

Phase 2 Acid Sulfate Soil Assessment: Richardsons Lagoon (40590)



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Assessment of Acid Sulfate Soil Materials (Phase 2)

Priority Region: Victorian Northern Flowing Rivers

Sequence Number: 40590

Wetland Name: Richardsons Lagoon

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For: Murray Darling Basin Authority

NOVEMBER 2011

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Cover Photograph:

Photographs of sampling at Richardsons Lagoon as part of the Phase 1 Assessment.

Photographer: Blake Dickson.

EXECUTIVE SUMMARY

Detailed assessments of acid sulfate soils within the Murray-Darling Basin (MDB) are conducted as a two-phase process under the MDB Acid Sulfate Soils Risk Assessment Project. An initial Phase 1 acid sulfate soil investigation of the Richardsons Lagoon wetland showed acid sulfate soils to be a priority concern within this system (SMEC 2010). Based on Phase 1 recommendations, a Phase 2 assessment was undertaken for the Richardsons Lagoon wetland to determine the nature, severity and the specific risks associated with acid sulfate soil materials. The Phase 2 assessment of the Richardsons Lagoon wetland examined the contaminant and metalloid dynamics, reactive metals and monosulfide formation potential associated with surface layers from 3 sites and 6 discrete samples throughout the wetland.

The contaminant and metalloid behaviour of the six Richardsons Lagoon soil materials during the 35 day inundation showed that some of the metals i.e. silver (Ag), cadmium (Cd) and zinc (Zn), showed a maximum concentration after 24 hours of inundation indicating that dissolution may control their release/mobility in the early stages of inundation. The remaining metals/metalloids may be controlled by redox processes.

Under the experimental laboratory conditions, 13 of the 15 of the metals examined i.e. silver (Ag), aluminium (Al), arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), vanadium (V) and zinc (Zn) were found to exceed the ANZECC water quality guidelines for environmental protection during inundation. The degree to which metal/metalloid concentrations exceed ANZECC guideline values was used to characterise the hazard. The hazards that these metals/metalloids represent based on ANZECC guidelines are:

- No significant hazard after inundation – antimony (Sb) and selenium (Se).
- Low hazard – silver (Ag), arsenic (As), cadmium (Cd), copper (Cu), manganese (Mn), nickel (Ni), lead (Pb), zinc (Zn).
- Moderate hazard – aluminium (Al), cobalt (Co), chromium (Cr), vanadium (V).
- High hazard – iron (Fe).
- Five metals i.e. cobalt (Co), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) were found to be a hazard at all sites sampled.

The reactive metals data for the Richardsons Lagoon soil materials showed all metals/metalloids were $\leq 33\%$ of the ANZECC Sediment Quality trigger value for the total metal/metalloid concentration.

The acidification hazard at Richardsons Lagoon is considered a **Moderate** consequence and the likelihood rating is considered **Possible**. Therefore there is a **Medium Risk** (Table 14) associated with acidification at Richardsons Lagoon and management action may be recommended.

The contaminant mobilisation hazard at Richardsons Lagoon is considered to pose a **Moderate** consequence and the likelihood rating is considered **Likely**. Therefore there is a **Medium Risk** associated with contaminant mobilisation at Richardsons Lagoon and management action may be recommended.

The monosulfide formation potential hazard at Richardsons Lagoon is considered to pose an **Insignificant** consequence and the likelihood rating is considered **Possible**. Therefore there is a **low risk** of deoxygenation associated with monosulfide formation potential and routine monitoring is suggested for Richardsons Lagoon.

The national guidance document on the management of inland acid sulfate soil landscapes (EPHC & NRMCC 2011) should be used to provide on-going management options for managing acid sulfate soils at Richardsons Lagoon. However, in designing a management strategy for dealing with acid sulfate soils in affected inland wetlands, other values and uses of a wetland need to be taken into account to ensure that any intervention is compatible with other management plans and objectives for the wetland.

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APPENDIX 1: SOIL ANALYTICAL DATA

1 INTRODUCTION

At its March 2008 meeting, the Murray–Darling Basin Ministerial Council discussed the emerging issue of inland acid sulfate soils and the associated risks to Murray–Darling Basin waterways and agreed that the extent of the threat posed by this issue required assessment. The purpose of the Murray–Darling Basin Acid Sulfate Soils Risk Assessment Project was to determine the spatial occurrence of, and risk posed by, acid sulfate soils at priority wetlands in the River Murray system, wetlands listed under the Ramsar Convention on Wetlands of International Importance and other key environmental sites in the Murray–Darling Basin. The project involved the selection of wetlands of environmental significance, as well as those that may pose a risk to surrounding waters. These wetlands were then subjected to a tiered assessment program, whereby wetlands were screened through a desktop assessment stage, followed by a rapid on-ground appraisal, and then detailed on-ground assessment if results of previous stages indicated an increased likelihood of occurrence of acid sulfate soils.

Detailed assessments of acid sulfate soils within the Murray-Darling Basin (MDB) are conducted as a two-phase process under the MDB Acid Sulfate Soils Risk Assessment Project (ASSRAP). Detailed Phase 1 acid sulfate soil assessments have been undertaken in both wetlands and channel systems throughout the MDB as part of the MDB ASSRAP. Phase 1 investigations are initially undertaken to determine whether acid sulfate soil materials are present (or absent) in the study area, and provide characterisation of the properties and types of acid sulfate soils. Phase 2 investigations are only conducted if the acid sulfate soil materials from Phase 1 are determined to be a priority concern for the study area and, based on Phase 1 recommendations, selected samples undergo further investigations to determine the nature, severity and the specific risks associated with the acid sulfate soil materials.

Phase 2 activities include:

1. Soil laboratory analysis to confirm and refine the hazards associated with contaminant mobilisation and/or deoxygenation.
2. A risk assessment.
3. Interpretation and reporting, including discussion on broad acid sulfate soil management options.

This report outlines the results of Phase 2 activities on selected samples from Richardsons Lagoon in the Northern Victoria region.

Following the Richardsons Lagoon Phase 1 assessment (SMEC 2010) and the priority ranking criteria adopted by the Scientific Reference Panel of the MDB ASSRAP (see Table 1 on following page), selected sites from within the wetland were chosen for Phase 2 detailed assessment.

The Phase 1 assessment identified four (4) high priority samples based on the presence of water soluble sulfate values that exceed the trigger criterion of 100 mg/kg for monosulfide formation potential, one (1) high priority sample with sulfuric materials and two (2) high priority samples with hypersulfidic materials. There were also eight (8) moderate priority samples with hyposulfidic materials $S_{CR} < 0.10\%$.

Phase 2 investigations were carried out on six (6) selected samples from high priority sites identified in the Phase 1 assessment.

Table 1 – Priority ranking criteria adopted by the Scientific Reference Panel of the Murray-Darling Basin Acid Sulfate Soils Risk Assessment Project, from MDBA (2010).

Priority	Soil Material
High Priority	All sulfuric materials.
	All hypersulfidic materials (as recognised by either 1) incubation of sulfidic materials or 2) a positive net acidity result with a Fineness Factor of 1.5 being used).
	All hyposulfidic materials with S _{CR} contents ≥ 0.10% S.
	All surface soil materials (i.e. within 0-20 cm) with water soluble sulphate (1:5 soil:water) contents ≥ 100 mg/kg SO ₄ .
	All monosulfidic materials.
Moderate Priority	All hyposulfidic materials with S _{CR} contents < 0.10% S.
No Further Assessment	Other acidic soil materials.
	All other soil materials.

A summary of the soil laboratory analyses undertaken as part of the Phase 2 assessment and the sample selection criteria for each analysis are provided in Table 2. Soil samples identified to undergo Phase 2 laboratory analysis are primarily from the surface layer, as this is the soil most likely to have initial contact with water. A list of the samples selected for Phase 2 analysis for the Richardsons Lagoon is presented in Table 3.

Table 2 – Rationale of sample selection for Phase 2 analysis.

Parameters	Samples Selected
Contaminant and metalloid dynamics	Conducted on selected upper two surface samples.
Monosulfide formation potential	Conducted on surface samples of dry sites that meet the water extractable sulfate criteria for monosulfides.
Reactive metals	Conducted on selected upper two surface samples.

Table 3 – Summary of Richardsons Lagoon samples analysed for Phase 2 Assessment.

Soil Laboratory Test	Richardsons Lagoon Phase 2 Sample Locations (Wetland ID 40590)	Sample Depth (cm)	¹ n
Contaminant and metalloid dynamics	Richardsons Lagoon: 40590_1.1	0 - 5	6
	Richardsons Lagoon: 40590_1.2	5 - 30	
	Richardsons Lagoon: 40590_2.1	0 - 5	
	Richardsons Lagoon: 40590_2.2	5 - 30	
	Richardsons Lagoon: 40590_3.1	0 - 5	
	Richardsons Lagoon: 40590_3.2	5 - 15	
Monosulfide formation potential	Richardsons Lagoon: 40590_1.1	0 - 5	2
	Richardsons Lagoon: 40590_3.1	0 - 5	
Reactive metals	Same samples as contaminant and metalloid dynamics test	As above	6

¹n = total number of samples analysed.

2 LABORATORY METHODS

2.1 Laboratory Analysis Report

2.1.1 Summary Of Laboratory Methods

A list of the parameters measured and each of the method objectives for the Phase 2 assessment are summarised below in Table 4. All soil samples analysed in this Phase 2 assessment were collected and subsequently stored as part of the Phase 1 field assessment.

Table 4 – Phase 2 data requirements - list of parameters and objective for conducting the test.

Parameter	Objective
Contaminant and metalloid dynamics (CMD)	Assists with determining impacts on water quality by simulating longer time frames that create anaerobic conditions. Identifies metal release concentrations that may occur over a 5 week time frame.
Monosulfide formation potential (MFP)	Determine relative propensity for monosulfides to form following inundation.
Reactive metals (RM)	Assists with determining impacts on water quality by determining weakly to moderately strongly bound metals.

Guidelines on the approaches that were followed as part of this Phase 2 assessment for the contaminant and metalloid dynamics (CMD) and monosulfide formation potential (MFP) methods are presented in full in the detailed assessment protocols (MDBA 2010) (see Appendices 7 and 8 of MDBA 2010). Any variations to the two methods outlined in the detailed assessment protocols are presented in Sections 2.1.2 and 2.1.3. The reactive metals method has only recently been added to the Phase 2 assessment procedure and is presented in Section 2.1.4.

2.1.2 Contaminant And Metalloid Dynamic Method (CMD)

The guidelines for the contaminant and metalloid dynamics method are outlined in Appendix 7 of the detailed assessment protocols (MDBA 2010). In this study supernatant was collected and assessed at four intervals including 24 hours, 7 days, 14 days and 35 days. The concentration of 15 metals/metalloids (i.e. silver (Ag), aluminium (Al), arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), vanadium (V) and zinc (Zn)) was determined by ICP-MS (Inductively Coupled Plasma – Mass Spectrometry) (APHA 2005).

Eh and pH were determined using calibrated electrodes linked to a TPS WP-80 meter; Eh measurements are presented versus the standard hydrogen electrode. Electrical conductivity (EC) was determined using a calibrated electrode linked to a TPS WP-81 meter. All parameters were measured on filtered (0.45 µm) water samples.

2.1.3 Monosulfide Formation Potential Method (MFP)

The guidelines for the monosulfide formation potential method are outlined in Appendix 8 of the detailed assessment protocols (MDBA 2010). In this study 3.6 g/L sucrose was used as an organic substrate instead of the 7.2 g/L outlined in the protocols. In addition to sampling after seven weeks, water samples were collected and analysed immediately after inundating the soils (i.e. Day 0). The pore-water pH and Eh were determined at Day 0.

The reactive iron (Fe) fraction in field moist sediments was extracted using 1.0 M HCl (Claff *et al.* 2010). The ferrous iron (Fe^{2+}) and total iron ($\text{Fe}^{2+} + \text{Fe}^{3+}$) fractions were immediately fixed following extraction. The ferrous iron trap was made up from a phenanthroline solution with an ammonium acetate buffer (APHA 2005), and the total iron trap also included a hydroxylamine solution (APHA 2005). The iron species were quantified colorimetrically using a Hach DR 2800 spectrophotometer.

Redox potential and pH were determined using calibrated electrodes linked to a TPS WP-80 meter; Eh measurements are presented versus the standard hydrogen electrode. In this study the solid phase elemental sulfur fraction was extracted using toluene as a solvent and quantified by high-performance liquid chromatography (HPLC) (McGuire and Hamers 2000).

2.1.4 Reactive Metals Method (RM)

A reactive metals method was carried out instead of the x-ray fluorescence (XRF) spectrometry method outlined in the detailed assessment protocols (MDBA 2010). In this method samples for analysis were prepared by disaggregation (not grinding) using a 'jaw crusher', and then sieved to include only the <2 mm fine earth fraction. A total of 2.5 g sediment was added to 40 mL of 0.1 M HCl, gently mixed for 1 hour and filtered through a pre-acid washed 0.45 micron nitro-cellulose filter. As with the contaminant and metalloid dynamics method, the metals examined included silver (Ag), aluminium (Al), arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), antimony (Sb), selenium (Se), vanadium (V) and zinc (Zn). The reactive metals test was conducted on all samples that underwent the contaminant and metalloid dynamics test.

2.1.5 Quality Assurance And Quality Control (QA/QC)

For all tests and analyses, the quality assurance and quality control procedures were equivalent to those endorsed by NATA (National Association of Testing Authorities). The standard procedures followed included the monitoring of blanks, duplicate analysis of at least 1 in 10 samples, and the inclusion of standards in each batch. Reagent blanks and method blanks were prepared and analysed for each method. All blanks examined here were either at, or very close to, the limits of detection. On average, the frequencies of quality control samples processed were: 10% blanks, \geq 10% laboratory duplicates, and 10% laboratory controls. The analytical precision was $\pm 10\%$ for all analyses. In addition, for all samples, reactive metals and contaminant and metalloid dynamics tests were duplicated.

3 RESULTS AND DISCUSSION

3.1 Summary Of Soil Laboratory Results

3.1.1 Contaminant And Metalloid Dynamics Data (CMD)

The contaminant and metalloid dynamics data for the six Richardsons Lagoon soil materials examined are presented in Appendix 1 (Tables A-1 to A-6) and summarised in Table 5 on the following page. Table 5 also compares the pore-water metal contents to the relevant national water quality guideline for environmental protection (ANZECC/ARMCANZ 2000). Results for all parameters measured are presented in Figures 1 to 4 in graphical form with comparison to ANZECC water quality guideline thresholds.

The pH, electrical conductivity (EC) and redox potential (Eh) dynamics over 35 days of inundation for the Richardsons Lagoon soil materials are presented in Figure 1. The pH was below the ANZECC guideline of 6.5 for all soil materials after the first 24 hour analysis. The pH of the majority of samples then increased by approximately 1.5 – 2.0 pH units at the 35 day (7 week) analysis. Samples 40590_1.1, 40590_1.2, 40590_2.1 and 40590_3.1 and 40590_3.2 were at or above pH 6.5 after 7 weeks.

All soil materials showed a decrease in Eh during inundation. The data indicates that the increase in pH observed with the majority of soil materials is a consequence of reduction processes consuming acidity over the timeframe of the analysis (35 days). Previous studies have often found inundation removes the acidity in partially-oxidised sediments as the acidity gets consumed from the reduction of iron (III) oxides, sulfates and other oxidised species by anaerobic bacteria (Dent 1986).

The electrical conductivities increased during the experiment and were well below the ANZECC upper guideline limit of 2,200 $\mu\text{S}/\text{cm}$ throughout the 35 day analysis (refer to Figure 1). The increase in conductivity may be related to release of minerals into solution or the breakdown of soil aggregates that were noted to be of a hard to firm, clay based structure over the course of the experiment.

It is well established that inundating oxic soils can dramatically alter the mobility of metals and metalloids. The metal/metalloid dynamics for the Richardsons Lagoon soil materials are presented in Figures 2 to 4 on the following pages. Under the experimental laboratory conditions, 13 of the 15 of the metals examined i.e. silver (Ag), aluminium (Al), arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), vanadium (V) and zinc (Zn) were found to exceed the ANZECC water quality guidelines during inundation (refer to Table 5). Antimony and selenium were below the ANZECC water quality guidelines over the 35 day inundation period.

Some of the metals i.e. cobalt (Co), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) were above the ANZECC guideline at all sampling intervals with one or more soil materials. The guidelines for aluminium (Al), cobalt (Co), chromium (Cr), iron (Fe) and vanadium (V) were exceeded by more than 10 times with one or more soil materials at 5 sites at Richardsons Lagoon. The guideline for iron (Fe) was exceeded by more than 100 times in the surface soil material (i.e. 0-10 cm) at site 40590_1 and 40590_3.

The metal/metalloid behaviour during the 35 day incubation period often varied between the metals/metalloids examined (Figures 2 to 4 on the following pages). Some of the metals i.e. silver (Ag), cadmium (Cd) and zinc (Zn), showed a maximum concentration after 24 hours of inundation indicating that dissolution may control their release/mobility in the early stages of inundation. The release of the majority of metals/metalloids may be controlled by redox processes with arsenic (As)

and iron (Fe) providing the most recognisable increases in release/mobility of the 35 day experiment (refer to Figures 2 and 3 on the following pages).

The increase in the iron (Fe) concentration observed during the incubation is a consequence of ferric iron (Fe (III)) reduction releasing ferrous iron (Fe (II)) into solution (Figure 3). Burton et al. (2008) found significant mobilisation of arsenic (As) associated with ferric iron (Fe (III)) reduction following the inundation of acid sulfate soil materials, and this was also observed in this assessment (Figure 2).

The magnitude of mobilisation is affected by many factors that include but are not exclusive to: 1) the abundance and form of metal and metalloid contaminants; 2) the abundance and lability of organic matter; 3) the abundance and reactivity of iron minerals; 4) availability of sulfate; 5) acid/alkalinity buffering capacity; 6) pH; 7) EC; 8) clay content; 9) microbial activity; 10) temperature; and 11) porosity (MDBA 2010).

3.1.2 Reactive Metals (RM)

The reactive metals data for the Richardsons Lagoon soil materials showed all metals/metalloids were $\leq 33\%$ of the ANZECC Sediment Quality trigger value for the total metal/metalloid concentration (see Table A10, Appendix 1). The majority of metals/metalloids concentrations $\geq 10\%$ of the ANZECC trigger value were related to nickel (Ni) and lead (Pb). However, the lead (Pb) concentration at Richardsons Lagoon was only observed to exceed the ANZECC water quality guidelines at one out of the six sites during the contaminant and metalloid dynamics test (Table 5). The nickel (Ni) concentration at Richardsons Lagoon was observed to exceed the ANZECC water quality guidelines at five out of the six sites during the contaminant and metalloid dynamics test (Table 5). All nickel (Ni) criterion exceedance were $\leq 10x$ the ANZECC guideline threshold.

Table 5 – Summary of contaminant and metalloid dynamics data.

Richardsons Lagoon														
Parameter	units	ANZECC Guidelines	40590_1.1		40590_1.2		40590_2.1		40590_2.2		40590_3.1		40590_3.2	
-	-	-	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
pH	-	6.5-8.0	4.84	6.92	4.27	6.56	5.18	6.53	4.32	4.71	6.08	7.16	4.64	6.71
EC	µS cm ⁻¹	125-2200	341.50	855.00	288.00	824.50	459.00	892.00	228.10	440.50	93.05	391.00	343.50	831.00
Eh	mV	-	131.25	452.55	149.40	450.85	150.75	384.05	221.30	462.25	134.50	415.55	129.00	464.40
Ag	ug/L	0.05	0.00	0.05	0.00	0.04	0.00	0.03	0.00	0.09	0.00	0.04	0.00	0.16
Al ^A	mg/L	0.055	0.01	0.04	0.11	0.17	0.01	0.02	0.06	0.10	0.02	0.85	0.15	0.62
As ^B	ug/L	13	0.94	28.38	0.75	32.86	1.01	9.55	0.21	0.46	2.14	37.11	1.05	50.73
Cd	ug/L	0.2	0.00	0.57	0.00	0.44	0.00	0.13	0.00	0.19	0.00	0.05	0.00	0.26
Co	ug/L	2.8	7.95	54.40	4.73	46.72	6.62	16.91	11.97	21.05	1.75	9.64	6.23	61.33
Cr ^C	ug/L	1	1.12	3.42	2.06	12.43	0.84	1.38	0.78	0.90	1.24	6.50	3.19	16.66
Cu ^H	ug/L	1.4	0.89	3.28	1.78	3.32	1.57	2.32	0.98	1.69	0.52	9.75	2.78	11.19
Fe	mg/L	0.3	1.18	49.74	0.23	24.66	0.13	4.71	0.13	1.81	0.79	18.09	0.28	39.31
Mn	mg/L	1.7	4.23	9.83	2.66	5.62	1.97	3.22	1.76	2.29	0.13	2.17	2.76	4.91
Ni ^H	ug/L	11	6.28	43.95	16.06	68.15	6.28	10.10	17.79	22.29	4.02	15.85	19.77	89.05
Pb ^H	ug/L	3.4	0.18	0.64	0.28	0.95	0.00	0.09	0.61	0.86	0.00	1.51	0.99	4.19
Sb	ug/L	9	0.00	0.41	0.00	1.58	0.00	0.22	0.00	1.36	0.00	0.82	0.69	1.12
Se	ug/L	11	1.10	1.65	0.47	2.19	1.49	2.09	0.00	0.42	0.00	0.72	0.90	4.15
V	ug/L	6	0.77	11.40	2.03	39.49	1.82	10.28	0.67	1.22	7.10	10.71	25.68	80.69
Zn ^H	ug/L	8	2.09	51.43	2.84	41.86	3.63	19.25	16.82	25.64	1.02	15.28	11.81	30.24

Exceed ANZECC Guideline (x1)	Exceed ANZECC Guideline (x10)	Exceed ANZECC Guideline (x100)
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Notes:

The ANZECC guideline values for toxicants refer to the Ecosystem Protection – Freshwater Guideline for protection of 95% of biota in 'slightly-moderately disturbed' systems, as outlined in the Australian Water Quality Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000).

* ANZECC water quality guidelines for freshwater lowland rivers in South-east Australia are provided for salinity (there are currently no trigger values defined for 'Wetlands').

Values outside the ranges defined in the ANZECC guidelines are indicated with yellow, orange and red background colours.

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

^B Guideline assumes arsenic in solution as Arsenic (AsV).

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

^H Hardness affected (refer to Guidelines).

Figure 1 - pH, EC and Eh dynamics over 35 days for the Richardsons Lagoon sites (40590_1.1, 40590_1.2, 40590_2.1, 40590_2.2, 40590_3.1 and 40590_3.2).

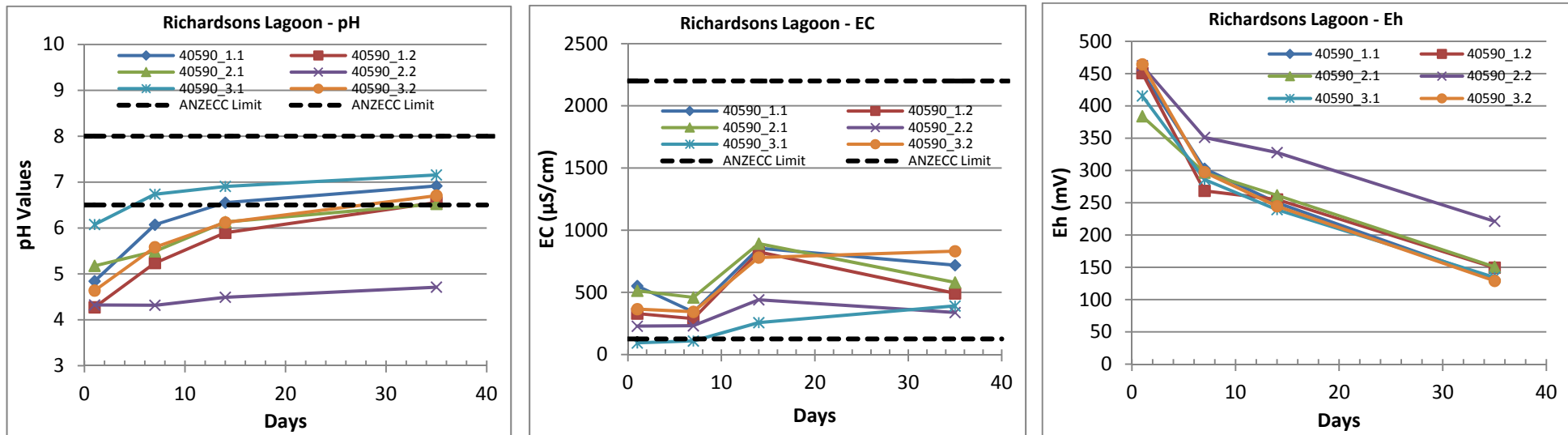


Figure 2 - Contaminant and metalloid dynamics (Ag, Al and As) over 35 days for the Richardsons Lagoon sites (40590_1.1, 40590_1.2, 40590_2.1, 40590_2.2, 40590_3.1 and 40590_3.2).

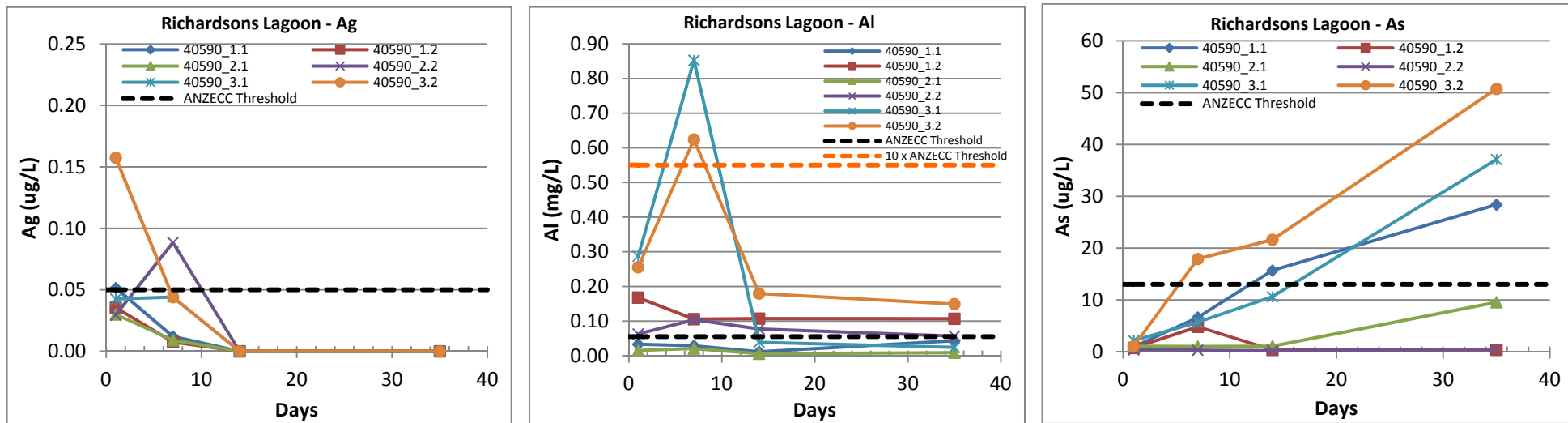


Figure 3 - Contaminant and metalloid dynamics (Cd, Co, Cr, Cu, Fe and Mn) over 35 days for the Richardsons Lagoon sites (40590_1.1, 40590_1.2, 40590_2.1, 40590_2.2, 40590_3.1 and 40590_3.2).

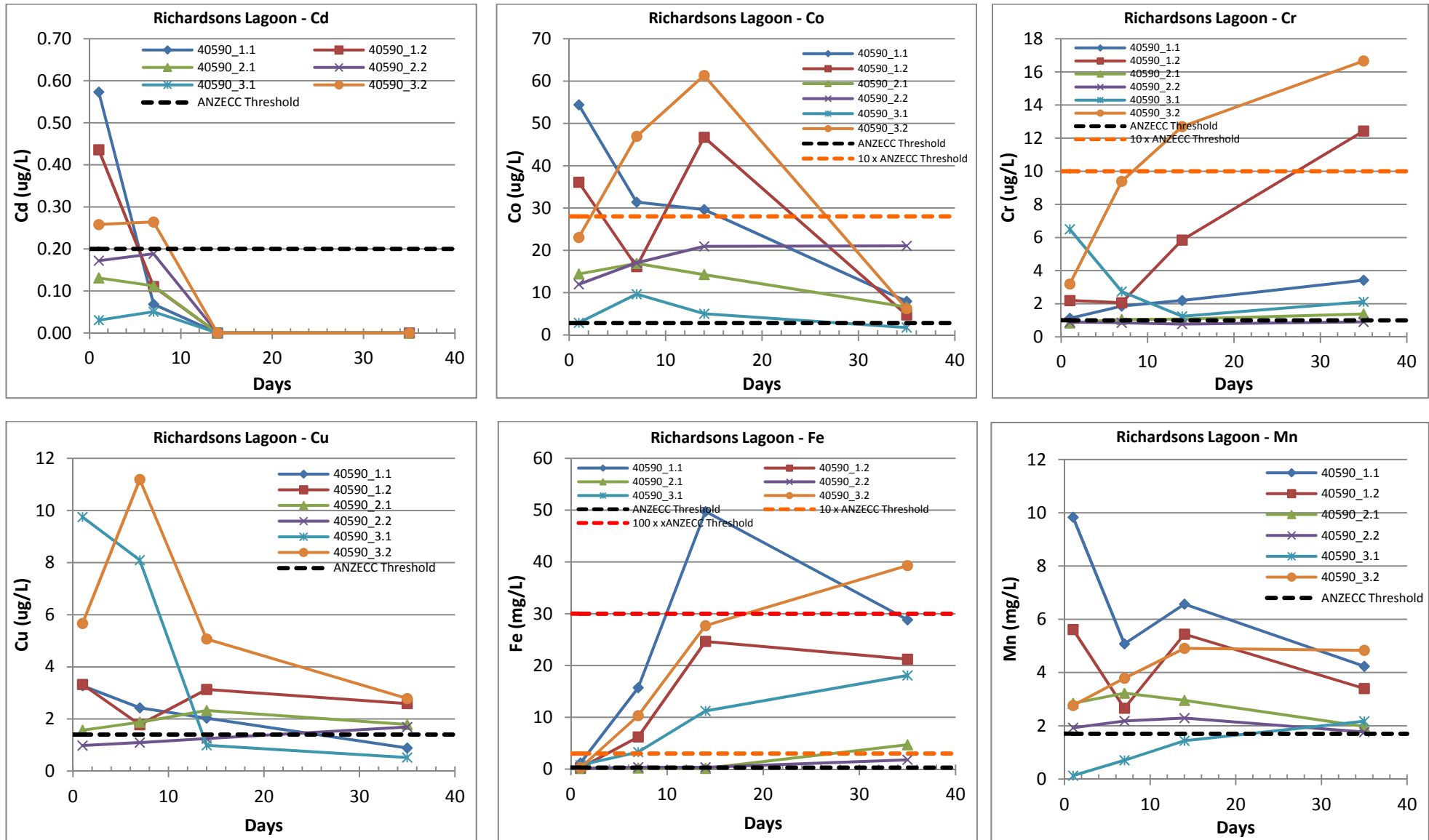
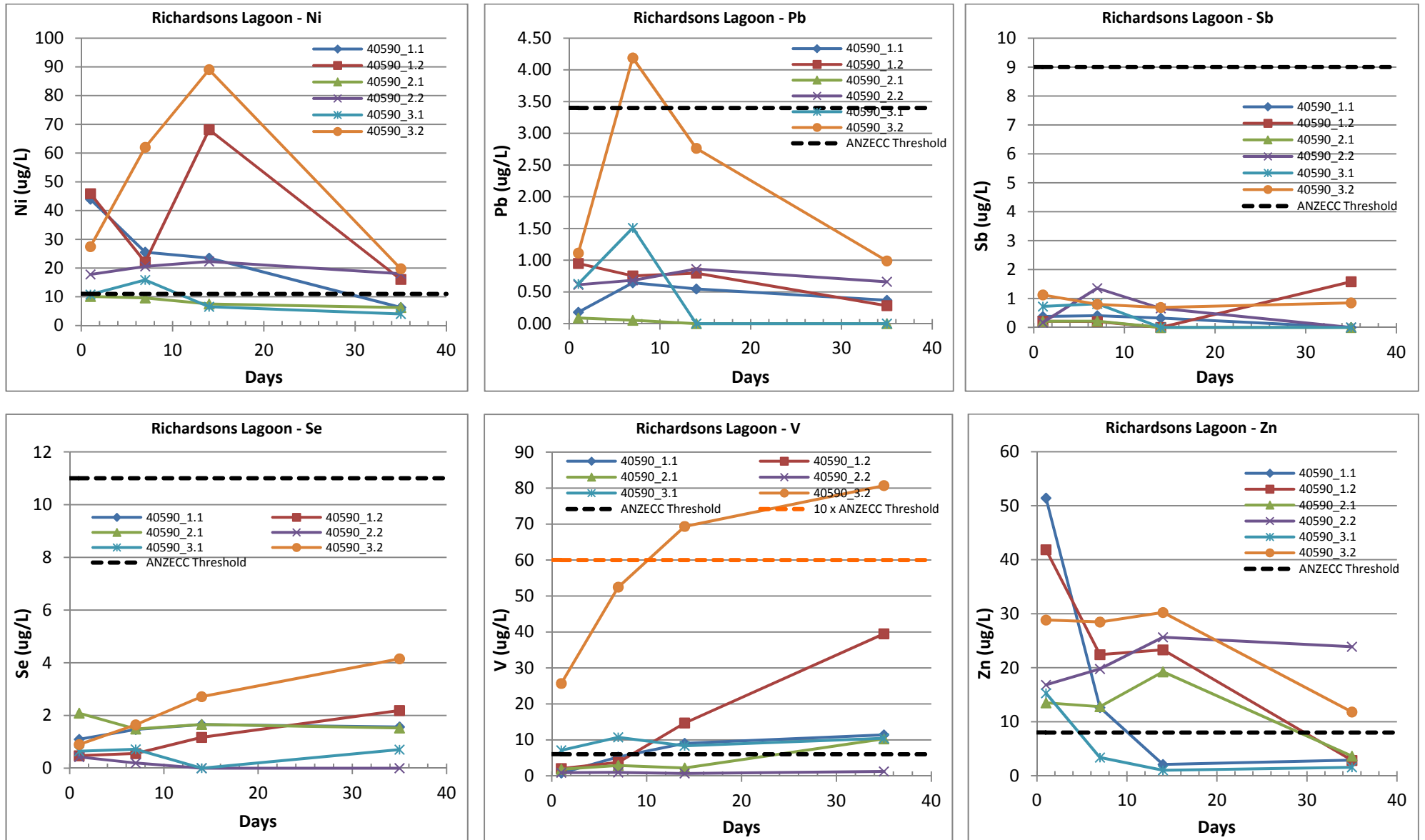


Figure 4 - Contaminant and metalloid dynamics (Ni, Pb, Sb, Se, V and Zn) over 35 days for the Richardsons Lagoon sites (40590_1.1, 40590_1.2, 40590_2.1, 40590_2.2, 40590_3.1 and 40590_3.2).



3.1.3 Monosulfide formation potential data (MFP)

The monosulfide formation potential data following inundation for the two surface soil materials examined from the Richardsons Lagoon are presented in Appendix 1 (Tables A8-A10) and summarised below in Table 6.

Table 6 – Summary of monosulfide formation potential data for the Richardsons Lagoon surface soil materials following inundation.

Inundation Time	Parameter	Units	40590_1.1	40590_3.1
Day 0	pH	-	5.00	6.08
-	Eh	mV	397	382
Week 7	pH	-	5.24	5.36
-	Eh	mV	220	234
-	S _{AV}	Wt. %S	<0.01	<0.01
-	Elemental S	Wt. %S	0.01	<0.01
-	Pyrite-S	Wt. %S	<0.01	<0.01
-	Dissolved S ²⁻	µg/L	4286	329

The pH of the pore-waters was observed to both increase slightly (40590_1.1) and decrease (40590_3.1) over the seven week incubation period (refer to Figure 5 on the following page). The pH of the pore-waters after seven weeks of inundation ranged between 5.24 and 5.36. The decrease in pH is a consequence of some acidity being released from the soil materials during inundation and the pore-waters having little inherent buffering capacity. The increase in pH may be related to the slight decrease in oxic conditions.

A significant decrease in pore-water Eh was not observed during inundation, with the Eh of the pore-waters after seven weeks being ≥ 220 mV (refer to Figure 6 on following page). The Eh range of the porewaters following inundation indicates oxic conditions at the laboratory experiment scale. The acid volatile sulfide (S_{AV}) and elemental sulfur results indicate that monosulfide formation potential is low for the two surface soil samples analysed at Richardsons Lagoon. Both soil materials have results less than the analytical limit of reporting (LOR) i.e. ≤0.01 (Table 6) for all analytes with the exception of elemental sulfur at 40590_1.1. The small amount of elemental sulfur present in the sample after the seven week incubation (0.01 %S) may not indicate monosulfide formation and is likely related to the higher water soluble sulfate levels (SMEC 2010) within the sample.

A summary of reactive iron (Fe) and water soluble sulfate data for the Richardsons Lagoon surface soil materials is provided in Table 7 on the following page.

Figure 5 – pH dynamics during inundation for the Richardsons Lagoon soil materials.

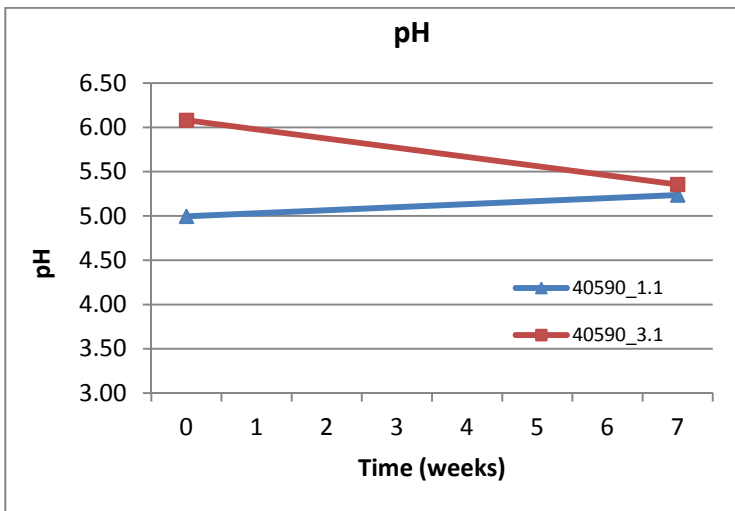


Figure 6 – Redox potential (Eh) dynamics during inundation for the Richardsons Lagoon soil materials.

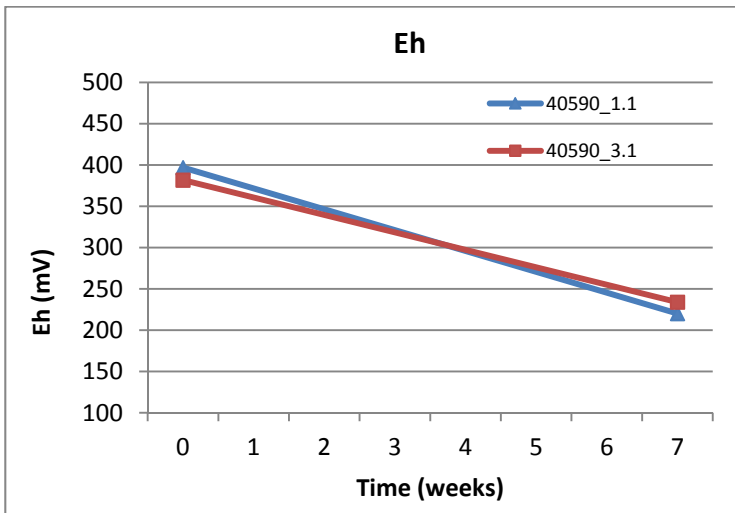


Table 7 – Summary of reactive iron and water soluble sulfate data for the Richardsons Lagoon surface soil materials.

Parameter	Units	40590_1.1	40590_3.1
Total Fe	mg/kg	9004	<i>i.s</i>
Fe(II)	mg/kg	2303	<i>i.s</i>
Sulfate*	mg/kg	2520	813

Notes:

* Data from Phase 1 assessment.

i.s. – insufficient sample volume.

3.2 Interpretation And Discussion Of Results

The contaminant and metalloid dynamics test undertaken as part of this Phase 2 assessment assists in determining the impacts on water quality by simulating the release of metal and metalloid concentrations that may occur under anaerobic conditions over a five week period (35 days). The contaminant and metalloid behaviour of the six Richardsons Lagoon soil materials during the 35 day inundation showed that some of the metals (i.e. silver (Ag), cadmium (Cd) and zinc (Zn)), showed a maximum concentration after 24 hours of inundation indicating that dissolution may control their release/mobility in the early stages of inundation. The remaining metals/metalloids may be controlled by redox processes with arsenic (As) and iron (Fe) providing the most recognisable increases in release/mobility of the 35 day experiment (refer to Figures 2 and 3).

Under the experimental laboratory conditions, 13 of the 15 of the metals examined i.e. silver (Ag), aluminium (Al), arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), vanadium (V) and zinc (Zn) were found to exceed the ANZECC water quality guidelines during inundation (Table 5). The guidelines for aluminium (Al), cobalt (Co), chromium (Cr), iron (Fe) and vanadium (V) were exceeded by more than 10 times with one or more soil materials at 5 sites at Richardsons Lagoon. The guideline for iron (Fe) was exceeded by more than 100 times in the surface soil material (i.e. 0-10 cm) at site 40590_1 and 40590_3.

While the contaminant and metalloid dynamics test gives an indication of the metal/metalloid content of the surface soil, the overlying water column will rarely have the concentration measured in solution during this test due to dilution in the receiving waters. It can therefore be assumed that if a metal/metalloid concentration did not exceed the ANZECC guideline during the contaminant and metalloid dynamics (CMD) test it does not represent a significant environmental hazard.

The ANZECC guideline thresholds for the degree of hazard associated with the contaminant and metalloid concentrations and a summary of the degree of hazard each of the metals/metalloids pose at the sites examined at Richardsons Lagoon is given in Table 8 and Table 9. Note the background colours presented in Table 5 also correspond to the degree of hazard (i.e. no colour (no hazard), yellow (low hazard), orange (moderate hazard) and red (high hazard)). Table 11 on the following pages provides a summary of the potential hazards posed by acid sulfate soil materials in the Richardsons Lagoon from the Phase 1 assessment (SMEC 2010).

Two metals were found to not pose a significant hazard after inundation (antimony (Sb) and selenium (Se)). Eight metals were found to exceed the ANZECC water quality guidelines during inundation and represent a low hazard (silver (Ag), arsenic (As), cadmium (Cd), copper (Cu), manganese (Mn), nickel (Ni), lead (Pb), zinc (Zn)). Four metals were found to exceed the ANZECC water quality guidelines during inundation and represent a moderate hazard (aluminium (Al), cobalt (Co), chromium (Cr) and vanadium (V)). One metal iron (Fe) was found to exceed the ANZECC water quality guidelines during inundation and represent a high hazard. Five metals (i.e. cobalt (Co), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn)) were found to be a hazard (above ANZECC threshold) at all sites sampled and analysed for Phase 2 analysis for the contaminant and metalloid dynamics (CMD) test.

The highest and moderate hazard metalloid concentrations were typically encountered in surface soils (0-10cm) collected from the lowest point sampling sites within Richardsons Lagoon. Although aluminium (Al) is considered a moderate hazard based on this test, it comes with the assumption of aluminium (Al) being soluble at pH > 5.50 which is unlikely. If an inundation event occurred, the input waters are likely to have a pH greater than pH 5.50. No surface or pore-water was evident at Richardsons Lagoon during the Phase 1 assessment (SMEC 2010) to assess current water quality.

The reactive metals data for the Richardsons Lagoon soil materials showed all metals/metalloids were $\leq 33\%$ of the ANZECC Sediment Quality trigger value for the total metal/metalloid concentration (see Table A10, Appendix 1).

During the monosulfide formation potential (MFP) test, the pH of the pore-waters was observed to both increase and decrease slightly over the seven week incubation period (refer to Figure 5). A significant decrease in pore-water Eh was not observed during inundation, with the Eh of the pore-waters after seven weeks being ≥ 220 mV (refer to Figure 1). The Eh range of the pore-waters following inundation indicates oxic conditions at the laboratory scale.

The acid volatile sulfide (S_{AV}) and elemental sulfur results indicate that monosulfide formation potential is low for the two surface soil samples analysed at Richardsons Lagoon. Both soil materials have results less than the analytical limit of reporting (LOR) i.e. ≤ 0.01 with the exception of elemental sulfur at 40590_1.1. The degree of hazard associated with acid volatile sulfide (S_{AV}) analysis is given in Table 10 on the following pages. The results indicate that there is typically no hazard or a low hazard (elemental sulfur) associated with acid volatile sulfide (S_{AV}) concentrations for Richardsons Lagoon soil materials analysed.

Table 8 – Summary of the degree of hazard associated with the measured contaminant and metalloid concentrations in the Richardsons Lagoon.

Degree of Hazard	Guideline Threshold	Metal/Metalloid
No Hazard	Value below ANZECC guideline threshold.	Sb, Se
Low Hazard	Value exceeds ANZECC guideline threshold, but is less than 10x exceedance.	Ag, As, Cd, Cu, Mn, Ni, Pb, Zn
Moderate Hazard	Value exceeds ANZECC guideline threshold by 10x or more, but is less than 100x exceedance.	Al*, Co, Cr, V
High Hazard	Value exceeds ANZECC guideline threshold by 100x or more.	Fe

* Based on aluminium being soluble – at pH > 5.5 this is unlikely.

Table 9 – Summary of the degree of hazard associated with the measured contaminant and metalloid concentrations in the wetland at each site.

Wetland (site)	Degree of Hazard			
	No Hazard	Low Hazard	Moderate Hazard	High hazard
-				
Richardsons Lagoon: 40590_1.1	Al*, Pb, Sb, Se	Ag, As, Cd, Cr, Cu, Mn, Ni, V, Zn	Co	Fe
Richardsons Lagoon: 40590_1.2	Ag, Pb, Sb, Se	Al*, As, Cd, Cu, Mn, Ni, V, Zn	Co, Cr, Fe	-
Richardsons Lagoon: 40590_2.1	Ag, Al*, As, Cd, Ni, Pb, Sb, Se	Co, Cr, Cu, Mn, V, Zn	Fe	-
Richardsons Lagoon: 40590_2.2	As, Cd, Cr, Pb, Sb, Se, V	Ag, Al*, Co, Cu, Fe, Mn, Ni, Zn	-	-
Richardsons Lagoon: 40590_3.1	Ag, Cd, Pb, Sb, Se	As, Co, Cr, Cu, Mn, Ni, V, Zn	Al*, Fe	-
Richardsons Lagoon: 40590_3.2	Sb, Se	Ag, As, Cd, Cu, Mn, Ni, Pb, Zn	Al*, Co, Cr, V	Fe

* Based on aluminium being soluble – at pH > 5.5 this is unlikely.

Table 10 – Guideline thresholds for the degree of hazard associated with acid volatile sulfide (S_{AV}) concentrations.

Degree of Hazard	Guideline Threshold for S_{AV}
No Hazard	< 0.01% S_{AV}
Low Hazard	0.01% S_{AV}
Moderate Hazard	>0.01% – 0.05% S_{AV}
High Hazard	≥ 0.05% S_{AV}

Table 11 – Summary of the potential hazards (from Phase 1 analyses) posed by acid sulfate soil materials in the Richardsons Lagoon, from SMEC (2010).

Wetland Name	Hazard Type and Class (Phase 1 assessment)		
	Acidification	De-oxygenation	Metal Mobilisation
-			
Richardsons Lagoon	Medium	Medium	Medium

4 RISK ASSESSMENT

4.1 Risk Assessment Framework

Risk is a measure of both the consequences of a hazard occurring, and the likelihood of its occurrence (MDBA 2011). According to the National Environment Protection Measures (NEPM), risk is defined as "*the probability in a certain timeframe that an adverse outcome will occur in a person, a group of people, plants, animals and/or the ecology of a specified area that is exposed to a particular dose or concentration of a hazardous agent, i.e. it depends on both the level of toxicity of hazardous agent and the level of exposure*" (NEPC 1999).

In this study a risk assessment framework has been applied to determine the specific risks associated with acidification, contaminant mobilisation and de-oxygenation. In this risk assessment framework a series of standardised tables are used to define and assess risk (MDBA 2011). The tables determine the consequence of a hazard occurring (Table 12), and a likelihood rating for the disturbance scenario for each hazard (Table 13). These two factors are then combined in a risk assessment matrix to determine the level of risk (Table 14).

Table 12 determines the level of consequence of a hazard occurring, ranging from insignificant to extreme, and primarily takes account of the environmental and water quality impacts, to the wetland values and/or adjacent waters.

Table 12 – Standardised table used to determine the consequences of a hazard occurring, from MDBA (2011).

Descriptor	Definition
Extreme	Irreversible damage to wetland environmental values and/or adjacent waters; localised species extinction; permanent loss of drinking water (including stock and domestic) supplies.
Major	Long-term damage to wetland environmental values and/or adjacent waters; significant impacts on listed species; significant impacts on drinking water (including stock and domestic) supplies.
Moderate	Short-term damage to wetland environmental values and/or adjacent waters; short-term impacts on species and/or drinking water (including stock and domestic) supplies.
Minor	Localised short-term damage to wetland environmental values and/or adjacent waters; temporary loss of drinking water (including stock and domestic) supplies.
Insignificant	Negligible impact on wetland environmental values and/or adjacent waters; no detectable impacts on species.

Table 13 determines the likelihood (i.e. probability) of disturbance for each hazard, ranging from rare to almost certain. This requires an understanding of the nature and severity of the materials (including the extent of the acid sulfate soil materials, the acid generating potential and the buffering capacity of wetland soil materials) as well as contributing factors influencing the risk (MDBA 2011). Examples of disturbance include: (i) rewetting of acid sulfate soil materials after oxidation, (ii) acid sulfate soil materials that are currently inundated and may be oxidised, or (iii) acid sulfate soil materials that are currently inundated and may be dispersed by flushing (e.g. scouring flows) (MDBA 2011). As mentioned previously, the consequence of a hazard occurring and the likelihood rating for the disturbance scenario for each hazard are then ranked using a standardised risk assessment matrix (Table 14).

Table 13 – Likelihood ratings for the disturbance scenario, from MDBA (2011).

Descriptor	Definition
Almost certain	Disturbance is expected to occur in most circumstances.
Likely	Disturbance will probably occur in most circumstances.
Possible	Disturbance might occur at some time.
Unlikely	Disturbance could occur at some time.
Rare	Disturbance may occur only in exceptional circumstances.

Table 14 – Risk assessment matrix, adapted from Standards Australia & Standards New Zealand (2004).

Likelihood Category	Consequences Category				
	Extreme	Major	Moderate	Minor	Insignificant
-					
Almost certain	Very High	Very High	High	Medium	Low
Likely	Very High	High	Medium	Medium	Low
Possible	High	High	Medium	Low	Low
Unlikely	High	Medium	Medium	Low	Very low
Rare	High	Medium	Low	Very low	Very low

Table Legend:

Very High: immediate action is recommended.

High: senior management attention is probably needed.

Medium: management action may be recommended.

Low or very low: routine condition monitoring is suggested.

These categories of management responses have been kept quite broad to acknowledge that jurisdictional authorities and wetland managers may choose to adopt different approaches in dealing with acid sulfate soils. The imprecise nature of these management responses is intended to provide flexibility in jurisdictional and wetland manager responses to the risk ratings associated with the acid sulfate soil hazards (MDBA 2011).

4.2 Assessment Of Risks

4.2.1 Risks Associated With Acidification

The Phase 1 assessment (SMEC 2010) identified a medium level of concern based on the high net acidities, low sulfidic results (from S_{CR}) and soil types present (i.e. clay based, fine grained). The degree of further acidification potential from sulfidic sources appeared to be low to medium for surface soils and subsoils that exhibited $pH_{incubation}$ results less than and near pH 4.00. The wetland is already considered to be acidic to slightly acidic based on current soil and water pH results from the Phase 1 assessment.

The Phase 2 assessment did not identify acid volatile sulfide and only minor elemental sulfur from the 7 week inundation experiment (monosulfide formation potential test). The pH of the pore-waters after seven weeks of inundation ranged between 5.24 and 5.36 during the monosulfide formation potential test. The slight decrease in pH for one sample is a consequence of some acidity being released from the soil materials during inundation and the pore-waters having little buffering capacity, while the slight increase in pH for the other sample may have resulted from reduction processes. The pH of the majority of samples during the contaminant and metalloid dynamics (CMD) test increased by approximately 1.5 – 2.0 pH unit at the 35 day (5 week) analysis.

The acidification hazard at Richardsons Lagoon is considered to present a **Moderate Consequence** (i.e. Short-term damage to wetland environmental values and/or adjacent waters; short-term impacts on species and/or drinking water (including stock and domestic) supplies). The likelihood rating is considered **Possible** (i.e. Disturbance might occur at some time). The disturbance mechanism would relate to an inundation event that filled the wetland and either did not provide flow or a high enough dilution factor to buffer the already low soil pH values for the wetland. Therefore there is a **Medium Risk** associated with acidification at Richardsons Lagoon and management action may be required.

4.2.2 Risks Associated With Contaminant Mobilisation

The contaminant and metalloid dynamics experiment showed that the ANZECC water quality guidelines were exceeded for many of the metals/metalloids. The reactive metals experiment did not exceed the ANZECC sediment quality thresholds. From a water and sediment quality perspective for Richardsons Lagoon, the release of iron (Fe) from the soils appears to be the greatest concern with regards to ANZECC threshold levels. Other metals/metalloids of concern at Richardsons Lagoon include mobilisation of aluminium (Al), cobalt (Co) and chromium (Cr).

Some of the metals (i.e. silver (Ag), cadmium (Cd) and zinc (Zn)), predominantly with the surface soils, showed a maximum concentration after 24 hours of inundation indicating that dissolution may control their release/mobility in the early stages of inundation. The release of the majority of metals/metalloids at Richardsons Lagoon may be controlled by redox processes with arsenic (As) and iron (Fe) providing the most recognisable increases in release/mobility of the 35 day experiment. Aluminium (Al) and cadmium (Cd) were largely released within 14 days of inundation while arsenic (As) and iron (Fe) increased in concentration typically as the experiment proceeded to the 35 day limit.

The degree of hazard that these soils pose to the wetland values and environment, would largely depend on the amount of contaminant dilution and release that occurs in the wetland and receiving waters (Murray River). If insufficient dilution or flow was to occur, there is a **Moderate** consequence of a contaminant mobilisation hazard occurring (i.e. Short-term damage to wetland environmental values and/or adjacent waters; short-term impacts on species and/or drinking water (including stock and domestic) supplies). The medium acidification risk also adds weight to this occurring under certain inundation scenarios such as low volume/high frequency events. This may be counteracted by the fine grained nature of the soils at Richardsons Lagoon (clays) which may not release contaminants (metals/metalloids) if a deep water column is present during an inundation event. A disturbance scenario is **Likely** (i.e. Disturbance will probably occur in most circumstances). Therefore there is a **Medium Risk** associated with contaminant mobilisation at Richardsons Lagoon and management action may be required.

4.2.3 Risks Associated With De-Oxygenation

Monosulfidic soil materials pose a de-oxygenation hazard if disturbed. The monosulfide formation potential experimental tests undertaken as part of the Phase 2 assessment for Richardsons Lagoon did not show monosulfide formation within seven weeks. Sample 40590_1.1 did show an elemental sulfur concentration of 0.01% S, however this may be due higher water soluble sulfate levels in the sample of 2,520 mg/kg (SMEC 2010). The presence of monosulfidic soil materials was not identified throughout the Richardsons Lagoon during the Phase 1 assessment (SMEC 2010). No surface water was present at the wetland during the Phase 1 assessment.

Water soluble sulfate for all surface soil materials collected during the Phase 1 assessment (4 in total) were typically ≤ 860 mg/kg with the exception of sample 40590_1.1 noted above. These water soluble sulfate concentrations are lower than encountered at other sites within the Northern Victoria Region that contained confirmed monosulfidic black ooze materials or potential monosulfidic black ooze materials currently in formation with inundation (i.e. Richardson River and

Wimmera River). All four surface soil materials were however exceeding the 100 mg/kg trigger value for monosulfide formation potential during the Phase 1 Assessment (SMEC 2010).

The data from the Phase 2 assessment indicates that there is a low potential for monosulfide formation under experimental laboratory conditions. Prolonged wet conditions within Richardsons Lagoon (via inundation) may however provide conditions that promote the formation of monosulfides if organic matter, neutral pH levels and increased iron and sulfate concentrations were to occur over a longer time period.

The findings of this study therefore indicate that the de-oxygenation hazard would present a “negligible impact on wetland environmental values and/or adjacent waters; no detectable impacts on species” (i.e. **Insignificant** consequence of hazard occurring). The likelihood of disturbance at the wetland is considered **Possible** (disturbance might occur at some time) although the lack of monosulfidic black ooze formation does not give this likelihood rating a high weighting in the risk assessment.

As both the Phase 1 and 2 assessments do not indicate current monosulfide formation or potential monosulfide formation, there is a **Low Risk** and routine monitoring is suggested for Richardsons Lagoon.

5 BROAD ACID SULFATE SOIL MANAGEMENT OPTIONS

The specific risks and concerns regarding management of Richardsons Lagoon include a medium risk of acidification and contaminant mobilisation after or during inundation. These risks relate to the inundation of surface soil materials and resultant potential for chemical changes to water quality that could impact wetland species and receiving waters.

Due to the lack of acid sulfate soils and monosulfidic black ooze identified at Richardsons Lagoon from the Phase 1 and 2 assessments carried out, the principal management options should currently be to ensure minimisation of the potential for further acid sulfate soil formation in wetland sediments. This could largely be managed by flow regimes and wetland water management. Due to the current acidic nature of soil materials at Richardsons Lagoon, any future inundation should be carefully managed to ensure sufficient dilution is available for the currently low pH and metal/metalloid concentrations in soil materials. This availability for dilution may be feasible with the Murray River near to Richardsons Lagoon.

Due to the medium risk for acidification and metal release at Richardsons Lagoon, any inundation management decisions may require additional field trials using in situ materials and monitoring with comparison to this Phase 2 assessment small scale laboratory experiments. The cost of this may be high and the wetland manager should provide input in regards the environmental value of the wetland prior to decision making.

Although soil salinity levels (including water soluble sulfate) at Richardsons Lagoon appear to be moderate to high, groundwater in the region may contribute to higher salinity levels if water tables rose in response to inundation events. A management aim for Richardsons Lagoon should be to ensure that salinity levels do not increase and provide a source of sulfate for acid sulfate soil formation. The wetland soils and water also have a low buffering capacity to buffer acidity present in soils and pore-water (SMEC 2010). This lack of buffering capacity presents a higher acidification risk during inundation where acidity could build up where low dilution and other geochemical conditions occur.

Some broad management options specifically related to Richardsons Lagoon and based on the Phase 1 and 2 assessments are provided in Table 15.

Table 15 – Broad Management Options for Richardsons Lagoon.

Management Issue	Management Options	Advantages	Disadvantages
Preventing Acidification	<ul style="list-style-type: none"> ▪ Trial inundation event with Murray River water to portions of the wetland to assess conditions and response. ▪ Complete high volume inundation with water column $\geq 1.0\text{m}$ depth. ▪ Avoid low volume low frequency inundation flow regimes. 	<ul style="list-style-type: none"> ▪ Assess response to small scale inundation event to portion of wetland will provide greater certainty to water regime management decisions. ▪ Lower cost for management of acidification. 	<ul style="list-style-type: none"> ▪ Trail inundation may reduce water levels in Murray River for short period. ▪ Water inundation may provide conditions suitable for reduction of sulfate to sulfide in sediments over longer timeframes.
Contaminant Mobilisation	<ul style="list-style-type: none"> ▪ Trial inundation event with Murray River water to portions of the wetland to assess conditions and response. ▪ Aim to dilute inundation events so that surface water pH is ≥ 6.50. ▪ Neutralise surface water. 	<ul style="list-style-type: none"> ▪ Assess response to small scale inundation event to portion of wetland will provide greater certainty to water regime management decisions. ▪ Neutralisation will increase pH levels and lower propensity for metals mobilisation. 	<ul style="list-style-type: none"> ▪ Trail inundation may reduce water levels in Murray River or feeder channels for short period. ▪ Neutralisation of surface water will incur costs for machinery and materials.
Preventing Salinisation	<ul style="list-style-type: none"> ▪ Keep irrigation return water out of wetland. ▪ Lower any potential for saline water day lighting into wetland. ▪ Maintain freshwater system. 	<ul style="list-style-type: none"> ▪ Reduces formation of ASS sediments. ▪ Limits damage/distress to aquatic ecosystem. 	<ul style="list-style-type: none"> ▪ Will require monitoring for salinity (costs). ▪ Restrict irrigation return water zone (if applicable to wetland)
Buffering Capacity	<ul style="list-style-type: none"> ▪ Increase buffering capacity of surface sediments with organic matter or ameliorants. ▪ Use stored alkalinity in the ecosystem (if available). 	<ul style="list-style-type: none"> ▪ Increases buffering capacity to wetland system. ▪ Increases wetland ability to cope with acidity spikes. 	<ul style="list-style-type: none"> ▪ High cost of dosing and ameliorant. ▪ May reduce carbonates in system for species that require shell i.e. Freshwater mussel.

5.1 National Inland Acid Sulfate Soil Guidance

A national guidance document on the management of inland acid sulfate soil landscapes has been produced titled “*National guidance for the management of acid sulfate soils in inland aquatic ecosystems*” (EPHC & NRMCC 2011). The national guidance document provides a hierarchy of management options for managing acid sulfate soils in inland aquatic ecosystems including:

1. Minimising the formation of acid sulfate soils in inland aquatic ecosystems.
2. Preventing oxidation of acid sulfate soils, if they are already present in quantities of concern or controlled oxidation to remove acid sulfate soils if levels are a concern but the water and soil has adequate neutralising capacity.
3. Controlling or treating acidification if oxidation of acid sulfate soils does occur.
4. Protecting connected aquatic ecosystems/other parts of the environment if treatment of the directly affected aquatic ecosystem is not feasible.

In some instances it may not be practical or even sensible to undertake any active intervention (for example in a pond used as part of a salt interception scheme), in which case the management objective is:

5. Limited further intervention.

The possible activities associated with each management objective is summarised in Table 16. Further information on each management option is provided in detail in the national guidance document.

Table 16 – Summary of management options and possible activities, from EPHC & NRMMC (2011).

Management Objective	Activities
Minimising the formation of acid sulfate soils in inland aquatic ecosystems.	<p>Reduce secondary salinisation through:</p> <ul style="list-style-type: none"> ▪ Lowering saline water tables. ▪ Maintaining the freshwater lens between saline groundwater and the aquatic ecosystem. ▪ Stopping the delivery of irrigation return water. ▪ Incorporating a more natural flow regime.
Preventing oxidation of acid sulphate soils or controlled oxidation to remove acid sulfate soils.	<p>Preventing oxidation:</p> <ul style="list-style-type: none"> ▪ Keep the sediments covered by water. ▪ Avoid flow regimes that could re-suspend sediments. <p>Controlled oxidation:</p> <ul style="list-style-type: none"> ▪ Assess whether neutralising capacity of the sediments and water far exceeds the acidity produced by oxidation. ▪ Assess the risk of de-oxygenation and metal release. Monitor intervention and have a contingency plan to ensure avoidance of these risks.
Controlling or treating acidification.	<ul style="list-style-type: none"> ▪ Neutralise water column and/or sediments by adding chemical ameliorants. ▪ Add organic matter to promote bioremediation by micro-organisms. ▪ Use stored alkalinity in the ecosystem.
Protecting adjacent or downstream environments if treatment of the affected aquatic ecosystem is not feasible.	<ul style="list-style-type: none"> ▪ Isolate the site. ▪ Neutralise and dilute surface water. ▪ Treat discharge waters by neutralisation or biological treatment.
Limited further intervention.	<ul style="list-style-type: none"> ▪ Assess risk. ▪ Communicate with stakeholders. ▪ Undertake monitoring. ▪ Assess responsibilities and obligations and take action as required.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary Of Key Findings And Outcomes

Phase 2 investigations were carried out on six (6) selected samples from high priority sites identified in the Phase 1 assessment. Soil samples identified to undergo Phase 2 laboratory analysis are primarily from the surface layer, as this is the soil most likely to have initial contact with water.

The contaminant and metalloid behaviour of the six Richardsons Lagoon soil materials during the 35 day inundation showed that some of the metals (i.e. silver (Ag), cadmium (Cd) and zinc (Zn)), showed a maximum concentration after 24 hours of inundation indicating that dissolution may control their release/mobility in the early stages of inundation. The remaining metals/metalloids may be controlled by redox processes.

Under the experimental laboratory conditions, 13 of the 15 of the metals examined (i.e. silver (Ag), aluminium (Al), arsenic (As), cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), vanadium (V) and zinc (Zn)) were found to exceed the ANZECC water quality guidelines during inundation. While the contaminant and metalloid dynamics test gives an indication of the metal/metalloid content of the surface soil, the overlying water column will rarely have the concentration measured in solution during this test due to dilution in the receiving waters. The hazards that these metals/metalloids represent based on exceedance of ANZECC water quality guidelines for environmental protection are:

- No significant hazard after inundation – antimony (Sb) and selenium (Se).
- Low hazard – silver (Ag), arsenic (As), cadmium (Cd), copper (Cu), manganese (Mn), nickel (Ni), lead (Pb), zinc (Zn).
- Moderate hazard – aluminium (Al), cobalt (Co), chromium (Cr), vanadium (V).
- High hazard – iron (Fe).
- Five metals i.e. cobalt (Co), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) were found to be a hazard at all sites sampled.

The reactive metals data for the Richardsons Lagoon soil materials showed all metals/metalloids were $\leq 33\%$ of the ANZECC Sediment Quality trigger value for the total metal/metalloid concentration.

The acid volatile sulfide (S_{AV}) and elemental sulfur results indicate that monosulfide formation potential is a no to low hazard for the two surface soil samples analysed at Richardsons Lagoon. One sample (40590_1.1) did contain an elemental sulfur concentration of 0.01%S. The results indicate that there is no significant hazard associated with monosulfide formation potential.

The acidification hazard at Richardsons Lagoon is considered to present a **Moderate** consequence and the likelihood rating is considered **Possible**. Therefore there is a **Medium Risk** associated with acidification at Richardsons Lagoon and management action may be required.

The contaminant mobilisation hazard at Richardsons Lagoon is considered to present a **Moderate** consequence and the likelihood rating is considered **Likely**. Therefore there is a **Medium Risk** associated with contaminant mobilisation at Richardsons Lagoon and management action may be required.

The monosulfide formation potential hazard at Richardsons Lagoon is considered to present an **Insignificant** consequence and the likelihood rating is considered **Possible**. Therefore there is a **Low Risk** of deoxygenation associated with monosulfide formation potential and routine monitoring is suggested for Richardsons Lagoon.

6.2 Assumptions Used And Uncertainties

The Phase 2 assessment results are subject to the following assumptions and uncertainties regarding the data and interpretation:

- Richardsons Lagoon may have flooded since Phase 1 assessment (sampling carried out in April 2010) or received increased water inputs. This may have changed the geochemical conditions of surface water and sub soils at the wetland when compared to current conditions or preceding conditions since sampling occurred.
- The contaminant and metalloid dynamics (CMD) data is often only from one or several discrete sites which may not represent the whole wetland.
- Soil materials that were analysed using the contaminant and metalloid dynamics (CMD) test may release greater metal concentrations at lower pH levels if they were to occur at a wetland scale.
- The degree of hazard and risk is based on an interpretation of wetland values and data provided in this Phase 2 assessment. Wetland managers may have additional “local” information that could change the risk profile generated from this assessment.

6.3 Recommendations For Monitoring And Further Work

SMEC recommends, based on the results of this Phase 2 assessment:

- The acidification and contaminant mobilisation risk at Richardsons Lagoon may require management action in regards to water flow regimes and inundation for environmental flows.
- The deoxygenation risk from monosulfidie formation potential at Richardsons Lagoon requires routine monitoring in regards to water flow regimes and inundation for environmental flows.

Further monitoring and work for Richardsons Lagoon would include:

- Water quality monitoring at surface water locations throughout the wetland (where water is present).
- Soil pH monitoring for surface and sub soils within the central wetland channel.
- Training of wetland managers and monitoring officers in regards to acid sulfate soil formation, identification and management.
- Visual assessment by trained wetland managers on a periodic basis of the wetland in regards to issues associated with acid sulfate soil formation.

The monitoring could be conducted and reported by local Catchment Management Authorities (CMA's) on a periodic basis for interpretation in regards to the degree of hazard and risk to wetland values.

6.4 Recommendations For Management

Broad management recommendations have been provided in Table 15 for Richardsons Lagoon based on the Phase 2 assessment data and degree of hazard and risk present. The national guidance document on the management of inland acid sulfate soil landscapes (EPHC & NRMCC 2011) should be used to provide on-going management options for managing acid sulfate soils at Richardsons Lagoon.

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APPENDIX 1: SOIL ANALYTICAL DATA

Table A-1. Sample 40590_1.1 contaminant and metalloid dynamics data. (The values in red text outside the relevant water quality guideline).

Parameter	units	ANZECC Guidelines	40590_1.1							
			24 Hours		7 Days		14 Days		35 Days	
			Av.	±	Av.	±	Av.	±	Av.	±
-	-	-								
pH	-	6.5-8.0	4.84	0.15	6.07	0.13	6.55	0.13	6.92	0.19
EC	µS cm ⁻¹	125-2200*	551.50	81.50	341.50	37.50	855.00	4.00	718.50	70.50
Eh	mV		452.55	14.85	302.70	81.60	249.95	31.05	131.25	29.35
Ag	µg/L	0.05	0.05	0.02	0.01	0.01	0.00	0.00	0.00	0.00
Al ^A	mg/L	0.055	0.03	0.01	0.03	0.01	0.01	0.00	0.04	0.02
As ^B	µg/L	13	0.94	0.06	6.62	0.78	15.68	1.70	28.38	5.77
Cd	µg/L	0.2	0.57	0.20	0.07	0.02	0.00	0.00	0.00	0.00
Co	µg/L	2.8	54.40	19.41	31.39	4.64	29.64	11.47	7.95	6.02
Cr ^C	µg/L	1	1.12	0.01	1.86	0.09	2.20	0.08	3.42	0.28
Cu ^H	µg/L	1.4	3.28	0.03	2.43	0.08	2.03	0.33	0.89	0.11
Fe	mg/L	0.3	1.18	0.48	15.73	0.16	49.74	7.25	28.83	4.96
Mn	mg/L	1.7	9.83	3.27	5.08	0.77	6.57	0.01	4.23	1.01
Ni ^H	µg/L	11	43.95	16.26	25.52	3.72	23.47	10.89	6.28	1.62
Pb ^H	µg/L	3.4	0.18	0.03	0.64	0.04	0.55	0.55	0.37	0.37
Sb	µg/L	9	0.38	0.03	0.41	0.08	0.32	0.32	0.00	0.00
Se	µg/L	11	1.10	0.03	1.47	0.03	1.65	0.00	1.57	0.34
V	µg/L	6	0.77	0.04	5.24	1.04	9.05	0.64	11.40	3.49
Zn ^H	µg/L	8	51.43	16.71	12.63	7.29	2.09	0.46	2.89	1.95

Notes:

The ANZECC guideline values for toxicants refer to the Ecosystem Protection – Freshwater Guideline for protection of 95% of biota in 'slightly-moderately disturbed' systems, as outlined in the Australian Water Quality Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000).

* ANZECC water quality guidelines for freshwater lowland rivers in South-east Australia are provided for salinity (there are currently no trigger values defined for 'Wetlands').

Values outside the ranges defined in the ANZECC guidelines are indicated with red text.

The deviation from the mean is represented by '±'.

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

^B Guideline assumes arsenic in solution as Arsenic (AsV).

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

^H Hardness affected (refer to Guidelines).

Table A-2. Sample 40590_1.2 contaminant and metalloid dynamics data. (The values in red text outside the relevant water quality guideline).

Parameter	units	ANZECC Guidelines	40590_1.2							
			24 Hours		7 Days		14 Days		35 Days	
-	-	-	Av.	±	Av.	±	Av.	±	Av.	±
pH	-	6.5-8.0	4.27	0.08	5.24	0.51	5.90	0.17	6.56	0.06
EC	µS cm ⁻¹	125-2200*	329.50	63.50	288.00	14.00	824.50	53.50	492.00	1.00
Eh	mV		450.85	9.65	268.45	38.05	255.15	1.05	149.40	17.50
Ag	µg/L	0.05	0.04	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Al ^A	mg/L	0.055	0.17	0.04	0.11	0.03	0.11	0.01	0.11	0.00
As ^B	µg/L	13	0.75	0.07	4.81	0.35	10.45	0.37	32.86	6.57
Cd	µg/L	0.2	0.44	0.06	0.11	0.09	0.00	0.00	0.00	0.00
Co	µg/L	2.8	36.10	0.37	16.15	0.90	46.72	4.08	4.73	1.99
Cr ^C	µg/L	1	2.19	0.20	2.06	0.83	5.85	0.54	12.43	1.07
Cu ^H	µg/L	1.4	3.32	0.34	1.78	0.20	3.13	0.26	2.59	0.32
Fe	mg/L	0.3	0.23	0.01	6.22	4.77	24.66	1.09	21.23	5.70
Mn	mg/L	1.7	5.62	0.10	2.66	0.33	5.44	0.04	3.40	0.18
Ni ^H	µg/L	11	45.89	1.08	22.08	0.49	68.15	9.40	16.06	1.12
Pb ^H	µg/L	3.4	0.95	0.22	0.75	0.23	0.80	0.03	0.28	0.28
Sb	µg/L	9	0.21	0.01	0.20	0.13	0.00	0.00	1.58	0.92
Se	µg/L	11	0.47	0.05	0.55	0.26	1.17	0.28	2.19	0.30
V	µg/L	6	2.03	0.35	3.76	0.74	14.69	0.92	39.49	0.99
Zn ^H	µg/L	8	41.86	0.03	22.43	6.29	23.31	14.61	2.84	1.82

Notes:

The ANZECC guideline values for toxicants refer to the Ecosystem Protection – Freshwater Guideline for protection of 95% of biota in 'slightly-moderately disturbed' systems, as outlined in the Australian Water Quality Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000).

* ANZECC water quality guidelines for freshwater lowland rivers in South-east Australia are provided for salinity (there are currently no trigger values defined for 'Wetlands').

Values outside the ranges defined in the ANZECC guidelines are indicated with red text.

The deviation from the mean is represented by '±'.

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

^B Guideline assumes arsenic in solution as Arsenic (AsV).

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

^H Hardness affected (refer to Guidelines).

Table A-3. Sample 40590_2.1 contaminant and metalloid dynamics data. (The values in red text outside the relevant water quality guideline).

Parameter	units	ANZECC Guidelines	40590_2.1							
			24 Hours		7 Days		14 Days		35 Days	
-	-	-	Av.	±	Av.	±	Av.	±	Av.	±
pH	-	6.5-8.0	5.18	0.00	5.49	0.08	6.13	0.26	6.53	0.48
EC	µS cm ⁻¹	125-2200*	513	52	459	36.	892	38	580	80
Eh	mV		384	26	296	21	261	6	150	61
Ag	µg/L	0.05	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00
Al ^A	mg/L	0.055	0.01	0.00	0.02	0.01	0.01	0.00	0.01	0.00
As ^B	µg/L	13	1.05	0.03	1.01	0.02	1.06	0.10	9.55	6.49
Cd	µg/L	0.2	0.13	0.01	0.11	0.03	0.00	0.00	0.00	0.00
Co	µg/L	2.8	14.41	1.86	16.91	3.15	14.27	2.17	6.62	2.43
Cr ^C	µg/L	1	0.84	0.03	1.06	0.37	1.08	0.45	1.38	0.68
Cu ^H	µg/L	1.4	1.57	0.03	1.88	0.30	2.32	0.02	1.79	1.29
Fe	mg/L	0.3	0.13	0.01	0.21	0.01	0.16	0.01	4.71	4.04
Mn	mg/L	1.7	2.84	0.14	3.22	0.66	2.95	0.16	1.97	0.15
Ni ^H	µg/L	11	10.10	0.44	9.59	0.94	7.47	0.70	6.28	0.29
Pb ^H	µg/L	3.4	0.09	0.01	0.05	0.00	0.00	0.00	0.00	0.00
Sb	µg/L	9	0.21	0.01	0.22	0.07	0.00	0.00	0.00	0.00
Se	µg/L	11	2.09	0.07	1.49	0.24	1.66	0.11	1.53	0.14
V	µg/L	6	1.82	0.36	2.88	0.03	2.19	0.52	10.28	7.81
Zn ^H	µg/L	8	13.50	0.35	12.80	1.52	19.25	3.02	3.63	3.63

Notes:

The ANZECC guideline values for toxicants refer to the Ecosystem Protection – Freshwater Guideline for protection of 95% of biota in ‘slightly-moderately disturbed’ systems, as outlined in the Australian Water Quality Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000).

* ANZECC water quality guidelines for freshwater lowland rivers in South-east Australia are provided for salinity (there are currently no trigger values defined for ‘Wetlands’).

Values outside the ranges defined in the ANZECC guidelines are indicated with red text.

The deviation from the mean is represented by ‘±’.

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

^B Guideline assumes arsenic in solution as Arsenic (AsV).

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

^H Hardness affected (refer to Guidelines).

Table A-4. Sample 40590_2.2 contaminant and metalloid dynamics data. (The values in red text outside the relevant water quality guideline).

Parameter	units	ANZECC Guidelines	40590_2.2							
			24 Hours		7 Days		14 Days		35 Days	
			Av.	±	Av.	±	Av.	±	Av.	±
-	-	-	4.32	0.04	4.32	0.07	4.49	0.01	4.71	0.06
pH	-	6.5-8.0	4.32	0.04	4.32	0.07	4.49	0.01	4.71	0.06
EC	µS cm ⁻¹	125-2200*	228.10	37.70	231.25	21.75	440.50	34.50	338.00	4.00
Eh	mV		462.25	8.55	351.25	6.65	327.80	0.50	221.30	79.90
Ag	µg/L	0.05	0.03	0.00	0.09	0.09	0.00	0.00	0.00	0.00
Al ^A	mg/L	0.055	0.06	0.01	0.10	0.02	0.08	0.01	0.06	0.01
As ^B	µg/L	13	0.37	0.04	0.30	0.04	0.21	0.21	0.46	0.46
Cd	µg/L	0.2	0.17	0.02	0.19	0.03	0.00	0.00	0.00	0.00
Co	µg/L	2.8	11.97	1.33	17.04	2.55	20.95	1.08	21.05	0.13
Cr ^C	µg/L	1	0.89	0.02	0.85	0.07	0.78	0.02	0.90	0.10
Cu ^H	µg/L	1.4	0.98	0.07	1.09	0.07	1.25	0.04	1.69	0.18
Fe	mg/L	0.3	0.13	0.00	0.38	0.01	0.35	0.08	1.81	1.64
Mn	mg/L	1.7	1.93	0.24	2.18	0.25	2.29	0.13	1.76	0.10
Ni ^H	µg/L	11	17.79	2.15	20.57	2.67	22.29	1.60	18.05	0.31
Pb ^H	µg/L	3.4	0.61	0.09	0.68	0.12	0.86	0.03	0.66	0.08
Sb	µg/L	9	0.17	0.01	1.36	1.19	0.66	0.66	0.00	0.00
Se	µg/L	11	0.42	0.03	0.20	0.11	0.00	0.00	0.00	0.00
V	µg/L	6	0.86	0.09	0.95	0.07	0.67	0.03	1.22	0.25
Zn ^H	µg/L	8	16.82	1.65	19.78	2.70	25.64	0.94	23.89	2.55

Notes:

The ANZECC guideline values for toxicants refer to the Ecosystem Protection – Freshwater Guideline for protection of 95% of biota in ‘slightly-moderately disturbed’ systems, as outlined in the Australian Water Quality Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000).

* ANZECC water quality guidelines for freshwater lowland rivers in South-east Australia are provided for salinity (there are currently no trigger values defined for ‘Wetlands’).

Values outside the ranges defined in the ANZECC guidelines are indicated with red text.

The deviation from the mean is represented by ‘±’.

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

^B Guideline assumes arsenic in solution as Arsenic (AsV).

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

^H Hardness affected (refer to Guidelines).

Table A-5. Sample 40590_3.1 contaminant and metalloid dynamics data. (The values in red text outside the relevant water quality guideline).

Parameter	units	ANZECC Guidelines	40590_3.1							
			24 Hours		7 Days		14 Days		35 Days	
			Av.	±	Av.	±	Av.	±	Av.	±
pH		6.5-8.0	6.08	0.02	6.74	0.03	6.91	0.04	7.16	0.00
EC	µS cm ⁻¹	125-2200*	93.05	5.05	108.85	7.55	257.00	36.00	391.00	14.00
Eh	mV		415.55	0.65	286.05	80.25	239.35	4.35	134.50	21.90
Ag	µg/L	0.05	0.04	0.00	0.04	0.04	0.00	0.00	0.00	0.00
Al ^A	mg/L	0.055	0.29	0.04	0.85	0.10	0.04	0.01	0.02	0.01
As ^B	µg/L	13	2.14	0.21	5.69	0.63	10.62	0.16	37.11	3.21
Cd	µg/L	0.2	0.03	0.00	0.05	0.01	0.00	0.00	0.00	0.00
Co	µg/L	2.8	2.87	0.54	9.64	1.68	5.00	2.41	1.75	0.10
Cr ^C	µg/L	1	6.50	2.31	2.74	0.32	1.24	0.50	2.12	0.22
Cu ^H	µg/L	1.4	9.75	1.36	8.10	3.22	0.99	0.19	0.52	0.04
Fe	mg/L	0.3	0.79	0.14	3.30	0.54	11.23	0.32	18.09	3.76
Mn	mg/L	1.7	0.13	0.05	0.70	0.07	1.44	0.08	2.17	0.24
Ni ^H	µg/L	11	10.79	1.49	15.85	4.63	6.52	3.53	4.02	0.26
Pb ^H	µg/L	3.4	0.63	0.05	1.51	0.29	0.00	0.00	0.00	0.00
Sb	µg/L	9	0.72	0.09	0.82	0.34	0.00	0.00	0.00	0.00
Se	µg/L	11	0.64	0.07	0.72	0.06	0.00	0.00	0.70	0.02
V	µg/L	6	7.10	0.89	10.71	1.29	8.34	2.35	10.44	0.06
Zn ^H	µg/L	8	15.28	11.72	3.37	0.72	1.02	0.09	1.56	1.56

Notes:

The ANZECC guideline values for toxicants refer to the Ecosystem Protection – Freshwater Guideline for protection of 95% of biota in ‘slightly-moderately disturbed’ systems, as outlined in the Australian Water Quality Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000).

* ANZECC water quality guidelines for freshwater lowland rivers in South-east Australia are provided for salinity (there are currently no trigger values defined for ‘Wetlands’).

Values outside the ranges defined in the ANZECC guidelines are indicated with red text.

The deviation from the mean is represented by ‘±’.

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

^B Guideline assumes arsenic in solution as Arsenic (AsV).

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

^H Hardness affected (refer to Guidelines).

Table A-6. Sample 40590_3.2 contaminant and metalloid dynamics data. (The values in red text outside the relevant water quality guideline).

Parameter	units	ANZECC Guidelines	40590_3.2							
			24 Hours		7 Days		14 Days		35 Days	
			Av.	±	Av.	±	Av.	±	Av.	±
-	-	-	4.64	0.02	5.58	0.19	6.12	0.07	6.71	0.04
pH	-	6.5-8.0	4.64	0.02	5.58	0.19	6.12	0.07	6.71	0.04
EC	µS cm ⁻¹	125-2200*	365	96	343	128	780	191	831	337
Eh	mV		464.40	4.70	297.40	29.50	244.65	17.65	129.00	4.60
Ag	µg/L	0.05	0.16	0.12	0.04	0.00	0.00	0.00	0.00	0.00
Al ^A	mg/L	0.055	0.26	0.13	0.62	0.30	0.18	0.02	0.15	0.12
As ^B	µg/L	13	1.05	0.02	17.91	6.09	21.63	3.40	50.73	11.81
Cd	µg/L	0.2	0.26	0.11	0.26	0.01	0.00	0.00	0.00	0.00
Co	µg/L	2.8	23.04	9.28	46.95	24.78	61.33	15.04	6.23	1.59
Cr ^C	µg/L	1	3.19	0.38	9.39	1.51	12.70	0.24	16.66	7.03
Cu ^H	µg/L	1.4	5.66	0.14	11.19	6.22	5.07	0.90	2.78	0.29
Fe	mg/L	0.3	0.28	0.02	10.32	1.09	27.70	3.75	39.31	25.96
Mn	mg/L	1.7	2.76	1.25	3.79	2.42	4.91	1.58	4.83	1.52
Ni ^H	µg/L	11	27.45	8.98	62.01	15.60	89.05	6.63	19.77	8.67
Pb ^H	µg/L	3.4	1.11	0.07	4.19	1.12	2.76	1.30	0.99	0.99
Sb	µg/L	9	1.12	0.95	0.80	0.01	0.69	0.13	0.85	0.35
Se	µg/L	11	0.90	0.22	1.65	0.01	2.71	0.11	4.15	0.14
V	µg/L	6	25.68	4.04	52.47	12.61	69.34	3.54	80.69	20.14
Zn ^H	µg/L	8	28.84	14.08	28.47	14.11	30.24	19.05	11.81	7.83

Notes:

The ANZECC guideline values for toxicants refer to the Ecosystem Protection – Freshwater Guideline for protection of 95% of biota in 'slightly-moderately disturbed' systems, as outlined in the Australian Water Quality Guidelines for Fresh and Marine Water Quality (ANZECC/ARMCANZ 2000).

* ANZECC water quality guidelines for freshwater lowland rivers in South-east Australia are provided for salinity (there are currently no trigger values defined for 'Wetlands').

Values outside the ranges defined in the ANZECC guidelines are indicated with red text.

The deviation from the mean is represented by '±'.

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

^B Guideline assumes arsenic in solution as Arsenic (AsV).

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

^H Hardness affected (refer to Guidelines).

Table A-7. Monosulfide formation potential reactive iron data.

-	Total Reactive Fe (mg/kg)		Fe(II) (mg/kg)	
Site ID	Mean	+/-	Mean	+/-
40590_1.1	9004	1438	2303	80
40590_3.1	i.s.	-	i.s.	-

Notes:

The deviation from the mean is represented by '±'.
i.s. – insufficient sample volume.

Table A-8. Monosulfide formation potential data (Day 0).

-	Eh (mV)		pH	
Site ID	Mean	+/-	Mean	+/-
40590_1.1	397	9	5.00	0.01
40590_3.1	382	17	6.08	0.09

Notes:

The deviation from the mean is represented by '±'.

Table A-9. Monosulfide formation potential data (Week 7).

-	-	AVS (%S)		Pyrite (%S)		Elemental S (%S)	
Site Name	Site ID	Mean	+/-	Mean	+/-	Mean	+/-
Richardsons Lagoon	40590_1.1	<0.01	<0.01	<0.01	<0.01	0.01	0.01
Richardsons Lagoon	40590_3.1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

-	-	pH		Eh (mV)		Aqueous Sulfide (µg/L)	
Site Name	Site ID	Mean	+/-	Mean	+/-	Mean	+/-
Richardsons Lagoon	40590_1.1	5.24	0.06	220	6	4286	2500
Richardsons Lagoon	40590_3.1	5.36	0.07	234	11	329	329

Notes:

The deviation from the mean is represented by '±'.

Table A-10. Reactive metals data (mg/kg dry wt). The values in red text outside the relevant sediment quality guideline.

Parameter	units	ANZECC Sediment Quality Guidelines*		Richardsons Lagoon											
		ISQG-Low (Trigger value)	ISQG-High	40590_1.1		40590_1.2		40590_2.1		40590_2.2		40590_3.1		40590_3.2	
				Av	±	Av	±	Av	±	Av	±	Av	±	Av	±
-	-														
Ag	mg/kg ⁻¹	1	3.7	0.01	-	0.01	-	0.02	-	0.01	-	i.s.	-	0.01	-
Al	mg/kg ⁻¹	-	-	526.31	-	663.95	-	338.28	-	573.93	-	i.s.	-	494.98	-
As	mg/kg ⁻¹	20	70	0.77	-	0.81	-	0.77	-	0.68	-	i.s.	-	0.96	-
Cd	mg/kg ⁻¹	1.5	10	0.12	-	0.05	-	0.05	-	0.04	-	i.s.	-	0.07	-
Co	mg/kg ⁻¹	-	-	4.37	-	2.98	-	3.72	-	2.46	-	i.s.	-	3.86	-
Cr	mg/kg ⁻¹	80	370	0.41	-	0.73	-	0.29	-	0.30	-	i.s.	-	0.44	-
Cu	mg/kg ⁻¹	65	270	4.45	-	5.17	-	3.19	-	4.03	-	i.s.	-	4.29	-
Fe	mg/kg ⁻¹	-	-	2524.32	-	2295.09	-	2642.28	-	1635.20	-	i.s.	-	1176.05	-
Mn	mg/kg ⁻¹	-	-	474.97	-	343.57	-	255.72	-	158.17	-	i.s.	-	276.83	-
Ni	mg/kg ⁻¹	21	52	5.75	-	5.99	-	4.21	-	5.52	-	i.s.	-	6.70	-
Pb	mg/kg ⁻¹	50	220	4.08	-	5.03	-	4.13	-	6.19	-	i.s.	-	5.32	-
Sb	mg/kg ⁻¹	2	25	0.01	-	0.01	-	0.01	-	0.02	-	i.s.	-	0.02	-
Se	mg/kg ⁻¹	-	-	0.15	-	0.16	-	0.17	-	0.10	-	i.s.	-	0.12	-
V	mg/kg ⁻¹	-	-	11.07	-	11.72	-	8.01	-	9.55	-	i.s.	-	10.42	-
Zn	mg/kg ⁻¹	200	410	14.59	-	10.14	-	8.84	-	7.75	-	i.s.	-	10.50	-

Notes:

* The ANZECC sediment quality guidelines are for total metal concentrations (ANZECC/ARMCANZ 2000).

The deviation from the mean is represented by '±'.

i.s. – insufficient sample volume.



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