Assessment of Acid Sulfate Soil Materials (Phase 2): Boiling Downs Creek

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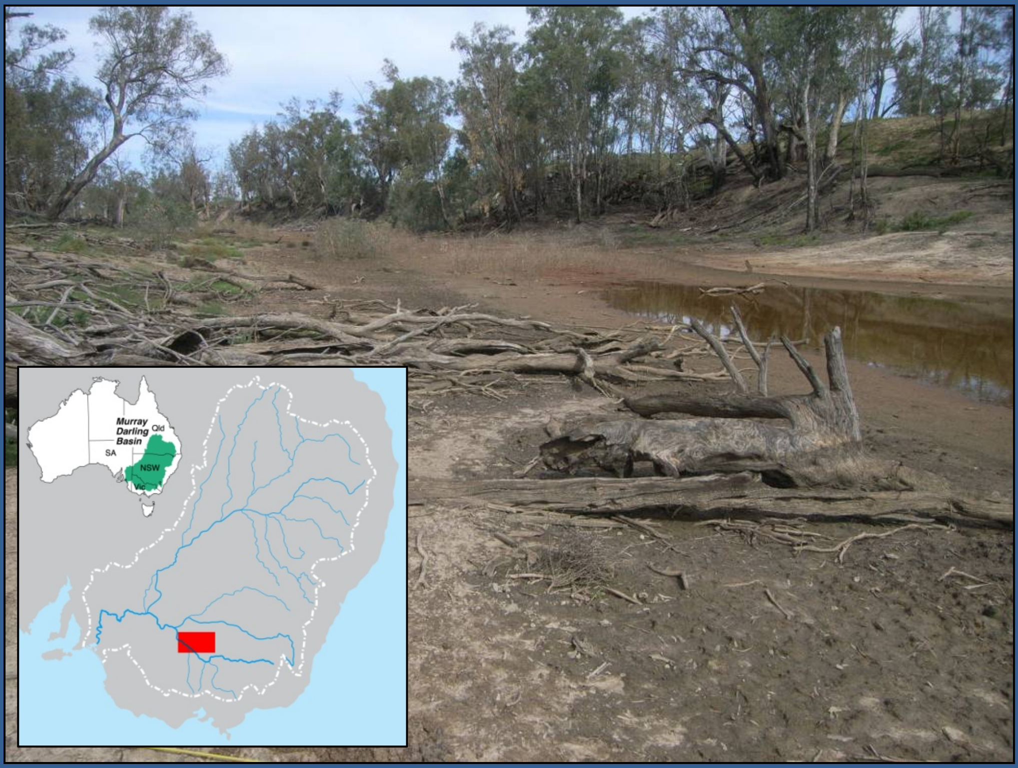
FINAL REPORT



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Cover Photograph:

Typical landscape in the Boiling Downs Creek wetland. Photograph taken at site 20177_3 in the Boiling Downs Creek wetland.
Photographer: Mitch Tulau

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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 (ASSRAP). An initial Phase 1 acid sulfate soil investigation of the Boiling Downs Creek wetland in April 2010 showed acid sulfate soils to be a priority concern within this wetland (Ward *et al.* 2010). Based on Phase 1 recommendations, a Phase 2 investigation was undertaken for the Boiling Downs Creek wetland to determine the nature, severity and the specific risks associated with acid sulfate soil materials. Phase 2 activities included soil laboratory analysis, a risk assessment, and interpretation and reporting, including discussion on broad acid sulfate soil management options.

The Phase 2 assessment of the Boiling Downs Creek wetland examined both the contaminant and metalloid dynamics and reactive metals associated with surface layers from a site within the creek. These results were used to determine the risks associated with contaminant mobilisation. The risks associated with both acidification and de-oxygenation were determined primarily using data from the Phase 1 assessment.

The contaminant and metalloid dynamics tests were undertaken to assess the release of metals during a water extraction, and to assess changes with time as saturated soils by incubating soil materials for periods of 1, 7, 14 and 35 days. The degree to which metal and metalloid concentrations exceed ANZECC/ARMCANZ water quality guideline values for environmental protection was used to characterise the degree of hazard. For Boiling Downs Creek wetland, the contaminant and metalloid dynamics test over 35 days showed that under the experimental conditions all metals and metalloids examined (with the exception of antimony (Sb), cadmium (Cd) and selenium (Se)) were found to exceed the water quality guidelines (ANZECC/ARMCANZ 2000). The guidelines for four metals (i.e. chromium (Cr), copper (Cu), iron (Fe) and zinc (Zn)) were exceeded by more than 10 times, and the guideline for aluminium was exceeded by more than 100 times.

The contaminant and metalloid behaviour often varied between the metals/metalloids examined during the inundation experiments. The reductive dissolution of iron and manganese minerals seemed to have partially controlled the release of sorbed arsenic and some other metals, although the controls on release were not always clear. The trend with some metals/metalloids indicates further potential for release had the incubation experiments been allowed to proceed for a longer timeframe; it is also likely that many of the metals/metalloids will become incorporated into sulfide minerals following further reduction.

As shown in the table below, the metals/metalloids found to exceed the ANZECC water quality guidelines during the inundation experiments represent a low to high hazard. The reactive metal concentrations were also found to be sufficiently high to be a potential hazard if released into surrounding waters. In natural systems the dynamics of metal release will be governed by the upward chemical flux, which is a function of soil type, water flow, diffusion and chemistry of the soils near the sediment-water interface (MDBA 2011).

A risk assessment framework was applied to determine the specific risks associated with acidification, contaminant mobilisation and de-oxygenation (MDBA 2011). The Phase 2 assessment identified the following risks associated with the presence of acid sulfate soils in the Boiling Downs Creek wetland:

- high acidification risk,
- medium contaminant mobilisation risk, and
- high de-oxygenation risk.

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

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

These findings indicate that, if not managed appropriately, the acid sulfate soil materials identified in the Boiling Downs Creek wetland have the potential to present a serious risk to the environmental values of both the wetland and adjacent waters. This report outlines the variety of management options available to manage acid sulfate soils in inland aquatic ecosystems. The most appropriate management strategy for the Boiling Downs Creek wetland would be to prevent oxidation of the acid sulfate soil materials identified. Neutralisation may be the best management strategy in the event of disturbance. 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.

It is important to note that the soil materials collected in April 2010 as part of the Phase 1 assessment only provided a snapshot of the acid sulfate soil materials present and the conditions at selected locations in the wetland. While recent inundation within the wetland may have minimised the risks identified in the short-term, it is also likely that this inundation will lead to further formation of acid sulfate soil materials.

This Phase 2 study only examined contaminant mobilisation in two layers collected from one site in Boiling Downs Creek wetland. Further studies would be required to determine how representative these soil materials are of the entire wetland in order to fully assess the risk of contaminant mobilisation.

It is recommended that, within the context of other management objectives for the wetland, consideration be given to undertaking water quality monitoring to identify potential contamination as a result of the disturbance of acid sulfate soils within the wetland. The presence of some high risks identified in this Phase 2 assessment indicates that senior management attention is probably needed (MDBA 2011).

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: (i) soil laboratory analysis to confirm and refine the hazards associated with contaminant mobilisation and/or deoxygenation, (ii) a risk assessment, and (iii) interpretation and reporting, including discussion on broad acid sulfate soil management options.

Detailed Phase 1 acid sulfate soil assessments were undertaken at almost 200 wetlands and river channels throughout the Murray-Darling Basin. In the Edward and Wakool Rivers region, 12 wetlands were investigated by Southern Cross GeoScience (Ward *et al*. 2010). From these Phase 1 investigations, Boiling Downs Creek, Glen Esk-Rusty Waterhole and Wakool River Billabong (Wetland ID 20246) were selected for further investigation. This report outlines the results of Phase 2 activities on selected samples from the Boiling Downs Creek wetland (Figure 1-1).

Following the Boiling Downs Creek wetland Phase 1 assessment (Ward *et al.* 2010) and the priority ranking criteria adopted by the Scientific Reference Panel of the MDB ASSRAP (see Table 1-1), a selected site from within the Boiling Downs Creek wetland was chosen for Phase 2 detailed assessment. The Boiling Downs Creek wetland Phase 1 assessment identified there was one high priority site based on sulfuric material, four high priority sites based on hypersulfidic material, and three high priority sites based on monosulfidic material in the Boiling Downs Creek wetland (Ward *et al.* 2010). In addition, all four sampling sites examined had a high priority ranking for Phase 2 detailed assessment based on monosulfidic black ooze (MBO) formation hazard (Ward *et al.* 2010). Phase 2 investigations were carried out on selected samples from a high priority site (i.e. site 20177_3) identified in the Phase 1 assessment.

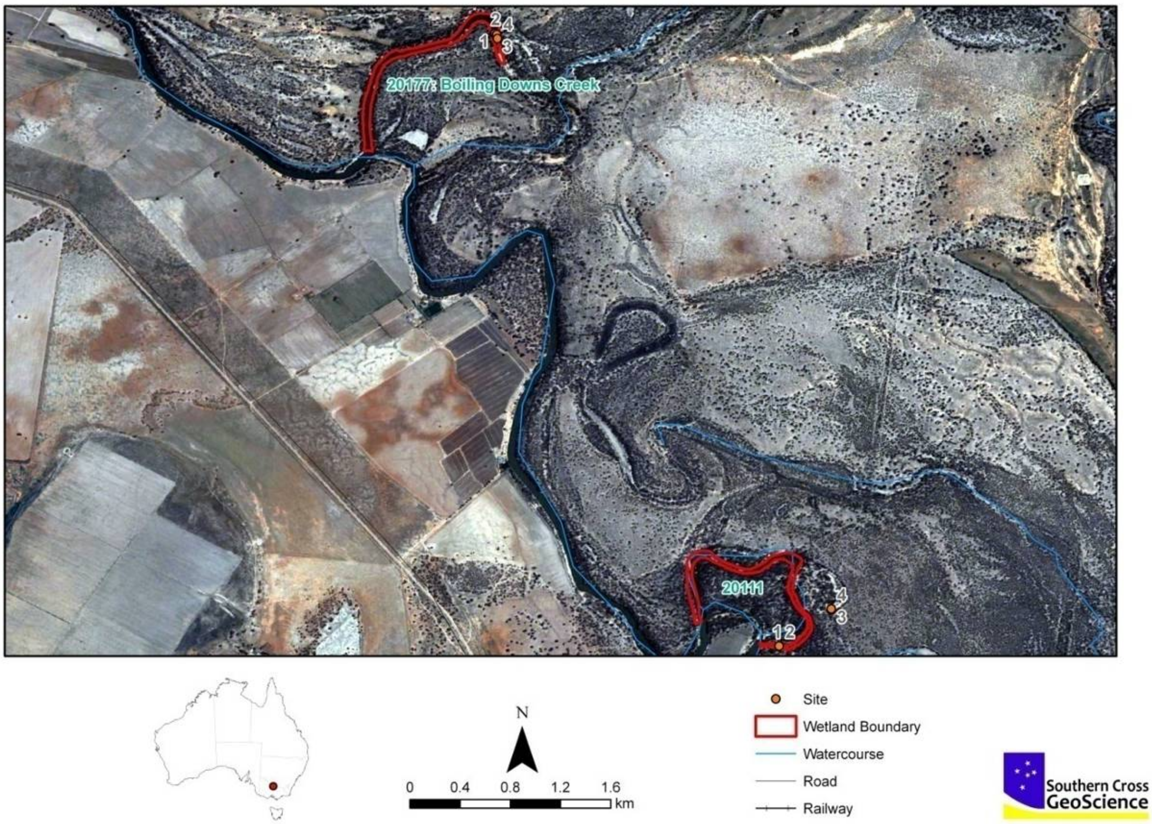

Figure 1-1: Map showing the areas assessed in the Boiling Downs Creek wetland during the Phase 1 assessment.

Table 1-1. 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 <u>either</u> 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 sulfate (1:5 soil:water) contents ≥ 100 mg SO_4 kg^{-1}.
	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 given in Table 1-2. 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 Boiling Downs Creek wetland is presented in Table 1-3.

Table 1-2. Rationale of sample selection for Phase 2 analysis.

Parameter	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 1-3. Summary of Boiling Downs Creek samples analysed for Phase 2 assessment.

Soil Laboratory Test	Boiling Downs Creek (Wetland ID 20177)	[1]n
Contaminant and metalloid dynamics	3.1 (0-5 cm), 3.2 (5-10 cm)	2
Monosulfide formation potential	none	0
Reactive metals	3.1 (0-5 cm), 3.2 (5-10 cm)	2

[1]n = total number of samples analysed

2. LABORATORY METHODS

2.1. Laboratory analysis methods

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 2-1. All soil samples analysed in this Phase 2 assessment were collected and subsequently stored as part of the Phase 1 field assessment.

Table 2-1. Phase 2 data requirements - list of parameters and objective for conducting the test.

Parameter	Objective
Contaminant and metalloid dynamics	Assists with determining impacts on water quality by simulating time frames that create anaerobic conditions. Identifies metal release concentrations that may occur over a 5 week time frame.
Monosulfide formation potential	Determine relative propensity for monosulfides to form following inundation.
Reactive metals	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 (see Appendices 7 and 8, 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 dynamics method

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. aluminium (Al), antimony (Sb), arsenic (As), cadmium (Cd), chromium (Cr). cobalt (Co), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), nickel (Ni), selenium (Se), silver (Ag), vanadium (V) and zinc (Zn)) was determined by ICP-MS (Inductively Coupled Plasma - Mass Spectrometry) (APHA 2005). Redox potential (Eh) and pH were determined at each interval 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

The guidelines for the monosulfide formation potential method are outlined in Appendix 8 of the detailed assessment protocols (MDBA 2010). No samples from the Boiling Down Creek were selected for monosulfide formation potential analysis.

2.1.4. Reactive metals method

In this Phase 2 assessment a reactive metals method was carried out instead of the x-ray fluorescence (XRF) spectrometry method outlined in the detailed assessment protocols (MDBA 2010). While the XRF method provides data on the total elements in the soil, the reactive metals method gives an indication of the potential metal concentrations that may be released into the surrounding waters. 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 were determined by ICP-MS and included aluminium (Al), antimony (Sb), arsenic (As), cadmium (Cd), chromium (Cr). cobalt (Co), copper (Cu), iron (Fe), lead (Pb), manganese (Mn), nickel (Ni), selenium (Se), silver (Ag), vanadium (V) and zinc (Zn). The reactive metals test was conducted on all samples that underwent the contaminant and metalloid dynamics test.

2.2. Quality assurance and quality control

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. In addition, the contaminant and metalloid dynamics tests were duplicated.

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, ≥ 10% laboratory duplicates, and 10% laboratory controls. The analytical precision was ±10% for all analyses.

3.RESULTS AND DISCUSSION

3.1. Summary of soil laboratory results

3.1.1. Contaminant and metalloid dynamics data

The contaminant and metalloid dynamics data for the two Boiling Down Creek soil materials examined (i.e. 20177_3.1 and 20177_3.2) are presented in Appendix 1 (Tables 8-1 and 8-2) and summarised below in Table 3-1. Table 3-1 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 3-1 to 3-4.

Table 3-1. Summary of contaminant and metalloid dynamics data.

Parameter	units	ANZECC Guidelines	20177_3.1 (0-5 cm)		20177_3.2 (5-10 cm)	
			Min.	**Max.**	**Min.**	**Max.**
pH		6.5-8.0	6.15	7.01	6.05	7.12
EC*	µS cm^{-1}	125-2200	429	770	178	298
Eh	mV	-	144	401	140	384
Ag	µg l^{-1}	0.05	<0.1	0.3	<0.1	0.3
Al[A]	mg l^{-1}	0.055	0.98	3.32	5.07	19.21
As[B]	µg l^{-1}	13	1.4	15.8	2.4	9.4
Cd	µg l^{-1}	0.2	<0.1	<0.1	<0.1	<0.1
Co	µg l^{-1}	2.8	1.6	5.1	4.0	24.2
Cr[C]	µg l^{-1}	1	2.6	5.3	6.0	21.4
Cu[H]	µg l^{-1}	1.4	4.2	13.3	22.1	42.7
Fe	mg l^{-1}	0.30	3.13	10.19	7.67	24.16
Mn	mg l^{-1}	1.70	0.42	1.06	0.49	2.38
Ni[H]	µg l^{-1}	11	2.0	7.3	5.9	17.0
Pb[H]	µg l^{-1}	3.4	2.5	9.7	6.6	18.2
Sb	µg l^{-1}	9	<1.0	<1.0	<1.0	<1.0
Se	µg l^{-1}	11	<1.0	2.3	<1.0	1.9
V	µg l^{-1}	6	7.5	17.2	16.7	46.9
Zn[H]	µg l^{-1}	8	3.8	44.5	87.1	183.2

Exceeded ANZECC Guideline (x1)

Exceeded ANZECC Guideline (x10)

Exceeded ANZECC Guideline (x100)

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 lowland rivers in South-east Australia are provided for salinity. 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 As in solution as Arsenic (AsV).*

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

[H] *Hardness affected (refer to Guidelines).*

The pH, electrical conductivity (EC) and redox potential (Eh) dynamics over 35 days of inundation for the Boiling Downs Creek soil materials are presented in Figure 3-1. The pH for both soil materials was initially below the ANZECC guideline of 6.5 following the inundation. However, an increase in pH during the incubation was observed with both soil materials, and the pH was within the ANZECC guidelines after 14 days of inundation. A decrease in Eh from oxic (>300 mV) to suboxic (≥ 140 mV) conditions was observed with both soil materials. Both soil materials also showed a similar rate of reduction during incubation. The data indicates that the increase in pH during the incubation is a consequence of reduction processes consuming acidity. 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).

There was a slight decrease in the electrical conductivity over the timeframe of the experiment and both soil materials were within the ANZECC guidelines throughout the experiment (Figure 3-1). The decrease in conductivity with time would suggest the formation of insoluble mineral phases during the inundation experiment.

It is well established that inundating oxic soils can dramatically alter the mobility of metals and metalloids. The contaminant and metalloid dynamics results for the Boiling Downs Creek soil materials are presented in Figures 3-2 to 3-4. Under the experimental conditions all metals and metalloids examined (with the exception of antimony (Sb), cadmium (Cd) and selenium (Se)) were found to exceed the ANZECC water quality guidelines during the inundation experiments (Table 3-1). Two metals (i.e. cadmium (Cd) and antimony (Sb)) were below the limit of detection for both soil materials over the 35 day inundation period. Many of the metals (i.e. cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), vanadium (V) and zinc (Zn)) were above the ANZECC guideline at all sampling intervals for one or both soil materials. The guidelines for aluminium (Al), chromium (Cr), copper (Cu), iron (Fe) and zinc (Zn) were exceeded by more than 10 times. The guideline for aluminium (Al) was exceeded by more than 100 times for one of the soil materials (i.e. 20177_3.2 5-10 cm). However, aluminium (Al) has a low solubility at pH values of greater than 5.5, and the elevated aluminium (Al) concentration at near neutral pH values can be attributed a fine particle fraction which passes through the 0.45 µm filter and/or the presence of soluble aluminium (Al) complexes; this phenomenon has been observed in previous studies.

The metal/metalloid behaviour during the 35 day inundation period often varied between the metals/metalloids examined (Figures 3-2 to 3-4). However, many of the metals/metalloids (particularly with the soil material from 20177_3.2 5-10 cm) showed a maximum concentration after 35 days of inundation. 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). It is expected the steady increase in the iron (Fe) concentration observed with both soil materials during incubation is largely a consequence of ferric iron (Fe^{3+}) reduction releasing ferrous iron (Fe^{2+}) into solution (Figure 3-3). Manganese (Mn) shows a similar trend suggesting reduction to a soluble form (i.e. Mn^{2+}) (Figure 3-3). Burton *et al.* (2008) found significant mobilisation of arsenic (As) associated with ferric iron reduction following the inundation of acid sulfate soil materials, and this was also observed in this study (Figure 3-2). In addition to arsenic (As), the mobilisation of some of the other metals appeared to be associated with the reduction of iron (Fe) and manganese (Mn) minerals (see Figures 3-3 and 3-4).

The trend with many of the metals/metalloids, particularly with the deeper soil material (i.e. 20177_3.2 5-10 cm), indicates there is the potential for further release had the incubation experiments been allowed to proceed for a longer timeframe. However, it is also expected that many of the metals/metalloids will become incorporated into iron sulfide minerals (due to sorption to and/or co-precipitation) or precipitated as non-ferrous sulfides following further reduction.

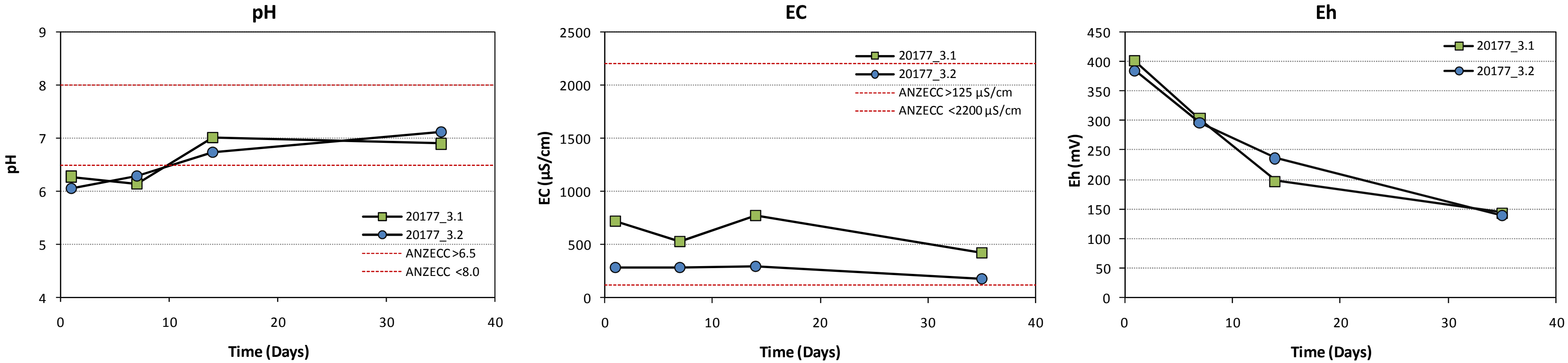

Figure 3-1: pH, EC and Eh dynamics over 35 days for the Boiling Downs Creek soil materials (20177_3.1 and 20177_3.2).

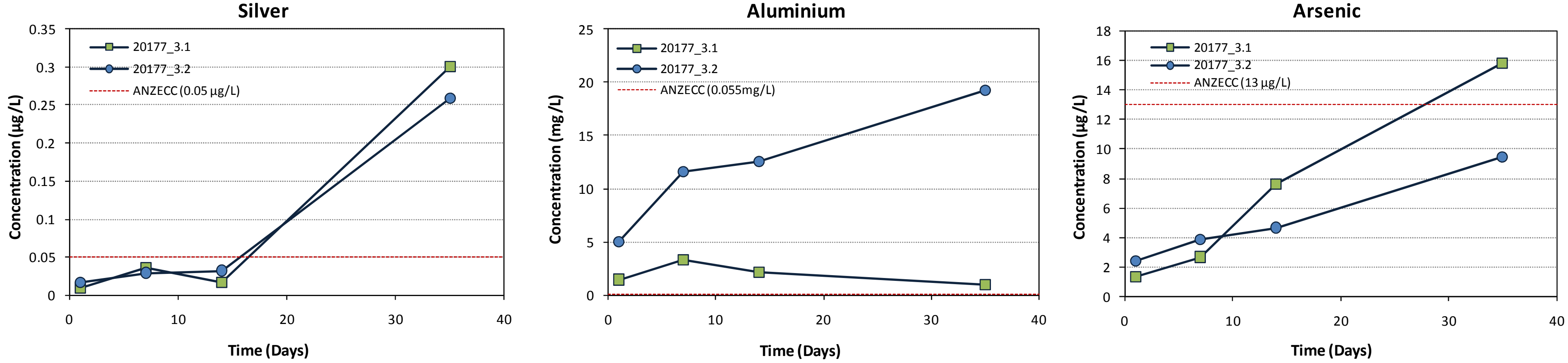

Figure 3-2: Contaminant and metalloid dynamics (Ag, Al and As) over 35 days for the Boiling Downs Creek soil materials (20177_3.1 and 20177_3.2).

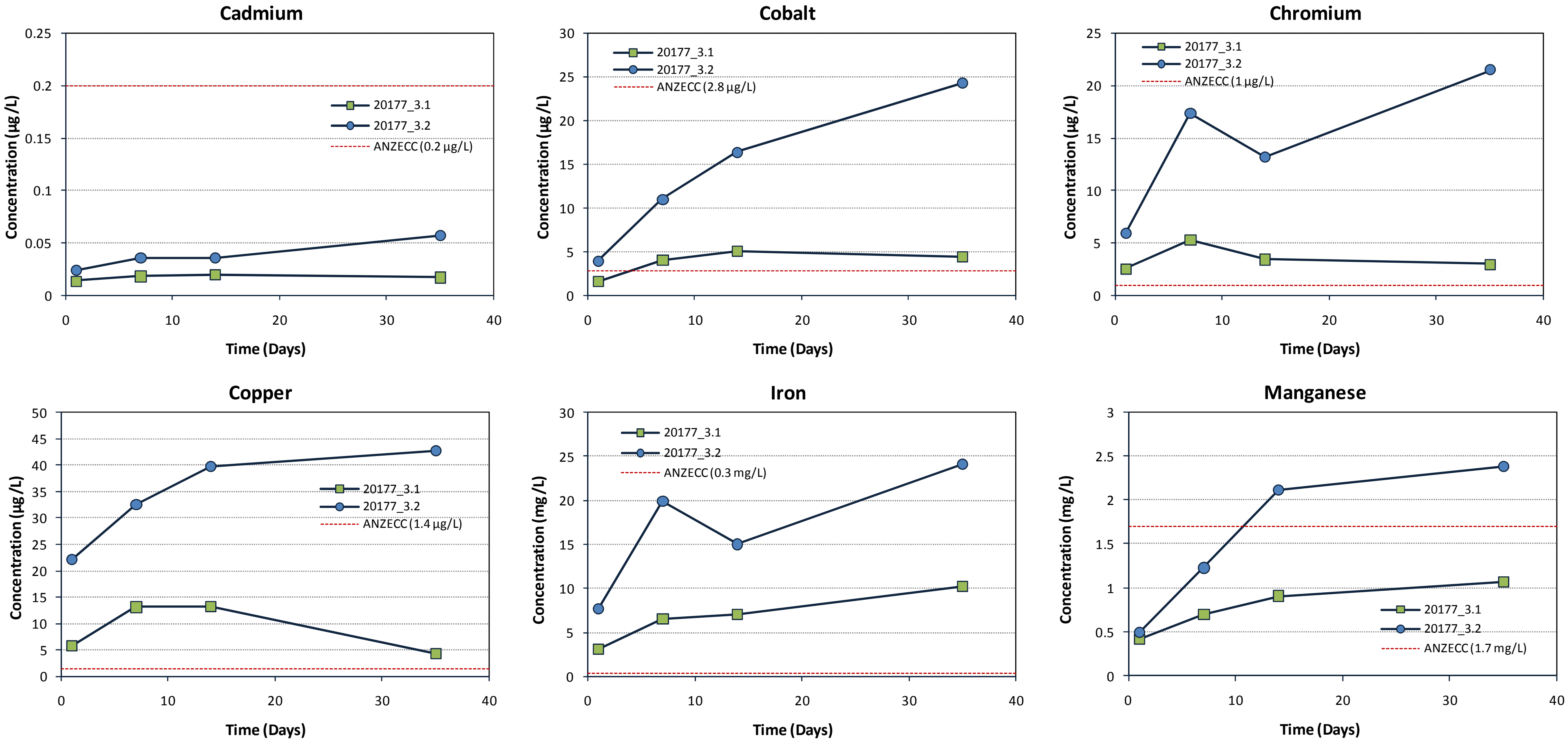

Figure 3-3: Contaminant and metalloid dynamics (Cd, Co, Cr, Cu, Fe and Mn) over 35 days for the Boiling Downs Creek soil materials (20177_3.1 and 20177_3.2).

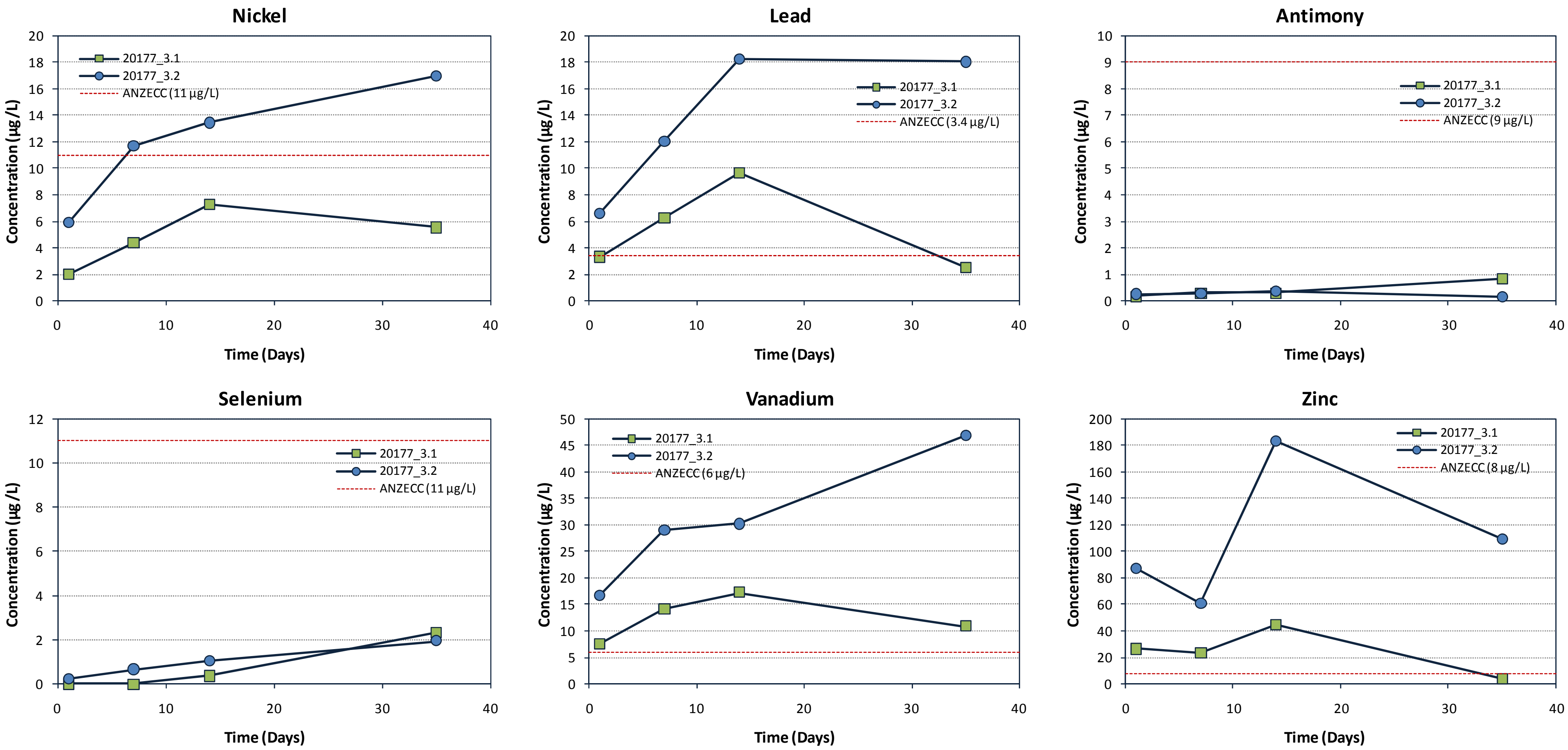

Figure 3-4: Contaminant and metalloid dynamics (Ni, Pb, Sb, Se, V and Zn) over 35 days for the Boiling Downs Creek soil materials (20177_3.1 and 20177_3.2).

3.1.2. Reactive metals data

The determination of the reactive metal fraction provides an indication of the total potential metal release from the sediment into surrounding waters. The reactive metals test used in this study gives an indication of the metals and metalloids that are more strongly bound to minerals (or weakly soluble with an acid extraction) than would be soluble with a water extraction. The moderately strong acid used (i.e. 0.1 M HCl) indicates the “stored metals” and metalloids associated with iron and manganese oxides, organic materials as well as acid soluble minerals. While the ANZECC sediment quality guidelines (ANZECC/ARMCANZ 2000) are based on total metal/metalloid concentrations, a reactive metal concentration near to or above guideline values indicate an elevated hazard.

The reactive metals data for the Boiling Downs Creek soil materials showed all metals/metalloids were ≤ 10% of the ANZECC trigger value for the total metal/metalloid concentration (see Table 8-3, Appendix 1). While all reactive metal concentrations were below the ANZECC trigger value, the metal concentrations measured were sufficiently high to be a potential hazard if the total reactive fractions were to be released into a surrounding water body (i.e. above ANZECC water quality guidelines).

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 several week period. The contaminant and metalloid behaviour of the two soils from Boiling Downs Creek during the 35 day inundation often varied between the metals/metalloids examined (see Figures 3-2 to 3-4). While the release of some metals/metalloids seemed to correlate with the reduction of iron (Fe) and manganese (Mn) minerals, the controls on release were not always clear. Iron (Fe) and manganese (Mn) oxides are often important sorbents for metals/metalloids, and once reduced these minerals can release the associated metals/metalloids into solution (MDBA 2011).

The contaminant and metalloid dynamics data for two soils from Boiling Downs Creek showed all metals and metalloids examined (with the exception of antimony (Sb), cadmium (Cd) and selenium (Se)) exceeded the ANZECC water quality guidelines during the inundation experiments (Table 3-1). The guidelines for chromium (Cr), copper (Cu), iron (Fe) and zinc (Zn) were exceeded by more than 10 times, and the guideline for aluminium (Al) with one of the soil materials (i.e. 20177_3.2 5-10 cm) was exceeded by more than 100 times. Two metals (i.e. antimony (Sb) and cadmium (Cd)) were below the limit of detection for both soil materials over the 35 day inundation period.

While the contaminant and metalloid dynamics test gives an indication of the metal/metalloid content of the soil, the overlying water 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 water quality guideline during the test it does not represent an environmental hazard. Thresholds for the degree of hazard associated with the contaminant and metalloid concentrations were developed with respect to the ANZECC water quality guidelines, and a summary of the degree of hazard each of the metals/metalloids pose at the site examined in the Boiling Downs Creek is given in Table 3-2. Note the background colours presented in Table 3-1 also correspond to the degree of hazard (i.e. no colour (no hazard), yellow (low hazard), orange (moderate hazard) and red (high hazard)).

Table 3-2. Summary of the degree of hazard associated with the measured contaminant and metalloid concentrations.

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

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

The twelve metals/metalloids found to exceed the ANZECC water quality guidelines during the inundation experiments represent a low to high hazard (Table 3-2). Aluminium (Al) was the only metal/metalloid observed to potentially have a high hazard, and only in the deeper (i.e. 20177_3.2 5-10 cm) soil material (Table 3-1). While four metals had a moderate hazard (i.e. chromium (Cr), copper (Cu), iron (Fe) and zinc (Zn)), they were predominantly found at this level of hazard in the deeper soil material (Table 3-1). Arsenic (As) only represents a hazard in the surface soil material (i.e. 20177_3.1 0-5 cm), and both manganese (Mn) and nickel (Ni) only represent a hazard in deeper soil material.

The reactive metal concentrations were significantly less than the ANZECC trigger value for total metals, although they were sufficiently high to be a potential hazard if released into a surrounding water body. In natural systems the dynamics of metal release will be governed by the upward chemical flux, which is a function of soil type, water flow, diffusion and chemistry of the soils near the sediment-water interface (MDBA 2011). It is also important to note that the surface soil materials from the three other Boiling Downs Creek sites examined in the Phase 1 assessment had greater sulfide contents (and net acidities) than the surface soil materials from site 20177_3, and therefore if these soil materials were to oxidise prior to inundation many of the metals/metalloids may pose a greater hazard due to their higher solubilities at lower pH values.

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 4-1), and a likelihood rating for the disturbance scenario for each hazard (Table 4-2). These two factors are then combined in a risk assessment matrix to determine the level of risk (Table 4-3).

Table 4-1 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 4-1: 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 4-2 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 and acid generating potential of acid sulfate soil materials, 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 4-3).

Table 4-2: 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 4-3: 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

It is suggested that:
- For *very high* risk immediate action is recommended.
- For *high* risk senior management attention is probably needed.
- Where a *medium* risk is identified management action may be recommended.
- Where the risk is *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

The following sub-sections discuss the risks associated with acidification (Section 4.2.1), contaminant mobilisation (Section 4.2.2) and de-oxygenation (Section 4.2.3) in the Boiling Downs Creek wetland. The risks associated with these hazards are dependent on a variety of factors including the scenario, wetland management regime and the species of aquatic organisms present. While likelihood of a disturbance scenario is taken into account in this risk assessment (see Table 4-2), the sensitivities and tolerances of different species of organism to each hazard has not been included. This risk assessment has primarily used the data obtained from both the Phase 1 and 2 acid sulfate soil assessments to give an overall assessment of each risk to the Boiling Downs Creek wetland and adjacent waters.

4.2.1. Risks associated with acidification

The Phase 1 assessment of acid sulfate soil materials in the Boiling Downs Creek wetland indicated the overall degree of acidification hazard was high (Ward *et al.* 2010). While the Phase 1 assessment found moderate net acidities were dominant within this wetland, three hypersulfidic materials had high net acidities. In addition, the water soluble sulfate content of surface soil materials at all four sites were over the trigger value for potential monosulfidic black ooze (MBO) formation.

Sulfuric, hypersulfidic and hypermonosulfidic soil materials which represent an acidification hazard were identified at the sites examined in the Boiling Downs Creek wetland. Hypersulfidic and/or hypermonosulfidic soil materials with moderate-high net acidities were observed at all four sites. Sulfuric soil materials with moderate net acidities were found below a depth of 20 cm at site 20177_3 on the lower stream bank.

It is expected that the consequence of an acidification hazard occurring would be *moderate* (i.e. short-term damage to wetland environmental values and/or adjacent waters; short-term impact on species and/or drinking water (including stock and domestic) supplies). The likelihood of these disturbance scenarios would be *almost certain*, and therefore there is a *high* risk associated with acidification in the Boiling Downs Creek wetland.

4.2.2. Risks associated with contaminant mobilisation

The high acidification hazard identified in the Boiling Downs Creek wetland Phase 1 assessment indicated that soil acidification may increase the solubility of metals and soil acidity may be sufficient for the mobilisation of aluminium (Al). In addition, the presence of monosulfidic materials in some surface soils and the potential for monosulfidic black ooze (MBO) formation identified in this wetland may also result in an appreciable metal release hazard. The contaminant and metalloid dynamics data showed many of the metals/metalloids examined (i.e. all except antimony (Sb), cadmium (Cd) and selenium (Se)) exceeded the ANZECC water quality guidelines. The metal/metalloid concentrations that exceeded the guidelines during the contaminant and metalloid dynamics test represented a low to high hazard, with five metals (i.e. aluminium (Al), chromium (Cr), copper (Cu), iron (Fe) and zinc (Zn)) having a moderate/high hazard (see Table 3-2). However, the surface soil materials from the three other Boiling Downs Creek sites examined in the Phase 1 assessment had greater sulfide contents (and net acidities) than the surface soil materials from site 20177_3, and therefore if these soil materials were to oxidise prior to inundation many of the metals/metalloids may pose a greater hazard due to their higher solubilities at lower pH values.

If insufficient dilution of the contaminants was to occur in the receiving waters, 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 impact on species and/or drinking water (including stock and domestic) supplies). This disturbance scenario would be considered *likely*, and therefore there is a *medium* risk associated with contaminant mobilisation in the Boiling Downs Creek wetland.

It should be noted that in this Phase 2 study contaminant mobilisation was only examined in two layers collected from one high priority site in Boiling Downs Creek wetland. Further studies would be required to determine how representative these soil materials are of the entire wetland in order to fully assess the risk of contaminant mobilisation.

4.2.3. Risks associated with de-oxygenation

Monosulfidic soil materials pose a de-oxygenation hazard if disturbed. Whilst the monosulfide formation potential test was not undertaken as part of the Phase 2 assessment for the Boiling Downs Creek wetland, the presence of monosulfidic soil materials was identified within the wetland (Ward *et al.* 2010). High monosulfide concentrations (S_{AV} up to 0.11% S) were observed in the surface soil at three sites and represent a high de-oxygenation hazard. As mentioned previously, the water soluble sulfate contents of surface soil materials at all four sites were also over the trigger value for potential monosulfidic black ooze (MBO) formation. The sulfate data indicates the possible development of an appreciable de-oxygenation hazard at all sites after prolonged wet conditions.

These findings therefore indicate that the de-oxygenation hazard would represent short-term damage to wetland environmental values and/or adjacent waters and short-term impacts on species and/or drinking water (including stock and domestic) supplies (i.e. *moderate* consequence of a hazard occurring). Disturbance is expected to occur in most circumstances (i.e. almost certain) and therefore there is a *high* de-oxygenation risk in the Boiling Downs Creek wetland.

A summary of the risks associated with the presence of acid sulfate soils in the Boiling Downs Creek wetland is presented below in Table 4-4.

Table 4-4: Summary of the risks associated with acid sulfate soils in Boiling Downs Creek wetland.

Hazard	Level of risk
Acidification	High risk
Contaminant mobilisation	Medium risk
De-oxygenation	High risk

5. BROAD ACID SULFATE SOIL MANAGEMENT OPTIONS

This Phase 2 assessment identified the following risks associated with the presence of acid sulfate soils in the Boiling Downs Creek wetland:

- high acidification risk,
- medium contaminant mobilisation risk, and
- high de-oxygenation risk.

The acid sulfate soil materials identified in the Boiling Downs Creek wetland have the potential to present a serious risk to the environmental values of both the wetland and adjacent waters if not managed appropriately. A variety of options are available to manage landscapes where acid sulfate soil materials are observed. A national guidance document on the management of inland acid sulfate soil landscapes titled "*National guidance for the management of acid sulfate soils in inland aquatic ecosystems"* has recently been released (EPHC & NRMMC 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.*

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.

The possible activities associated with each management objective are summarised in Table 5-1. Further information on each management option is provided in detail in the national guidance document (EPHC & NRMMC 2011).

The presence of acid sulfate soil materials with high acidification and de-oxygenation risks and medium contaminant mobilisation risk would suggest that the most appropriate management strategy for the Boiling Downs Creek wetland would be to prevent oxidation of the identified acid sulfate soils materials. As outlined in Table 5-1, in order to prevent oxidation it is necessary to keep the acid sulfate soils inundated, and if possible avoid flow regimes that could re-suspend these sediments. In the event of disturbance chemical ameliorants such as lime can be added to neutralise the water column and/or sediments. Details on the ameliorants available including their advantages and disadvantages are provided in the national guidance document (EPHC & NRMMC 2011). Controlled oxidation would not be a recommended management strategy in the Boiling Downs Creek wetland due to the lack of neutralising capacity within the sediments examined, the medium risk of contaminant release and the presence of hypermonosulfidic soil materials at the time of sampling.

Table 5-1: 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	**Reduce secondary salinisation through:** • 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 sulfate soils or controlled oxidation to remove acid sulfate soils	**Preventing oxidation:** • Keep the sediments covered by water • Avoid flow regimes that could re-suspend sediments. **Controlled oxidation:** • 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	• 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	• Isolate the site • Neutralise and dilute surface water • Treat discharge waters by neutralisation or biological treatment.
Limited further intervention	• Assess risk • Communicate with stakeholders • Undertake monitoring • Assess responsibilities and obligations and take action as required.

The Phase 1 acid sulfate soil assessment of the Boiling Downs Creek wetland (Ward *et al*. 2010) only provided a snapshot of the acid sulfate soil materials present and the conditions at selected locations in the wetland in April 2010. Since sampling the prolonged drought in the Murray-Darling Basin has come to an end and many regions have experienced major flooding. While flooding was probably not strong enough to scour the acid sulfate soil materials from the Boiling Downs Creek wetland, inundation of this wetland may have minimised the risks identified in this study in the short-term. However, it is also likely that the recent inundation will lead to further formation of acid sulfate soil materials, particularly highly reactive monosulfidic soil materials, within the Boiling Downs Creek wetland.

It should be noted that further understanding of the complex interactions between surface water flow, groundwater processes, biogeochemistry and the different pathways for the development of acid sulfate soils in inland aquatic ecosystems is required for satisfactory management and preventative strategies. A more robust understanding of these complex interactions is needed before implementing any new strategies for multiple benefits.

6. CONCLUSIONS AND RECOMMENDATIONS

This report provides the results of a Phase 2 investigation that was undertaken for the Boiling Downs Creek wetland to determine the nature, severity and the specific risks associated with acid sulfate soil materials. The Phase 2 assessment of the Boiling Downs Creek wetland examined both the contaminant and metalloid dynamics and reactive metals associated with surface layers from a site within Boiling Downs Creek to identify the risk associated with contaminant mobilisation. The risks associated with both acidification and de-oxygenation were primarily determined using data from the Phase 1 assessment (Ward *et al.* 2010).

The contaminant and metalloid dynamics over 35 days of inundation showed under the experimental conditions all metals and metalloids examined (with the exception of antimony (Sb), cadmium (Cd) and selenium (Se)) were found to exceed the ANZECC water quality guidelines. The guidelines for four metals (i.e. chromium (Cr), copper (Cu), iron (Fe) and zinc (Zn)) were exceeded by more than 10 times, and the guideline for aluminium (Al) was exceeded by more than 100 times.

The contaminant and metalloid behaviour often varied between the metals/metalloids examined during the inundation experiments. The reductive dissolution of iron and manganese minerals seemed to have partially controlled the release of sorbed arsenic and some other metals, although the controls on release were not always clear. The trend with some metals/metalloids indicates further potential for release had the incubation experiments been allowed to proceed for a longer timeframe; it is also likely that many of the metals/metalloids will become incorporated into sulfide minerals following further reduction.

The metals/metalloids found to exceed the ANZECC water quality guidelines during the inundation experiments represent a low to high hazard (see Table 3-2). The reactive metal concentrations were also found to be sufficiently high to be a potential hazard if released into surrounding waters. In natural systems the dynamics of metal release will be governed by the upward chemical flux, which is a function of soil type, water flow, diffusion and chemistry of the soils near the sediment-water interface (MDBA 2011).

A risk assessment framework was applied to determine the specific risks associated with acidification, contaminant mobilisation and de-oxygenation (MDBA 2011). The Phase 2 assessment identified the following risks associated with the presence of acid sulfate soils in the Boiling Downs Creek wetland:

- high acidification risk,
- medium contaminant mobilisation risk, and
- high de-oxygenation risk.

These findings indicate that, if not managed appropriately, the acid sulfate soil materials identified in the Boiling Downs Creek wetland have the potential to present a serious risk to the environmental values of both the wetland and adjacent waters. This report outlines the variety of management options available to manage acid sulfate soils in inland aquatic ecosystems. The most appropriate management strategy for the Boiling Downs Creek wetland would be to prevent oxidation of the acid sulfate soil materials identified. Neutralisation may be the best management strategy in the event of disturbance. 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.

It is important to note that the soil materials collected in April 2010 as part of the Phase 1 assessment only provided a snapshot of the acid sulfate soil materials present and the conditions at selected locations in the wetland. While recent inundation within the wetland may have minimised the risks identified in the short-term, it is also likely that this inundation will lead to further formation of acid sulfate soil materials.

This Phase 2 study only examined contaminant mobilisation in two layers collected from one site in Boiling Downs Creek wetland. Further studies would be required to determine how representative these soil materials are of the entire wetland in order to fully assess the risk of contaminant mobilisation.

It is recommended that, within the context of other management objectives for the wetland, consideration be given to undertaking water quality monitoring to identify potential contamination as a result of the disturbance of acid sulfate soils within the wetland. The presence of some high risks identified in this Phase 2 assessment indicates that senior management attention is probably needed (MDBA 2011).

7. REFERENCES

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8. APPENDICES

APPENDIX 1. SOIL ANALYTICAL DATA

Table 8-1. Sample 20177_3.1 contaminant and metalloid dynamics data.

Parameter	**units**	**ANZECC Guidelines**	**24 hours**		**7 days**		**14 days**		**35 days**	
			Av.	**±**	**Av.**	**±**	**Av.**	**±**	**Av.**	**±**
pH		6.5-8.0	6.28	*0.03*	6.15	*0.06*	7.01	*0.20*	6.89	*0.17*
EC*	µS cm^{-1}	125-2200	720	*45*	529	*217*	770	*44*	429	*12*
Eh	mV		401	*8*	303	*3*	198	*38*	144	*24*
Ag	µg l^{-1}	0.05	<0.10	*<0.10*	<0.10	*<0.10*	<0.10	*<0.10*	0.30	*0.19*
Al[A]	mg l^{-1}	0.055	1.45	*0.69*	3.32	*0.05*	2.18	*0.05*	0.98	*0.08*
As[B]	µg l^{-1}	13	1.4	*<1.0*	2.7	*<1.0*	7.6	*3.7*	15.8	*5.6*
Cd	µg l^{-1}	0.2	<0.1	*<0.1*	<0.1	*<0.1*	<0.1	*<0.1*	<0.1	*<0.1*
Co	µg l^{-1}	2.8	1.6	*<1.0*	4.1	*<1.0*	5.1	*<1.0*	4.5	*<1.0*
Cr[C]	µg l^{-1}	1	2.6	*<1.0*	5.3	*<1.0*	3.5	*<1.0*	3.0	*<1.0*
Cu[H]	µg l^{-1}	1.4	5.7	*2.1*	13.2	*1.7*	13.3	*<1.0*	4.2	*<1.0*
Fe	mg l^{-1}	0.30	3.13	*1.47*	6.55	*0.55*	7.04	*0.20*	10.19	*1.09*
Mn	mg l^{-1}	1.70	0.42	*0.05*	0.70	*0.05*	0.91	*0.11*	1.06	*0.06*
Ni[H]	µg l^{-1}	11	2.0	*<1.0*	4.4	*<1.0*	7.3	*1.8*	5.5	*<1.0*
Pb[H]	µg l^{-1}	3.4	3.3	*1.4*	6.3	*<1.0*	9.7	*4.0*	2.5	*<1.0*
Sb	µg l^{-1}	9	<1.0	*<1.0*	<1.0	*<1.0*	<1.0	*<1.0*	<1.0	*<1.0*
Se	µg l^{-1}	11	<1.0	*<1.0*	<1.0	*<1.0*	<1.0	*<1.0*	2.3	*<1.0*
V	µg l^{-1}	6	7.5	*2.5*	14.1	*<1.0*	17.2	*7.2*	10.8	*3.4*
Zn[H]	µg l^{-1}	8	26.4	21.7	23.3	*9.3*	44.5	*15.4*	3.8	*<1.0*

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 lowland rivers in South-east Australia are provided for salinity.*
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 As in solution as Arsenic (AsV).*
[C] *Guideline for Chromium is applicable to Chromium (CrVI) only.*
[H] *Hardness affected (refer to Guidelines).*

Table 8-2. Sample 20177_3.2 contaminant and metalloid dynamics data.

Parameter	units	ANZECC Guidelines	24 hours		7 days		14 days		35 days	
			Av.	**±**	**Av.**	**±**	**Av.**	**±**	**Av.**	**±**
pH		6.5-8.0	6.05	*0.38*	6.28	*0.00*	6.74	*0.06*	7.12	*0.13*
EC*	μS cm^{-1}	125-2200	293	*23*	284	*2*	298	*7*	178	*5*
Eh	mV		384	*2*	297	*26*	236	*5*	140	*38*
Ag	μg l^{-1}	0.05	<0.10	*<0.10*	<0.10	*<0.10*	<0.10	*<0.10*	0.26	*<0.10*
Al^{A}	mg l^{-1}	0.055	5.07	*0.46*	11.59	*1.17*	12.55	*1.46*	19.21	*2.89*
As^{B}	μg l^{-1}	13	2.4	*<1.0*	3.9	*<1.0*	4.7	*<1.0*	9.4	*3.3*
Cd	μg l^{-1}	0.2	<0.1	*<0.1*	<0.1	*<0.1*	<0.1	*<0.1*	<0.1	*<0.1*
Co	μg l^{-1}	2.8	4.0	*<1.0*	11.0	*2.5*	16.3	*3.1*	24.2	*<1.0*
Cr^{C}	μg l^{-1}	1	6.0	*<1.0*	17.3	*2.9*	13.2	*2.2*	21.4	*<1.0*
Cu^{H}	μg l^{-1}	1.4	22.1	*3.2*	32.5	*2.8*	39.7	*4.0*	42.7	*7.2*
Fe	mg l^{-1}	0.30	7.67	*0.86*	19.93	*3.09*	15.03	*1.40*	24.16	*0.52*
Mn	mg l^{-1}	1.70	0.49	*0.03*	1.23	*0.16*	2.12	*0.23*	2.38	*0.04*
Ni^{H}	μg l^{-1}	11	5.9	*<1.0*	11.7	*1.9*	13.4	*<1.0*	17.0	*<1.0*
Pb^{H}	μg l^{-1}	3.4	6.6	*<1.0*	12.1	*<1.0*	18.2	*<1.0*	18.0	*<1.0*
Sb	μg l^{-1}	9	<1.0	*<1.0*	<1.0	*<1.0*	<1.0	*<1.0*	<1.0	*<1.0*
Se	μg l^{-1}	11	<1.0	*<1.0*	<1.0	*<1.0*	1.0	*<1.0*	1.9	*<1.0*
V	μg l^{-1}	6	16.7	*2.0*	29.0	*4.9*	30.2	*5.3*	46.9	*<1.0*
Zn^{H}	μg l^{-1}	8	87.1	*1.9*	61.0	*5.0*	183.2	*51.8*	109.5	*11.3*

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 lowland rivers in South-east Australia are provided for salinity.*

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 As in solution as Arsenic (AsV).*

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

[H] *Hardness affected (refer to Guidelines).*

Table 8-3. Reactive metals data (mg/kg dry wt.).

Parameter	ANZECC Sediment Quality Guidelines*		Reactive metals		% of Trigger value	
			20177_3.1	20177_3.2	20177_3.1	20177_3.2
	SQG-Low (Trigger value)	SQG-High	Av.	Av.	%	%
Ag	1	3.7	0.010	0.012	1%	1%
Al			337	299		
As	20	70	0.26	0.14	1%	<1%
Cd	1.5	10	0.007	0.007	<1%	<1%
Co			1.37	0.86		
Cr	80	370	0.17	0.14	<1%	<1%
Cu	65	270	3.48	2.92	5%	4%
Fe			893	582		
Mn			216	132		
Ni	21	52	2.01	1.34	10%	6%
Pb	50	220	3.94	2.68	8%	5%
Sb	2	25	0.004	0.003	<1%	<1%
Se			0.11	0.07		
V			4.75	2.02		
Zn	200	410	5.10	4.47	3%	2%

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

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