Coorong, Lower Lakes and Murray Mouth Program

Acid Sulfate Soil and Ecology Research Workshop

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SUMMARY

This report summarises the outcomes of a workshop held in Adelaide in December 2011 to identify key research programs to address critical knowledge gaps relating to acid sulfate soil and ecological issues in the Lower Lakes. The research work is intended to follow on from previously completed research work and provide answers to some outstanding issues.

The workshop was based around providing answers to some important management questions:

- How long will it take for the lakes to recover and what are the indicators of recovery/problems?
- What we would do differently to manage acidification risks in the future?
- What are the toxicological and synergistic effects of acidification on key aquatic organisms?
- What are the minimum water levels required to protect key species from the effects of acidification?
- What are the implications of likely functional changes to ecosystem processes?
- What are the medium and longer term consequences of different bioremediation techniques/processes?
- What are the rates of recovery of acidic sediments and what is driving recovery in different sediment types and locations?
- Are the lake sediments now more susceptible to future acidification events?
- How significant are surface and groundwater interactions in reducing or increasing the risk of acidification to soil and lake water and what can we do about it?

While some of these questions can be answered, or partially answered, with the research work that has already been completed there are a number that cannot. Further work is required to provide the information required to better manage the Lower Lakes in the future if drought conditions return.

Based on the findings of the workshop six research programs have been identified as high priority. These programs build on the acid sulfate research work undertaken to date but provide an important link to ecosystem process affected by acidification events:

1. Development of a detailed conceptual model of the Lower Lakes system
2. Toxicological and synergistic effects of acidification on key aquatic organisms
3. Minimum water levels required to protect key species from the effects of acidification.
4. Determination of rates of recovery of acidic sediments and what is driving recovery in different sediment types and locations.
5. Medium and longer term consequences of different bioremediation techniques/processes
6. Determination of the significance of surface and groundwater interactions in reducing or increasing the risk of acidification.

Details of the key management questions and the research programs are provided in the report.

INTRODUCTION

The 2004-2009 drought resulted in unprecedented lower water levels in Lake Alexandrina and Lake Albert (the Lower Lakes) with extensive areas of acid sulfate soils being exposed. This caused soil acidification (pH<4) over large areas of both lakes with acidification of surface waters in some localised areas.

To better inform management decision making, a research program was undertaken to fill some critical knowledge gaps related to the risks posed by exposure of acid sulfate soils in the Lower Lakes. The findings of this work have been published in a series of technical reports and a summary report (DENR 2010). The major findings were:

- Acid sulfate soils comprising sulfuric material with severe acidification have occurred over a large area around the margins (about 20% of the total Lower Lakes area) and acid sulfate soils with potential acidity are widespread throughout the area with highest net acidities in the clay rich middle areas of both lakes.
- The rate of oxidation of acid sulfate soils was high.
- Acidity and associated contaminants were being transported to the lakes via shallow groundwater.
- The introduction of seawater could increase contaminant release from the sediments compared to freshwater.
- Modelling indicated broad scale acidification of Lake Albert if water levels fall below minus 0.75m AHD and if they are maintained below minus 1.75m AHD in Lake Alexandrina.

The main management implications from this work were:

- Some acid sulfate soil hot spots can be managed or treated locally.
- The risk of broad scale lake acidification is reduced if water levels are stabilised above minus 1.5m AHD for Lake Alexandrina and above minus 0.5m AHD for Lake Albert.
- Sea water addition is a higher risk management option compared with freshwater.
- Recovery of water quality following lake acidification could take months to years whereas recovery from soil acidification could take much longer.

Subsequent to the completion of this research program further targeted research was undertaken in the flowing areas:

- The measurement of acid fluxes generated on wetting and rewetting of the sediments and diffusion of acidity back into the surrounding water (Cook et al, 2011). This work found that water flow in exposed sediments is mainly vertical and lateral groundwater flow was an unlikely mechanism for significant acid transport to the lakes. It was concluded that the most dangerous period for acidification was immediately after rapid refilling.
- The further development and validation of the hydrodynamic and geochemical model (Hipsey et al, 2011). This work indicated that a renewed phase of water level decline below minus 1.0m AHD would lead to acidification risks, despite potential depletion of sulfidic material over the past two years. It was concluded that the model and the parameters adopted could accurately capture the spatial extent and timing of acidification events and was therefore a valuable management tool.
- An investigation into the effects of bioremediation processes on acidified Lower Lakes sediments (Sullivan et al, 2011) found that sulfur cycling occurring in the sediments as a result of bioremediation and over the short to medium term (up to

18 months) did not lead to the accumulation of sulfide minerals such as monosulfides and pyrite in the surficial lake sediments. Consequently, bioremediation did not lead to the development of appreciable hazards due to acidification, metal and metalloid mobilisation, and deoxygenation associated with these sulfide minerals. It was concluded that the bioremediation of the exposed acidified lake sediments by revegetation produced substantial benefits in terms of reduced erosion and acidity of the surficial lake sediments.

As a consequence of the excellent targeted research work that has been undertaken there is now a much better understanding of the issues surrounding acidification of the Lower Lakes and the management actions that are required to address the problem should it reoccur in the future.

The breaking of the drought and the return of good river flows into the Lower Lakes has significantly lessened the acidification risks. Nevertheless risks remain and a return to drought conditions in the future remains a concern. It is therefore important that the momentum that has been generated over the last few years is not lost and that critical further research work is identified and undertaken so that we are better prepared in the future.

Funding sourced through the Coorong and Lower Lakes Recovery Program provides an opportunity to undertake targeted acid sulfate soil research work with an ecosystem focus. The objectives include filling critical knowledge gaps regarding:

- acidification;
- metal and mono-sulfidic black-ooze (MBO) risks; and
- implications for the ecology in the region.

The Research Priorites draft Work Plan for 2011/12 to 2015/16 proposes funding of $350,000 for the first year however this may be reduced depending on the outcomes from the research workshop. Funding for subsequent years of $200,000 per year is possible for suitable programs. Research programs will need to leverage other funding sources to be successful.

To help identify suitable research programs it was decided to hold an acid sulfate soils and ecology research workshop with key researchers to scope out a suitable program. The main aims of the workshop were to:

1) determine what acid sulfate soil related research should be completed to support adaptive management decisions in the Coorong Lower Lakes and Murray Mouth (CLLMM) region (Ramsar site);

2) investigate who/which organisations would be best to do what research in the short term (to June 2012) and over the next financial years 2012/13 to 2015/16; and

3) identify how to best link in with other funding e.g. ARC linkage.

This report details the findings of the workshop and provides recommendations for further research work in line with the objectives of the CLLMM program.

MANAGEMENT REQUIREMENTS AND RESEARCH IDEAS

An acid sulfate soils and ecology research workshop was held in Adelaide on 7 December 2011 to formulate ideas for further targeted research on the effects of acid sulfate soils in the Lower Lakes region on ecosystems. The workshop comprised key researchers in their field and covered an excellent depth and breadth of knowledge. The agenda for the day and a list of attendees is provided in Appendix 1.

Prior to the workshop a list of management questions or issues was developed in discussions with key staff from DENR and the EPA. These were based on some of the issues that arose out of previous research work as well as strategic requirements going forward. The questions provided a focus for research discussions at the workshop.

The first discussion session at the workshop involved reviewing each of the management questions and where appropriate expressing the question in terms that could be more directly linked to research. This was undertaken interactively. The agreed revised management questions are as follows:

Overarching Questions

- How long will it take for the lakes to recover and what are the indicators of recovery/problems?
- What we would do differently to manage acidification risks in the future?

Ecosystem

- What are the toxicological and synergistic effects of acidification on key aquatic organisms?
- What are the minimum water levels required to protect key species from the effects of acidification?
- What are the implications of likely functional changes to ecosystem processes?

Bioremediation

- What are the medium and longer term consequences of different bioremediation techniques/processes?

Sediment chemistry

- What are the rates of recovery of acidic sediments and what is driving recovery in different sediment types and locations?
- Are the lake sediments now more susceptible to future acidification events?

Groundwater

- How significant are surface and groundwater interactions in reducing or increasing the risk of acidification to soil and lake water and what can we do about it?

The second discussion session then looked at what research work was required to address each of the questions and the issues that need to be considered. A summary of the findings of these discussions is presented in Table 1 below.

Table 1: Management questions and research ideas.

Management question	Comment and research ideas
1. Overarching Questions 1.1 How long will it take for the lakes to recover and what are the indicators of recovery/problems?	This question was raised during the first round of research work and is a complex question that could only be partly answered at that time. Issues around what does recovery mean, will the lakes recover to the state they were in prior to the drought, does recovery relate to acid sulfate soils alone or include ecosystems as well as socio-economic and other considerations. There are others factors to be considered such as salinity and turbidity impacts as well as habitat loss that are important drivers of ecosystem change. It is a fundamental question but difficult to provide an answer without some clear boundaries. One of these is to define and agree on a recovery target. A useful way forward would be to develop a detailed conceptual model comprising of various sub-models of the entire system. Some of this work has already been undertaken, e.g. the geochemistry and hydrodynamic modelling work has developed a conceptual model of the sediment:water interaction, but much more would need to be undertaken in order to develop a more complete understanding of the entire system. The development of a conceptual model of the lakes system could possibly be undertaken as a masters project through a university. It should include literature searches, discussions with researchers on processes and identification of knowledge gaps, discussions with mangers and others on recovery targets and objectives, and being able to condense all this information into a form that summarises the functional aspects of the system. It should identify what we currently know as well as identify areas where critical information is lacking and provide the links between the different components of the system. It is likely that any conceptual model will be dynamic and added to as new information becomes available. The synthesis of sub-models and development of an ecosystem conceptual model is a high priority task
1.2 What we would do differently to manage acidification risks in the future?	A number of steps were taken during the drought to ameliorate the impact of acid sulfate soils in localised areas. For example limestone dosing was tried in some areas, regulators were installed to prevent some areas from drying out, Lake Albert was isolated from Lake Alexandrina and bioremediation was attempted by aerial sowing of rye grasses. The impact of these measures and their effectiveness needs to be properly assessed. The critical factor is, however, maintenance of adequate fresh water levels in the lakes to prevent exposure of acid sulfate soils. This issue has been successfully addressed by the geochemical and hydrodynamic modelling work. A specific research program was not considered necessary for this management question as it links in with a number of the other questions including the recovery question raised above.
2. Ecosystem 2.1 What are the toxicological and synergistic effects of acidification on key aquatic organisms?	The impact of acid sulfate soils on ecosystems and key aquatic organisms is not well understood but is crucial in understanding the ecological significance of the risks posed by acid sulfate soils in the Lower Lakes region. As there is still acidic sediment and pore water present under the Lower Lakes there is potential for the recovery of the ecosystem, in particular the benthic organisms, to be hindered. Ecotoxicity studies are needed on key species to provide answers. The studies need to consider sub-lethal and behavioural effects as well as lethal effects and would need to be both laboratory and mesocosm based. Confounding factors include: metal speciation, bioturbation, physical smothering, effects of colloids, loss of habitat, sulfide toxicity, salinity effects and turbidity effects. Key species would need to include acid sensitive groups such as crustaceans (ostracods, freshwater shrimp and crab), molluscs (bivalves such as the freshwater mussel, gastropods), diatoms and macroinvertebrates. While a focus should be on microbial and benthic organisms, submerged or riparian vegetation, other biota (insect larvae, spiders) and pelagic (zooplankton, fish) organisms could also be included. The confounding effects listed above would need to be fully identified and properly evaluated in a variety of coordinated studies Ecotoxicity investigations are regarded as high priority but are complex, costly and likely to take considerable time.
2.2 What are the minimum water levels required to protect key species from the effects of acidification?	The geochemical and hydrological model has identified critical water levels in the Lower Lakes based on sediment chemistry. The question arises whether these levels would change if protection of key species from the effects of acidification were included as management targets in the modelling work. If ecotoxicity and habitat information was available the model could be developed to determine minimum water levels to protect key species. This is a high priority project but depends on the ecotoxicity work being completed. Other information such as habitat data (type and special distribution) would also be required.
2.3 What are the implications of likely functional changes to ecosystem	After a major shock, ecosystems do often not return to the state they were in prior to the shock but to some altered state. So too the kinetics of drawdown are much faster than

processes?	those of recovery. Knowledge of the functional changes to ecosystem processes can help understand what has occurred and how systems are interlinked. This is important in determining recovery targets and objectives. Having unrealistic expectations of what determines "recovery" can result in inappropriate and costly expectations. Work would need to include analysis of existing monitoring data, experimental work in both the field and laboratory and use of tools such as genomics. This question is linked to the overarching recovery question above and to bioremediation discussed below.
3. Bioremediation 3.1 What are the medium and longer term consequences of different bioremediation techniques/processes?	Bioremediation has been shown to be partially successful in ameliorating the effects of acid sulfate soils in localised areas around the Lower Lakes. Further work is needed to better understand how bioremediation works and what type of bioremediation should be used in different areas. Key issues include: • Importance of sulfur, iron and carbon cycles • Co-precipitation and adsorption of metals • MBO and monosulfide accumulation • Influence of macrophytes, filter feeders and benthic-pelagic coupling Field work would be required to look at the translocation of macrophytes and ways of protecting plantings from wave action. Further research work on bioremediation should be given high priority as it offers ways in which to manage localised hot spot areas and reduce risks to ecosystems in these areas.
4. Sediment chemistry 4.1 What are the rates of recovery of acidic sediments and what is driving recovery in different sediment types and locations?	Understanding the factors affecting recovery of sediments and knowing the rates of recovery in different soil types and at different locations (i.e. exposed, partially exposed and fully inundated) is important in determining the risks associated with repeated wetting and drying events. A number of steps are required: • Continue broad-scale monitoring to assess changes • Undertake specific field and laboratory research to understand geochemical processes better • Link in with geochemical modelling It is important to continue to support sediment investigations to better understand rates of sediment recovery.
4.2 Are the lake sediments now more susceptible to future acidification events?	Modelling has been undertaken using current data to assess whether the acidification events that occurred during the drought have changed the risk profile if such an event was to occur in the near future again. Using depleted and regenerated scenarios, the modelling work has found that the risk profile has not substantially changed from the conditions that prevailed during the drought. While the question is important the work is closely linked to the modelling work and has essentially been answered, although continued monitoring activities could further validate modelling if required. No specific research work is proposed to address this question.
5. Groundwater 5.1 How significant are surface and groundwater interactions in reducing or increasing the risk of acidification and what can we do about it?	Diffusion of acidity from sediment to the water column is likely based on CSIRO pore water profiles and observations of low levels of soluble acidity persisting in the water overlying some of the lake margins that previously acidified. These observations are consistent with modelling results that show that diffusion, particularly from cracked clays, is likely to persist for some time after re-inundation, The diffusion rates and processes require further research particularly to inform the risk of re-acidification under lower flow conditions when the released acidity would be less diluted. Further modelling on the diffusion processes should be undertaken and the research information integrated into the lake geochemical model and ecological risk assessments. Apart from continuing the bioremediation programs, there are unlikely to be any direct management actions that can reduce the risk or acidification by diffusion.
6. Other issues	The workshop identified some other matters that did not specifically relate to the management questions raised but were considered to be sufficiently important to warrant consideration in their own right.
6.1 Establishment of a permanent ASS database.	The CSIRO has collected a large number of sediment cores and these are currently being stored in fridges. More work could be done with these cores and the data from them stored in a suitable database. This would aid future research work.
6.2 Water quality inputs into the Lower Lakes and implications for the lakes.	The impact of upstream contaminants on the lower lakes could be an issue in the future. Identification of the possible contaminants and the risk they pose to the lower lakes could be useful.
6.3 Impacts on the Coorong	The work to date has focussed o the Lower Lakes and not the Coorong. More work could be undertaken looking into ASS impacts on the Coorong.

RECOMMENDATIONS FOR FURTHER RESEARCH

Based on the findings of the workshop six research programs have been identified as high priority. These programs build on the acid sulfate research work undertaken to date but provide an important link to ecosystem process affected by acidification events. The start date for the different programs has been staggered as the outcomes for some are required inputs for others.

1. Development of a detailed conceptual model of the Lower Lakes system.

   Description

   An important question relating to the overall management of the Lower Lakes is how long will it take for recovery to occur and what are the indicators of recovery. This is a complex question. Issues around what does recovery mean, will the lakes recover to the state they were in prior to the drought or some other altered state, how do the different components of the system interact, how do salinity, turbidity and habitat loss affect recovery, what are the socio-economic as well as aesthetic and recreational values that can influence the recovery process.

   The development of a detailed conceptual model comprising of various sub-models of the entire system would provide a framework for better understanding the complexities of the system. Some of this work has already been undertaken, e.g. the geochemistry and hydrodynamic modelling work has developed a conceptual model of the sediment:water interaction, but much more would need to be undertaken in order to develop an understanding of the entire system.

   Potential researcher

   University masters program student

   Linkages

   This work has links with all the other research work on the Lower Lakes. The researcher will need to liaise with key researchers and managers.

   Timing

   Two years commencing in 2012

2. Toxicological and synergistic effects of acidification on key aquatic organisms.

   Description

   The impact of acid sulfate soils on ecosystems and key aquatic organisms is not well understood but is crucial in understanding the ecological significance of the risks posed by acid sulfate soils in the Lower Lakes region. As there is still acidic sediment and pore water present under the Lower Lakes there is potential for the recovery of the ecosystem, in particular the benthic organisms, to be hindered.

   Ecotoxicity studies are needed on key species to provide answers. The studies need to consider sub-lethal and behavioural effects as well as lethal effects and would need to be both laboratory and mesocosm based. Confounding factors include: metal speciation, bioturbation, physical smothering, effects of colloids, loss of habitat, sulfide toxicity, salinity effects and turbidity effects. Key species would need to include acid sensitive groups such as crustaceans (ostracods, freshwater shrimp and crab), molluscs (bivalves such as the freshwater mussel, gastropods), diatoms and macroinvertebrates. While a focus should be on microbial and benthic organisms, submerged or riparian vegetation, other biota (insect larvae, spiders) and pelagic (zooplankton, fish) organisms could also be included.

The confounding effects listed above would need to be fully identified and properly evaluated in a variety of coordinated studies

Potential researcher

CSIRO or University. Possible PhD project.

Linkages

The outcome of this work will be used to inform the model. The work also has links to sediment chemistry and MBO effects.

Timing

Three years commencing in 2012

3. Minimum water levels required to protect key species from the effects of acidification.

Description

The geochemical and hydrological model has identified critical water levels in the Lower Lakes based on sediment chemistry. The question arises whether these levels would change if protection of key species from the effects of acidification were included as management targets in the modelling work. If ecotoxicity and habitat information was available the model could be developed to determine minimum water levels to protect key species.

Potential researcher

Matt Hipsey, University of WA

Linkages

Dependant on findings from ecotoxicological work described above. The modeller and ecotoxicological researcher would need to liaise closely in this work.

Timing

One year commencing in 2014/15

4. Determination of rates of recovery of acidic sediments and what is driving recovery in different sediment types and locations.

Description

Understanding the factors affecting recovery of sediments and knowing the rates of recovery in different soil types and at different locations (i.e. exposed, partially exposed and fully inundated) is important in determining the risks associated with repeated wetting and drying events. The work will entail continuation of broad-scale monitoring to assess changes and undertaking specific field and laboratory research to understand geochemical processes better

Potential researcher

Southern Cross University, CSIRO, Freeman Cook and Associates

Linkages

The researchers will need to liaise with the geochemical and hydrodynamic modeller.

Timing

Two years commencing in 2012

5. Medium and longer term consequences of different bioremediation techniques/processes

Description

Bioremediation has been shown to be partially successful in ameliorating the effects of acid sulfate soils in localised areas around the Lower Lakes. Further work is needed to better understand how bioremediation works and what type of bioremediation should be used in different areas.

Key issues include:

- Importance of sulfur, iron and carbon cycles
- Co-precipitation and adsorption of metals
- MBO and monosulfide accumulation
- Influence of macrophytes, filter feeders and benthic-pelagic coupling

Field work would be required to look at the translocation of macrophytes and ways of protecting plantings from wave action.

Potential researcher

Southern Cross University, CSIRO

Linkages

The researchers will need to liaise with key managers at DENR

Timing

Two years commencing in 2013/14

6. Determination of the significance of surface and groundwater interactions in reducing or increasing the risk of acidification.

Description

As there is still acidic sediment and pore water present under the Lower Lakes there is potential for the recovery of the ecosystem, in particular the benthic organisms, to be hindered. The acid flux from the sediments to the lake requires determination, in particular the amount and time scale for these fluxes as related to acid distribution in the sediments. The subsequent impacts and risks to surface water chemistry and benthic ecology needs to be determined.

<u>Potential researcher</u>

Freeman Cook and Associates, CSIRO, EPA

<u>Linkages</u>

EPA/ DENR groundwater monitoring project

<u>Timing</u>

Three months commencing in 2012

REFERENCES

DENR 2010, Acid sulfate soils research program summary report, Prepared by the Lower Lakes Acid Sulfate Soils Research Committee for the SA Department of Environment and Natural Resources, Adelaide

Cook FJ, McLachlan G, Leyden E and Mosley L, 2011. Physical Properties of Soils/Sediments of Lower Murray Lakes and Modelling of Acid Fluxes. CSIRO: Water for a Healthy Country National Research Flagship

Hipsey MR, Busch BD, Lower Lakes Water Quality Recovery Dynamics, Final Report (Draft V1), report prepared for the Department of Environment and Natural Resources, Government of South Australia

Sullivan LA, Burton ED, Ward NJ, Bush RT, Coughran J, Cheetham MD, Fyfe DM, Cheeseman PJ and McIntyre T (2011) *Lower Lakes sulfate reduction study*. Southern Cross GeoScience Technical Report No. 711. Prepared for the SA Department of Environment and Natural Resources, Adelaide.

APPENDIX 1 – RESEARCH WORKSHOP AGENDA

Attendees

Chair: John Cugley

DENR: Liz Barnett, Russell Seaman, Alec Rolston, Ann Marie Jolley and Amy George

EPA: Luke Mosley, Peter Goonan and Emily Leyden

CSIRO: Rob Fitzpatrick, Merrin Adams, Jason Kirby and Paul Shand

UNIVERSITY: Justin Brookes (University of Adelaide), Sabine Dittman (Flinders University), Matt Hipsey (University of Western Australia), Leigh Sullivan and Annabelle Keene (Southern Cross University)

CONSULTANT: Freeman Cook (Freeman Cook and Associates)

Agenda

10:00 Welcome and introductions

10:05 Purpose of meeting (John Cugley)

10:10 Program delivery and funding (Liz Barnett)

10:30 Background and update on CLLMM ASS research to date (Luke Mosley)

11:00 Strategic direction and management requirements (Group discussion)

11:30 Critical knowledge gaps (Group discussion)

12:30 Lunch

13:00 Research program discussions (Group Discussion)

14:30 Summary of discussions

15:00 Close