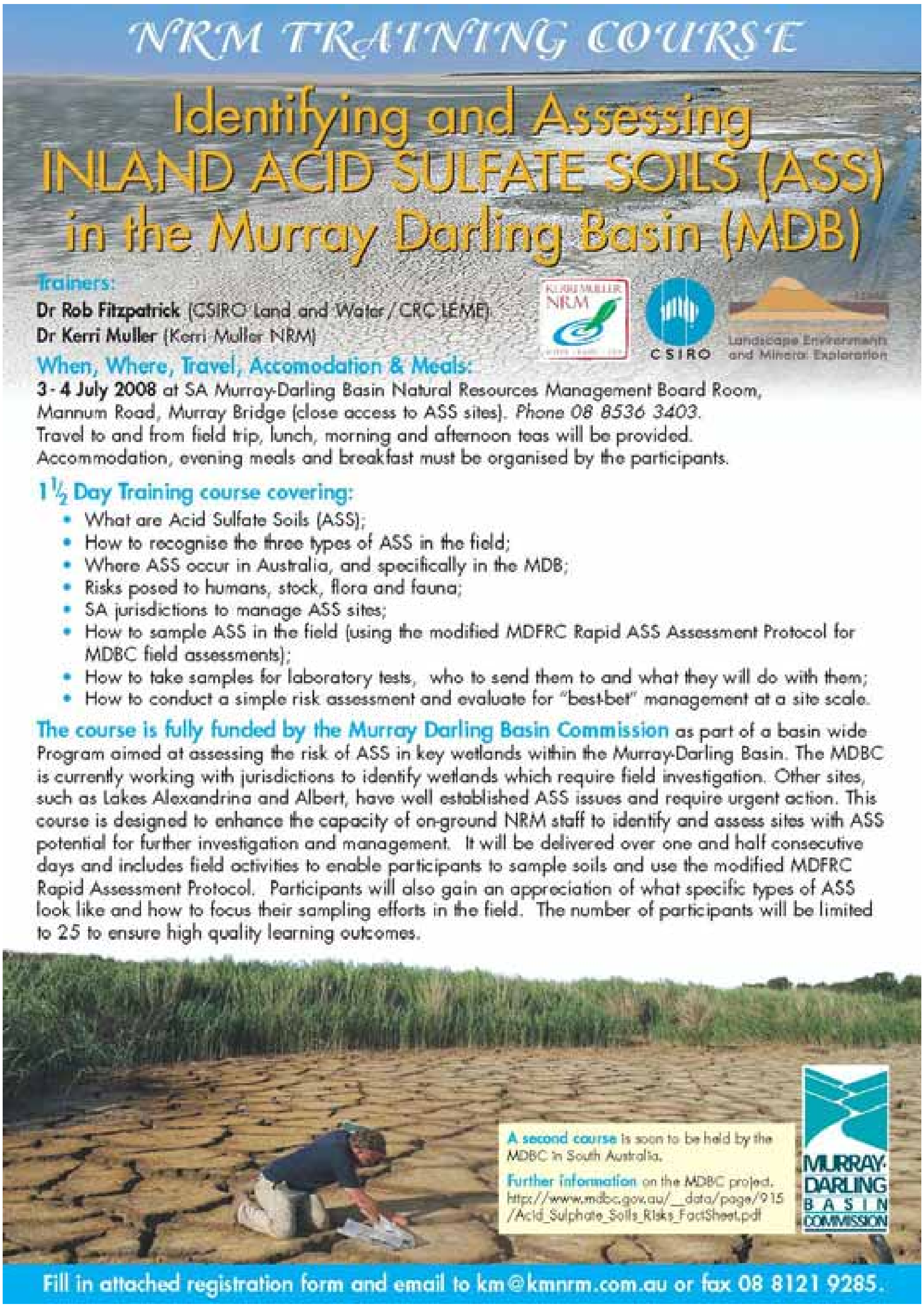
Element	Ni	Pb	Rb	Sb	Sc	Se	Sm	Sn	Sr	Ta	Th	Tl	U	V	Y	Yb	Zn	Zr
	Concentration (ppm)																	
Lower detection limit (ppm)	**2**	**2**	**2**	**6**	**3**	**1**	**9**	**2**	**1**	**6**	**3**	**2**	**2**	**6**	**2**	**9**	**2**	**1**
SPM1.4	34	14	127	<6	14	1	5	<2	93	<6	17	6	5	117	35	3	85	212
SPM1.5	32	12	130	<6	12	1	1	<2	95	<6	17	6	6	109	33	1	75	223
SPM1.6	30	12	129	<6	12	1	12	<2	91	4	18	9	6	108	31	5	67	218
SPM1.7	35	11	133	1	17	0	5	2	92	0	16	6	3	126	31	6	64	173
SPM1.8	33	15	136	<6	17	1	4	<2	94	4	19	5	6	137	32	5	65	174
MUR1.1	10	<2	12	<6	2	1	4	<2	134	1	4	11	2	23	5	1	19	20
MUR1.2	34	13	100	<6	13	2	3	<2	103	<6	14	13	5	105	22	<8	78	144
MUR1.3	37	12	95	0	14	1	3	<2	90	4	13	11	7	111	22	3	69	121
MUR2.1	17	6	57	<6	7	1	2	<2	87	<6	11	11	4	60	20	5	34	258
MUR2.2	29	10	101	<6	13	2	9	1	86	1	15	14	6	92	25	4	54	215
MUR2.3	21	16	130	0	13	2	5	<2	112	2	22	11	10	136	39	7	50	185
MUR2.4	33	13	106	<6	14	2	8	2	89	<6	14	13	9	110	27	0	64	155
MUR3.1	22	15	123	<6	13	2	14	<2	123	2	21	11	8	122	38	9	45	169
MUR3.2	40	7	72	<6	10	2	11	<2	64	1	11	12	4	94	14	0	57	91

APPENDIX 5: CONCENTRATIONS OF MAJOR ELEMENTS

Table 24. Concentrations of major elements in samples from nine wetlands.

Client ID	SiO_2 (%)	TiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	Mn (%)	MgO (%)	CaO (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)	SO_3 (%)	Cl (ppm)	Sum (%)
Lower Limit of Detection (ppm)	**29**	**21**	**24**	**10**	**5**	**37**	**20**	**14**	**17**	**5**	**9**	**3**	
MUR 1.1	5.16	0.06	1.90	2.07	0.00	0.50	1.25	0.53	0.17	0.23	0.41	1590	12.44
MUR 1.2	50.86	0.67	16.75	5.32	0.02	1.28	0.74	0.57	1.47	0.13	0.23	677	78.10
MUR 1.3	54.99	0.66	18.47	5.78	0.02	1.32	0.74	0.45	1.42	0.15	0.13	254	84.16
MUR 2.1	65.84	0.45	8.28	2.65	0.03	0.60	0.64	0.72	1.19	0.15	0.13	353	80.72
MUR 2.2	66.76	0.71	14.56	4.47	0.02	0.99	0.52	0.58	1.63	0.10	0.08	158	90.44
MUR 2.3	60.70	1.05	16.81	4.09	0.02	1.00	0.63	0.62	2.11	0.11	0.08	202	87.23
MUR 2.4	47.96	0.71	15.57	5.23	0.02	1.14	0.64	0.51	1.56	0.11	0.36	311	73.85
MUR 3.1	56.12	0.97	15.71	3.76	0.02	1.05	0.74	0.56	2.02	0.10	0.18	147	81.25
MUR 3.2	31.60	0.47	12.85	6.15	0.01	0.97	0.50	0.31	1.08	0.11	0.68	226	54.73
UKE 1.1	73.36	0.72	10.76	3.01	0.02	0.71	0.43	0.72	1.87	0.05	0.37	69	92.04
UKE 1.2	68.95	0.78	12.08	3.86	0.03	0.87	0.48	0.70	1.88	0.07	0.54	81	90.22
UKE 2.1	70.99	0.48	8.36	2.16	0.01	0.62	0.63	0.69	1.52	0.07	0.17	265	85.74
UKE 2.2	71.33	0.85	12.22	3.64	0.03	0.82	0.52	0.74	1.96	0.06	0.66	83	92.84
UKE 3.1	21.39	0.18	4.74	6.76	0.11	3.21	12.04	1.43	0.94	0.18	7.87	3843	59.23
UKE 3.2	41.57	0.38	7.34	4.88	0.07	2.17	3.40	1.69	1.15	0.18	1.25	2456	64.31
UKE 3.3	55.15	0.58	9.81	4.50	0.02	0.74	0.47	0.84	1.42	0.12	0.57	1298	74.34
UKE 3.4	61.67	0.70	14.40	5.19	0.03	1.14	0.54	0.62	1.75	0.11	0.39	643	86.60
UKE 3.5	93.62	0.16	3.98	0.68	0.01	0.13	0.20	0.64	1.25	0.03	0.08	0	100.77
UKE 3.6	56.38	0.74	15.38	6.17	0.04	1.32	0.72	0.58	1.75	0.12	0.63	597	83.88
UKE 3.7	76.65	0.70	11.04	3.26	0.02	0.80	0.45	0.76	2.11	0.06	0.18	218	96.04
UKE 5.1	55.43	0.48	7.57	5.49	0.02	0.48	5.85	0.86	1.62	0.13	1.33	1083	79.36
UKE 5.2	61.04	0.57	9.35	4.16	0.02	0.84	0.48	1.08	1.54	0.13	0.38	2968	79.88
UKE 5.3	57.13	0.63	10.56	4.69	0.03	0.94	0.85	0.97	1.59	0.13	0.43	2346	78.19
UKE 6.1	57.21	0.58	9.55	4.18	0.02	0.88	0.63	0.91	1.44	0.13	0.55	1151	76.20
UKE 6.2	53.21	0.69	13.13	5.04	0.03	1.00	0.59	0.49	1.63	0.11	0.49	232	76.42
UKE 6.3	58.86	0.88	19.41	7.74	0.02	1.63	0.69	0.58	2.04	0.13	0.09	211	92.09

APPENDIX 6: NRM TRAINING COURSE: IDENTIFYING AND ASSESSING INLAND ACID SULFATE SOILS (ASS) IN THE MURRAY DARLING BASIN (MDB)



NRM TRAINING COURSE

Identifying and Assessing INLAND ACID SULFATE SOILS (ASS) in the Murray Darling Basin (MDB)

Trainers:

Dr Rob Fitzpatrick (CSIRO Land and Water / CRC LEME)
Dr Kerri Muller (Kerri Muller NRM)

KERRI MULLER NRM

CSIRO

Landscape Environments and Mineral Exploration

When, Where, Travel, Accomodation & Meals:

3 - 4 July 2008 at SA Murray-Darling Basin Natural Resources Management Board Room, Mannum Road, Murray Bridge (close access to ASS sites). *Phone 08 8536 3403.*
Travel to and from field trip, lunch, morning and afternoon teas will be provided.
Accommodation, evening meals and breakfast must be organised by the participants.

1½ Day Training course covering:

- What are Acid Sulfate Soils (ASS);
- How to recognise the three types of ASS in the field;
- Where ASS occur in Australia, and specifically in the MDB;
- Risks posed to humans, stock, flora and fauna;
- SA jurisdictions to manage ASS sites;
- How to sample ASS in the field (using the modified MDFRC Rapid ASS Assessment Protocol for MDBC field assessments);
- How to take samples for laboratory tests, who to send them to and what they will do with them;
- How to conduct a simple risk assessment and evaluate for "best-bet" management at a site scale.

The course is fully funded by the Murray Darling Basin Commission as part of a basin wide Program aimed at assessing the risk of ASS in key wetlands within the Murray-Darling Basin. The MDBC is currently working with jurisdictions to identify wetlands which require field investigation. Other sites, such as Lakes Alexandrina and Albert, have well established ASS issues and require urgent action. This course is designed to enhance the capacity of on-ground NRM staff to identify and assess sites with ASS potential for further investigation and management. It will be delivered over one and half consecutive days and includes field activities to enable participants to sample soils and use the modified MDFRC Rapid Assessment Protocol. Participants will also gain an appreciation of what specific types of ASS look like and how to focus their sampling efforts in the field. The number of participants will be limited to 25 to ensure high quality learning outcomes.

A second course is soon to be held by the MDBC in South Australia.

Further information on the MDBC project. http://www.mdbc.gov.au/__data/page/915/Acid_Sulphate_Soils_Risks_FactSheet.pdf

MURRAY-DARLING BASIN COMMISSION

Fill in attached registration form and email to km@kmnrm.com.au or fax 08 8121 9285.