SINCLAIR KNIGHT MERZ

SKM

Government of South Australia

SA Water

Lower Lakes Acidification Management Alternative Options Appraisal

REPORT ON ALTERNATIVE OPTIONS SCORING

- FINAL
- 15 November 2010

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Executive Summary

As a result of ongoing drought conditions across the Murray-Darling basin and associated low river flows into South Australia, water levels in the Lower Lakes system (including Lake Alexandrina, Lake Albert, and associated tributaries) have been at all time lows and may decrease further in the future if drought conditions continue as predicted.

In response to this situation, the Government of South Australia has referred a proposal to open the barrages that separate Lake Alexandrina from the Coorong to the Commonwealth Department of the Environment, Water, Heritage and the Arts under the provisions of the *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act). It has been recognised that this action may be necessary as a means of preventing serious and permanent damage to the Lower Lakes system, although the use of seawater is seen as an 'action of last resort' to minimise the environmental consequences of acidification of the Lower Lakes system.

It has been determined that the proposed action to open the barrages and allow seawater to flow into the Lower Lakes system would require approval by the Minister for the Environment, Heritage and the Arts as it has the potential to significantly impact on matters of national environmental significance (NES) as recognised by the EPBC Act. Therefore, SA Water (on behalf of the Government of South Australia) is developing an Environmental Impact Statement for the proposed action. The Environmental Impact Statement is required to consider management options alternative to the proposed action. Sinclair Knight Merz Pty Ltd (SKM) was engaged by SA Water to undertake a comparative technical feasibility and practicality assessment of options that may be used to manage acid sulfate soil derived acidification of the Lower Lakes system, based on currently available studies and reports.

The general methodology applied in this assessment of potential alternative options was based on Multi Criteria Analysis (MCA), which provides a robust evaluation of multiple options against common criteria using a transparent and defendable assessment framework. Using this framework, qualitative information sourced from site specific studies, as well as broader sources, was translated into quantitative scores, so that each option could be assessed relatively. The assessment was undertaken over two stages, with stage one assessing all the nominated alternative options in relation to the proposed action, and stage two focussing on the potential benefit of combining those options assessed as being high ranking in stage one.

The assessment criteria were broadly divided under the two headings of 'technical & practical feasibility' and 'costs (direct & indirect)'. Each option was also assessed with respect to potential negative risks to the environment as a result of its implementation, and whether the option could be considered as a preventative measure rather than a treatment measure.

Sensitivity analysis of the effect of variation in contribution from each of the two broad criteria (i.e. technical versus costs) was undertaken. The stage one assessment indicated that the ‘provision of freshwater via environmental allocations’ option is generally ranked as the number one option across the majority of technical versus costs contribution ratios. The provision of freshwater (buy-backs) also shares the number one ranking when costs contribution is minimised (i.e. 0%). The vegetation option ranks at number two for certain contribution ratios. However, further analysis of the scores indicates that the vegetation option scores poorly on a technical basis (i.e. in terms of acidification management), but retains a high ranking due to scores awarded on the costs contribution, coupled to a high multiplier for the perceived low environmental risks.

The ranking of the transfer of seawater (via barrages) option increases when the cost contribution is increased, as it is a low cost option. It does not score significantly well on the technical contribution as a management measure, as it is downgraded by its potentially high environmental risk, associated with inundating oxidised sediments. However, as the option scores a technical ranking of four (of eight), there may be merit in using this option as a preventative measure under certain conditions, to prevent exposure of clays in the central areas of the Lakes.

Particular focus was given to the potential environmental risks associated with the implementation and operation of each option. The considered likelihood and severity of potential risks were applied as adjustment factors, which produced an overall score for relative assessment. The high ranking options (i.e. provision of freshwater via environmental allocations and buy-backs) were assessed as having less environmental risks associated with their implementation / operation than the option of last resort (i.e. the proposed action). Further, the majority of the alternative options were considered to have less environmental risk than the proposed action with respect to mitigating acidity, even when assuming seawater is used as a preventative measure. This high risk is associated with the potential for mobilisation of acidity and metal species to the overlying water column (with respect to sandy soils, less generally for clay soils) should seawater be applied to oxidised sediments (assuming no preliminary lime dosing – neutralisation – activity / management has occurred).

Stage two of the assessment considered the key management questions associated with the Lakes, based on the findings of stage one that freshwater inundation was the highest scoring alternative option. It was considered that freshwater inundation could be used to manage the system to an arbitrary water management level, and a combination of symbiotic options (based on the findings of stage one and referred to as enhanced bioremediation) could then be implemented as a localised management action. The assumption of localised management is based on the heterogeneity of the sediments around the Lakes, and the rationale that hazard does not necessarily equal risk (i.e. management may be applied in a prioritised manner based on the perceived risk). This option combination also included the reactive neutralisation of localised sediments / acidified water.

The implementation of enhanced bioremediation with freshwater stabilisation (option ombination 1) was comparatively assessed against the use of seawater as a method of stabilisation (i.e. the proposed action, option combination 2) and also against a drawdown of water level (option combination 3).

The assessment of these three combinations indicates that option combination 1 (enhanced bioremediation with freshwater stabilisation) is the top scoring / ranking option combination.

Sensitivity analysis of the ratio of technical and cost contribution to the overall score indicated no change in the ranking of the combined options across all technical / costs contribution, indicating that option combination 1 is a significantly robust option.

It is considered that the implementation of option combination 1 would have the following potential environmental benefits:

- maintenance of current ecological characteristics / regimes;
- once environmental flows resumed to historical levels, the transition from stabilisation to normal regime would be relatively easy (i.e. return to pre-action state);
- opportunities for feeding bird species (primarily wading species) may develop, arising from vegetation works;
- less potential mobilisation of acidity and heavy metals than associated with other considered options;
- more buffering capacity than seawater; and
- desired level could be achieved via managed water savings across basin.

In addition, the adoption of option combination 1 would allow the natural resilience of the Lakes system to be stimulated, and potentially result in a more harmonised and natural environment.

It was also considered that the other option combinations (2 and 3) would not provide several of these benefits, and may have adverse results, including:

- potential for the increased generation of hydrogen sulfide gas due to high quantities of sulfate in saltwater (as a result of an imbalance between sulfur and available iron);
- risk of water body becoming hyper-saline (as observed within the Coorong) as system flushing may not be sufficient;
- risk of mobilisation of acidity, metals and nutrients following inundation of oxidising sediments with seawater;
- significantly lower Lake levels (option combination 3, including a stabilisation of Lake Alexandrina at approximately - 2.3m AHD); and

- dust generation / erosion of exposed lake beds.

Significantly, increased exposure and oxidation of acid generating sediments would occur, potentially leading to the increased mobilisation of acidity and metals. Besides the significant environmental detriment that may occur, there would likely be significant additional costs associated with increased requirement for vegetation across exposed areas, coupled to the additional costs associated with the need for increased neutralisation of acidified sediment (and potentially of the remnant Lakes as a whole).

Assuming that drawdown was allowed, the rehabilitation of the Lakes following re-commencement of environmental flows would also most likely incur significant resources.

Overall, the key findings of this comparative study, undertaken to support the Environmental Impact Statement for the proposed action of opening the barrages, are as follows:

1. An increase in freshwater to the Lower Lakes system (via environmental allocations) and inundation of acid generating sediments, is the number one option from a technical, practicality and high level costs (both direct and indirect) aspect.

2. The inundation of the system using freshwater but via buy-back also scored well on the technical and environmental risks areas (being essentially the same option as the freshwater via allocations option) although the cost component reduces its ranking as the cost contribution increases.

3. The comparative assessment indicated that the proposed action (seawater inundation via barrages) for the Lakes system does not score highly from a technical aspect as a preventative measure, and is further downgraded by its potentially high environmental risk, associated with inundating oxidised sediments.

4. The freshwater options (i.e. allocations or buy-backs) may be affected by the same potential risk, although it is considered that more cation exchange (and buffering capacity) would be available when using freshwater over that available when using seawater. Use of seawater may also lead to hyper-salinity of the water body.

5. With respect to Lake Albert, the pumping of saltwater from the Coorong is ranked low overall, based on the cost contribution score. However the mid ranking of the technical contribution indicates that the option may be of merit as a preventative last resort measure for those areas of the Lake which exhibit significant potential acidity and this option could be defined and investigated further.

6. Assuming a certain level of sediment heterogeneity around the periphery of the water bodies, and the rationale that hazard does not necessarily equate to risk, localised management based on risk prioritisation (and potentially coupled to socio-economic factors) was considered more relevant than a system wide management response.

7. Based on the findings of stage one (freshwater inundation was the highest scoring alternative option), and the rationale of localised management, freshwater inundation may be used to manage the system to an arbitrary water management level, in conjunction with a combination of symbiotic options (bioremediation supported by use of vegetation and reactive neutralisation of sediments and acidified water - referred to as enhanced bioremediation).

8. When comparatively assessed using the MCA methodology, the use of freshwater stabilisation in conjunction with enhanced bioremediation scored significantly higher than both the use of seawater (via barrages) and drawdown. Sensitivity analysis of the ratio of technical and cost contribution to the overall score indicated no change in the ranking of the combined options across all technical / costs contribution, indicating that option combination 1 is a significantly robust option.

9. It is considered that the implementation of a combined option comprising freshwater stabilisation of the system and enhanced bioremediation would have several potential environmental benefits and would allow the natural resilience of the Lakes system to be stimulated, and potentially result in a more harmonised and natural environment.

10. The other option combinations (i.e. seawater and drawdown) may have varied significant detrimental environmental impacts, including increased exposure and oxidation of acid generating sediments with subsequent mobilisation of acidity and metals. Besides the significant environmental detriment that may occur, there would likely be significant additional costs associated with increased requirement for vegetation across exposed areas, coupled to the additional costs associated with the need for increased neutralisation of acidified sediment (and potentially of the remnant lakes as a whole).

11. The implementation of a drawdown approach may result in significant resources being required to rehabilitate the Lakes, following re-commencement of environmental flows.

1. Introduction

Sinclair Knight Merz Pty Ltd (SKM) was engaged by SA Water to undertake a technical feasibility and practicality assessment of options that may be used to manage acid sulfate soil derived acidification of the Lower Lakes system in South Australia.

This study provides a comparative analysis of the impacts of proposed options on Lower Lakes acidification, and qualitatively discusses the potential for recovery of the system from the employment of each alternative.

1.1. Background

As a result of ongoing drought conditions across the Murray-Darling Basin and associated low river flows into South Australia, water levels in the Lower Lakes system (including Lake Alexandrina, Lake Albert, and associated tributaries) have been at all time lows and are likely to drop further if drought conditions continue as predicted.

As the water levels drop, previously sub-aqueous soils eventually become exposed and are dewatered, subsequently becoming dry and oxidised, leading to oxidation of pyrite and concomitant generation of sulfuric acid (i.e. resulting in a pH <4), assuming sufficient sulfidic material is present in the drying layers. The acid generated (along with pH sensitive metals) may then migrate to the aquatic environment and detrimentally impact ecosystems. These acid generating sediments are termed Acid Sulfate Soils (ASS). An overview of ASS is presented in Appendix A.

In response to this situation, the Government of South Australia has referred a proposal to open the barrages that separate the Coorong from Lake Alexandrina to the Commonwealth Department of the Environment, Water, Heritage and the Arts (DEWHA) under the provisions of the *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act). It has been recognised that this action may be necessary as a means of preventing serious and permanent damage to the Lower Lakes system, although the use of seawater is seen as an ‘action of last resort’ to minimise the environmental consequences of acidification of the Lower Lakes system.

It has been determined that the proposed action to open the barrages and allow seawater to flow into the Lower Lakes system would require approval by the Minister for the Environment, Heritage and the Arts as it has the potential to significantly impact on the following matters of national environmental significance (NES) as recognised by the EPBC Act:

- Wetlands of international importance;
- Listed threatened species and communities;
- Listed migratory species; and
- Commonwealth land.

The proposed action to open the barrages will be assessed by an Environmental Impact Statement (EIS). The preparation of the EIS and the array of supporting technical studies that will be integral to the EIS is the responsibility of the South Australian Water Corporation (SA Water).

The EIS is required to address a range of environmental, social and economic impacts associated with:

- The proposed action to open the barrages (noting that the action be identified as only allowing sufficient seawater into the system to maintain the water level at an agreed acidification trigger level);
- Likely mitigation measures to be employed to restore the 'ecological character' of the Lower Lakes system if the proposed action proceeds; and
- The employment of alternative management options to the proposed action.

Thus as part of the suite of supporting studies required for the EIS, an assessment of alternative options to the proposed seawater action (i.e. the opening of the barrages) is required, based on a comparative analysis of the technical feasibility and practicality of alternative management options. An assessment of the impacts associated with each management option alternative to the proposed action is also a key priority.

The nominated alternative management options are described in Section 2.

1.2. Development of the comparative assessment

In order to provide a justifiable and transparent comparative (qualitative) analysis of the alternative options, a Multi Criteria Analysis (MCA) framework was developed in conjunction with the alternative options study management team (SMT), which comprised the following members:

- Dr. Donna Ferretti – SA Water (SMT Leader);
- Jacqueline Frizenschaf – SA Water;
- Dr. Liz Barnett – Department of Environment and Natural Resources (DENR);
- Russell Seaman – Department of Environment and Natural Resources;
- Dr. Luke Mosley – South Australian Environment Protection Authority;
- Paul Harvey – Government of South Australia
- John Williams – SA Water

During the inception workshop, the boundaries of the assessment were developed:

- Being a nested MCA inside a broader EIS MCA, the assessment should focus on the technical and practicality aspects of nominated options and provide a high level cost assessment (comparative); and
- As other components of the EIS were assessing socio-economic factors, an in-depth assessment of the socio-economic impacts / benefits of the implementation of each alternative option was not required in addition to the high level cost / benefit metrics developed for the MCA.

1.3. Multi criteria analysis

MCA (or multi objective decision-making) does not impose limits on the forms of criteria, allowing for consideration of varied parameters (e.g. technical, environmental and other forms of equity). MCA can be broken down into three groups: one that requires quantitative data, a second that uses only qualitative data, and a third that handles both simultaneously. MCA does not require the use of definitive financial information, although such information can be included to arrive at a score. MCA uses weighting involving relative priorities of different groups.

MCA calls for desirable objectives to be specified via the use of metrics. These often exhibit a hierarchical structure. The highest level represents the broad overall objectives. The high level statement may be broken down into more operational lower level objectives so that the extent to which the latter are met may be practically assessed. Sometimes only proxies are available, and value judgments may be required in choosing the proper attribute. However measurement can be in the form of varied 'currency' (i.e. not monetary terms, but in terms of response and in relation to how well the different objectives can be fulfilled).

The MCA framework developed for the comparative assessment of alternative options comprised key metrics to draw out the technical feasibility and practicality of each nominated alternative option. A high level cost assessment (i.e. cost to Government and wider community) was also included in the MCA assessment. The bottom line score was then adjusted based on the function of the respective option as either a preventative measure (more attractive) or a treatment (less attractive) and any perceived potential environmental impacts associated with the option. The methodology for the development and application of the MCA is provided in Section 3.

1.4. Objectives of the alternative options study

A large number of studies have been completed or are currently being undertaken that are relevant to the consideration of alternative management options for the Lower Lakes system. As these studies have been undertaken by a range of Government agencies and consultants, a key objective of the Alternative Options Study (AOS) is to bring together and review these studies as a necessary first step in assessing the technical feasibility and practicality of alternate potential management options.

A further consideration of this study is to identify possible combinations of alternative management options.

The use of a purposefully developed MCA to qualitatively compare alternative options formed the basis for achieving the objectives of the study.

1.5. Scope of work

The scope of work was developed from the Request For Tender (RFT, reference CS4582B) for the assessment of environmental acidification management options alternative to the proposed action (i.e. opening of the barrages). The scope of work is a direct response to the requirement of certain supporting studies for the EIS of the proposed action and is not designed to fulfil any other capacity. The scope of work was also developed in consultation with the SMT, during the project inception workshop component of the project. The scope of work comprised:

- *review and analyse the literature and array of studies listed as provided;*
- *describe and compare the impacts of each alternative management option (as outlined in Section 2 of this report) on acidification of the Lower Lakes system;*
- *describe and compare the environmental costs and benefits of employing each alternative management option;*
- *determine the technical feasibility/effectiveness and practicality of employing each alternative management option to prevent/remediate/neutralise acidification of the Lower Lakes System;*
- *identify and propose effective alternative management options to prevent/remediate/neutralise environmental harm to the Lower Lakes system;*
- *propose a suitable timeframe to develop and implement effective alternative management options identified as technically feasible and practicable; and*
- *list uncertainties in the assessment of the effectiveness and practicality of different options and make recommendations (where required) to reduce those uncertainties.*

2. Nominated alternative management options

The alternative options nominated for assessment via the EIS are as follows:

1. Drawdown of water level;
2. Bioremediation;
3. Vegetation;
4. Neutralisation;
5. Provision of freshwater via buy-backs; and
6. Provision of freshwater (environmental allocations).

In addition, the transfer of seawater directly into Lake Albert from the Coorong was also considered in relation to the above options. The alternative options were assessed in relation to the proposed action, i.e. inundation of the system with seawater (via opening of the barrages). A summary of each option is provided below.

2.1. Drawdown

This option considers that no active preventative management measures will be undertaken to address environmental acidification of the Lower Lakes, assuming that the Wellington Weir and the Clayton regulator will both be in place and operational. This will result in water level within the system being drawn down, and the previously inundated sediment being exposed.

2.2. Bioremediation

Bioremediation refers to management approaches that aim to promote microbial activity (sulfate-reducing bacterial activity) in order to convert dissolved sulfate to sulfide minerals, while consuming acid. This essentially reverses the pyrite/iron mono-sulfide oxidation reactions that generated acidity in the first place.

2.3. Vegetation

In the context of this project *vegetation* is the term used for covering with vegetation the soils exposed by water-level decline within the Lower Lakes system.

The vegetation may include local native plant species, exotic annuals or exotic perennials identified as effective in covering soils to assist in the bioremediation of the area.

Although biodiversity is extremely important in this region, the vegetation that is proposed does not have the sole purpose of improving biodiversity. Rather, the primary purpose of the initial vegetation is to provide ecosystem stability or resilience by immediate soil cover, stabilising moving sand to reduce the impacts on the natural ecosystem, individuals and communities. These actions are likely to have an effect on reducing soil acidification by assisting to maintain soil moisture in the short-term, and by providing longer-term benefits as part of a bioremediation process.

2.4. Neutralisation

Generally, in environmental or development works, where the disturbance of ASS is unavoidable, the most common technique for managing ASS is neutralisation of the acidity using a neutralising agent such as limestone.

2.5. Provision of freshwater via buy-backs

Under this option, the sediments identified as being potentially acid sulfate generating would be saturated (not necessarily inundated) with freshwater to maintain a low redox environment and prevent pyrite oxidation. Freshwater would be resourced from water purchase.

2.6. Provision of freshwater via environmental allocations

As Section 2.5 above but using freshwater from environmental allocations and re-allocation of current licenses not required / used. This option also encompasses water saving programs which assess the re-direction of water from inland wetlands of low ecological value (following appropriate technical, ecological and risk assessment).

2.7. Transfer of seawater from the Coorong to Lake Albert

Although the intent is to maintain freshwater in Lake Albert, if water levels and water quality drop below a critical point and acidification is imminent then allowing seawater into the Lake may need to be considered. This would not involve flooding the Lake with seawater, but allowing just enough water into the Lake to maintain the level of the Lake at a management level of -0.5 metres below sea level. The transfer of water into Lake Albert would be achieved via

- pumping of water from the Coorong; or
- establishment of a channel from the Coorong to the Lake.

2.8. Transfer of seawater via the barrages (Proposed Action)

As with Lake Albert, the intent is to maintain freshwater in Lake Alexandrina and the tributaries. However if water levels and water quality drop below a critical point and acidification is imminent then allowing seawater into the Lower Lakes may need to be considered. This would not involve flooding the Lower Lakes with seawater, but allowing just enough water through the barrages to maintain the level of Lake Alexandrina at or above an arbitrary management level of -1.5 metres below sea level.

3. Assessment methodology

3.1. Overview

As discussed in the introduction, the general methodology applied in this study to review and comparatively analyse potential alternative options was based on Multi Criteria Analysis (MCA). The key principles of the MCA approach being as follows:

- Provides robust evaluation of multiple options against common criteria;
- Transparent and defendable assessment framework;
- Gain strong stakeholder 'buy-in' to process and therefore to outcomes;
- Minimisation of individual bias (consensus outcomes); and
- Objective assessment where possible (minimise subjectivity).

The first step of the methodology was a Project Inception Meeting (Step 1), which was undertaken in order to open up an early dialogue with the Study Management Team (SMT) and research teams, and develop / finalise the MCA framework, the review methodology and communication plans.

Step 2 involved the development and finalisation of the MCA framework, using the criteria and parameters agreed with the Study Team during the project inception workshop. Both the criteria and options were developed using a SMART approach:

- Specific;
- Measurable;
- Achievable;
- Relevant; and
- Time bound

This collaboratively designed and SMART reviewed assessment tool allowed the review to be approached with clear goals in mind.

Following the achievement of a consensus on the assessment metrics, the review was better positioned to determine each option's suitability, with respect to technical feasibility, practicality and lifecycle / environmental costs (note that these terms and the weighting contribution of each of the metrics are defined in Appendix B - Weighting Justification).

Step 3 comprised the review of each option in light of currently available studies / information, to identify potential shortcomings with respect to the chosen assessment criteria. The opinions derived from the review of each option were used to determine relative scores within the MCA framework (Step 4). The significance of the technical and practicality merits of each potential option were identified during the data and information review using an issue decision process (IDP) with the ultimate outcome of Step 4 being the identification of which alternative options (or sub-components) are potentially effective.

The fifth and final Step (Step 5) comprised the assessment of a combination of options identified as potentially suitable for the management of the system.

Steps 1 to 4 were grouped as ‘Stage 1’, and Step 5 was termed ‘Stage 2’.

A more detailed description of the individual steps is provided below.

3.2. Stage one assessment

3.2.1. Step one – project inception

This step involved SKM and the SMT working collaboratively to identify and articulate the objectives, requirements, constraints and sensitivities for future activities. This inception workshop supported the development of the review framework and parameters and the Issue Decision Process (IDP) for managing the review of the current information and data (i.e. amendment and finalisation of the Step 2 framework).

The assessment criteria for the MCA Framework were based on criteria developed for the EIS, which were deemed directly relevant to the alternative options, and agreed upon within the Project Inception workshop. The assessment focussed on the following broad criteria:

1. Technical and Practical Feasibility of the option (with regards to mitigating environmental acidification of the Lower Lakes); and
2. Costs – both direct (i.e. to Government) and indirect (i.e. the Lakes region and the wider environment).

A summary of the chosen criteria is presented below (Table 1).

▪ Table 1 - MCA Criteria

Criteria Level	Criteria	
Heading	**Technically feasible and achievable in practice on the scale required**	
Sub-criteria	Technically feasible (theoretically, will it work?)	
Base Criteria		• A - Option is theoretically viable • B– Theoretically viable on the scale (spatial) required
Sub-criteria	Achievable in practice (has it been proven to work?)	
Base Criteria		• A - Generic Proof of Concept established • B - Proof of Concept established in similar (representative) environs • C – Proof of concept established in Lower Lakes environments and environs
Sub-criteria	Implemented successfully before acidification of the Lakes occurs – Dependant on Lakes recharge	
Base Criteria		• A1 – on a large scale • A2 – on a localised scale

Heading	Costs to Government (State or Federal)		
Sub-criteria		8.1 Direct lifecycle costs (dollar costs directly apportioned to the entire lifecycle of the option.)	
Base Criteria			• Capital / Establishment costs are minimal • Operational / Maintenance costs are minimal • Decommissioning costs are minimal
Sub-criteria		8.2 Indirect or environmental costs & benefits (limited to impacts that Government may be liable for through the application of the option)	
Base Criteria			• Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes region) • Maximises the indirect benefits experienced in the wider Lower Lakes region (e.g./ tourism, agriculture, wine, lifestyle)

3.2.2. Step two – MCA development

The chosen criteria (or metrics) were processed through a SMART review (see Section 3.1) in order to fully define the exact interpretation of each criterion to sub-criteria level, as presented in Table 2.

Table 2 - SMART Interpretation of criteria

Criteria			Technically feasible and achievable in practice on the scale required		Costs to Government (State or Federal)	
	Sub Criteria		Technically feasible on the scale required.	Achievable in practice on the scale required.	Direct lifecycle costs (dollar costs directly apportioned to the entire lifecycle of the option)	Indirect or environmental costs & benefits.
		Specific	Requires 'proof of concept' or high levels of confidence to determine technical feasibility	Requires modelling confidence to determine achievability at this scale	Requires assessment of the relative dollar value associated with the lifecycle costs of the option	Assessment of the relative socio-economic costs
		Measurable	Yes – if relevant parameters are defined	Yes – if relevant parameters are defined	Yes – all options will have high level determinable lifecycle costs	Yes – all options will have high level socio-economic costs
		Achievable	Unknown – could be limited by resources (dollars and other)	Unknown – could be limited by resources (dollars and other)	Achievability is related to unknown dollar value of resource	As defined by chosen acceptable boundaries for socio economic impact
		Relevant	Relevant parameters need to be chosen	Relevant research and testing needs to occur and then parameters need to be chosen to gauge success	Relevant to other options due to unknown available dollar value	Relevant to socio-economic study (separate) but as indicator here
		Time bound	Over what period of time is the criteria expected to be relevant?	Over what period of time is the criteria expected to be relevant?	Over what period of time are financial inputs required?	Period of time socio-economic effects / benefits are of concern?

A SMART review was also undertaken for each of the proposed potential alternative options, in order to assess each option in the same ‘currency’ as the criteria, as presented in Table 3.

Table 3 - Interpretation of SMART parameters for potential options

SMART Component	Descriptive
Specific	Define the specific scope of the option
Measurable	How do we measure what happens?
Achievable	Is there proof of concept, trials etc
Relevant	Is the option suitable in the Lower Lakes environs?
Time bound	When do we expect to see results? / How long are we measuring for?
Other Comments	Risks, costs etc (i.e. input as adjustments to MCA Framework)

The metrics were then built into an MCA framework, which allowed increasing points to be awarded against each criteria (i.e. ‘0’ for no benefit, up to a maximum of ‘10’ for maximum benefit) in relation to how each option aligned with the criteria, as follows:

Alignment with Criteria:

- No / Not Applicable = 0
- Unlikely = 2
- Probable = 5
- Yes = 10

The criteria headings (Table 1) were weighted on a percentage basis, in order to assess the sensitivity of the contribution of ‘technical & practical feasibility’ vs. ‘costs (direct & indirect)’. These heading weightings were set at 50 % / 50 %, with subsequent sensitivity analysis demonstrating a sliding scale of contribution from 100% Technical & Practicality / 0% Costs to 0% Technical & Practicality / 100% Costs.

The contribution of each criteria sub-heading was then allocated from 100% total, with the base criteria also having an allocation from 100% Total. Table 1 presents the contribution hierarchy. The weighting given to each of these criteria is presented in Appendix B along with a justification for the allocated weighting.

Decision confidence adjustment

Each of the individual scores was assessed in terms of the confidence of the decision, as follows:

- High confidence that the score is accurate = 1.0
- Medium confidence score = 0.75
- Low confidence score = 0.5

These confidence scores were allocated based on which parameter specific status was most applicable to the review / output of the review (Appendix C). The sub total of the scores allocated across all criteria was then processed through several adjustment factors, as outlined below:

- **Preventative vs. Treatment**

  The sub total was multiplied by either a factor of 1.0 if it was deemed to be a preventative measure, or a factor of 0.75 if deemed to be a treatment (i.e. post acidification). The multiplier for 'preventative' was higher than 'treatment' to allow benefit to be provided for a measure likely to mitigate acidification before it may occur, and thereby minimising risk to the environment.

- **Risk of negative impact**

  This adjustment factor is a reflection of the direct environmental negative impacts associated with the option being scored, in terms of implementation, and is split over two multipliers:

  - Likelihood of negative impact
  - Severity of negative impact

  Likelihood and severity are brought together in the standard risk assessment matrix presented in Table 4:

Table 4 - Risk Matrix for Assessment of Negative Impacts

Severity Level					
Likelihood	**1** (negligible)	**2** (slight)	**3** (moderate)	**4** (dangerous)	**5** (critical)
E (almost certain)	H	H	E	E	E
D (likely)	M	H	H	E	E
C (possible)	L	M	H	E	E
B (unlikely)	L	L	M	H	E
A (very rare)	L	L	M	H	H

Where:

Risk Level	
E =	**Extreme Risk**
H =	**High Risk**
M =	**Moderate Risk**
L =	**Low Risk**

Thus risks are categorised according to the likelihood of the risk occurring and the consequence of its occurrence. A description of the matrix phrases is provided below in Table 5 and Table 6:

- **Table 5 - Likelihood of risk**

Likelihood – Qualitative measures		
Level	**Descriptor**	**Detailed Description**
E	Almost Certain	The event ***will occur*** during the implementation / operation.
D	Likely	The event ***is likely to occur*** during the implementation / operation.
C	Possible	The event ***may occur*** during the implementation / operation.
B	Unlikely	The event is ***not likely to occur*** in the implementation / operation.
A	Very Rare	The event will ***only occur in exceptional circumstances***.

- **Table 6 - Consequence of risk**

Consequence – Qualitative measures		
Level	**Descriptor**	**Detailed Description**
5	Critical	Disaster – loss of human life, extensive loss of flora and fauna, loss of property, reputation, financial resources. (Financial consequences: 75% or greater of operation budget).
4	Dangerous	Critical event, which with proper management can be endured. (Financial consequences: 50% - 75% of operation budget).
3	Moderate	Significant event that can be managed under normal operating procedures. (Financial consequences: 20% - 50% of operation budget).
2	Slight	Consequences can be readily absorbed but management effort is still required to minimise impacts. (Financial consequences: 10% - 20% of operation budget).
1	Negligible	Very low significance.

		(Financial consequences: less than 10% of operation budget).

3.2.3. Step three - options review

This step comprised a review of available data and information as supplied by the SMT, coupled with a review of existing system conditions, in order to better understand the Lower Lakes system, its environmental characteristics and potential data gaps associated with the studies supporting the current ensemble options. A comprehensive list of the studies and reports undertaken on the Lower Lakes with respect to acid sulfate soils (as provided to SKM by the SMT) is provided as Appendix D. The focus of the review was guided by the criteria and parameters finalised in the MCA Framework (See output from Step 2).

Maintaining a justifiable and transparent record of the technical issues arising from the review was recognised as a necessary part of the review process. Therefore the potential issues were assessed using the Issue Decision Process (IDP) to identify the significance of each issue. The IDP used in this review is presented in Figure 1.

Note that the term 'effectiveness' used in the IDP figure and herein is defined by SKM as representing technical effectiveness and practicality. The proposed IDP results in five possible levels of significance dependant on certain review criteria, as follows:

1. Non-significant issue;
2. Review Criterion met;
3. Review Criterion met (observations);
4. Review criterion met (reservations); and
5. Review criterion failed.

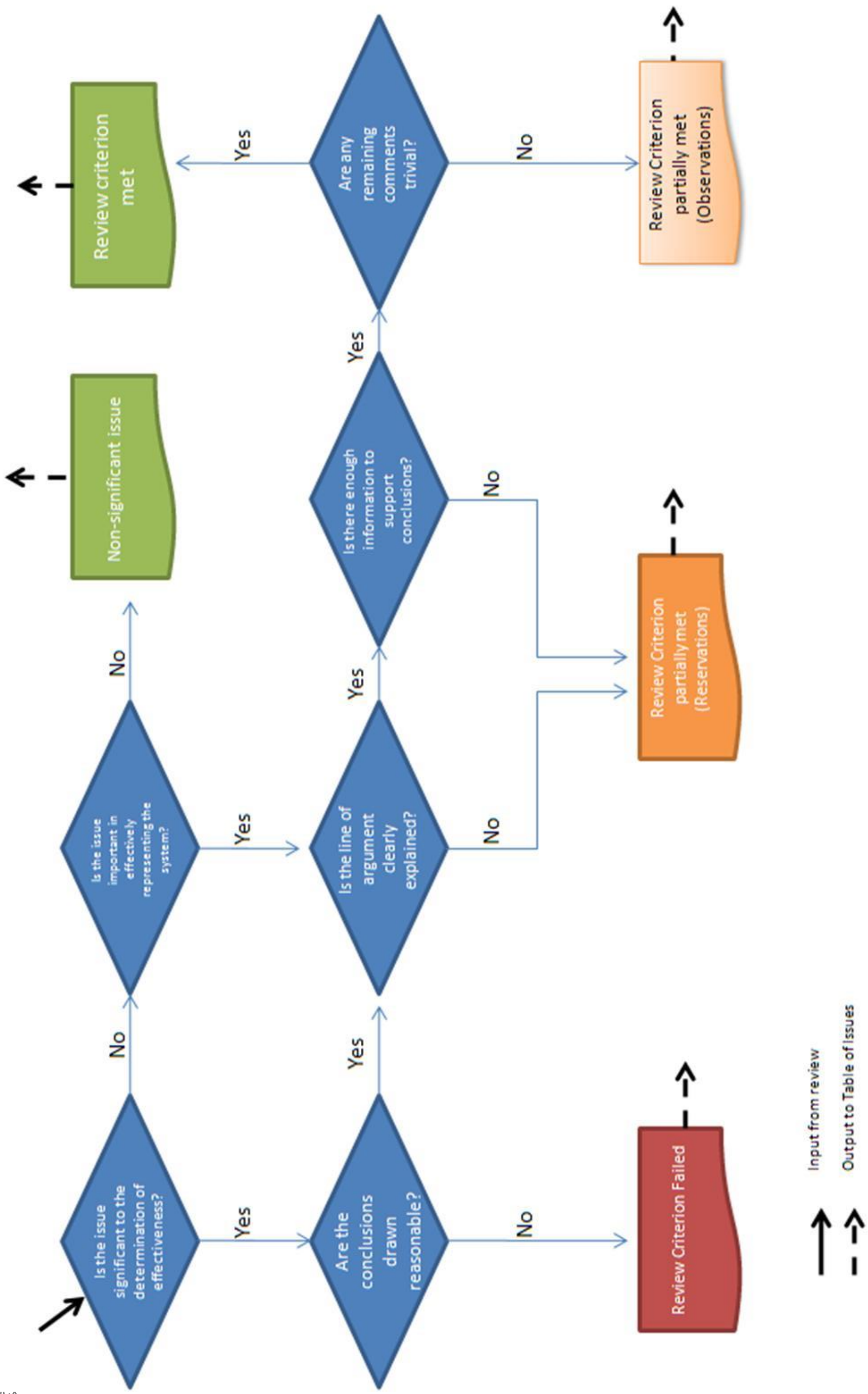
Outcomes 1 and 2 indicate that the specific issue is unlikely to be significant to the robustness / effectiveness of the option. Outcome 3 indicates that the issue is potentially significant although is not thought to unduly affect the overall robustness / effectiveness of the option. Outcome 4 indicates that the specific issue may seriously affect the robustness / effectiveness of the option unless further supporting information / data or option amendment is available, while Outcome 5 indicates that the specific issue is likely to seriously affect the robustness / effectiveness of the option and that no further information / data or amendment would be likely to resolve the situation.

An Issues Register was developed for each option that was used to record all the comments, issues and level of significance arising from the review process. The Issues Register allows ease of access to the comments that form the core of the review (and output), and the decisions made on each review issue[1].

[1] These Issue Registers are presented alongside the review discussion for each option, in the respective appendices.

The findings of this Step were drawn together and used to develop scorings for each option (with full justification provided, Section 3 and respective appendices).

- **Figure 1 - Issue Decision Process for review of information**



3.2.4. Step four – MCA scoring & reporting

Step 4 of the process comprises the collation of scoring justification and translation of the determinations into a semi-quantitative result using the MCA scoring process.

The results of the MCA for each option can then be assessed in relation to each other to indicate where each option may be potentially beneficial / detrimental to the environment, and indicate potential high level cost issues.

3.3. Stage two assessment

3.3.1. Step five – assessment of combination of options

Following the culmination of Stage 1, the options deemed potentially suitable (technically and practically) were further assessed with respect to their implementation as a combination. The same MCA approach was used for the scoring and assessment.

4. Results of the stage one options assessment

A summary of the MCA comparative assessment is presented in this section, with the justification for parameter scores and confidence adjustments (limitations) presented in the appendices. The Issues Registers providing the underpinning support to the justification (and completed during the review of each option) are also presented in the respective appendices. The rationale for the confidence determination for each parameter is based on the parameter specific requirements presented in Appendix C.

4.1. Drawdown as an alternative option

This option comprises no active preventative measures being undertaken to address acidification of the Lower Lakes, and constitutes the drawdown of the water level in the system. The MCA assessment justification for this alternative option is provided in Appendix E.

A summary of the SMART assessment (i.e. key characteristics of the option) for the drawdown option is presented in Table 7.

Table 7 - SMART assessment for water level drawdown

SMART Component	Discussion Points	Response
Specific	• Assumes no remedial action is taken; • Barrage operations continue as normal (under current operating rules for the drought conditions); and • No additional weir structures are constructed – what about Pomander Island? (Wellington Weir) and also Clayton Regulator?	No active preventative management measures will be undertaken to address environmental acidification of the Lower Lakes, assuming that the Wellington Weir and the Clayton regulator will both be in place and operational.
Measureable	Potentially difficult to measure as many preventative actions have been implemented – such as pumping stopped into Lake Albert, weirs in place Currency / Finniss?	Measurable for this option include: • Water quality parameters(lake health) • Soil pH and acidity
Achievable	Considered to be achievable	
Relevant	• Incorporates issues surrounding ecology, water quality and water chemistry. Does it also include visual and aesthetics (i.e. odour generation)	This is considered a control option (i.e. if no active management is implemented) and therefore is relevant to both the Lakes environment and the assessment.

	• Clarify extent of study area – To include Lake Alexandria, Lake Albert to the extent of the Barrages. Does not include the Coorong. Includes Finniss and Currency Creek.	
Time bound	Should take into account the estimated / predicted target date when acidification occurs. Should be considered to 'occur' until in- flows to system return to historical volumes (or additional management occurs).	Option span is indefinite here as no active management is being considered.

The option (as defined by its SMART analysis) was assessed, and scores provided, using the MCA framework. The resulting MCA scoring assessment is presented as Table 8.

The MCA assessment for the drawdown option resulted in a low overall score, both before and after adjustment for potential environmental impacts is applied. Further analysis of the MCA matrix for this option indicates that the non-adjusted technical feasibility and practicality contribution scores low (i.e. considered generally unlikely to be technically feasible or practical with respect to acid sulfate soil management, refer Appendix E). The metrics relating to cost scored higher than the technical / practicality metrics, mainly as a result of the direct costs scoring highly (i.e. no capital, operational or decommissioning infrastructure required etc).

The perceived environmental risks (impacts) associated with this option are significant and thus multipliers applied during adjustment derive an overall score of 443 and 120 prior to, and after, consideration of potential environmental risks respectively (and assessment of whether the option is either a preventative measure or a treatment).

As the MCA matrix indicates, the confidence provided in the scoring assessment is generally medium to high across all metrics, with an average of 0.92 (i.e. average of 12 confidence scores ranging between 0.75, medium, and 1.0, high), indicating that there is a reasonably high confidence in the scoring assessment for this option (refer to Appendix C for respective confidence score interpretations).

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Table 8 - MCA matrix for the water level drawdown option

Assessment Criteria	Weight (Out of 100)	Alignment with Criteria: Yes	Probable	Unlikely	No/NA	Raw Value Score	Weighted Value Score	Value Confidence Score (H=1 / M=0.75 / L=0.5)	Confidence Weighted Score
		10	5	2	0				
4 - Technically feasible and achievable in practice on the scale required	50								
4.1 TECHNICALLY FEASIBLE (theoretically, will it work?)	10								
A - Option is theoretically viable	25		5			125	6.3	1.00	6.3
B– Theoretically viable on the scale (spatial) required	75			2		150	7.5	1.00	7.5
Sub Total						275	13.8		13.8
4.2 ACHIEVABLE IN PRACTICE (Has it been proven to work?)	45								
A - Generic Proof of Concept established	15		5			75	16.875	0.75	12.7
B - Proof of Concept established in similar (representative) environments	35			2		70	15.75	0.75	11.8
C – Proof of concept established in Lower Lakes circumstances	50				0	0	0	1.00	0.0
Sub Total						145	32.625		24.5
4.3 - Implemented successfully before acidification of the Lakes occurs	45								
A1 – on a large scale	65			2		130	29.25	1.00	29.3
A2 – on a localised scale	35			2		70	15.75	0.75	11.8
Sub Total						200	45		41.1
B – The Lakes can be returned to their pre-action trophic state	*To be assessed qualitatively*								
C – A salinity of <1500EC is achievable in the long term									
D - An alkalinity concentration >25mg/l is maintained in the Lower Lakes									
Sub-Total - Technically feasible and achievable in practice on the scale required									79.3
8 - Costs to Government (State or Federal)	50								
8.1 DIRECT LIFECYCLE COSTS (Dollar costs directly apportioned to the entire lifecycle of the option.)	70								
Capital / Establishment costs are minimal	40	10				400	140.0	1.00	140.0
Operational / Maintenance costs are minimal	40	10				400	140.0	1.00	140.0
Decommissioning costs are minimal	20	10				200	70.0	1.00	70.0
Sub Total						1000	350		350.0
8.2 INDIRECT OR ENVIRONMENTAL COSTS & BENEFITS (Limited to impacts that Government may be liable for through the application of the option)	30								
Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes Region)	60			2		120	18	0.75	13.5
Maximises the indirect benefits experienced in the wider Lower Lakes Region (eg/ tourism, agriculture, wine, lifestyle)	40				0	0	0	1.00	0.0
Sub Total						120	18		13.5
Sub-Total - Costs and Transparency									363.5
					Total		459		443

Adjustments		
	Preventative Measure or Treatment	After Event Treatment
	Likelihood of negative impacts	Likely
	Severity of negative impacts	Dangerous
	Risk Multiplier	0.36
	Score	120

4.2. Bioremediation as an alternative option

Bioremediation refers to management approaches that aim to promote microbial activity (sulfate-reducing bacterial activity) in order to convert dissolved sulfate to insoluble sulfide minerals, while consuming acid. This essentially reverses the pyrite/iron mono-sulfide oxidation reactions that generated acidity in the first place.

Whilst this option is primarily bioremediation (microbial breakdown, algal flocculants etc), this option also comprises measures to optimise conditions to enable bioremediation (i.e. sulfate reduction) to occur. Therefore, assessment of this option takes into account provision of freshwater, lime additions, establishment of vegetation and any associated infrastructure to enable this. The MCA assessment justification for this alternative option is provided in Appendix F.

A summary of the SMART review is presented in Table 9.

Table 9 - SMART Assessment of the bioremediation option

SMART Component	Discussion Points	Response
Specific	Bioremediation refers to management approaches that aim to promote microbial activity (sulfate-reducing bacterial activity) in order to convert dissolved sulfate to sulfide minerals, while consuming acid. This essentially reverses the pyrite/iron mono-sulfide oxidation reactions that generated acidity in the first place. Essentially bioremediation involves promoting naturally occurring bacteria to return contaminated environments to a healthy state.	Bioremediation represents management approaches that aim to promote microbial activity (sulfate-reducing bacterial activity) via addition of organic matter in order to convert dissolved sulfate to sulfide minerals, while consuming acid.
Measureable	Specify Monitoring in relation to pH, vegetation and bio-remedial processes	Measurable include the standard criteria for water health plus the following: • Soil physics • Soil geochemistry • Soil microbiology
Achievable	Assumed to be achievable.	
Relevant	Extent of study area is considered.	Conisdered to be relevant.

Time bound	Should take into account the estimated / predicted target date when acidification occurs, with a view to implementation prior to target date. Should be considered to 'occur' until in- flows to system return to historical volumes (or additional management occurs).	Proof of effectiveness prior to determined date of system acidification.

The option (as defined by its SMART analysis) was assessed, and scores provided, using the MCA framework. The resulting MCA scoring assessment is presented as Table 10.

The MCA assessment for the bioremediation option resulted in an overall score (pre-adjustment for environmental impacts) of 434, with the technical component and the cost component being relatively equal (when contributions are set at 50:50). The bioremediation option scores generally well across the metrics although it was considered that there are some data gaps in the technical contribution of this option, notably:

- Direct evidence of sulfate reducing bacteria activity and capacity within the Lower Lakes sediments (although expected to be ubiquitous); and
- Sufficient information relating to groundwater yield with respect to mounding of groundwater to encourage bioremediation to occur (assuming no freshwater inflow is available).

These gaps have been reflected in the current scoring, with the confidence in the scoring for certain metrics given as 'medium'. It is considered that the technical contribution scores for this option would require review following the completion of data gaps. However, it is worth noting that the bioremediation option currently scores poorly on the theoretically viable on the scale required criterion, due to the possible requirement for broad scale inundation (see discussion in Appendix F). Hence this option may prove to be more beneficial as a 'hotspot' option in combination with other options.

The perceived environmental risks (impacts) associated with this option were considered to have a probable likelihood of occurring but with a slight impact (in terms of severity). The resulting risk multiplier lowered the pre-adjusted score to 243 (note that this option is considered a preventative measure).

As the MCA matrix indicates, the confidence provided in the scoring assessment is generally medium to high across all metrics, with an average of 0.85 (i.e. average of 12 confidence scores ranging between 0.75, medium, and 1.0, high), indicating that there is a reasonably medium to high confidence in the scoring assessment for this option (refer to Appendix C for respective confidence score interpretations).

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Table 10 - MCA matrix for the bioremediation option

		Alignment with Criteria						H=1 / M=0.75 / L=0.5	
		Yes	Probable	Unlikely	No/NA				
Assessment Criteria	Weight (Out of 100)	10	5	2	0	Raw Value Score	Weighted Value Score	Value Confidence Score	Confidence Weighted Score
4 - Technically feasible and achievable in practice on the scale required	**50**								
4.1 TECHNICALLY FEASIBLE (theoretically, will it work?)	**10**								
A - Option is theoretically viable	25	10				250	12.5	1.00	12.5
B– Theoretically viable on the scale (spatial) required	75		5			375	18.8	0.75	14.1
Sub Total						625	31.3		26.6
4.2 ACHIEVABLE IN PRACTICE (Has it been proven to work?)	**45**								
A - Generic Proof of Concept established	15	10				150	33.75	1.00	33.8
B - Proof of Concept established in similar (representative) environments	35		5			175	39.375	0.75	29.5
C – Proof of concept established in Lower Lakes circumstances	50		5			250	56.25	0.75	42.2
Sub Total						575	129.375		105.5
4.3 - Implemented successfully before acidification of the Lakes occurs	**45**								
A1 – on a large scale	65			2		130	29.25	1.00	29.3
A2 – on a localised scale	35	10				350	78.75	0.75	59.1
Sub Total						480	108		88.3
B – The Lakes can be returned to their pre-action trophic state	*To be assessed qualitatively*								
C – A salinity of <1500EC is achievable in the long term									
D - An alkalinity concentration >25mg/l is maintained in the Lower Lakes									
Sub-Total - Technically feasible and achievable in practice on the scale required									**220.3**
8 - Costs to Government (State or Federal)	**50**								
8.1 DIRECT LIFECYCLE COSTS (Dollar costs directly apportioned to the entire lifecycle of the option.)	**70**								
Capital / Establishment costs are minimal	40		5			200	70.0	1.00	70.0
Operational / Maintenance costs are minimal	40		5			200	70.0	0.75	52.5
Decommissioning costs are minimal	20		5			100	35.0	1.00	35.0
Sub Total						500	175		157.5
8.2 INDIRECT OR ENVIRONMENTAL COSTS & BENEFITS (Limited to impacts that Government may be liable for through the application of the option)	**30**								
Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes Region)	60		5			300	45	0.75	33.8
Maximises the indirect benefits experienced in the wider Lower Lakes Region (eg/ tourism, agriculture, wine,	40		5			200	30	0.75	22.5
Sub Total						500	75		56.3
Sub-Total - Costs and Transparency									**213.8**
					Total		519		434

Adjustments	Preventative Measure or Treatment	Prevention	
	Likelihood of negative impacts	Possible	
	Severity of negative impacts	Slight	
	Risk Multiplier	0.56	
	Score		243

4.3. Use of vegetation as an alternative option

In the context of this project 'vegetation' is the term used for covering the soils affected by exposure (i.e. drawdown of water and reduction of freshwater inflows) with vegetation to manage soil / sediment acidity.

Vegetation may include local native plant species, exotic annuals or exotic perennials identified as effective in covering soils to assist in the bioremediation of the area.

Although biodiversity is extremely important in this region, the vegetation that is proposed does not have the sole purpose of improving biodiversity. Rather, the primary purpose of the initial vegetation is to provide ecosystem stability or resilience by immediate soil cover, stabilising moving sand to reduce the impacts on the natural ecosystem, individuals and communities. These actions are likely to have an effect on reducing soil acidification by assisting to maintain soil moisture in the short-term, and by providing longer-term benefits as part of a bioremediation process (see Section 4.2).

The vegetation option is also in accordance with the processes described in Study 4 (Appendix D) and relates to the active use of vegetation to actively manage soil / sediment pH. The MCA assessment justification for this alternative option is provided in Appendix G.

A summary of the SMART review is presented in Table 11.

Table 11 - SMART assessment for the vegetation option

SMART Component	Discussion Points	Response
Specific	Below taken from Study 6: • In the context of this project vegetation is the term used for covering with vegetation the soils affected by lack of water within the Lower Lakes system. • The vegetation may include local native plant species, exotic annuals or exotic perennials identified as effective in covering soils to assist in the bioremediation of the area. • Although biodiversity is extremely important in this region, the vegetation that is proposed does not have the sole purpose of improving biodiversity. Rather, the primary purpose of the initial vegetation is to provide ecosystem stability	The vegetation option aims to stabilise the soils and prevent soil erosion around the Lower Lakes whilst also being effective in the management of acid sulfate soils in terms of minimising oxygen diffusion in the soil while water uptake by the plant reduces infiltration of water into the underlying minerals. Organic litter that eventually builds up also helps to buffer large fluctuations in water and oxygen movement into and out of the soil, so that cracking of soils and oxygen penetration is reduced.

	or resilience by immediate soil cover, stabilising moving sand to reduce the impacts on the natural ecosystem, individuals and communities. • These actions are likely to have an effect on reducing soil acidification by assisting to maintain soil moisture in the short-term, and by providing longer-term benefits as part of a bioremediation process.	
Measurable		
Achievable	Considered to achievable given assumptions and constraints under 'specific'.	
Relevant	The option is considered to be relevant for the system and suitable for assessment.	
Time-bound	What is the timescale likely to be (realistically) for mass planting? What is the timescale for development?	

The option (as defined by its SMART analysis) was assessed, and scores provided, using the MCA framework. The resulting MCA scoring assessment is presented as Table 12.

The MCA assessment for the vegetation option resulted in an overall score (pre-adjustment for environmental impacts) of 521.

The vegetation option scores higher with respect to the costs contribution (452.5) than the technical contribution (68.2). There is a mild adjustment with respect to potential environmental risks which lowers the score to 333. This adjustment is based on the consideration that the option is a preventative measure and is unlikely to result in significant environmental impacts (and that any negative impacts would be of a slight severity).

The vegetation option was considered to potentially have alternative benefits with respect to soil stabilisation and prevention of further erosion of exposed Lake sediments. Additionally, the seasonal die-back of vegetation is potentially likely to benefit bio-remediation processes and / or potentially assist in the maintenance of reducing conditions within sediments, thereby potentially preventing sulfide oxidation.

As the MCA matrix indicates, the confidence provided in the scoring assessment is generally medium to high across all metrics, with an average of 0.92 (i.e. average of 12 confidence scores ranging between 0.75, medium, and 1.0, high), indicating that there is a reasonably high confidence in the scoring assessment for this option (refer to Appendix C for respective confidence score interpretations).

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Table 12 - MCA matrix for the vegetation option

Assessment Criteria	Weight (Out of 100)	Alignment with Criteria						H=1 / M=0.75 / L=0.5	
		Yes	Probable	Unlikely	No/NA				
		10	5	2	0	Raw Value Score	Weighted Value Score	Value Confidence Score	Confidence Weighted Score
4 - Technically feasible and achievable in practice on the scale required	50								
4.1 TECHNICALLY FEASIBLE (theoretically, will it work?)	10								
A - Option is theoretically viable	25			2		50	2.5	0.75	1.9
B– Theoretically viable on the scale (spatial) required	75			2		150	7.5	1.00	7.5
Sub Total						200	10.0		9.4
4.2 ACHIEVABLE IN PRACTICE (Has it been proven to work?)	45								
A - Generic Proof of Concept established	15				0	0	0	1.00	0.0
B - Proof of Concept established in similar (representative) environments	35				0	0	0	1.00	0.0
C – Proof of concept established in Lower Lakes circumstances	50				0	0	0	0.75	0.0
Sub Total						0	0		0.0
4.3 - Implemented successfully before acidification of the Lakes occurs	45								
A1 – on a large scale	65			2		130	29.25	1.00	29.3
A2 – on a localised scale	35		5			175	39.375	0.75	29.5
Sub Total						305	68.625		58.8
B – The Lakes can be returned to their pre-action trophic state	*To be assessed qualitatively*								
C – A salinity of <1500EC is achievable in the long term									
D - An alkalinity concentration >25mg/l is maintained in the Lower Lakes									
Sub-Total - Technically feasible and achievable in practice on the scale required									68.2
8 - Costs to Government (State or Federal)	50								
8.1 DIRECT LIFECYCLE COSTS (Dollar costs directly apportioned to the entire lifecycle of the option.)	70								
Capital / Establishment costs are minimal	40	10				400	140.0	1.00	140.0
Operational / Maintenance costs are minimal	40	10				400	140.0	1.00	140.0
Decommissioning costs are minimal	20	10				200	70.0	0.75	52.5
Sub Total						1000	350		332.5
8.2 INDIRECT OR ENVIRONMENTAL COSTS & BENEFITS (Limited to impacts that Government may be liable for through the application of the option)	30								
Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes Region)	60	10				600	90	1.00	90.0
Maximises the indirect benefits experienced in the wider Lower Lakes Region (eg/ tourism, agriculture, wine,	40		5			200	30	1.00	30.0
Sub Total						800	120		120.0
Sub-Total - Costs and Transparency									452.5
					Total		549		521

Adjustments	Preventative Measure or Treatment	Prevention
	Likelihood of negative impacts	Unlikely
	Severity of negative impacts	Slight
	Risk Multiplier	0.64
	Score	333

4.4. Use of neutralisation of sediments as an alternative option

The 'neutralisation' option comprises the addition of a neutralising agent that is capable of buffering (neutralising) acid generated in the subsurface as a result of pyrite oxidation. This option considers the application of neutralising agent to the sediment and the treatment of associated acidified water bodies.

Note that the contemporary literature on acid landscape treatments discusses both Anoxic Limestone Drains (ALDs) and Oxic Limestone Drains (OLDs), which are often used in the treatment of acid sulfate soil related drainage. However, these are not considered here as they are designed for treatment of a 'stream' of drainage rather than large scale exposed sediments.

A summary of the SMART review is presented in Table 13.

Table 13 - SMART assessment of the neutralisation option

SMART Component	Discussion Points	Response
Specific	• Rephrase to capture neutralisation process. • Processes which act to increase alkalinity. • To include, but not limited all forms of neutralisation and not just lime dosing. • Include soil and/or water column.	• The addition of a neutralising agent that is capable of buffering acid generated in the subsurface as a result of pyrite oxidation. This option includes the various types of neutralising agents available: • Limestone (dry, fine) • Limestone slurry • Caustic soda (NAOH)
Measureable	• In relation to average pH over a certain area (as surely there will be a degree of variation depending on environmental conditions) • Specify pH Monitoring	It is considered that the standard criteria would be required, plus the following criteria: • Localised monitoring where lime is applied (soil and groundwater)
Achievable	Assumed to be achievable	
Relevant	Clarify extent of study area	Assumed to be relevant
Time bound	Consider predicted time of acidification onset.	Proof of effectiveness prior to determined date of system acidification.

The option (as defined by its SMART analysis) was assessed, and scores provided, using the MCA framework. The resulting MCA scoring assessment is discussed in Appendix H, and presented as Table 14

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Table 14 - MCA matrix for the neutralisation option

Assessment Criteria	Weight (Out of 100)	Alignment with Criteria: Yes	Probable	Unlikely	No/NA	Raw Value Score	Weighted Value Score	H=1 / M=0.75 / L=0.5 Value Confidence Score	Confidence Weighted Score
		10	5	2	0				
4 - Technically feasible and achievable in practice on the scale required	**50**								
4.1 TECHNICALLY FEASIBLE (theoretically, will it work?)	**10**								
A - Option is theoretically viable	25	10				250	12.5	1.00	12.5
B– Theoretically viable on the scale (spatial) required	75	10				750	37.5	0.75	28.1
Sub Total						1000	50.0		40.6
4.2 ACHIEVABLE IN PRACTICE (Has it been proven to work?)	**45**								
A - Generic Proof of Concept established	15	10				150	33.75	1.00	33.8
B - Proof of Concept established in similar (representative) environments	35	10				350	78.75	1.00	78.8
C – Proof of concept established in Lower Lakes circumstances	50		5			250	56.25	0.75	42.2
Sub Total						750	168.75		154.7
4.3 - Implemented successfully before acidification of the Lakes occurs	**45**								
A1 – on a large scale	65			2		130	29.25	0.75	21.9
A2 – on a localised scale	35		5			175	39.375	0.75	29.5
Sub Total						305	68.625		51.5
B – The Lakes can be returned to their pre-action trophic state	*To be assessed qualitatively*								
C – A salinity of <1500EC is achievable in the long term									
D - An alkalinity concentration >25mg/l is maintained in the Lower Lakes									
Sub-Total - Technically feasible and achievable in practice on the scale required									**246.8**
8 - Costs to Government (State or Federal)	**50**								
8.1 DIRECT LIFECYCLE COSTS (Dollar costs directly apportioned to the entire lifecycle of the option.)	**70**								
Capital / Establishment costs are minimal	40			2		80	28.0	1.00	28.0
Operational / Maintenance costs are minimal	40			2		80	28.0	0.50	14.0
Decommissioning costs are minimal	20		5			100	35.0	0.75	26.3
Sub Total						260	91		68.3
8.2 INDIRECT OR ENVIRONMENTAL COSTS & BENEFITS (Limited to impacts that Government may be liable for through the application of the option)	**30**								
Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes Region)	60				0	0	0	0.75	0.0
Maximises the indirect benefits experienced in the wider Lower Lakes Region (eg/ tourism, agriculture, wine,	40			2		80	12	0.75	9.0
Sub Total						80	12		9.0
Sub-Total - Costs and Transparency									**77.3**
					Total		390		324

Adjustments		
	Preventative Measure or Treatment	After Event Treatment
	Likelihood of negative impacts	Possible
	Severity of negative impacts	Moderate
	Risk Multiplier	0.49
	Score	119

The MCA assessment for the neutralisation option resulted in an overall score (pre-adjustment for environmental impacts and application) of 324.

The neutralisation option scores higher with respect to the technical contribution (246.8) than the technical contribution (77.3). There is a moderate adjustment with respect to potential environmental risks which lowers the score to 119. This adjustment is based on the consideration that the likelihood of environmental impacts is possible, and that any negative impacts would be of moderate severity. The option also scores lower following adjustment as it is considered to be a treatment rather than a preventative measure (it is noted that the option could be used in a preventative role also, e.g. proactive neutralisation of sediments prior to oxidation).

As the MCA matrix indicates, the confidence provided in the scoring assessment is generally medium to high across all metrics, with an average of 0.81 (i.e. average of 12 confidence scores ranging between 0.75, medium, and 1.0, high), indicating that there is a generally medium level of confidence in the scoring assessment for this option (refer to Appendix C for respective confidence score interpretations). However the confidence multiplier applied to the operational / maintenance costs was 'low confidence' to reflect the uncertainty regarding the operational costs, which is considered to be subject to several variables. Thus the response / score provided for this metric ('unlikely' / '2') is provided with low confidence and could be amended following further assessment of operational costs. This would help to increase the costs contribution overall score.

4.5. Provision of freshwater via buy-backs as an alternative option

The provision of freshwater option comprises the sediments identified as being potentially acid generating being saturated (not necessarily inundated) with freshwater to maintain a low redox environment and prevent pyrite oxidation. This option differs from the bioremediation option in that it is preventative rather than a treatment and is resourced by buy-backs.

A summary of the SMART review is presented in Table 15.

▪ Table 15 – SMART assessment of the freshwater (buy-backs) option

SMART Component	Discussion Points	Response
Specific	• The *Restoring the Balance in the Murray-Darling Basin Program* - The Australian Government has committed $3.1 billion over 10 years to purchase water in the Murray-Darling Basin. • Should other measures to achieve sustainable water management in the Basin be considered in assessment? • Is the quota available for the system sufficient from this program? • Lost production for irrigators a consideration? • Variation in buy-back prices? • Sustainability of purchase program? • Socio-political impacts?	Other water saving measures are unknown and of too much variability and detail to be assessed here so assessment should focus on actual buy back and use of freshwater from a technical and practicality aspect. Assume that all quotas are available and restrictive only by dollar value. Socio-political inputs should not be considered – technical and practical assessment.
Measureable	• Is there a quantity that is specific – likely to change as situation develops so adopt a worst case scenario? • Clarify extent of inundation – is it to completely inundate, saturate soils, or combination of both depending on area of Lower Lakes. • Specify Monitoring – stage boards?	The sediments identified as being potentially acid sulfate generating would be saturated (not necessarily inundated) with freshwater to maintain a low redox environment and prevent pyrite oxidation. Freshwater would be resourced from the following sources: • Water purchase; • Potential provision of groundwater resources to provide saturation.
Achievable	Assumed to be achievable not accounting for socio-economic / political aspects (i.e. Government policy and State government discussions). Therefore a ‘utopian’ decision environment is assumed.	
Relevant	Considered relevant for system as processes are already in place at various levels for buy-backs from irrigators etc.	

Time-bound	What are the likely timescales for development of buy-back process? What are system lag times?	Proof of effectiveness prior to determined date of system acidification.

The option (as defined by its SMART analysis) was assessed, and scores provided, using the MCA framework. The MCA assessment justification for this alternative option is provided in Appendix I.

The resulting MCA scoring assessment is presented as Table 16Table 12.

The MCA assessment for the freshwater (buy-backs) option resulted in an overall score (pre-adjustment for environmental impacts) of 416.

This option scores higher with respect to the technical contribution (272.3) than the technical contribution (143.5). There is a minor adjustment with respect to potential environmental risks which lowers the score to 233. This adjustment is based on the consideration that the likelihood of environmental impacts is 'unlikely', but that any negative impacts would be of moderate severity.

The MCA matrix indicates that the confidence provided in the scoring assessment is generally medium to high across all metrics, with an average of 0.83 (i.e. average of 12 confidence scores ranging between 0.75, medium, and 1.0, high), indicating that there is generally a medium level of confidence in the scoring assessment for this option (refer to Appendix C for respective confidence score interpretations). However two of the metrics were awarded a 'low confidence' multiplier in the technical contribution section:

- 'theoretically viable on the scale (spatial) required'; and
- 'implementation on a large scale prior to acidification of the system'.

Table 16 - MCA matrix for the freshwater (buy-backs) option

Assessment Criteria	Weight (Out of 100)	Alignment with Criteria: Yes (10)	Probable (5)	Unlikely (2)	No/NA (0)	Raw Value Score	Weighted Value Score	Value Confidence Score (H=1 / M=0.75 / L=0.5)	Confidence Weighted Score
4 - Technically feasible and achievable in practice on the scale required	50								
4.1 TECHNICALLY FEASIBLE (theoretically, will it work?)	10								
A - Option is theoretically viable	25	10				250	12.5	1.00	12.5
B– Theoretically viable on the scale (spatial) required	75	10				750	37.5	0.50	18.8
Sub Total						1000	50.0		31.3
4.2 ACHIEVABLE IN PRACTICE (Has it been proven to work?)	45								
A - Generic Proof of Concept established	15	10				150	33.75	1.00	33.8
B - Proof of Concept established in similar (representative) environments	35	10				350	78.75	1.00	78.8
C – Proof of concept established in Lower Lakes circumstances	50	10				500	112.5	0.75	84.4
Sub Total						1000	225		196.9
4.3 - Implemented successfully before acidification of the Lakes occurs	45								
A1 – on a large scale	65			2		130	29.25	0.50	14.6
A2 – on a localised scale	35		5			175	39.375	0.75	29.5
Sub Total						305	68.625		44.2
B – The Lakes can be returned to their pre-action trophic state	*To be assessed qualitatively*								
C – A salinity of <1500EC is achievable in the long term									
D - An alkalinity concentration >25mg/l is maintained in the Lower Lakes									
Sub-Total - Technically feasible and achievable in practice on the scale required									272.3
8 - Costs to Government (State or Federal)	50								
8.1 DIRECT LIFECYCLE COSTS (Dollar costs directly apportioned to the entire lifecycle of the option.)	70								
Capital / Establishment costs are minimal	40				0	0	0.0	1.00	0.0
Operational / Maintenance costs are minimal	40			2		80	28.0	1.00	28.0
Decommissioning costs are minimal	20	10				200	70.0	0.75	52.5
Sub Total						280	98		80.5
8.2 INDIRECT OR ENVIRONMENTAL COSTS & BENEFITS (Limited to impacts that Government may be liable for through the application of the option)	30								
Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes Region)	60			2		120	18	1.00	18.0
Maximises the indirect benefits experienced in the wider Lower Lakes Region (eg/ tourism, agriculture, wine, lifestyle)	40	10				400	60	0.75	45.0
Sub Total						520	78		63.0
Sub-Total - Costs and Transparency									143.5
					Total		520		416

Adjustments		
Preventative Measure or Treatment	Prevention	
Likelihood of negative impacts	Unlikely	
Severity of negative impacts	Moderate	
Risk Multiplier	0.56	
Score		233

4.6. Provision of freshwater via environmental allocations as an alternative option

As with the freshwater (buy-back) option discussed in Section 4.5, the provision of freshwater option (as allocations) comprises saturating (not necessarily inundating) the sediments identified as being potentially acid generating with freshwater, in order to maintain a low redox environment.

This option differs from the buy-backs option in that it is resourced by environmental allocation (i.e. re-allocations and water saving programs). Thus the significant difference between freshwater (buy-backs) and freshwater (environmental allocations) is likely to be predominantly cost based. A summary of the SMART review is presented in Table 17.

Table 17 - SMART assessment of the freshwater (allocations) option

SMART Component	Discussion Points	Response
Specific	• Use of re-allocated water from elsewhere within the Murray-Darling system without jeopardising other water dependant ecosystems. • Identification of what are and where are the known water-dependent ecosystems available? • Assessment of the quality, quantity, frequency and timing of water required by the water-dependent ecosystems. • Assessment of the environmental water requirements and environmental water provisions for water-dependent ecosystems. • Assessment of environmental impacts of the use of the proposed resource on the water-dependent ecosystems within the prescribed area. • Assessment of the environmental impacts of the use of imported and effluent water on the water-dependent ecosystems within the prescribed area. • Prioritisation process for providing environmental water to water-dependent ecosystems likely to have an associated effect?	• Identification of what are and where are the known water-dependent ecosystems which are available for reallocation, could be difficult to totally assess and only a high level response is possible. • Assessment of the quality, quantity, frequency and timing of water required by other water-dependent ecosystems likely to impinge on supply. • Water available only after assessment of environmental impacts of the use of the prescribed resource on the water-dependent ecosystems within the prescribed area. • Would assume Lower Lakes may have some level of priority over inland wetlands / back-swamps.
Measureable	• Is there a quantity required for complete inundation – adopt a worst case volume? • Clarify extent of inundation – is it to	The sediments identified as being potentially acid sulfate generating would be saturated (not necessarily inundated) with freshwater to maintain a low redox

	completely inundate, saturate soils, or combination of both depending on area of lower lakes. • Specify Monitoring – stage boards? • Identification of the environmental and other public benefit outcomes.	environment and prevent pyrite oxidation. Freshwater would be resourced from the following sources: • Re-allocation from risk assessed water savings programs throughout the Murray-Darling basin. • Potential provision of groundwater resources to provide saturation.
Achievable	Assumed to be achievable given assumptions provided under 'specific'.	
Relevant	Relevant to area and water savings programs are under way on other dependant ecosystems (risk assessment).	Assumed to be relevant.
Time-bound	As per Table 15.	Proof of effectiveness prior to determined date of system acidification.

The option (as defined by its SMART analysis) was assessed, and scores provided, using the MCA framework. The MCA assessment justification for this alternative option is provided in Appendix J.

The resulting MCA scoring assessment is presented as Table 18.

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▪ Table 18 - MCA matrix for the freshwater (allocations) option

Assessment Criteria	Weight (Out of 100)	Alignment with Criteria: Yes	Probable	Unlikely	No/NA	Raw Value Score	Weighted Value Score	Value Confidence Score (H=1 / M=0.75 / L=0.5)	Confidence Weighted Score
		10	5	2	0				
4 - Technically feasible and achievable in practice on the scale required	50								
4.1 TECHNICALLY FEASIBLE (theoretically, will it work?)	10								
A - Option is theoretically viable	25	10				250	12.5	1.00	12.5
B– Theoretically viable on the scale (spatial) required	75	10				750	37.5	0.50	18.8
Sub Total						1000	50.0		31.3
4.2 ACHIEVABLE IN PRACTICE (Has it been proven to work?)	45								
A - Generic Proof of Concept established	15	10				150	33.75	1.00	33.8
B - Proof of Concept established in similar (representative) environments	35	10				350	78.75	1.00	78.8
C – Proof of concept established in Lower Lakes circumstances	50	10				500	112.5	0.75	84.4
Sub Total						1000	225		196.9
4.3 - Implemented successfully before acidification of the Lakes occurs	45								
A1 – on a large scale	65			2		130	29.25	0.50	14.6
A2 – on a localised scale	35		5			175	39.375	0.75	29.5
Sub Total						305	68.625		44.2
B – The Lakes can be returned to their pre-action trophic state	*To be assessed qualitatively*								
C – A salinity of <1500EC is achievable in the long term									
D - An alkalinity concentration >25mg/l is maintained in the Lower Lakes									
Sub-Total - Technically feasible and achievable in practice on the scale required									272.3
8 - Costs to Government (State or Federal)	50								
8.1 DIRECT LIFECYCLE COSTS (Dollar costs directly apportioned to the entire lifecycle of the option.)	70								
Capital / Establishment costs are minimal	40	10				400	140.0	1.00	140.0
Operational / Maintenance costs are minimal	40	10				400	140.0	1.00	140.0
Decommissioning costs are minimal	20	10				200	70.0	1.00	70.0
Sub Total						1000	350		350.0
8.2 INDIRECT OR ENVIRONMENTAL COSTS & BENEFITS (Limited to impacts that Government may be liable for through the application of the option)	30								
Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes Region)	60		5			300	45	1.00	45.0
Maximises the indirect benefits experienced in the wider Lower Lakes Region (eg/ tourism, agriculture, wine,	40	10				400	60	0.75	45.0
Sub Total						700	105		90.0
Sub-Total - Costs and Transparency									440.0
					Total		799		712

Adjustments				
Adjustments	Preventative Measure or Treatment	Prevention		
	Likelihood of negative impacts	Unlikely		
	Severity of negative impacts	Moderate		
	Risk Multiplier		0.56	
	Score			399

The MCA assessment for the freshwater (allocations) option resulted in an overall score (pre-adjustment for environmental impacts) of 712.

This option scores higher with respect to the cost contribution (440) than the technical contribution (272.3). There is a minor adjustment with respect to potential environmental risks (note that the option is considered a preventative measure) which lowers the score to 399. This adjustment is based on the consideration that the likelihood of environmental impacts is 'unlikely', and that any negative impacts would be of moderate severity.

The MCA matrix indicates that the confidence provided in the scoring assessment is generally medium to high across all metrics, with an average of 0.81 (i.e. average of 12 confidence scores ranging between 0.75, medium, and 1.0, high), indicating that there is generally a medium level of confidence in the scoring assessment for this option (refer to Appendix C for respective confidence score interpretations). However as with the freshwater (buy-backs) option, two of the metrics were awarded a 'low confidence' multiplier in the technical contribution section (see Appendix J):

- 'theoretically viable on the scale (spatial) required'; and
- 'implementation on a large scale prior to acidification of the system'.

4.7. Transfer of seawater from Lake Alexandrina to Lake Albert

This option would not involve flooding Lake Albert with seawater, but allowing just enough water into the Lake to maintain the level of the Lake above an arbitrary management level of -0.5 metres AHD. Note that the option considers transfer of water from the Coorong, and not from the ocean, in line with the recommendations provided in Tonkin (2008). Additionally, water could be transferred from Lake Alexandrina following implementation of the proposed action (i.e. opening of the barrages). This would result in 'shandied' water comprising remnant freshwater flows and seawater. The SMART review for this option (Table 19) details the assumptions made regarding implementation / operation and high level conceptual design.

- **Table 19 - SMART assessment for the transfer of seawater to Lake Albert option**

SMART Component	Discussion Points	Response
Specific	• Define extent of inundation and process of managing the barrages. • Assessment to comprise transfer of water from the Coorong into Lake Albert via overland pumping or channel. • Assessment not to consider direct transfer from ocean. • Consider future transfer of shandied water from Lake Alexandrina?	Although the intent is to maintain freshwater in the Lake Albert, if water levels and water quality drop below a critical point and acidification is imminent then allowing seawater into the Lake will need to be considered. This would not involve flooding the Lake with seawater, but allowing just enough water into the Lake to maintain the level of the Lake above the trigger level of -0.5 metres AHD (arbitrary). The transfer of water into Lake Albert would be achieved via: • pumping of water from the Coorong; or • establishment of a channel from the Coorong to the Lake Transfer of shandied water from Alexandrina to Albert should be assessed under seawater inundation for this assessment as infrastructure in place for this purpose.
Measurable	Specify Monitoring – stage boards? Water quality	Measurable are water quality and water level (inundation of sediments) in Lake Albert.
Achievable	Assumed to be achievable (realistic) for comparative assessment.	
Relevant	Assumed to be relevant as a potential option for Lake Albert exclusively disregarding costs in the first instance – i.e. costs no barrier to implementation.	
Time bound	• Lag time in upper system storage? • Volume influx required (gigalitre influx) • Point of inception • Time-span for construction / implementation.	Until system returns to long term 'stable' natural conditions (i.e. cessation of drought conditions)

The option (as defined by its SMART analysis) was assessed, and scores provided, using the MCA framework. The MCA assessment justification for this alternative option is provided in Appendix K, and the resulting MCA scoring assessment is presented as Table 20.

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Table 20 - MCA matrix for the transfer of seawater to Lake Albert

Assessment Criteria	Weight (Out of 100)	Alignment with Criteria: Yes 10	Probable 5	Unlikely 2	No/NA 0	Raw Value Score	Weighted Value Score	Value Confidence Score (H=1 / M=0.75 / L=0.5)	Confidence Weighted Score
4 - Technically feasible and achievable in practice on the scale required	50								
4.1 TECHNICALLY FEASIBLE (theoretically, will it work?)	10								
A - Option is theoretically viable	25		5			125	6.3	0.75	4.7
B– Theoretically viable on the scale (spatial) required	75		5			375	18.8	0.75	14.1
Sub Total						500	25.0		18.8
4.2 ACHIEVABLE IN PRACTICE (Has it been proven to work?)	45								
A - Generic Proof of Concept established	15	10				150	33.75	1.00	33.8
B - Proof of Concept established in similar (representative) environments	35		5			175	39.375	1.00	39.4
C – Proof of concept established in Lower Lakes circumstances	50			2		100	22.5	0.75	16.9
Sub Total						425	95.625		90.0
4.3 - Implemented successfully before acidification of the Lakes occurs	45								
A1 – on a large scale	65	10				650	146.25	0.75	109.7
A2 – on a localised scale	35		5			175	39.375	0.50	19.7
Sub Total						825	185.625		129.4
B – The Lakes can be returned to their pre-action trophic state	*To be assessed qualitatively*								
C – A salinity of <1500EC is achievable in the long term									
D - An alkalinity concentration >25mg/l is maintained in the Lower Lakes									
Sub-Total - Technically feasible and achievable in practice on the scale required									238.1
8 - Costs to Government (State or Federal)	50								
8.1 DIRECT LIFECYCLE COSTS (Dollar costs directly apportioned to the entire lifecycle of the option.)	70								
Capital / Establishment costs are minimal	40				0	0	0.0	1.00	0.0
Operational / Maintenance costs are minimal	40			2		80	28.0	1.00	28.0
Decommissioning costs are minimal	20			2		40	14.0	0.75	10.5
Sub Total						120	42		38.5
8.2 INDIRECT OR ENVIRONMENTAL COSTS & BENEFITS (Limited to impacts that Government may be liable for through the application of the option)	30								
Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes Region)	60		5			300	45	0.75	33.8
Maximises the indirect benefits experienced in the wider Lower Lakes Region (eg/ tourism, agriculture, wine, lifestyle)	40			2		80	12	0.75	9.0
Sub Total						380	57		42.8
Sub-Total - Costs and Transparency									81.3
					Total		405		319

Adjustments			
Preventative Measure or Treatment	Prevention		
Likelihood of negative impacts	Possible		
Severity of negative impacts	Critical		
Risk Multiplier		0.35	
Score			112

The MCA assessment for the transfer of seawater to Lake Albert (exclusively) resulted in an overall score (pre-adjustment for environmental impacts) of 319.

This option scores higher with respect to the technical contribution (238.1) than the costs contribution (81.3). This is a reflection of the potential significant outlay (dollar value) involved with the commissioning and operation of such a system. Also the aesthetic / recreational value of the Coorong area was considered to be impacted by the construction and operation of the required infrastructure.

The environmental impact multiplier indicated that the likelihood of negative impacts was ‘possible’ and that the severity of such impacts might be critical. This is based on a consideration of the potential impacts of transferring saline water to a terminal lake (resulting in a hyper-saline Lake Albert) and also the impact that extraction may have on the Coorong (increasing salinity levels due to increased drawdown and decreased flushing action). The resulting overall score (post-adjustment) was therefore 112, despite the option being considered a preventative measure.

The MCA matrix indicates that the confidence provided in the scoring assessment is generally medium to high across all metrics, with an average of 0.81 (i.e. average of 12 confidence scores ranging between 0.75, medium, and 1.0, high), indicating that there is a medium confidence (based on the average) in the scoring assessment for this option (refer to Appendix C for respective confidence score interpretations). The metric concerning application on a ‘local scale’ within the technical contribution section was awarded a ‘low confidence’ multiplier. This was a result of the uncertainty of the option being ‘probably’ capable of localised area management (see Appendix K).

4.8. Proposed action – transfer of seawater via barrages

It is envisaged that this option would not involve flooding the Lower Lakes with seawater, but allowing just enough water through the barrages to maintain the level of Lake Alexandrina above an arbitrary management level of -1.5 metres AHD (i.e. inundation), resulting in a ‘shandied’ water when mixed with remnant freshwater flows.

As per the SMART assessment for the option (Table 21), the assessment considers the option in the absence of specific information regarding operating rules for the barrages and means of delivering water via the barrages.

▪ **Table 21 - SMART assessment of the proposed action - opening of the barrages**

SMART Components	Discussion Points	Response
Specific	Define extent of inundation and process of managing the barrages Define amount of mixing (linked to above point).	Although the intent is to maintain freshwater in the Lower Lakes, if water levels and water quality drop below a critical point and acidification is imminent then allowing seawater into the Lower Lakes will need to be considered. This would not involve flooding the Lower Lakes with seawater, but allowing just enough water through the barrages to maintain the level of Lake Alexandrina above the trigger level of -1.5 metres below sea level.
Measureable	Specify Monitoring – stage boards?	Measurable are water quality and water levels
Achievable	Assumed to be achievable.	
Relevant	Considered relevant to system as is proposed action under EIS.	
Time bound	• Rainfall • System allocation • Lag time in system storage?	Until system returns to long term 'stable' natural conditions (i.e. cessation of drought conditions).

The option (as defined by its SMART analysis) was assessed, and scores provided, using the MCA framework. The MCA assessment justification for this alternative option is provided in Appendix L, and the resulting MCA scoring assessment is presented as Table 22 .

Table 22 - MCA matrix for the proposed action (opening of the barrages)

Assessment Criteria	Weight (Out of 100)	Alignment with Criteria							
		Yes	Probable	Unlikely	No/NA			H=1 / M=0.75 / L=0.5	
		10	5	2	0	Raw Value Score	Weighted Value Score	Value Confidence Score	Confidence Weighted Score
4 - Technically feasible and achievable in practice on the scale required	**50**								
4.1 TECHNICALLY FEASIBLE (theoretically, will it work?)	**10**								
A - Option is theoretically viable	25		5			125	6.3	0.75	4.7
B– Theoretically viable on the scale (spatial) required	75		5			375	18.8	0.75	14.1
Sub Total						500	25.0		18.8
4.2 ACHIEVABLE IN PRACTICE (Has it been proven to work?)	**45**								
A - Generic Proof of Concept established	15	10				150	33.75	1.00	33.8
B - Proof of Concept established in similar (representative) environments	35			2		70	15.75	1.00	15.8
C – Proof of concept established in Lower Lakes circumstances	50			2		100	22.5	0.75	16.9
Sub Total						320	72		66.4
4.3 - Implemented successfully before acidification of the Lakes occurs	**45**								
A1 – on a large scale	65	10				650	146.25	0.75	109.7
A2 – on a localised scale	35		5			175	39.375	0.50	19.7
Sub Total						825	185.625		129.4
B – The Lakes can be returned to their pre-action trophic state	*To be assessed qualitatively*								
C – A salinity of <1500EC is achievable in the long term									
D - An alkalinity concentration >25mg/l is maintained in the Lower Lakes									
Sub-Total - Technically feasible and achievable in practice on the scale required									**214.5**
8 - Costs to Government (State or Federal)	**50**								
8.1 DIRECT LIFECYCLE COSTS (Dollar costs directly apportioned to the entire lifecycle of the option.)	**70**								
Capital / Establishment costs are minimal	40	10				400	140.0	1.00	140.0
Operational / Maintenance costs are minimal	40	10				400	140.0	1.00	140.0
Decommissioning costs are minimal	20			2		40	14.0	0.75	10.5
Sub Total						840	294		290.5
8.2 INDIRECT OR ENVIRONMENTAL COSTS & BENEFITS (Limited to impacts that Government may be liable for through the application of the option)	**30**								
Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes Region)	60	10				600	90	1.00	90.0
Maximises the indirect benefits experienced in the wider Lower Lakes Region (eg/ tourism, agriculture, wine,	40		5			200	30	0.50	15.0
Sub Total						800	120		105.0
Sub-Total - Costs and Transparency									**395.5**
					Total		697		610

Adjustments	Preventative Measure or Treatment	Prevention	
	Likelihood of negative impacts	Possible	
	Severity of negative impacts	Critical	
	Risk Multiplier	0.35	
	Score		214

The MCA assessment for the proposed action resulted in an overall score (pre-adjustment for environmental impacts) of 610.

This option scores higher with respect to the costs contribution (395.5) than the technical contribution (214.5). This reflects that the option is likely to be of low dollar value in terms of operation, although the decommissioning metric is scored low to reflect the unlikely ability for the system to be easily returned to a freshwater environment. With respect to the technical contribution, the proof of concept for the option to be achievable in practise is scored low.

The environmental impact multiplier indicated that the likelihood of negative impacts was ‘possible’ and that the severity of such impacts might be critical. This is a reflection of the significant ecological impact of changing the environment from that of freshwater to saltwater, and also accounts for the potential for seawater to be ineffective at buffering (neutralising) the acidity generated from exposed acidic soils (and also at mitigating short term release of metals, see Appendix L). The resulting overall score (post-adjustment) was 214.

The MCA matrix indicates that the confidence provided in the scoring assessment is generally medium to high across all metrics, with an average of 0.81 (i.e. average of 12 confidence scores ranging between 0.75, medium, and 1.0, high), indicating that there is a medium level of confidence in the scoring assessment for this option (based on the average confidence, refer to Appendix C for respective confidence score interpretations). The metric concerning application on a ‘local scale’ within the technical contribution section was awarded a ‘low confidence’ multiplier. This was a result of the uncertainty of the option being ‘probably’ capable of localised area management, and also the metric concerning ‘indirect benefits’ was awarded a low confidence with respect to the ‘probable’ score. It was considered that the score awarded (‘probable’) could be adjusted depending on the various stakeholder views associated with indirect benefits to the wider region (i.e. loss of extractable resource for viniculture, but potential boost in recreational usage).

5. Summary of stage one results

5.1. Results

The options as reported in Section 4 were assessed at the default setting of 50/50 contribution from each of the technical and costs stream (see the description of the assessment methodology provided in Section 3 for further detail). At this 50/50 contribution ratio, and applying the adjustment parameters, the freshwater (allocations) option is ranked as the highest scoring option. Table 23 presents the 50/50 ratio rankings and scores when applying the following adjustment parameters:

- Implementation of option as either prevention or treatment; and
- Risk of negative impacts

Table 23 - Ranking of adjusted options at 50/50 costs vs. technical contribution

50/50 Ranking	Option	50/50 Score
1	Provision of freshwater (allocations)	399
2	Vegetation	288
3	Bioremediation	243
4	Provision of freshwater (buy-backs)	233
5	Seawater inundation (barrages)	222
6	Neutralisation	188
7	Drawdown	120

5.2. Pre-adjustment results

The ranking of the options changes when both of the following adjustment parameters are removed:

- Implementation of option as either prevention or treatment; and
- Risk of negative impacts

This indicates the significance of the adjustment parameters upon the actual initial score, depending on the considered ‘benefit’ of being a preventative measure vs. treatment, and the likelihood and severity of negative environmental impacts (‘risk’).

Table 24 presents the 50/50 option rankings (and scores) when the adjustment parameters are removed.

▪ **Table 24 - Ranking of non-adjusted options at 50/50 costs vs. technical contribution**

50/50 Ranking	Option	50/50 Score
1	Provision of freshwater (allocations)	712
2	Seawater inundation (barrages)	610
3	Vegetation	451
4	Neutralisation	450
5	Drawdown	443
6	Bioremediation	434
7	Provision of freshwater (buy-backs)	416

Thus the non-adjusted ranking at 50/50 contribution indicates that the provision of freshwater (allocations) option achieves the highest score. Notably, when environmental risk is not considered, the proposed action achieves second place in the ranking, driven mostly by its high cost contribution score. On a technical basis, the proposed action is considered to score less well, as discussed in Section 5.3.

5.3. Technical versus costs

Following the removal of preventative or treatment and environmental risk considerations, the overall scores can be further analysed to provide rankings based on the relative contributions of technical feasibility (Table 25) and costs (Table 26).

▪ **Table 25 - Ranking of non-adjusted options based on technical contribution (50/50)**

50/50 Ranking	Option	50/50 Score
1	Provision of freshwater (allocations)	272
2	Provision of freshwater (buy-backs)	272
3	Neutralisation	247
4	Bioremediation	220
5	Seawater inundation (barrages)	215
6	Drawdown	79
7	Vegetation	68

- **Table 26 - Ranking of non-adjusted options based on cost contribution (50/50)**

50/50 Ranking	Option	50/50 Score
1	Provision of freshwater (allocations)	440
2	Seawater inundation (barrages)	396
3	Vegetation	383
4	Drawdown	364
5	Bioremediation	214
6	Neutralisation	203
7	Provision of freshwater (buy-backs)	144

The provision of freshwater (environmental allocations) option ranks as the highest scored non-adjusted option in the technical contribution, and also in the cost contribution, when the ratio of contributions is equal (i.e. 50/50).

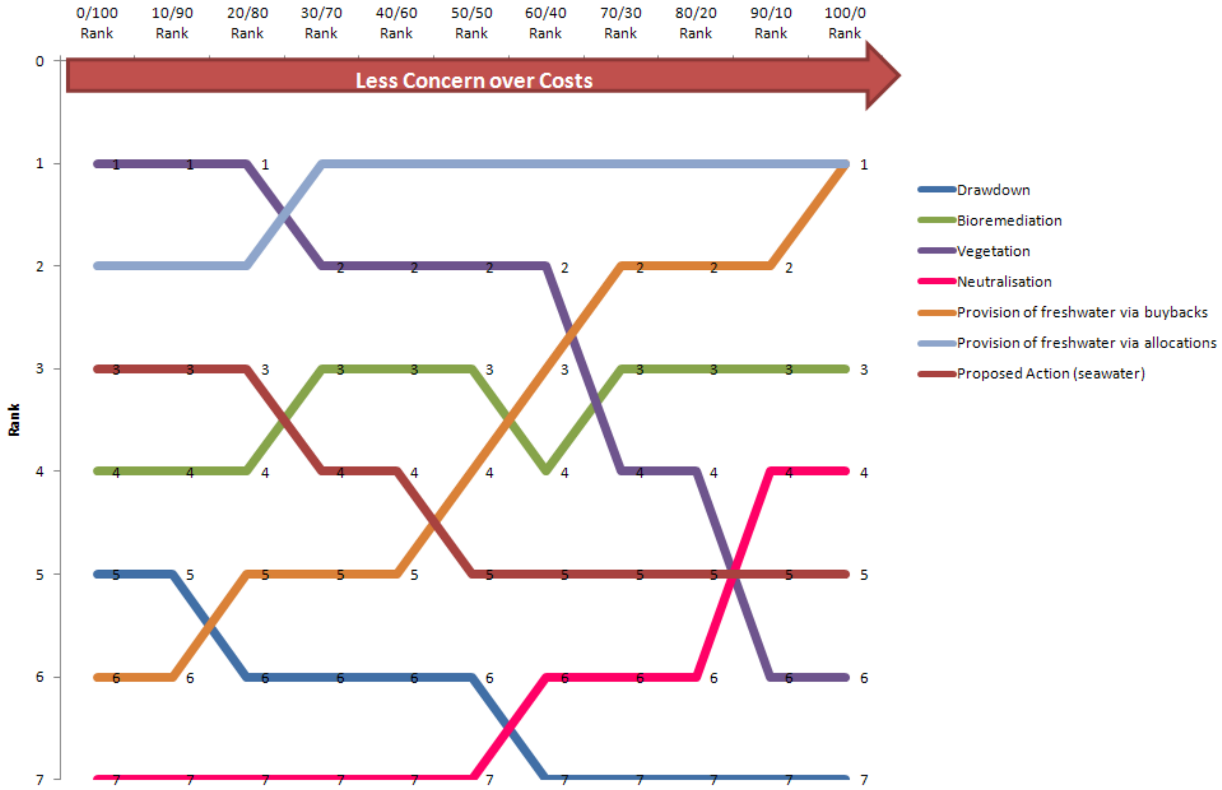
As discussed previously in Section 3, the MCA scores were developed across a sliding scale of change in contribution from each of the two heading criteria (technical and costs) in order to present the potential change in option ranking depending on the required contribution from technical / practical feasibility versus costs. This contribution scale (based on the ranking of options) is presented as Figure 2. Note that the figure accounts for the adjusted values (i.e. multipliers for the preventative vs. treatment and risk of negative impact adjustments have been applied). The specific scores are presented in terms of contribution ratio in Figure 3.

The variation in the option ranking over the ratio of contribution is based on the change in contribution from heading criteria and not the sub and base criteria weighting (refer to Appendix B for a summary of the weighting criteria across headings and sub / base criteria). The option ranking scale (Figure 2) indicates the following:

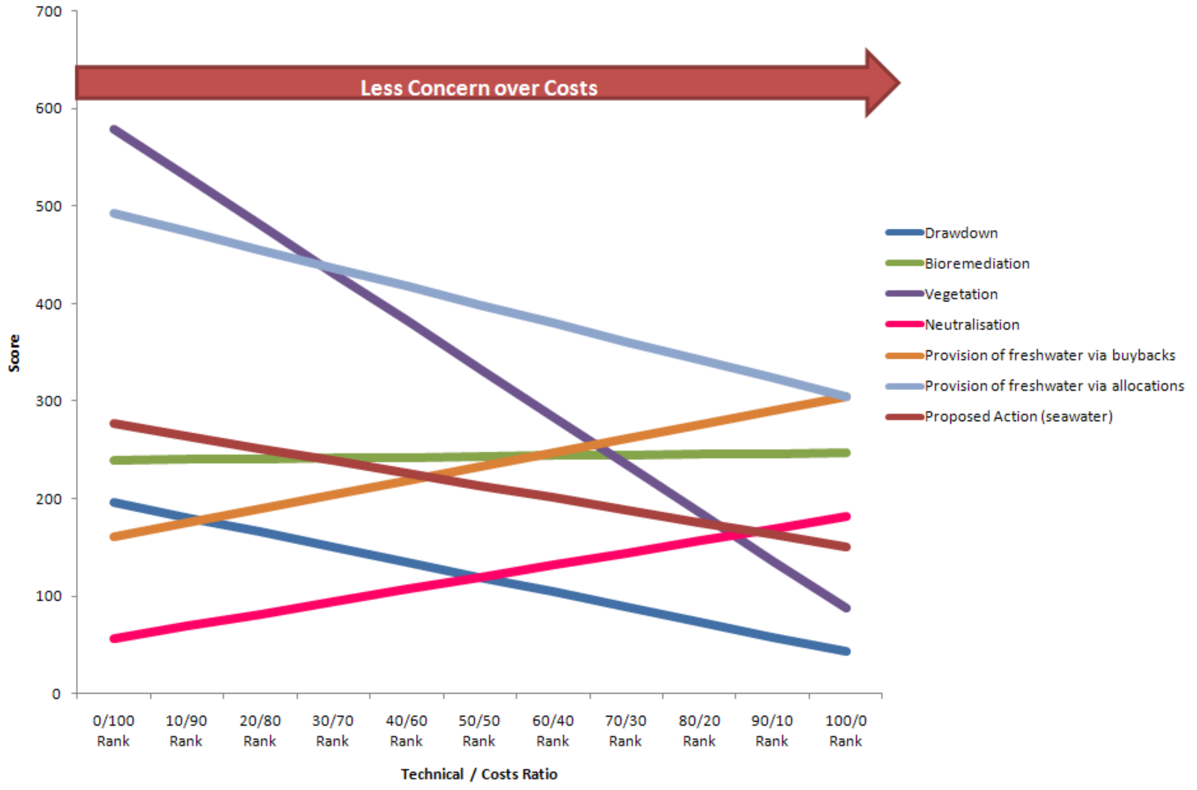
- freshwater (allocations) is ranked as the number one ranked option across all contribution ratios'
- the freshwater (buy-backs) option also shares the number one ranking with 'allocations' when cost contribution is placed at 0% - as a result of the costs not being important;
- bioremediation generally scores well (between ranks three and four) across all contributions;
- the drawdown option is ranked low across all contributions generally; and

- the proposed action scores in the mid-range (rank three) when costs are given more priority, although decreases to fifth place following an increase in the priority of the technical contribution.

▪ **Figure 2 - Option ranks and ratio of contribution (adjusted)**



- **Figure 3 - Option scores and ratio of contribution (adjusted)**



5.4. Lake Albert

Potential alternative options for Lake Albert were reviewed as discussed above for the entire system, but with the inclusion of the transfer of seawater option from the Coorong (Lake Albert exclusively).

At the default setting of 50/50 contribution from each of costs and technical stream, and applying the adjustment parameters, the freshwater (allocations) option appears to be ranked as the highest scoring option. Table 27 presents the 50/50 rankings when the adjustment parameters are applied.

- **Table 27 - Adjusted options at 50/50 costs vs. technical contribution – Lake Albert**

50/50 Ranking	Option	50/50 Score
1	Provision of freshwater (allocations)	399
2	Vegetation	288
3	Bioremediation	243
4	Provision of freshwater (buy-backs)	233
5	Seawater inundation (barrages)	222
6	Neutralisation	188
7	Drawdown	120
8	Use of seawater – Lake Albert only	112

Note that the transfer of seawater as a management option is ranked at number eight (of eight). The seawater inundation (barrages) accounts for the transfer of shandied water from Lake Alexandrina via infrastructure already in place around Narrung.

The non-adjusted ranking also shows transfer of seawater to be ranked 8 out of all options also (Table 28). The technical ranking (non-adjusted) places the transfer of seawater option for Lake Albert at number four, whereas the cost ranks at number eight.

- **Table 28 - Non-adjusted options at 50/50 costs vs. technical contribution – Lake Albert**

50/50 Ranking	Option	50/50 Score
1	Provision of freshwater (allocations)	712
2	Seawater inundation (barrages)	610
3	Vegetation	451
4	Neutralisation	450
5	Drawdown	443
6	Bioremediation	434
7	Provision of freshwater (buy-backs)	416
8	Use of seawater – Lake Albert only	238

6. Discussion of stage one assessment

6.1. Sensitivity of metrics contribution

Based on the adjusted metrics, the freshwater (allocations) option is ranked as the number one option across 90% of the costs contribution. When the contribution from costs becomes non-existent (i.e. 0% contribution) the freshwater (buy-backs) option also shares the number one ranking. This increase in the ranking of the buy-backs option is a result of the removal of potentially significant costs factors associated with the process of buying back freshwater from irrigators across the Murray-Darling basin. Note that the freshwater buy-backs option is ranked in seventh place in terms of costs contribution, Table 26). The freshwater (allocations) option scores well on both the technical and costs contributions, and the perceived risks to the environment with respect to this option are also relatively low, as indicated by the overall adjusted rank at 50/50 contribution (ranked in first place, Table 23 - *Ranking of adjusted options at 50/50 costs vs. technical contribution*).

Although the vegetation option ranks at number two between the 0/100 and 60/40 split (technical and costs respectively), it actually scores poorly when considering the technical contribution alone (ranked seven of seven, Table 25). A combination of high scores on the costs contribution, coupled to a mild adjustment when processed through the adjustment parameters, is sufficient to raise the options rank above the other considered options (which intuitively must collectively score poorly on both costs and the adjustment options, i.e. risks to the environment). However, it is noted that the vegetation option is likely to have alternative benefits with respect to soil stabilisation and prevention of further erosion of Lake beds. Additionally, the seasonal die-back of vegetation is potentially likely to benefit bio-remediation processes and / or potentially assist in the maintenance of reducing conditions within sediments, thereby potentially preventing sulfide oxidation.

The bioremediation option scores generally well across the contribution scale, and the overall rank (adjusted) at 50/50 contribution is high (number three, Table 23). Bioremediation scores relatively low in both pre-adjustment technical and costs contribution (ranks four and five, technical and costs respectively) although performs better on the perceived low risks to the environment following adjustment, which raises the overall adjusted ranking to number three. It is considered that there are some data gaps in the technical contribution of this option, notably:

- Direct evidence of sulfate reducing bacteria activity and capacity within the Lower Lakes sediments; and
- Sufficient information relating to groundwater yield with respect to mounding of groundwater to encourage bioremediation to occur.

These gaps have been reflected in the current scoring, although with respect to the first bullet point above, the sulfate reducing bacteria are expected to be ubiquitous. It is considered that the technical contribution scores for this option may require further review following the completion of data gaps. It is worth noting that the bioremediation option currently scores poorly with respect to the metric concerning the option being 'theoretically viable on the scale required', due to the potential requirement for broad scale inundation of freshwater. This option may therefore prove to be more beneficial as a 'hotspot' option in combination with other options.

The neutralisation option scores reasonably well on technical contribution, pre adjustment (rank three, Table 25), although it scores relatively low on cost contribution (both direct and indirect) given the material input required for this option. This is evident from the increase in rank as costs contribution becomes less important. The successful application of this option over a large scale was determined to be 'unlikely'. However, the results indicate that as a localised treatment measure where reduced costs may be apparent, the neutralisation option is likely to be of some merit.

The assessment indicates that the drawdown option scores relatively low overall, both before and after adjustment is applied (overall ranks of five and seven respectively). Further analysis indicates that the non-adjusted technical contribution is low (rank six), whereas the cost contribution is slightly higher (rank three), mainly as a result of the direct costs scoring highly (i.e. no infrastructure or management required etc).

The transfer of seawater (via the barrages) for the Lakes system ranks at number three when the cost contribution is increased (i.e. >70%). This is a result of the option being mostly considered as a low cost measure (the SMART review considered that the weir required at Pomanda Island was in place, however there is likely to be significant costs associated with this option with respect to the commissioning of the required weir at the confluence of the River Murray and Lake Alexandrina). The transfer of seawater for inundation does not score highly on the technical contribution as a preventative measure, and the pre-adjustment score is downgraded by the potentially high environmental risks associated with inundating oxidised sediments.

It is noted that the freshwater options may potentially be affected by the same risk, although it is considered that more buffering capacity (and cation exchange) would be available when using freshwater over that available when using seawater (Hicks et al., 2009). In addition, consideration could be given to pre-neutralisation of oxidised sediments using neutralising agents, prior to inundation.

6.2. Environmental risks

A summary of the potential environmental risks per option is presented in Table 29.

The options that score relatively well in the adjusted assessment are generally the options that have perceived low environmental risks:

- vegetation (0.64 multiplier);
- bioremediation (0.56); and
- provision of freshwater allocations / buy-backs (0.56).

If the risks adjustment is ignored, then the ranking at 50/50 contribution is un-altered, and the number one option remains freshwater allocations.

Focussing on the non-adjusted contributions, the seawater option is ranked fifth for technical contribution and second for costs, indicating that (if applied correctly) the option does have potential to manage acidification of sediments (but should not be used as a treatment, and given the risks, only as an option of last resort).

The high scores awarded to the proposed action in the direct costs criteria indicate that the option was not considered to require significant financial outlay in terms of capital (implementation and ongoing maintenance). However, there are several highlighted risks associated with the implementation of the proposed action.

▪ **Table 29 – Summary of potential environmental risks for each of the options**

Option	Combined Ranking @ 50/50	Likelihood of Negative Impact	Severity	Risk of Negative Impact		Summary Impact Comments
Drawdown	6	0.6	0.6	Extreme	**Negative**	▪ Significantly lower Lake levels (including a completely dry Lower Lakes environment); ▪ Increased salinity due to a lack of flushing and evaporative concentration; ▪ Dust generation and erosion of exposed Lake beds; ▪ Pyrite oxidation and mobilisation of acidity and metals through Lake seiching and flushing from rainfall events ; ▪ Eutrophication as water levels recede; and ▪ Anoxic conditions developing.
					Positive	▪ Low implementation cost option ▪ Relative ease of returning Lower Lakes to pre-action state upon re-flooding
Seawater via Barrages	4	0.7	0.5	Extreme	**Negative**	▪ Salinisation of a freshwater resource (with the potential to become hyper-saline due to lack of flushing regime). ▪ Potential generation of hydrogen sulfide gas due to high quantities of sulfate in water from the Coorong that could result in an imbalance between sulphur and available iron ▪ Risk of adverse impacts on the Coorong and Murray Mouth associated with altered flow dynamics ▪ Potential loss of freshwater connection to the Coorong and with particular impacts upon diadromous fish species ▪ Disconnection of Murray Mouth to River Murray, with particular impacts upon diadromous fish species (this assumes fish passage is not possible for the proposed weir

						▪ at Pomanda Island) ▪ Mobilisation studies have indicated that seawater mobilises a significant amount of acidity and heavy metals / nutrients during inundation, if sulfidic sediments have oxidised.
					Positive	▪ The provision of a refuge environment within the AMLR tributaries (Currency Creek and Finniss Creek) presents significant ecological safeguards should the Lower Lakes become a saltwater environment. ▪ Barrages management could allow more natural estuarine environment to develop in the Lower Lakes ▪ High rainfall events could be managed to provide flushing flows within Lake Alexandrina to reduce salt levels ▪ Installation of fish passages at the proposed weir near Wellington could allow connection to the freshwater environment of the River Murray), important for diadromous fish species. ▪ Creation of a saltwater environment, potentially providing habitat for marine fish species ▪ Aesthetic benefits through provision of inundated Lower Lakes environment
Bioremediation	2	0.7	0.8	Moderate	**Negative**	▪ Suitable redox conditions must be maintained to prevent acid re-generation ▪ Loss of freshwater environment and associated flora and fauna impacts and significant species loss ▪ Salinisation of lake basin as water levels recede ▪ Potential for eutrophication to occur as water levels recede ▪ Ecological disturbance impacts during installation of infrastructure and ongoing management and monitoring ▪ Potential disturbance of PASS and ASS environments which may create acidification issues

					Positive	▪ Relative ease of returning Lower Lakes to pre-action state upon re-flooding ▪ Some opportunities for feeding bird species (primarily wading species)may develop, arising from Vegetation works
Vegetation	1	0.8	0.8	Low	**Negative**	▪ Loss of freshwater environment and associated flora and fauna impacts and significant species loss ▪ Salinisation of lake basin as water levels recede ▪ Potential for eutrophication to occur as water levels recede ▪ Ecological disturbance impacts during installation of infrastructure and ongoing management and monitoring ▪ Introduction of mono-cultures of non-native vegetation species, loss of diversity and potential longer term weed management issues ▪ Potential disturbance of PASS and ASS environments which may create acidification issues
					Positive	▪ Relative ease of returning Lower Lakes to pre-action state upon re-flooding ▪ Some opportunities for feeding bird species (primarily wading species)may develop

Neutralisation	5	0.7	0.7	High	**Negative**	▪ Flora impacts associated with addition of large volumes of neutralising agents, including smothering and inhibition of photosynthesis ▪ Fauna impacts, primarily aquatic species, associated with addition of large volumes of neutralising agents, including increased turbidity and associated impacts to fish and invertebrate populations ▪ Loss of freshwater environment as waters recede and associated flora and fauna impacts and significant species loss ▪ Salinisation of lake basin as water levels recede ▪ Potential for eutrophication to occur as water levels recede; and ▪ Ecological disturbance impacts during neutralisation material addition and ongoing management and monitoring.
					Positive	▪ Relative ease of returning Lower Lakes to pre-action state upon re-flooding
Provision of water via freshwater buy backs	3	0.8	0.7	Moderate	**Negative**	▪ Potential mobilisation of acidified sediments; ▪ Initial turbidity increases; and ▪ Relatively low level salinisation (in the medium to long term through evaporation) ▪ Inconsistent inundation may exacerbate the oxidation of pyrite and generation of acidity with subsequent mobilisation of acidity and heavy metals to the environment.
					Positive	▪ A secure water supply maintaining adequate water levels within the Lower Lakes will provide significant benefits to the ecology of the area

Lake Albert seawater use exclusively	7	0.7	0.5	Extreme	**Negative**	▪ High chance of ineffective treatment as inundation must be accurately timed prior to the sediments turning acidic, to reduce the risk of mobilising both acidity and heavy metals; ▪ Salinisation of a freshwater resource (with the potential to become hyper-saline due to lack of flushing regime), which has no refuge habitat for fish; ▪ Potential generation of hydrogen sulfide gas due to high quantities of sulfate in water from the Coorong that could result in an imbalance between sulphur and available iron; ▪ Risk of adverse impacts on the Coorong and Murray Mouth associated with altered flow dynamics. ▪ Loss of freshwater environment and associated ecosystem, including large scale loss of existing fish populations within Lake Albert ▪ Lake Albert would become a closed system, with no connection with freshwater or marine species.
					Positive	▪ An initial water connection into Lake Alexandrina may allow existing fish populations an exit route as Lake Albert fills with saltwater reducing the impact of this option with regard to fish. ▪ In the longer term a saltwater environment would develop at Lake Albert which could provide habitat for marine fish species if able to colonise, or where stocking activities occur; ▪ Aesthetic benefits through provision of inundated Lake Albert

6.3. Lake Albert and seawater

It is recognised that the transfer of seawater option (i.e. the proposed action to open the barrages) is considered an option of last resort. However the assessment has shown that if it is required, then the technical contribution may be sufficient to prevent acidification (subject to time conditions on application to sediments). This may be of benefit particularly to Lake Albert where inundation over the central area of the Lake (comprised of clay bearing high net acidity) may be required in the future. High net acidity in the central areas of the Lake may be difficult to manage by alternative means, and the mid-range technical ranking of the seawater transfer option (technical contribution rank of four from eight) suggests that there is some technical merit in the option. However, the alternative options assessment has indicated that one or more of the alternative options which score higher than seawater transfer may also be selected for the management of the central area.

The direct costs associated with the transfer of water from the Coorong into the Lake are considered potentially significant, and so the transfer option scores poorly on the direct cost criteria.

As an overall adjusted score, in comparison to the other options, the transfer of water from the Coorong into Lake Albert is ranked eighth (of eight), predominantly due to the direct and indirect costs involved, and the potentially 'extreme' risk of negative environmental impacts to both the Lake and the Coorong. Note that the ranking of this option does not improve when the adjustments are removed, due to the significant cost associated. As in indicator, when cost contribution is reduced, the ranking of this option would improve to fourth at 100% technical contribution (and 0% cost).

6.4. Assessment of alternative options

It is evident from the stage one assessment that the following options score highly on the technical and costs contributions and are least likely to have significant negative impacts:

- provision of freshwater allocations / buy-backs;
- vegetation; and
- bioremediation.

It is also evident from the assessment process that these options overlap and to some extent are symbiotic. The appropriate selection of multiple options (particularly those of a low environmental risk) as a combination approach is potentially likely to be of more benefit than a blanket homogeneous approach to management (i.e. using one option), based on the following:

- overlap / symbiosis of various alternative options (i.e. bioremediation, vegetation, freshwater inundation and also neutralisation);

- the spatial extent of acid sulfate soil / sediment;
- the ability for prevention / treatment to be prioritised based on risk assessment; and
- variability in acid flux (migration) to the aquatic environment.

The stage one assessment of alternative options considers the options as stand-alone options and not as combined options. Stage two of the assessment process is therefore crucial to the assessment of alternative options with respect to key management drivers, considering the following:

- The stage one assessment indicates that the freshwater (allocations) option is the number one ranked option.
- The vegetation option (although ranked second for several technical / cost contributions) scores lower on a technical basis than costs (i.e. in terms of acidification management), but is kept high in the rankings due to high scores awarded on the costs contribution, coupled to a high multiplier for the perceived low environmental risks.
- The bioremediation option scores in the mid-range generally, although this option requires further assessment / revision following the completion of additional studies and requires an organic carbon input (i.e. vegetation).
- The freshwater (buy-backs) option scores well on the technical and environmental risks areas (as per the freshwater 'allocations') but the cost component reduces its ranking as the cost contribution increases (although it does share number one spot with 'allocations' when costs contribution is set to 0%) .
- The drawdown option scores poorly overall, with a low technical ranking, but its ranking is marginally increased when considering maximum cost contribution, as expected from an option that has no significant direct costs.
- With respect to Lake Albert, the transfer of water from the Coorong is ranked low overall, based on the cost contribution, both pre and post adjustment. However the mid ranking of the technical contribution indicates that the option may be of merit as a preventative last resort measure for certain areas of the Lake.
- The proposed action is ranked mid-range when the cost contribution is favoured, but less well on a technical basis, and could also have significant environmental impacts.

7. Stage two - combination of selected options

Stage two of the assessment process focuses on the alternative options that showed most promise with respect to the management of acidification in the Lower Lakes. However, it was considered that a key question when further assessing potential options is what is being managed and why?

7.1. Management of soils / sediments – hazard and risk

The key management question with respect to the soils of the Lower Lakes is “what is the management for?” The responses can be given as follows:

- avoid water body acidification – spatial modelling, trigger levels, (real time management strategy);
- reduce acidity hazard at lake margins – prevention, control, treatment;
- mitigate metal release – pH sensitive metals (aluminium, iron, manganese, arsenic);
- avoid water de-oxygenation (Mono-sulfidic Black Ooze formation[2]) and increased eutrophication (algal blooms in the water body);
- promote ecological recovery – e.g. Finniss River ecological refuge; and
- enhance community benefits – e.g. Dunns Lagoon.

The spatial distribution of acid sulfate soils within the Lakes system (i.e. the hazard) does not necessarily directly equate with the true risk to the aquatic environment. For a risk to exist, there must be a source of acidity (and associated pH dependant metals), a receptor that may be impacted and a pathway connecting them. Such a source-pathway-receptor relationship is termed a ‘pollutant linkage’. If one or more of the source, pathway or receptor is absent, no linkage exists and thus there is no likelihood of risk.

Based on the consideration of the ‘pollutant linkage’, it is more likely that a risk exists in localised peripheral areas (assuming drawdown to a predicted point of acidification has not occurred), rather than a homogeneous concentric band of ‘risk’ peripheral to the water body (i.e. as an elevated source of net acidity with a complete pollutant linkage). Therefore management of acid sulfate soils / sediments within the heterogeneous Lakes system with the aim of meeting the above objectives

[2] Organic oozes enriched in iron mono-sulfide, which when mixed with water, the react within minutes to completely consume dissolved oxygen. MBO has the potential to cause rapid and severe effects on water quality.

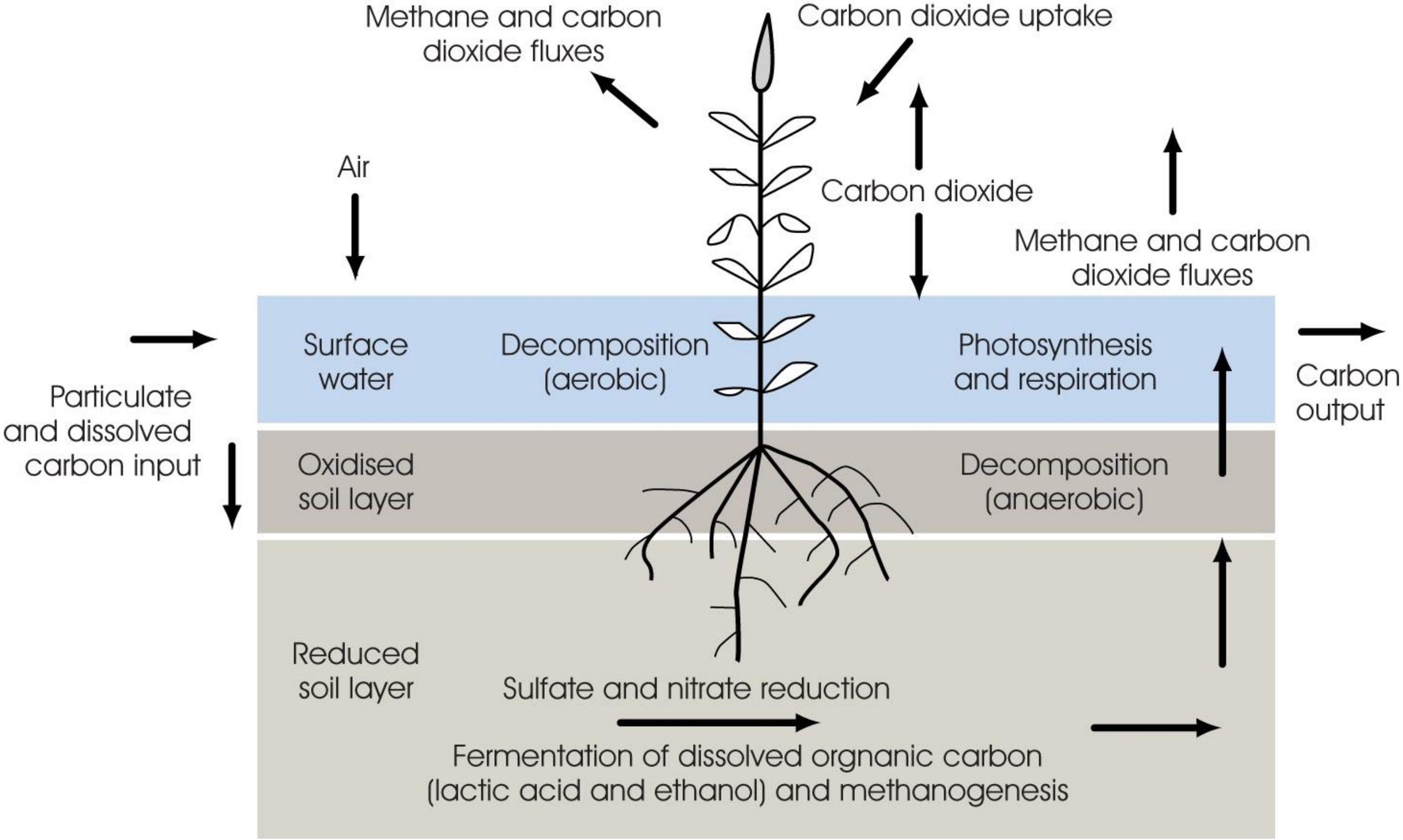
is considered more achievable on a localised basis (rather than a blanket homogeneous approach).

The stage one MCA indicated that the provision of freshwater (via environmental allocation) is the highest scoring alternative management option. However, other alternative options were noted to have the potential for managing acidification of sediments following the drawdown of the water level within the system.

It should also be noted that the Lakes system is likely to comprise some inherent natural ability to buffer acid generation and attenuate subsequent acid and metal flux. Therefore alternative management options should be considered in light of their ability to stimulate a natural response from the Lakes system.

As acidification mitigation measures, freshwater provision, bioremediation, vegetation and neutralisation (limestone treatment of acidified soils and water) are intrinsically linked with some overlap (Figure 4). These combined options are considered to constitute an overarching option that is referred to herein as enhanced bioremediation (assuming a certain level of co-ordination between the respective options) which is discussed in further detail in Section 7.2.

- **Figure 4 - Conceptualisation of Enhanced Bioremediation (note that additional reactive neutralisation of both water body and soil is required)**



7.2. Enhanced bioremediation

Enhanced bioremediation refers to management approaches that aim to promote in-situ microbial activity (sulfate-reducing bacterial activity) in order to convert sulfate to insoluble sulfide minerals, while consuming acid[3]. This essentially reverses the pyrite/iron mono-sulfide oxidation reactions that generated acidity in the first place. Whilst this option is primarily bioremediation (microbial breakdown, algal flocculants etc), this option also comprises measures to optimise conditions to enable bioremediation to occur. Therefore, assessment of this option takes into account provision of neutralisation of soils / sediments, provision of vegetation (as ongoing organic substrate) and any associated infrastructure to enable this (and that use of such options is co-ordinated). The components of enhanced bioremediation are as follows:

i. establishment of vegetation to provide ongoing organic matter source to sediments (and provide secondary benefit of minimising wind erosion of exposed sediment;
ii. the enhancement of natural in situ conditions via addition of organic matter to promote the microbially mediated transformation of sulfate to sulfide and partition sulfuric related acidity;
iii. the ‘tactical’ and responsive use of neutralising agent (e.g. ultrafine lime) to pre-dose sediments already subject to low pH outside the required pH range for successful vegetation colonisation; and
iv. the reactive localised dosing of the water body where mobilisation of acidity from sediment to the water body has inadvertently occurred.

In the context of this project vegetation is the term used for covering the soils affected by exposure (following drawdown and decline of freshwater inflows) within the Lower Lakes system with vegetation. As mentioned previously, a key assumption is that the plant species chosen as part of the plant colonisation /establishment are species suitable for the Lower Lakes environment, and that ‘vegetation’ may include local native plant species, exotic annuals or exotic perennials identified as effective in covering soils to assist in the bioremediation of the area.

Although biodiversity is extremely important in this region, the vegetation that is proposed does not have the sole purpose of improving biodiversity. Rather, the primary purpose of the initial vegetation is to provide ecosystem stability or resilience by immediate soil cover, stabilising moving sand to reduce the impacts on the natural ecosystem, individuals and communities and as a source for ongoing organic matter (carbon) to sediments. These actions are likely to have an effect on reducing soil acidification by assisting to maintain soil moisture in the short-term, and by providing longer-term benefits as part of the bioremediation process.

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[3] A detailed discussion of microbially mediated bioremediation (i.e. transformation of sulfate to sulfide) is presented in Appendix F.

The targeted and responsive use of neutralising agents (i.e. limestone) to both sediment and water-bodies should also remain an option that can be applied to the system based on the results of ongoing water quality monitoring.

It is considered that significantly increased neutralisation of the system would be required following further drawdown (e.g. to -2.0 m AHD) and thus neutralisation would become the more substantial component in this combined option. The use of water to inundate exposed sediments to an arbitrary management level (e.g. -1.5m AHD in Lake Alexandrina and -0.5m AHD in Lake Albert) would therefore be of significant benefit in reducing the area of exposed sediment requiring management and would also assist in preventing oxidation of the higher potential acidity areas within the central regions of both Lakes (as outlined in Appendix A).

7.3. Combined options

Based on the consideration of the following:

- use of freshwater (by either environmental allocations or 'buy-backs') is the highest scoring alternative option to mitigate environmental acidification associated with exposure of acid sulfate soils; and
- management of acid sulfate soil above the management level is more realistic in a peripheral localised manner (thus areas could be managed by more sustainable options, in particular a combination of options referred to as enhanced bioremediation, based on risk based prioritisation and / or restoration targets).

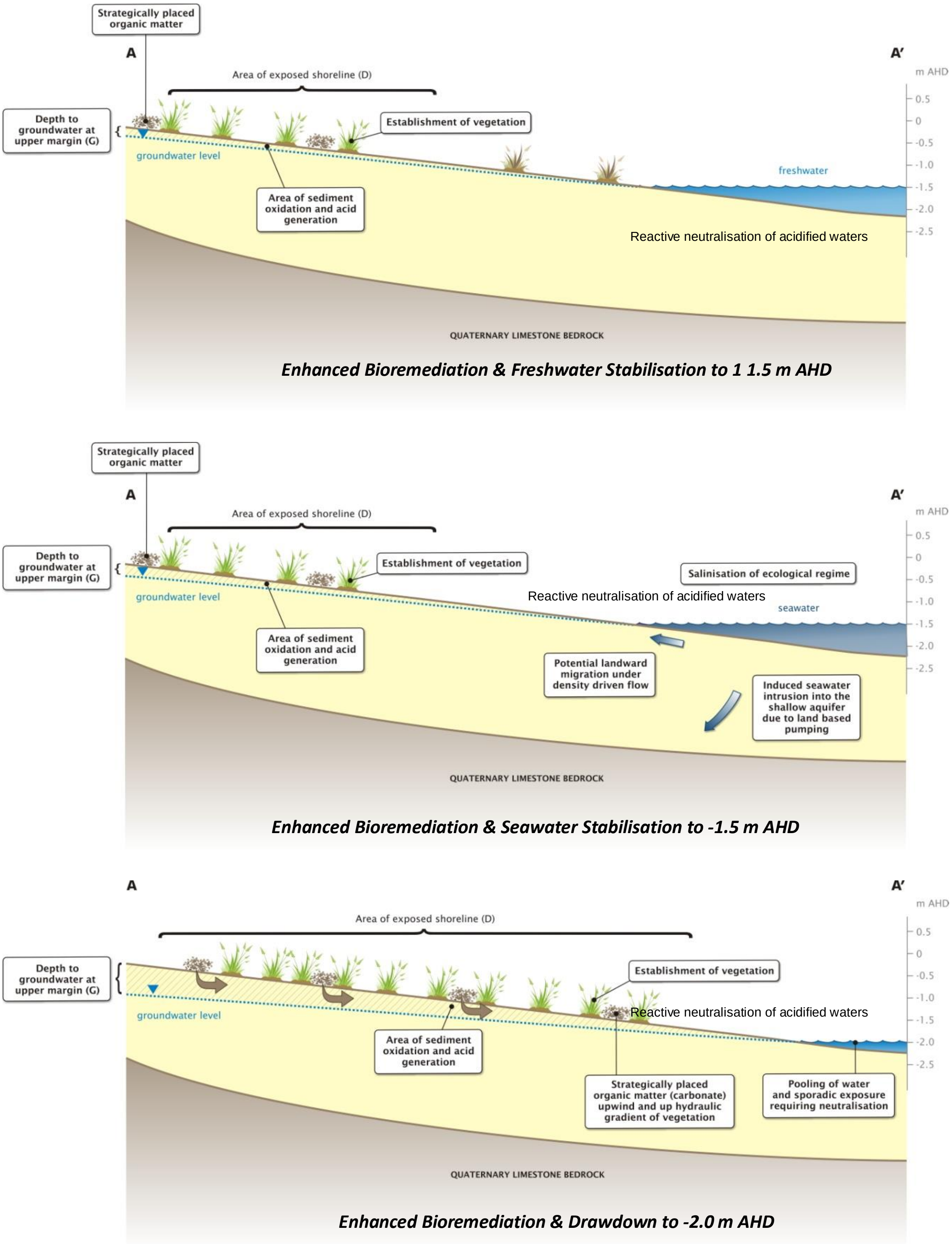
The SMT decided up the qualitative assessment of the following three combinations:

1. Enhanced bioremediation with freshwater stabilisation to -1.5 m AHD (Lake Alexandrina arbitrary management level);
2. Enhanced bioremediation with seawater stabilisation to -1.5 m AHD (Lake Alexandrina arbitrary management level); and
3. Enhanced bioremediation with drawdown to -2.0 m AHD (Lake Alexandrina arbitrary management level).

Note that for Lake Albert the arbitrary prescribed management level for the purposes of assessment is -0.5 m AHD.

All three option combinations share the concept of 'enhanced bioremediation' as a common denominator. The predominant variation across the option combinations is the introduction of freshwater / seawater as a stabilisation method, or the managed drawdown of the water level. The simplistic conceptual schematics for each of the combined options are presented in Figure 5.

Figure 5 - Simplistic Conceptual Schematics of Combined Options



8. Results of stage two assessment

This section summarises the results of the stage two assessment, relating to the combined options.

8.1. Option combination 1

This option comprises the stabilisation of the water level to -1.5 m AHD in Lake Alexandrina and -0.5m AHD in Lake Albert (arbitrary management level) using freshwater from either environmental allocations or buy-backs, with application of enhanced bioremediation around the peripheral areas according to risk prioritisation of areas and rehabilitation mapping.

The SMART assessment for this option is presented in Table 30.

- **Table 30 – SMART assessment for option combination 1**

SMART Component	Discussion Points	Response
Specific	Enhanced bioremediation refers to the combined management options that are symbiotic and that aim to promote microbial activity (sulfate-reducing bacterial activity) in order to convert dissolved sulfate to sulfide minerals, while consuming acid. This essentially reverses the pyrite/iron mono-sulfide oxidation reactions that generated acidity in the first place. Essentially bioremediation involves promoting naturally occurring bacteria to return contaminated environments to a healthy state. The vegetation component is required to provide ongoing organic carbon to drive the reduction process. Complementary neutralisation of both soil and water is required alongside the process (i.e. coordinated) and also could be used as a responsive measure. Option to work in conjunction with freshwater stabilisation of system to required depth (arbitrary management level defined here as -1.5 m AHD.	Enhanced bioremediation represents management approaches that aim to promote microbial activity (sulfate-reducing bacterial activity) via addition of organic matter in order to convert dissolved sulfate to sulfide minerals, while consuming acid.

Measureable	Specify Monitoring in relation to ongoing assessment of system including water quality (alkalinity, pH etc) soil characteristics in , vegetation and bio-remedial processes	The measurable include the standard criteria for water health plus the following: • Soil physics • Soil geochemistry • Soil microbiology
Achievable	Assumed to be achievable.	
Relevant	Considered to be relevant.	
Time bound	Should take into account the estimated / predicted target date when acidification occurs, with a view to implementation prior to target date. Should be considered to 'occur' until in- flows to system return to historical volumes (or additional management occurs).	Proof of effectiveness prior to determined date of system acidification.

The option (as defined by its SMART analysis) was assessed, and scores provided, using the MCA framework. The MCA assessment justification for this alternative option is provided in Appendix M, and the resulting MCA scoring assessment is presented as Table 31.

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SKM

■ Table 31 - MCA matrix for option combination 1

Assessment Criteria	Weight (Out of 100)	Alignment with Criteria: Yes 10	Probable 5	Unlikely 2	No/NA 0	Raw Value Score	Weighted Value Score	H=1 / M=0.75 / L=0.5 Value Confidence Score	Confidence Weighted Score
4 - Technically feasible and achievable in practice on the scale required	50								
4.1 TECHNICALLY FEASIBLE (theoretically, will it work?)	10								
A - Option is theoretically viable	25	10				250	12.5	1.00	12.5
B– Theoretically viable on the scale (spatial) required	75		5			375	18.8	0.75	14.1
Sub Total						625	31.3		26.6
4.2 ACHIEVABLE IN PRACTICE (Has it been proven to work?)	45								
A - Generic Proof of Concept established	15	10				150	33.75	1.00	33.8
B - Proof of Concept established in similar (representative) environments	35	10				350	78.75	1.00	78.8
C – Proof of concept established in Lower Lakes circumstances	50	10				500	112.5	0.75	84.4
Sub Total						1000	225		196.9
4.3 - Implemented successfully before acidification of the Lakes occurs	45								
A1 – on a large scale	65		5			325	73.125	0.75	54.8
A2 – on a localised scale	35		5			175	39.375	0.75	29.5
Sub Total						500	112.5		84.4
B – The Lakes can be returned to their pre-action trophic state	*To be assessed qualitatively*								
C – A salinity of <1500EC is achievable in the long term									
D - An alkalinity concentration >25mg/l is maintained in the Lower Lakes									
Sub-Total - Technically feasible and achievable in practice on the scale required									307.8
8 - Costs to Government (State or Federal)	50								
8.1 DIRECT LIFECYCLE COSTS (Dollar costs directly apportioned to the entire lifecycle of the option.)	70								
Capital / Establishment costs are minimal	40	10				400	140.0	1.00	140.0
Operational / Maintenance costs are minimal	40	10				400	140.0	1.00	140.0
Decommissioning costs are minimal	20	10				200	70.0	1.00	70.0
Sub Total						1000	350		350.0
8.2 INDIRECT OR ENVIRONMENTAL COSTS & BENEFITS (Limited to impacts that Government may be liable for through the application of the option)	30								
Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes Region)	60		5			300	45	1.00	45.0
Maximises the indirect benefits experienced in the wider Lower Lakes Region (eg/ tourism, agriculture, wine,	40	10				400	60	0.75	45.0
Sub Total						700	105		90.0
Sub-Total - Costs and Transparency									440.0
					Total		824		748
Adjustments	Preventative Measure or Treatment	Prevention							
	Likelihood of negative impacts	Unlikely							
	Severity of negative impacts	Moderate							
	Risk Multiplier		0.56						
	Score			419					

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The MCA assessment for option combination 1 resulted in an overall score (pre-adjustment for environmental impacts) of 748.

This option scores higher with respect to the costs contribution (440) than the technical contribution (307.8). This reflects that the option is likely to be of low dollar value in terms of operation and maintenance.

The environmental impact multiplier indicated that the likelihood of negative impacts was unlikely and that the severity of such impacts was moderate. The resulting overall score (post-adjustment) was 419.

The MCA matrix indicates that the confidence provided in the scoring assessment is generally medium to high across all metrics, with an average of 0.90 (i.e. average of 12 confidence scores ranging between 0.75, medium, and 1.0, high), indicating that there is a medium to high confidence in the scoring assessment for this option (refer to Appendix C for respective confidence score interpretations).

8.2. Option combination 2

This option comprises the stabilisation of the water level to -1.5 m AHD using seawater via the barrages, with application of enhanced bioremediation around the peripheral areas according to risk prioritisation of areas and rehabilitation mapping.

The SMART assessment for option combination 2 is presented as Table 32.

- **Table 32 – SMART assessment for option combination 2**

SMART Component	Discussion Points	Response
Specific	Enhanced bioremediation is as discussed in Table 30. However freshwater is substituted here for seawater. Seawater inundation considered to be via barrages and in accordance with the seawater inundation.	Combination of seawater inundation option and the combined enhanced bioremediation option.
Measureable	Specify Monitoring in relation to pH, vegetation and bio-remedial processes	Measurable include the standard criteria for water health plus the following: • Soil physics • Soil geochemistry • Soil microbiology
Achievable	Assumed to be achievable.	
Relevant	Considered to be relevant.	
Time bound	Should take into account the estimated / predicted target date when acidification occurs, with a view to implementation prior to target date. Should be considered to 'occur' until in- flows to system return to historical volumes (or additional management occurs).	Proof of effectiveness prior to determined date of system acidification.

The option (as defined by its SMART analysis) was assessed, and scores provided, using the MCA framework. The MCA assessment justification for this alternative option is provided in Appendix N, and the resulting MCA scoring assessment is presented as Table 33.

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Table 33 - MCA matrix for option combination 2

Assessment Criteria	Weight (Out of 100)	Alignment with Criteria: Yes 10	Probable 5	Unlikely 2	No/NA 0	Raw Value Score	Weighted Value Score	H=1 / M=0.75 / L=0.5 Value Confidence Score	Confidence Weighted Score
4 - Technically feasible and achievable in practice on the scale required	50								
4.1 TECHNICALLY FEASIBLE (theoretically, will it work?)	10								
A - Option is theoretically viable	25		5			125	6.3	0.75	4.7
B– Theoretically viable on the scale (spatial) required	75		5			375	18.8	0.75	14.1
Sub Total						500	25.0		18.8
4.2 ACHIEVABLE IN PRACTICE (Has it been proven to work?)	45								
A - Generic Proof of Concept established	15	10				150	33.75	1.00	33.8
B - Proof of Concept established in similar (representative) environments	35		5			175	39.375	1.00	39.4
C – Proof of concept established in Lower Lakes circumstances	50			2		100	22.5	0.75	16.9
Sub Total						425	95.625		90.0
4.3 - Implemented successfully before acidification of the Lakes occurs	45								
A1 – on a large scale	65	10				650	146.25	0.75	109.7
A2 – on a localised scale	35		5			175	39.375	0.50	19.7
Sub Total						825	185.625		129.4
B – The Lakes can be returned to their pre-action trophic state	*To be assessed qualitatively*								
C – A salinity of <1500EC is achievable in the long term									
D - An alkalinity concentration >25mg/l is maintained in the Lower Lakes									
Sub-Total - Technically feasible and achievable in practice on the scale required									238.1
8 - Costs to Government (State or Federal)	50								
8.1 DIRECT LIFECYCLE COSTS (Dollar costs directly apportioned to the entire lifecycle of the option.)	70								
Capital / Establishment costs are minimal	40	10				400	140.0	1.00	140.0
Operational / Maintenance costs are minimal	40	10				400	140.0	1.00	140.0
Decommissioning costs are minimal	20			2		40	14.0	0.75	10.5
Sub Total						840	294		290.5
8.2 INDIRECT OR ENVIRONMENTAL COSTS & BENEFITS (Limited to impacts that Government may be liable for through the application of the option)	30								
Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes Region)	60	10				600	90	1.00	90.0
Maximises the indirect benefits experienced in the wider Lower Lakes Region (eg/ tourism, agriculture, wine,	40		5			200	30	0.50	15.0
Sub Total						800	120		105.0
Sub-Total - Costs and Transparency									395.5
					Total		720		634
Adjustments	Preventative Measure or Treatment	Prevention							
	Likelihood of negative impacts	Possible							
	Severity of negative impacts	Critical							
	Risk Multiplier		0.35						
	Score			222					

The MCA assessment for the proposed action resulted in an overall score (pre-adjustment for environmental impacts) of 634.

This option scores higher with respect to the costs contribution (395.5) than the technical contribution (238.1). This reflects that the option is likely to be of low dollar value in terms of operation, although the decommissioning metric is scored low to reflect the unlikely ability for the system to be easily returned to a freshwater environment. With respect to the technical contribution, the proof of concept for the option to be achievable in practise is scored low.

The environmental impact multiplier indicated that the likelihood of negative impacts was possible and that the severity of such impacts might be critical – this is a reflection of the impact of changing the environment from that of freshwater to saltwater but also accounts for the potential for seawater to be ineffective at buffering acidic soils (and at mitigating short term release of metals, see Appendix N). The resulting overall score (post-adjustment) was 222.

The MCA matrix indicates that the confidence provided in the scoring assessment is lower than option combination 1 but is generally medium to high across all metrics, with an average of 0.81 (i.e. average of 12 confidence scores ranging between 0.75, medium, and 1.0, high), indicating that there is generally a medium level of confidence in the scoring assessment for this option (refer to Appendix C for respective confidence score interpretations).

As with the proposed action discussed earlier in the report, the metrics concerning application on a ‘local scale’ within the technical contribution section was awarded a ‘low confidence’ multiplier. This was a result of the uncertainty of the option being ‘probably’ capable of localised area management, and also the metric concerning ‘indirect benefits’ was awarded a low confidence with respect to the ‘probable’ score. It was considered that the score awarded (‘probable’) could be adjusted depending on the various stakeholder views associated with indirect benefits to the wider region (i.e. loss of extractable resource for viniculture, but potential boost in recreational usage).

8.3. Option combination 3

This option comprises the drawdown of the water level to -2.0 m AHD but with application of enhanced bioremediation around the peripheral areas according to risk prioritisation of areas and rehabilitation mapping.

The SMART assessment for option combination 3 is presented as Table 34Table 36.

- **Table 34 – SMART assessment for option combination 3**

SMART Component	Discussion Points	Response
Specific	As option combination 1 but with no managed in flow / stabilisation of water level	Bioremediation represents management approaches that aim to promote microbial activity (sulfate-reducing bacterial activity) via addition of organic matter in order to convert dissolved sulfate to sulfide minerals, while consuming acid.
Measureable	Specify Monitoring in relation to pH, vegetation and bio-remedial processes	Measurable include the standard criteria for water health plus the following: • Soil physics • Soil geochemistry • Soil microbiology
Achievable	Assumed to be achievable.	
Relevant	Considered relevant.	
Time bound	Should take into account the estimated / predicted target date when acidification occurs, with a view to implementation prior to target date. Should be considered to 'occur' until in- flows to system return to historical volumes (or additional management occurs).	Proof of effectiveness prior to determined date of system acidification.

The option (as defined by its SMART analysis) was assessed, and scores provided, using the MCA framework. The MCA assessment justification for this alternative option is provided in Appendix O, and the resulting MCA scoring assessment is presented as Table 35.

Table 35 - MCA matrix for option combination 3

Assessment Criteria	Weight (Out of 100)	Alignment with Criteria: Yes	Probable	Unlikely	No/NA	Raw Value Score	Weighted Value Score	Value Confidence Score (H=1 / M=0.75 / L=0.5)	Confidence Weighted Score
		10	5	2	0				
4 - Technically feasible and achievable in practice on the scale required	50								
4.1 TECHNICALLY FEASIBLE (theoretically, will it work?)	10								
A - Option is theoretically viable	25		5			125	6.3	1.00	6.3
B– Theoretically viable on the scale (spatial) required	75			2		150	7.5	1.00	7.5
Sub Total						275	13.8		13.8
4.2 ACHIEVABLE IN PRACTICE (Has it been proven to work?)	45								
A - Generic Proof of Concept established	15		5			75	16.875	0.75	12.7
B - Proof of Concept established in similar (representative) environments	35			2		70	15.75	0.75	11.8
C – Proof of concept established in Lower Lakes circumstances	50				0	0	0	1.00	0.0
Sub Total						145	32.625		24.5
4.3 - Implemented successfully before acidification of the Lakes occurs	45								
A1 – on a large scale	65			2		130	29.25	1.00	29.3
A2 – on a localised scale	35			2		70	15.75	0.75	11.8
Sub Total						200	45		41.1
B – The Lakes can be returned to their pre-action trophic state	*To be assessed qualitatively*								
C – A salinity of <1500EC is achievable in the long term									
D - An alkalinity concentration >25mg/l is maintained in the Lower Lakes									
Sub-Total - Technically feasible and achievable in practice on the scale required									79.3
8 - Costs to Government (State or Federal)	50								
8.1 DIRECT LIFECYCLE COSTS (Dollar costs directly apportioned to the entire lifecycle of the option.)	70								
Capital / Establishment costs are minimal	40	10				400	140.0	0.75	105.0
Operational / Maintenance costs are minimal	40	10				400	140.0	0.75	105.0
Decommissioning costs are minimal	20	10				200	70.0	1.00	70.0
Sub Total						1000	350		280.0
8.2 INDIRECT OR ENVIRONMENTAL COSTS & BENEFITS (Limited to impacts that Government may be liable for through the application of the option)	30								
Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes Region)	60			2		120	18	0.75	13.5
Maximises the indirect benefits experienced in the wider Lower Lakes Region (eg/ tourism, agriculture, wine, lifestyle)	40			2		80	12	0.75	9.0
Sub Total						200	30		22.5
Sub-Total - Costs and Transparency									302.5
					Total		471		382
Adjustments	Preventative Measure or Treatment	After Event Treatment							
	Likelihood of negative impacts	Likely							
	Severity of negative impacts	Dangerous							
	Risk Multiplier		0.36						
	Score			103					

The MCA assessment for the proposed action resulted in an overall score (pre-adjustment for environmental impacts) of 382.

This option scores higher with respect to the costs contribution (302.5) than the technical contribution (79.3). This reflects that the option is likely to be of low dollar value in terms of operation, although the decommissioning metric is scored low to reflect the unlikely ability for the system to be easily returned to a freshwater environment. With respect to the technical contribution, the proof of concept for the option to be achievable in practise is scored low.

The environmental impact multiplier indicated that the likelihood of negative impacts was possible and that the severity of such impacts might be critical – this is a reflection of the potential for oxidation of sediments following drawdown and the subsequent risk of migration of acidity and metals to the aquatic environment. The resulting overall score (post-adjustment) was 103.

The MCA matrix indicates that the confidence provided in the scoring assessment is generally medium to high across all metrics, with an average of 0.85 (i.e. average of 12 confidence scores ranging between 0.75, medium, and 1.0, high), indicating that there is a medium to high confidence in the scoring assessment for this option (refer to Appendix C for respective confidence score interpretations).

9. Summary of stage two results

At the default setting of 50/50 contribution from each of the technical and costs contributions, and applying the adjustment parameters, option combination 1 (enhanced bioremediation with freshwater stabilisation) is ranked as the highest scoring option. Table 36 presents the 50/50 ratio rankings when the adjustment parameters are applied.

Table 36 - Ranking of adjusted options at 50/50 costs vs. technical contribution

50/50 Ranking	Option	50/50 Score
1	enhanced bioremediation with freshwater stabilisation	419
2	enhanced bioremediation with seawater stabilisation	222
3	enhanced bioremediation with drawdown	103

The order of the option combinations ranking does not change when both of the following adjustment parameters are removed:

- Prevention vs. treatment
- Risk of negative environmental impacts

However the scores between option combinations 2 and 3 become much closer. Table 37 presents the 50/50 rankings when the adjustment parameters are removed.

- **Table 37 - Ranking of non-adjusted options at 50/50 costs vs. technical contribution**

50/50 Ranking	Option	50/50 Score
1	enhanced bioremediation with freshwater stabilisation	748
2	enhanced bioremediation with seawater stabilisation	392
3	enhanced bioremediation with drawdown	382

Thus the non-adjusted ranking at 50/50 contribution indicates that the enhanced bioremediation with freshwater stabilisation combination achieves the highest score.

These scores can be analysed further to provide rankings based on the relative contributions of both technical feasibility (Table 38) and costs (Table 39).

- **Table 38 - Ranking of non-adjusted options based on technical contribution (50/50)**

50/50 Ranking	Option	50/50 Score
1	enhanced bioremediation with freshwater stabilisation	308
2	enhanced bioremediation with seawater stabilisation	150
3	enhanced bioremediation with drawdown	79

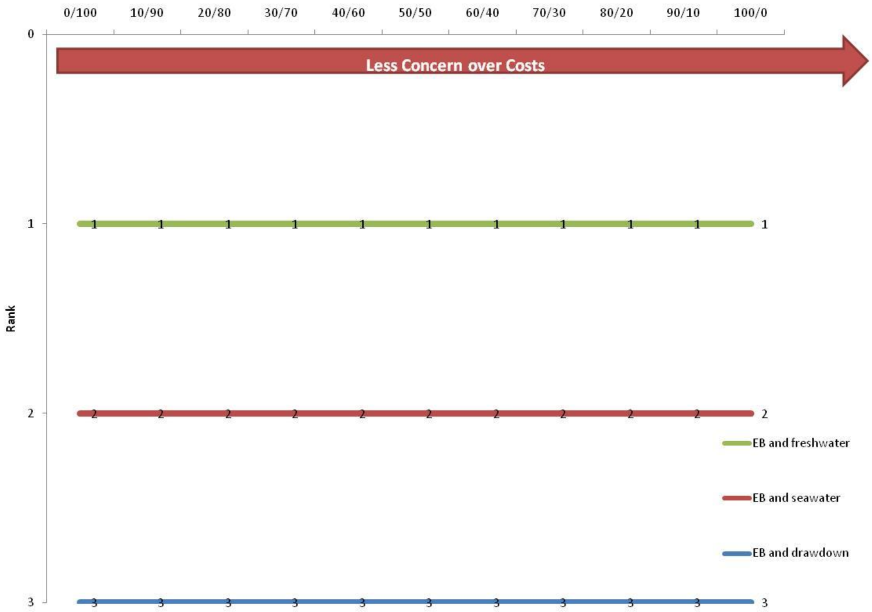
- **Table 39 - Ranking of non-adjusted options based on cost contribution (50/50)**

50/50 Ranking	Option	50/50 Score
1	enhanced bioremediation with freshwater stabilisation	440
2	enhanced bioremediation with drawdown	303
3	enhanced bioremediation with seawater stabilisation	242

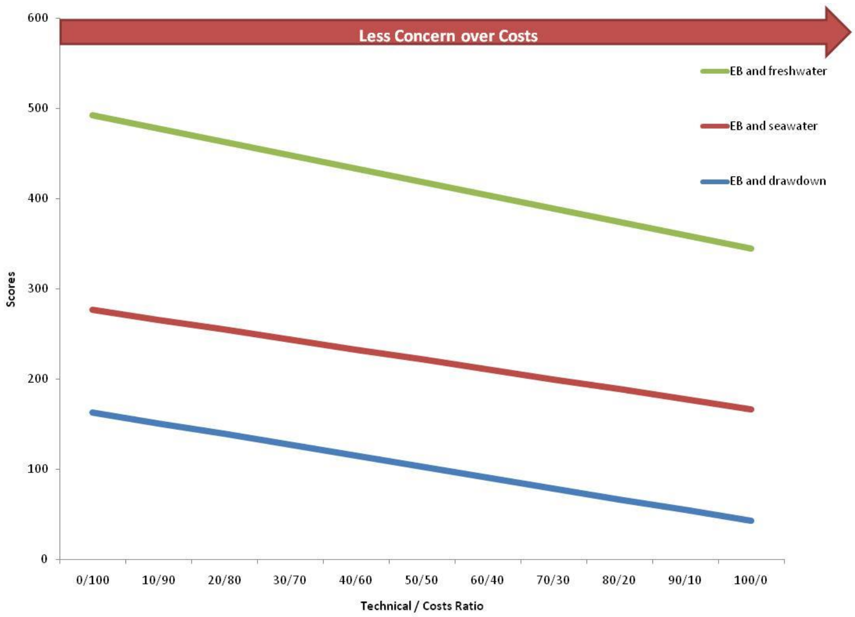
The enhanced bioremediation with freshwater stabilisation combination ranks as the highest scored non-adjusted option in the technical contribution, and in the cost contribution, when the ratio of contributions is 50/50.

As with the stage one assessment, the MCA scores were developed across a sliding scale of contribution from each of the two heading criteria (technical and costs) in order to present the potential change in option ranking depending on the required contribution from cost vs. technical / practical feasibility. This contribution ratio based on option ranking is presented as Figure 6. Note that the scale accounts for adjusted values (i.e. preventative vs. treatment and risk of negative impact). The actual scores used to produce the contribution scale are presented as a score scale in Figure 7.

- **Figure 6- Combined options and contribution ratio (rankings)**



- **Figure 7 - Combined options and contribution ratio (scores)**



9.1. Environmental risks of combined options

A description of the potential environmental risks that were identified for each of the option combinations is presented in Table 40. Option combination 1 has a significantly lower environmental risk (as indicated by the risk multiplier) than option combinations 2 and 3, which have relatively similar risk multipliers:

- Option combination 1 (0.56 multiplier);
- Option combination 3 (0.36); and
- Option combination 2 (0.35).

The low multiplier for option combination 2 (use of seawater for stabilisation) indicates that the perceived environmental risks (if not managed correctly) are relatively equal to the potential generation of acidity following drawdown.

■ **Table 40 - Description of potential risks for the combined options**

Option Combination	Combined Ranking @ 50/50	Likelihood of Negative Impact	Severity	Risk of Negative Impact		Summary of Negative Impact Comments
1 –enhanced bioremediation with Freshwater Stabilisation to -1.5 m AHD	1	Unlikely (0.8)	Moderate (0.7)	Moderate		▪ Significantly lower lake levels (including a completely dry Lower Lakes environment); ▪ Increased salinity due to a lack of flushing and evaporative concentration; ▪ Dust generation and erosion of exposed lake beds; ▪ Pyrite oxidation and mobilisation of acidity and metals through Lake seiching and flushing from rainfall events ; and ▪ Eutrophication as water levels recede.

▪ **Table 40 - Description of potential risks for the combined options**

Option Combination	Combined Ranking @ 50/50	Likelihood of Negative Impact	Severity	Risk of Negative Impact	Summary of Negative Impact Comments
2 - Enhanced bioremediation with Seawater Stabilisation to -1.5 m AHD	2	Possible (0.7)	Critical (0.5)	Extreme	▪ Salinisation of a freshwater resource (with the potential to become hyper-saline due to lack of flushing regime). ▪ Potential generation of hydrogen sulfide gas due to high quantities of sulfate in water from the Coorong that could result in an imbalance between sulphur and available iron ▪ Risk of adverse impacts on the Coorong and Murray Mouth associated with altered flow dynamics ▪ Potential loss of freshwater connection to the Coorong and with particular impacts upon diadromous fish species ▪ Disconnection of Murray Mouth to River Murray, with particular impacts upon diadromous fish species (this assumes fish passage is not possible for the proposed weir at Pomanda Island) ▪ Mobilisation studies have indicated that seawater mobilises a significant amount of acidity and heavy metals / nutrients during inundation, if sulfidic sediments have oxidised.

▪ **Table 40 - Description of potential risks for the combined options**

Option Combination	Combined Ranking @ 50/50	Likelihood of Negative Impact	Severity	Risk of Negative Impact	Summary of Negative Impact Comments
3 - Enhanced bioremediation with Drawdown to -2.0 m AHD	3	Likely (0.6)	Dangerous (0.6)	Extreme	▪ Significantly lower lake levels (including a completely dry Lower Lakes environment); ▪ Increased salinity due to a lack of flushing and evaporative concentration; ▪ Dust generation and erosion of exposed lake beds; ▪ Pyrite oxidation and mobilisation of acidity and metals through Lake seiching and flushing from rainfall events ; ▪ Eutrophication as water levels recede; and Anoxic conditions developing.

10. Discussion: combination of options

As discussed previously in this report, the future management of acid sulfate soils and sediments within the Lakes system may consider that:

- although the ‘hazard’ of acid sulfate soils exists within the system, it is more realistic to consider the actual risk to the environment, based on the source-pathway-receptor linkage; and
- management actions focus on localised management of the risk to the environment, rather than a homogeneous system wide response.

This section discusses the findings of the comparative assessment of the following three combinations:

1. Enhanced bioremediation with Freshwater Stabilisation to -1.5 m AHD / -0.5m AHD (Lakes Alexandrina and Albert respectively);

2. Enhanced bioremediation with Seawater Stabilisation to -1.5 m AHD (Lakes Alexandrina and Albert respectively); and

3. Enhanced bioremediation with Drawdown to -2.0 m AHD (Lakes Alexandrina and Albert respectively).

10.1. Technical vs. costs

Based on both the adjusted and non-adjusted assessments, the enhanced bioremediation with freshwater stabilisation combination (option combination 1) is ranked as the number one option across all contribution ratios. There is a marginal decrease in the scores of each combination as the importance of the costs contribution decreases.

Option combination 1 achieved a significantly higher score than the other combinations, being strong (i.e. being awarded the maximum alignment on several metrics) across both contribution areas. Although being awarded maximum alignment across most metrics, some of the metrics for Option combination 1 were awarded a ‘probable’ alignment (i.e. lower scoring alignment) in both contribution categories:

- Technical – it was considered that the combination would *probably* be viable on the scale required, assuming that the area of interest (management) is likely to be on a localised basis. This was further assumed to be linked to risk assessment of the system (risk area identification, mapping and prioritisation) and identified areas of rehabilitation. Thus the exact areas (both in size and location) are not pre-determined, and a reduced alignment score was awarded. These considerations are also reflected in the metric concerning successful implementation prior to Lakes acidification, as the exact management areas are to some extent unknown.

- Costs – It was considered that based on the best available information at the time of the assessment, that the use of this option (in particular the freshwater component) would *probably* minimise the extent of indirect costs in other environments. It was considered that the maximum alignment could not be awarded as there may be some impacts resulting from re-allocation (or buy-back) such as impacts to irrigators. However, a lesser alignment (i.e. 'unlikely') was not considered relevant as there is also the potential for benefits to the basin as a whole.

10.2. Environmental risks

A summary of the potential environmental risks per option is presented in Table 41. Option combination 1 has a significantly lower environmental risk (as indicated by the risk multiplier) than option combinations 2 and 3, which have relatively similar risk multipliers:

- Option combination 1 (0.56 multiplier);
- Option combination 3 (0.36); and
- Option combination 2 (0.35).

Option combination 1 was considered to be of low risk with respect to environmental impacts (i.e. impacts to the environment as a result of implementation and maintenance of the combined option). Research into the inundation of exposed sediments using freshwater indicates that there could be some minor increase in turbidity (in the short term) and salinity of the water body when operating a partial inundation approach (i.e. to -1.5m AHD) in comparison to fully increasing the water level to historical levels, although sporadic freshwater inflows could be sufficient to mitigate this. An additional issue is the development of wetting / drying cycles which lead to the increased generation of acid generating sediments. This may occur due to inconsistency in the management of the water level. However, it is considered that reactive neutralisation of the water body and or sediment would be able to mitigate this process. Furthermore, the perceived environmental benefits of this option included the relative ease of returning the Lower Lakes system to its pre-action state upon the re-commencement of historical flows, and that the current ecological characteristics of the system could be maintained. The option was also considered less likely (based on available research at the time of assessment) to result in the significant mobilisation of acidity and metals.

With respect to combinations 2 and 3, the low multiplier for option combination 2 (use of seawater for stabilisation) indicates that the perceived environmental risks (if not managed correctly) are equal to the potential generation of acidity following drawdown.

It was considered that option combination 2 may have varied significant detrimental environmental impacts, such as a potential for the increased generation of hydrogen sulfide gas due to high quantities of sulfate in salt water (as a result of an imbalance between sulfur and available iron). Importantly, there is also a risk that the water body could become hyper-saline (as observed within the Coorong) as system flushing may not be sufficient. A significant issue associated with the use (and the timing of use) of seawater (as reported by the various research studies) is that seawater may mobilise a significant amount of acidity and metals / nutrients during inundation, if sulfidic sediments have oxidised.

Option combination 3 may result in significantly lower Lake levels (including a stabilisation of Lake Alexandrina at approximately - 2.3m AHD), which could increase both salinity due to a lack of flushing and evaporative concentration, and dust generation / erosion of exposed lake beds.

Significantly, increased exposure and oxidation of acid generating sediments would occur, leading to the increased mobilisation of acidity and metals. Besides the significant environmental detriment that may occur, there would likely be significant additional costs associated with increased requirement for vegetation across exposed areas, coupled to the additional costs associated with the need for increased neutralisation of acidified sediment (and potentially of the remnant lakes as a whole).

Assuming that drawdown was allowed, the rehabilitation of the Lakes following re-commencement of environmental flows would also most likely incur significant resources.

Table 41 – Summary of potential environmental risks for each option combination

Negative	Positive
1 – Enhanced bioremediation with freshwater stabilisation to -1.5 m AHD	
▪ Salinisation of a freshwater resource (with the potential to become hyper-saline due to lack of flushing regime). ▪ Suitable redox conditions must be maintained to prevent acid re-generation. ▪ Loss of freshwater environment and associated flora and fauna impacts and significant species loss ▪ Salinisation of Lake basin as water levels recede. ▪ Potential for eutrophication to occur as water levels recede (although some evidence of this status already). ▪ Ecological disturbance impacts during installation of infrastructure and ongoing management and monitoring. ▪ Potential disturbance of PASS and ASS environments which may create acidification issues.	▪ Relative ease of returning Lower Lakes to pre-action state upon re-flooding ▪ Some opportunities for feeding bird species (primarily wading species)may develop, arising from vegetation works ▪ Maintenance of current ecological characteristics ▪ Less potential mobilisation of acidity and heavy metals ▪ More buffering capacity than seawater ▪ Desired level could be achieved via managed water savings across basin. ▪ Aesthetic benefits through provision of an inundated Lower Lakes environment.

2 – Enhanced bioremediation with seawater stabilisation to -1.5 m AHD	
▪ Potential generation of hydrogen sulfide gas due to high quantities of sulfate in water from the Coorong that could result in an imbalance between sulfur and available iron. ▪ Risk of hyper-saline water body if system flushing is reduced. ▪ Risk of adverse impacts on the Coorong and Murray Mouth associated with altered flow dynamics. ▪ Potential loss of freshwater connection to the Coorong and with particular impacts upon diadromous fish species. ▪ Disconnection of Murray Mouth to River Murray, with particular impacts upon diadromous fish species (this assumes fish passage is not possible for the proposed weir at Pomanda Island). ▪ Mobilisation studies have indicated that seawater mobilises a significant amount of acidity and heavy metals / nutrients during inundation, if sulfidic sediments have oxidised.	▪ The provision of a refuge environment within the EMLR tributaries (Currency Creek and Finniss Creek) presents significant ecological safeguards should the Lower Lakes become a saltwater environment. ▪ Barrages management could allow more natural estuarine environment to develop in the Lower Lakes ▪ High rainfall events could be managed to provide flushing flows within Lake Alexandrina to reduce salt levels ▪ Installation of fish passages at the proposed weir near Wellington could allow connection to the freshwater environment of the River Murray), important for diadromous fish species.
3 - Enhanced bioremediation with drawdown to -2.0 m AHD	
▪ Significantly lower lake levels (including a stabilisation of Lake Alexandrina at approximately -2.3m AHD). ▪ Increased salinity due to a lack of flushing and evaporative concentration; ▪ Dust generation and erosion of exposed lake beds. ▪ Pyrite oxidation and mobilisation of acidity and metals through Lake seiching and flushing from rainfall events. ▪ Eutrophication as water levels recede. ▪ Anoxic conditions developing. ▪ Additional costs associated with increased requirement for vegetation across exposed areas. ▪ Additional costs (and indirect impacts) due to the need for increased volumes of limestone (neutralisation of acidified hotspots and potentially of the lakes as a whole. ▪ Increased monitoring (indirect management) required of system to gauge / confirm likely impacts.	▪ Relative ease of returning Lower Lakes to pre-action state upon re-flooding. ▪ Low level of direct management required with respect to water levels.

11. Conclusions

A comparative assessment of environmental acidification mitigation options was undertaken for the Lower Lakes system, using a MCA approach.

This comparative assessment was required as part of a broader MCA assessment, supporting the EIS for the proposed action of opening the barrages to allow seawater to inundate the Lakes system. The proposed action is an action of last resort and may be required for the inundation of sediments that may generate and mobilise acidity (and metals / nutrients) following a drawdown in system water level.

A two stage approach was employed to first compare all nominated alternative options with the proposed action, and then to identify a suitable combination of options that could be employed to manage the system with respect to acidification. The comparative assessment was designed solely to consider the technical and practicality aspects of each option in relation to the Lakes, and also to provide a high level assessment of direct and indirect costs, as required by the EIS.

The stage one comparative assessment of nominated alternative options reported that an increase in freshwater to the system (via environmental allocations) and inundation of acid generating sediments, is the number one option.

Further analysis of the scores indicated that the vegetation option (although ranked second for several technical / cost contributions) scored poorly on a technical basis (i.e. in terms of acidification management), but was kept high in the rankings due to high scores awarded on the costs contribution, coupled to a high multiplier for the perceived low environmental risks.

The freshwater (buy-backs) option also scored well on the technical and environmental risks areas (being essentially the same option as the freshwater via allocations option), but the cost component reduces its ranking as the cost contribution increases (although it does share a number one ranking with ‘allocations’ when costs contribution is set to 0%).

The bioremediation option was scored in the mid-range generally (i.e. with respect to overall rankings), although this requires further assessment / revision following the completion of additional studies.

The proposed action (seawater inundation via barrages) for the Lakes system ranked at number three when the cost contribution was increased (i.e. >70% costs versus technical), as it a ‘low cost’ option. It does not score highly on the technical contribution as a preventative measure, and is downgraded by its potentially high environmental risk, associated with inundating oxidised sediments.

The freshwater options may be affected by the same potential risk, although it is considered that more cation exchange (and buffering capacity) would be available when using freshwater over that available when using seawater (and that use of seawater may also lead to hyper-salinity of the water body). In addition, it was noted that consideration could be given to pre-neutralisation of oxidised sediments using neutralising agents, prior to inundation.

With respect to Lake Albert, the transfer of water from the Coorong is ranked low overall, based on the cost contribution score, both pre and post adjustment. However the mid ranking of the technical contribution indicates that the option may be of merit as a preventative last resort measure for those areas of the Lake which exhibit significant potential acidity, and could be defined and investigated further.

The drawdown option scores low overall, and has a low technical ranking. The drawdown option ranking was marginally increased when considering maximum cost contribution, as expected from an option that has no significant direct costs.

Stage two of the assessment considered the key management questions associated with the Lakes, based on the findings of stage one that freshwater inundation was the highest scoring alternative option. It was considered that freshwater inundation could be used to manage the system to an arbitrary water management level, and a combination of symbiotic options (referred to as enhanced bioremediation) could then be implemented as a localised management action. The assumption of localised management is based on the heterogeneity of the sediments around the Lakes, and the rationale that hazard does not necessarily equal risk. This option combination also included the reactive neutralisation of localised sediments / acidified water.

The implementation of enhanced bioremediation with freshwater stabilisation (option combination 1) was comparatively assessed against using seawater as a method of stabilisation (i.e. proposed action, option combination 2) and also against a drawdown of water level (option combination 3).

The assessment of these three combinations indicates that option combination 1 (enhanced bioremediation with freshwater stabilisation to a level of -1.5 m AHD) is the top scoring / ranking option combination.

Sensitivity analysis of the ratio of technical and cost contribution to the overall score indicated no change in the ranking of the combined options across all technical / costs contribution, indicating that option combination 1 is a significantly robust option.

There is no significant variation in ranking considering both adjusted and non adjusted assessments, although option combinations 2 and 3 do become more closely scored.

There is a marginal decrease in all scores as the costs contribution decreases. Option combination 1 has a significantly lower environmental risk (as indicated by the risk multiplier) than combinations 2 and 3, which have relatively similar risk multipliers:

- Option combination 1 (0.56 multiplier);
- Option combination 3 (0.36); and

- Option combination 2 (0.35).

The low multiplier for option combination 2 (use of seawater for stabilisation) indicates that the perceived environmental risks (if not managed correctly) are equal to the potential generation of acidity following drawdown.

It is considered that the implementation of option combination 1 would have the following potential environmental benefits:

- maintenance of current ecological characteristics / regimes;
- transition from stabilisation to normal regime would be relatively easy (i.e. return to pre-action state) following re-commencement of environmental (historical) flows;
- opportunities for feeding bird species (primarily wading species) may develop, arising from vegetation works;
- less potential mobilisation of acidity and heavy metals than associated with other considered options;
- more buffering capacity than seawater; and
- desired level could be achieved via managed water savings across basin, following appropriate risk assessment.

In addition, the adoption of option combination 1 would allow the natural resilience of the Lakes system to be stimulated, and potentially result in a more harmonised and natural environment. The other option combinations considered may have varied significant detrimental environmental impacts, including:

- potential for the increased generation of hydrogen sulfide gas due to high quantities of sulfate in saltwater (as a result of an imbalance between sulfur and available iron);
- risk of water body becoming hyper-saline (as observed within the Coorong) as system flushing may not be sufficient;
- risk of mobilisation of acidity, metals and nutrients following inundation of oxidising sediments with seawater;
- significantly lower Lake levels (option combination 3, including a stabilisation of Lake Alexandrina at approximately - 2.3m AHD); and
- dust generation / erosion of exposed lake beds.

Significantly, increased exposure and oxidation of acid generating sediments would occur, leading to the increased mobilisation of acidity and metals. Besides the significant environmental detriment that may occur, there would likely be significant additional costs associated with increased requirement for vegetation across exposed areas, coupled to the additional costs associated with the need for increased neutralisation of acidified sediment (and potentially of the remnant lakes as a whole).

Assuming that drawdown was allowed, the rehabilitation of the Lakes following re-commencement of environmental flows would also most likely incur significant resources.

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13. Limitations

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All reports and conclusions that deal with environmental and / or sub-surface conditions are based on interpretation and judgement and as a result have uncertainty attached to them. You should be aware that this report contains interpretations and conclusions which are uncertain, due to the nature of the assessment / investigations. No study can completely eliminate risk, and even a rigorous assessment and/or sampling programme may not detect all problem areas within a system / site. The following information sets out the limitations of the Report.

This Report should only be presented in full and should not be used to support any objective other than those detailed within the Agreement. In particular, the Report does not contain sufficient information to enable it to be used for any use other than the project specific requirements for which the Report was carried out, which are detailed in our Agreement. SKM accepts no liability to the Client for any loss and/or damage incurred as a result of changes to the usage, size, design, layout, location or any other material change to the intended purpose contemplated under this Agreement.

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The Report is based on assumptions that the site conditions as revealed through selective sampling and / or modelling are indicative of conditions throughout the site. The findings are the result of standard assessment techniques used in accordance with normal practices and standards, and (to the best of our knowledge) they represent a reasonable interpretation of the current conditions on the site. However, these interpretations and assumptions cannot be substantiated until specifically tested and the Report should be regarded as preliminary advice only.

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Appendices

Appendix A – Acid Sulfate Soils and the Lower Lakes Environs

A - Acid Sulfate Soils

Acid sulfate soils (ASS) is a term used to describe soils or sediments that contain significant amounts of sulfide, which upon oxidation can potentially generate sulfuric acid. During the last major sea level rise, rapid sedimentation led to the formation of new coastal landscapes. Bacteria in these waterlogged landscapes converted sulfate from seawater, and iron present in the sediments to produce iron pyrite (FeS_2). When exposed to oxygen, these iron pyrites oxidise to sulfate, which is generated in the form of sulfuric acid.

Acid sulfate soils can be either ‘sulfidic’ or ‘sulfuric’ acid sulfate soil:

- sulfidic soils are soils / sediments which contain sulfidic material that have not been oxidised (i.e. they are below the water table). The pH of these soils / sediments in their un-oxidised state is above pH 4. Upon oxidation (e.g. contact with air) the sulfide within these PASS will oxidise and generate sulfuric acid, and the pH of the soil / sediment will decrease to below pH 4.
- sulfuric soils are soils/sediments containing sulfidic material that have been oxidised and have produced sulfuric acid, resulting in an existing pH of below pH 4 and often accompanied by a yellow and/or red mottling in the soil profile. ASS generally contain residual potential acidity (as sulfides) as well as existing (actual) acidity.

Herein, the acronym ASS will be used to mean both sulfidic and sulfuric acid sulfate soils.

The sulfuric acid produced by oxidation of iron sulfides affects both soil and water, and significantly damage the environment. Most aquatic life needs a minimum pH of 6 to survive. The pH of acid sulfate soil associated drainage and water bodies can be as low as pH 2 and is often around pH 4. Massive fish kills can occur when sulfuric acid is washed into water bodies. This particularly occurs following drawdown of the watertable and subsequent oxidation of the iron pyrite layer in the sediment (note that the rate of acid flux to a water body is dependent on several factors including the rate at which pyrite oxidises following exposure to oxygen). Seasonal rainfall, a rebound of the water level / table and seiching of exposed sediments by water from the water body can wash substantial quantities of acidity (and pH dependant metals) into water bodies, resulting in significant detrimental effects to the ecosystem.

Describing Acid Sulfate Soils

Acid sulfate soils are characterised by the amount of net acidity (as mol H^+ / t), which is determined by chemical analysis. From the analytical results, the amount of neutralising agent needed to be added to the soil to prevent the possibility of net acid export (i.e. neutralisation) can be calculated, using an acid-base account (ABA). While several ABA models have been used for ASS, they all share a common underlying principle, as per the following equation:

Net Acidity = **Potential Sulfidic Acidity** + **Existing Acidity** – **Acid Neutralising Capacity**

A detailed description of this approach can be found in Ahern et al., 2004.

In South Australia, the net acidity of soils disturbed for example during development works can be compared to the guideline net acidity criteria (SA EPA, 2007), as shown in Table A1. However, the net acidity of sediments across the Lakes is generally likely to exceed the guideline criteria, and the guideline criteria are only presented here for comparison purposes.

Table A1 - South Australian EPA. EPA Guidelines – Site Contamination – Acid Sulfate Soil Material EPA Guideline 638/07. Issued November 2007

Soil or Sediment Texture	Criteria	
	Sulfur trail % oxidisable sulphur (oven dry basis)	Acid trail mol H^+/tonne (oven dry basis)
Sands to loamy sands	0.03	18
Sandy loams to light clays	0.06	36
Medium to heavy clays and silty clays	0.1	62

Acid Sulfate Soil in the Lower Lakes Environment

Previous preliminary investigations undertaken by CSIRO (Fitzpatrick et al., 2008) combined current bathymetry, soil and vegetation mapping in Geographical Information Systems (GIS) to predict the distribution of the fourteen sub-types of ASS identified in the Lower Lakes and River Murray below Lock 1, according to the following water level scenarios:

- Pre-drought water level, i.e. +0.5 m AHD; and
- The water level in the system as of February 2008, i.e. -0.5 m AHD.

Field verification inspections were used to assist in the calibration of the predictive GIS mapping, which consisted of the development of the following predictive ASS maps:

i. Lake Albert (Figure A1); and

ii. Lake Alexandrina (Figure A2).

These maps predict the spatial range of ASS sub-types when the water levels were at pre-drought levels (i.e. +0.5 m AHD) and the approximate present day levels (i.e. -0.5m AHD and -1.5m AHD).

Figure A1 - Predictive scenario maps depicting changes in ASS materials at different water levels in Lake Albert (after Fitzpatrick et al., 2008)

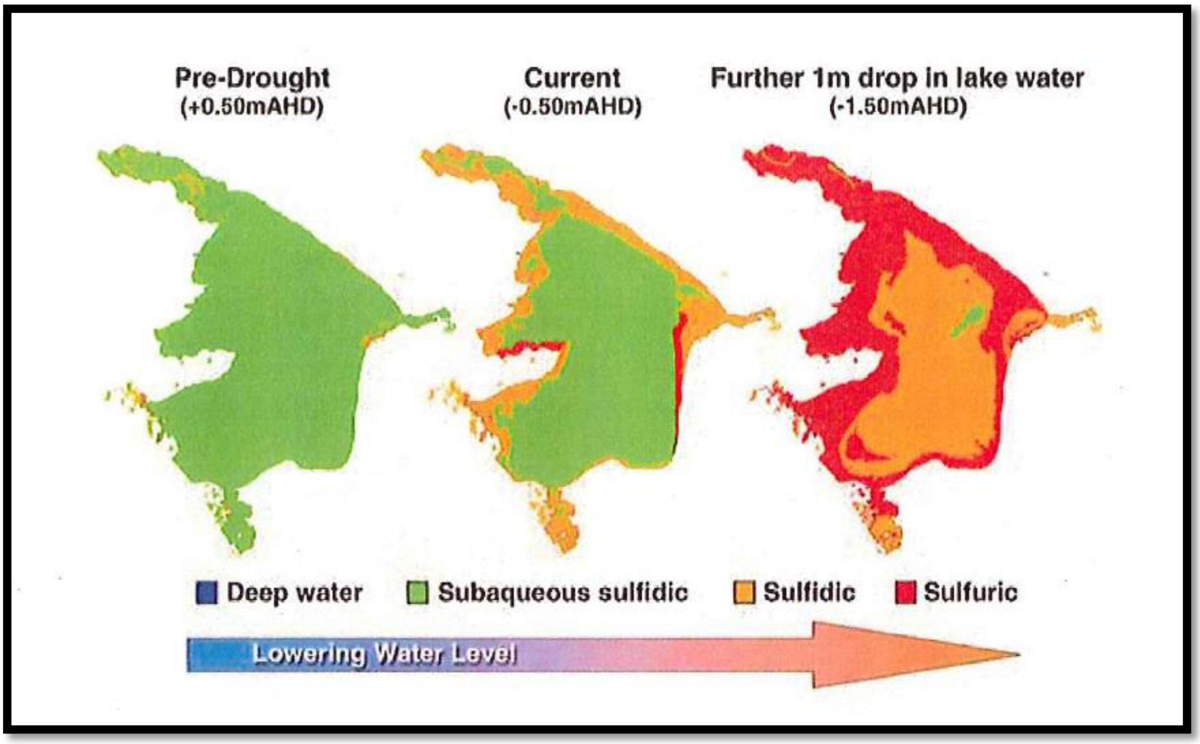
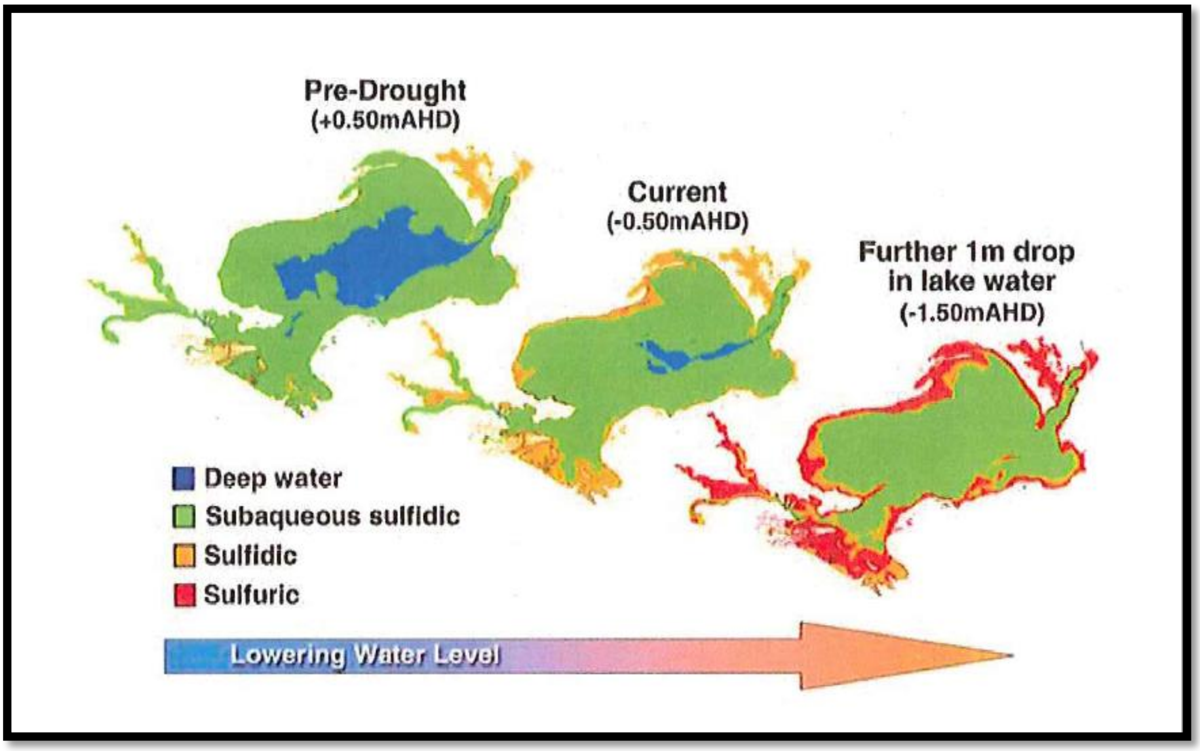


Figure A2 - Predictive scenario maps depicting changes in ASS materials at different water levels in Lake Alexandrina (after Fitzpatrick et al., 2008)



As the water levels drop, previously deep water soils become sub-aqueous, with these sub-aqueous soils eventually becoming exposed as water levels decrease further (although these soils are still waterlogged and therefore anaerobic). These sub-aqueous soils are dewatered, and become dry and oxidised, leading to oxidation of pyrite and concomitant generation of sulfuric acid (i.e. resulting in a pH <4), where sulfidic material is present in the drying layers. This acidity (and pH sensitive metals such as aluminium) may then mobilise and migrate to aquatic environments.

As shown in the predictive GIS maps developed by CSIRO, the oxidation (and consequential acid generation) of sulfidic materials in the shallow Lower Lakes is a potentially significant hazard.

Building on the predictive mapping undertaken in 2008, increased spatial variability assessment of sub-aqueous and terrestrial acid sulfate soils within the Lower Lakes was undertaken in 2009 (Grealish et al., in preparation). The resulting updated maps identified areas of concern where low $pH_{soil:water}$ (sulfuric material) or/and high net acidity and medium to high electrical conductivity occurred at Loveday Bay, near the barrages to the south of Alexandrina, near Clayton, Finniss River and Currency Creek, in the north of Lake Alexandrina (Boggy Lake and Dog Lake), and numerous isolated areas around the margins of Lake Albert.

The areas of higher net acidity are located in the central areas of Lake Alexandrina, and in the north-western and south-eastern quadrants of Lake Albert. The lithology of Lake Albert comprises more clays than Lake Alexandrina, with an associated higher net acidity than Lake Alexandrina (pers.comm. Department of Environment and Natural Resources to SKM).

To outline this occurrence of higher net acidity in Lake Albert, Table A2 and Table A3 present the net acidity of sediments associated with each drawdown level (i.e. concentric water level) for Lake Albert and Lake Alexandrina respectively.

Table A2 - Lake Albert Net Acidity - Excluding <0 range (Grealish et al., in prep.)

Water Levels	Mean Net Acidity (mol H^+ /t)
>-0.5	274
-0.75 to -0.5	298
-1.0 to -0.75	506
-2.0 to -1.0	452
<-2.0	190

With respect to Lake Alexandrina, a significant range of net acidity was predicted throughout all ranges of bathymetry, although the highest mean was predicted to occur as the water level falls below -2.3m AHD (i.e. the central area of the Lake).

Table A3 - Lake Alexandrina Net Acidity (Grealish et al., in prep.)

Water Levels	Mean Net Acidity (mol H^+/ t)
>-1m	85.0
-1.5m to -1m	29.6
-2.0m to -1.5m	49.4
-2.3m to -2.0m	92.5
<-2.3m	231.2

In addition, the net acidity data presented in Tables A1 and A2 highlights the principle risk to the environment of acid sulfate soils, which is the drawdown of water level to below -1.5 m AHD. A subsequent rise back above this datum may leach (i.e. transport) a significant amount of acidity into the environment.

Environmental Impacts of Acid Sulfate Soils in the Lower Lakes Environs

A significant proportion of the lakes environs demonstrate elevated net acidity. Some peripheral areas within the Lower Lakes environs have experienced water level drawdown and subsequent exposure of acid sulfate soils, with significant generation and mobilisation of acidity. Around 200 ha of acidic water was reported in Loveday Bay in 2009, in the southern region of Lake Alexandrina. Monitoring of pH in Loveday Bay lake water has reported values less than 3. Completely or partially dissolved mussel shells were identified in this area (DENR, 2009a), although there has been less acidity in 2010. Similar effects on water quality have been observed in Boggy Lake and Currency Creek.

Appendix B - Weighting Justification

Criteria Weighting Justification

Assessment Criteria	Weighting identified in MCA Tables	Criteria True Weighting %*	Justification
4 - Technically feasible and achievable in practice on the scale required	50	50	
4.1 TECHNICALLY FEASIBLE (theoretically, will it work?)	10	5	A low weighting has been attributed to this criterion due to the potentially large gap between theory and practical implementation of a particular option.
A - Option is theoretically viable	25	1.25	A low weighting has been attributed to this sub-criterion due to the potential large number of unknown variables involved in treating a system as complex as the Lower Lakes. An option which may be theoretically viable, yet cannot be proven to work presents a high risk action to address the potential acidification impacts.
B– Theoretically viable on the scale (spatial) required	75	3.75	Due to the large scale of the Lower Lakes environment, encompassing high spatial complexity, an option which can theoretically be implemented on the scale required has been attributed a higher allocation of this sub-criterion.
4.2 ACHIEVABLE IN PRACTICE (Has it been proven to work?)	45	22.5	A high weighting allocation has been attributed to this sub criterion where an option can be proven to address the potential acidification impacts.

A - Generic Proof of Concept established	15	3.375	This component of the sub-criterion receives a low weighting, due to the complexity of issues and spatial scales involved for the Lower Lakes system.
B - Proof of Concept established in similar (representative) environments	35	7.9	A moderate weighting has been allocated to this sub-criterion where an option has been proven to be success in addressing acidification in a similar environment. Some reservations remain due to the complexities and unique environments found within the Lower Lakes.
C – Proof of concept established in Lower Lakes circumstances	50	11.3	A high weighting has been allocated to this sub-criterion, where clear proof that an option has successfully addressed acidification in sections of the Lower Lakes, which can be confidently predicted to be practicable on the scale required.
4.3 - Implemented successfully before acidification of the Lakes occurs – Dec 2010	45	22.5	Trigger acidification levels within sections of the Lower Lakes are anticipated to lead to further complexity surrounding implementation and the success of some of the options. In many cases, acidification may negate the success of an option, or lead to significant environment impacts. A high weighting has thus been attributed to capture the importance of these timeframes.
A1 – on a large scale	65	14.6	This sub-criterion has been attributed the highest relative weighting within criteria 4. Where an option can be implemented successfully before acidification occurs is considered the most important

			criterion with respect to an options' feasibility.
A2 – on a localised scale	35	7.9	A moderate weighting has been attributed to this sub-criterion to capture instances where an option may only be successfully implemented on a small scale within the Lower Lakes. As acidification risks often occur on a localised scale within the Lower Lakes, this would allow hotspot management to occur, using an option, or combination of options.
8 - Costs to Government (State or Federal)	50	50	
8.1 DIRECT LIFECYCLE COSTS (Dollar costs directly apportioned to the entire lifecycle of the option.)	70	35	Predicting life cycle costs is a significant factor in scoring each option. Costs are identified in 'orders of magnitude'.
Capital / Establishment costs are minimal	40	14	The initial financial costs associated with implementing an option have been attributed a high weighting to reflect the importance of securing financial funding to implement an option.
Operational / Maintenance costs are minimal	40	14	This criterion addresses on-going costs associated with maintaining the implementation of an option. This has been attributed a relatively high weighting, to reflect options which may have significant operational costs. This includes options which are considered 'reactive', such as the neutralisation option, where implementation occurs in combination with a continual monitoring program to identify when and how best to maintain a desired pH.

			As such, life cycle costs are difficult to accurately identify for reactive options.
Decommissioning costs are minimal	20	7	A moderate to low weighting has been attributed to this criterion weighting, which captures recoverable costs (such as re-saleable infrastructure) and direct costs associated removal of infrastructure. The costs associated with returning the Lower Lakes to a defined state following implementation of an option are not considered as part of this criterion. This weighting captures the lesser importance of decommissioning an option in life cycle cost planning and to reflect its lower relevance with respect to how government bodies secure funding to implement an option.
8.2 INDIRECT OR ENVIRONMENTAL COSTS & BENEFITS (Limited to impacts that Government may be liable for through the application of the option)	30	15	
Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes Region)	60	9	Options which require resources to be sourced and transported to the Lower Lakes Region are assessed within this component. A moderate to high weighting has been attributed to identify significant external environmental impacts resulting in the implementation of an option. This assessment component considers physical impacts, such as mining/quarrying activities, together with the carbon footprint associated with transporting resources, such as pipeline and pumping infrastructure. This criterion also considers where an option impacts upon an environment where resources are

			no longer available, such as restricting water allocations to wetlands.
Maximises the indirect benefits experienced in the wider Lower Lakes Region (eg/ tourism, agriculture, wine, lifestyle)	40	6	A moderate to low weighting has been attributed to this criterion, which addresses beneficial outcomes of implementing an option, such as provision of water resources for tourism activities.

Key:

Main Criteria	
Sub Criteria Tier 1	
Sub Criteria Tier 2	

*True weighting refers to actual weighting calculation, presented as an actual percentage for Criteria 4 and 8.

Appendix C - Decision Confidence Assessment

Appendix C – Decision Confidence Assessment

Assessment Criteria	Confidence Score Summary Justification		
	Low (0.5)	**Moderate (0.75)**	**High (1)**
4 - Technically feasible and achievable in practice on the scale required			
4.1 TECHNICALLY FEASIBLE (theoretically, will it work?)			
A - Option is theoretically viable	Limited information available, significant data gaps evident, draft findings only, significant limitations to study identified.	Documented evidence (generally excluding peer reviewed journal/documents) with reasonably sound scientific rigour applied to study. Some data gaps and limitations identified.	Study documented within a peer reviewed journal/document, sound scientific rigour, limited information gaps and absence of significant limitations.
B– Theoretically viable on the scale (spatial) required	As noted above, with significant data gaps relating to scalability	As noted above, with some limitations identified regarding scalability.	As noted above, with detailed information/ feasibility studies undertaken to identify scalability associated with implementing an option.
4.2 ACHIEVABLE IN PRACTICE (Has it been proven to work?)			
A - Generic Proof of Concept established	Limited or no information available, significant data gaps evident, only draft findings available, significant limitations to study identified.	• Documented evidence (excluding peer reviewed journal/documents) or draft document with reasonably sound scientific rigour applied to study. Some data gaps and limitations identified. • Study not identified, yet reasonable possibility it may have been undertaken and has not been sourced, as deemed by the study team.	Option documented within a peer reviewed journal/document, sound scientific rigour applied, limited information gaps and absence of significant limitations.

B - Proof of Concept established in similar (representative) environments	• Limited applicability of option to the Lower Lakes, although study may include proof of concept of acid sulphate treatment, e.g. within a terrestrial environment. • Study not identified, yet reasonable possibility it may have been undertaken and has not been sourced (as deemed by the study team).	Draft findings only available at the time of assessment, studies with limitations or data gaps, studies undertaken in wetland environment (including lake environments), although in a distinctly different climatic region (e.g. acidic lakes in Scandinavia).	• Proof of concept established within a similar environment, such as a large shallow large, within a relatively comparable climatic region. • Alternatively, the absence of a study can allow a high level of confidence to be attributed where no proof of concept has been established.
C – Proof of concept established in Lower Lakes circumstances	Draft findings only identified for the Lower Lakes environment. Small scale study.	Proof of concept identified for the Lower Lakes, although undertaken on a relatively small scale, with limitations present.	Proof of concept within the Lower Lakes on a reasonably scale, with no significant limitations identified. Alternatively, the absence of a study can allow a high level of confidence to be attributed where no proof of concept has been established.
4.3 - Implemented successfully before acidification of the Lakes occurs			
A1 – on a large scale	Limited or no information available or significant data gaps identified, regarding implementation of an option on a large scale.	Some information available regarding implementation of an option on a large scale. Some limitations identified, only draft study available, or data gaps identified.	Study undertaken with scientific rigour discussing implementation on a large scale. Absence of significant limitations or data gaps.
A2 – on a localised scale	Limited or no information available regarding implementation of an option on a localised scale.	Some information available regarding implementation of an option on a localised scale. Some limitations identified, only draft study available.	Study undertaken with scientific rigour discussing implementation on a localised scale. Absence of significant limitations or data gaps.

B – The Lakes can be returned to their pre-action trophic state			
C – A salinity of <1500EC is achievable in the long term			
D - An alkalinity concentration >25mg/l is maintained in the Lower Lakes			
8 - Costs to Government (State or Federal)			
8.1 DIRECT LIFECYCLE COSTS (Dollar costs directly apportioned to the entire lifecycle of the option.)			
Capital / Establishment costs are minimal	Detailed cost estimates are not available.	Cost estimates have been undertaken on comparable studies which can be extrapolated to some degree.	Detailed cost estimates have been prepared.
Operational / Maintenance costs are minimal	Detailed operational and maintenance costs are not available.	Operational and maintenance cost estimates have been undertaken on comparable studies which can be extrapolated to some degree	Detailed operational and maintenance costs have been prepared.
Decommissioning costs are minimal	Decommissioning costs (e.g. infrastructure and equipment) associated are not available.	• Decommissioning costs (e.g. infrastructure and equipment) cost estimates have been undertaken on comparable studies which can be extrapolated to some degree. • Draft document only available or assessment undertaken by non-recognised authority. Cost estimates undertaken by study team alone with some limitations.	Decommissioning costs (e.g. infrastructure and equipment) have been estimated by a recognised authority, or can be estimated by the study team with no significant limitations.

8.2 INDIRECT OR ENVIRONMENTAL COSTS & BENEFITS (Limited to impacts that Government may be liable for through the application of the option)			
Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes Region)	Absence of information relating to indirect costs in other environments.	Limited information, only draft information available, risks clearly identifiable by study team relating to indirect costs in other environments.	Studies undertaken to identify indirect costs to other environments by a recognised authority.
Maximises the indirect benefits experienced in the wider Lower Lakes region (eg/ tourism, agriculture, wine, lifestyle)	Absence of information relating to indirect benefits, which are not readily identifiable by the study team.	Indirect benefits identified by the study team where limited information is available.	Studies undertaken to identify indirect benefits to other environments by a recognised authority; or indirect benefits readily identifiable by the study team.

▪ Appendix D - Lower Lakes Studies / Reports

Doc ref/Hyperlink	Document Title	Corporate/ Agency Author	Year	Document Summary Description
Study 1.pdf	Acid, Metal and Nutrient Mobilisation Following Rewetting of Acid Sulfate Soils in the Lower Murray	CSIRO	2008	Acid sulphate soils: effects of re-wetting dried ASS. Results of soils testing study, including pH, and subsequent nutrient and heavy releases. Modelling results and interpretation of impacts upon ecology of Lower River Murray system.
Study 2.pdf	Acid, metal and nutrient mobilisation dynamics in response to suspension of MBOs in freshwater and to freshwater inundation of dried MBO and sulfuric soil materials	Southern Cross GeoScience (Centre for Acid Sulfate Soil Research)	2008	The acid, metal and nutrient mobilisation following rewetting of acid sulfate soils in the Lower Murray Project. Examines results of tests on Monosulfidic Black Oozes and ASS from lower lakes and mobilisation of contaminants. Specific discussion covering nutrients, metals and metalloids, and individual reactions to scenarios of ASS tests. No discussion of ecological impacts.
Study 3-Earth Systems.pdf	Acid sulfate soil (ASS) management strategy for Currency Creek, Finiss River and Goolwa Channel, and project critical work program for ASS management in the Lower Murray Lakes	Earth Systems	2009	Proposed approach/management strategy for the avoidance, minimisation and control of acid generation from acid sulfate soils for Currency Creek, Finniss River and Goolwa Channel. Builds upon previous feasibility studies by Earth Tech.
Study 4.pdf	Acid sulfate soils in subaqueous, waterlogged and drained soil environments in Lake Albert, Lake Alexandrina and River Murray below Blanchetown (Lock 1): properties, distribution, genesis, risks and management	CSIRO	2008	Explanation and predictions of ASS, prediction of impacts of further drought on ASS formation and decline in water quality, development of remediation and management options for specific ASS environments.

Study 5.pdf	Hydrodynamic and water quality model for the Lower River Murray – The 'Lower Murray HydroModel' Final Report	University of Adelaide & University of Western Australia	2009	Development of a high resolution, process-based, three-dimensional coupled hydrodynamic-biogeochemical-ecological modelling system used as a tool to understand how key water quality variables will respond to continued drought and engineering interventions, such as flow diversions, weirs, and pumping, including the do nothing option. Planned future applications of the model include investigation of the potential effects of seawater flooding of exposed acid sulfate soils in the Lower Lakes.
Study 6.pdf	Lower Lakes Rehabilitation Opportunity Review & Revegetation Plan. Draft Report	Rural Solutions/ SA DEH	2009	Draft report providing a review of the vegetation opportunities and process recommendations required to assist in the rehabilitation of the Lower Lakes. Results of vegetation trails undertaken within the Lower Lakes. Species selection, concept implementation and cost estimates for vegetation works.
Study 7-draft.pdf	The potential impacts of heavy metals and acidity on fish communities in the Lower Lakes and Coorong area, due to the exposure of acid sulfate soils: A literature review.	SARDI Aquatic Sciences	2009	Relatively brief Literature review of ASS, fishes within the lower lakes, impacts of heavy metals and low pH on fish communities.
Study 8.pdf	Inland acid sulfate soils in Australia: Overview and conceptual modelsINLAND ACID SULFATE SOILS IN AUSTRALIA: OVERVIEW AND CONCEPTUAL MODELS	CSIRO Land and Water/ CRC LEME, Adelaide, South Australia	2008	Comprehensive background information concerning ASS. Case studies include Lower Lakes.
Study 9.doc	Literature Review on the Impacts of Liming to Mitigate Acidification, Coorong, Lower Lakes & Murray Mouth Projects	Department for Environment and Heritage	Not dated	Discussion of ASS, use of liming techniques with specific reference to fish, macro-invertebrates, and vegetation. Methods for undertaking liming activities.

Study 11A NSW Acid Sulfate Manual Part 1.pdf	Acid Sulfate Soil Manual (Part 1)	New South Wales Acid Sulfate Soil Management Advisory Committee	2008	Comprehensive background information concerning ASS. Case studies do not include Lower Lakes.
Study 11B. NSW Acid Sulfate Manual Part 2.pdf	Acid Sulfate Soil Manual (Part 2)	New South Wales Acid Sulfate Soil Management Advisory Committee	2008	This part of the manual comprises separate guidance documents relating to Acid Sulfate Soils developed by ASSMAC (Acid Sulfate Soils Management Advisory Committee) including Groundwater Guidelines (1998), sampling techniques, laboratory analysis, and drainage guidelines.
Study 12.pdf	Numerical Assessment of Acid-Sulfate Soil Impact on the River Murray Lower Lakes During Water Level Decline	Centre for Water Research	2008	Prediction of ASS impact in Murray Lakes, 2008-2010. New acidity loading model in ELCOM-CAEDYM. Recommendations for management. Recommendations for water levels in Lake Albert be maintained above -1.0 mAHD to avoid significant effects of acidification.
Study 13-Aquaterra Peer Review.pdf	PEER REVIEW OF ACIDI FICAT ION THRESHOLDS FOR LAKE ALEXANDRINA AND LAKE ALBERT	Aquaterra Consulting	2008	Impartial technical peer review to provide independent advice to the Murray-Darling Basin Commission (MDBC) on the robustness of the identified acidification thresholds for Lakes Alexandrina and Albert ("the Lower Lakes"). Results presented in summary identifying limitations to studies within key elements. Documents/reports reviewed include some identified within this alternate options study.
Study 14 Reid ASS Discussion Paper.pdf	Plant-Based Strategies for Remediation of Acid Sulphate Soils Will they work?	School of Earth and Environmental Sciences, University of Adelaide	2009	Discussion paper on plant-based strategies for remediation of acid sulphate soils, with focus upon *P. australis*.

Study 15-Preliminary Assessment of ASS.pdf	Preliminary Assessment of Acid Sulfate Soil Materials in Currency Creek, Finniss River, Tookayerta Creek and Black Swamp region, South Australia	CSIRO	2009	Results of field investigations to assess the potential acidification risks and the extent of acid sulfate soils (ASS) in the lower reaches of Currency Creek and Finniss River, and at Tookayerta Creek and Black Swamp further upstream.
Study 16.pdf	Risk assessment of proposed management scenarios for Lake Alexandrina on the resident fish community	SARDI Aquatic Sciences	2009	Discussion of impacts upon fish within the lower lakes resulting from saltwater intrusion. Literature review of fish and life cycles within Lower Lakes, salinity models, findings of mitigating actions identified from a workshop. Additional document included within appendix: Literature review of the ecology of fishes of the Lower Lakes and Coorong and development of conceptual models for the risk assessment of proposed management options for the Lower Lakes, Bice (2008).
Study 17.pdf	Water Quality Screening Risk Assessment of Acid Sulfate Soil Impacts in the Lower Murray, SA	CSIRO	2008	The major objective of this project was to undertake a rapid screening level risk assessment to determine the potential impacts of ASS on aquatic ecosystems in the Lower River Murray below Lock 1 and Lakes Alexandrina and Albert. Water quality assessments presented in relation to SA Water river offtakes.
Study 18 Earth Systems Lake Albert.pdf	Draft: Preliminary management plan for acid sulphate soils in Lake Albert, South Australia	Earth Systems	2009	Preliminary management plan presenting an assessment of the acid sulphate soil strategies for Lake Albert, and a range of options to manage potential acidification. Four strategies are presented, which include semi quantitative assessments of risk, timeframes costs, and ease of implementation. A preferred option is discussed in detail, which includes a combination of options.

Appendix E – Assessment of the Drawdown Option

E – Drawdown Option

The Drawdown option was assessed via the review of studies relating to the option, both specific to the Lower Lakes and from the wider research community (i.e. published research). Any identified potentially significant issues were recorded in the option's issue table, following assessment via the Issue Decision Process. The issue table for the option is presented in Table E1 (below), with the considerations derived from the review being presented against each metric (E.1 to E.3).

Table E1 – Summary of Identified Issues and Potential Consequences – Drawdown Option

Issue	Parent Document	Summary	Consequence[4]	Comments	Potential Data Gap (Confidence)
1-1	DENR brief on Creeks water quality	Surface water	Review criterion partially met (observations)	Some surface water pH has been reported as low as pH 2 in isolated pools within Finniss / currency creek – is this symptomatic of system, is there a pathway to main water bodies? Sieching of water body would appear to be predominant risk here to acid soils – wind blown??	Potential (Finniss/ currency creek trend stated. No discussion of main water body or sieching)
1-2	Study 1	Oxidation of PASS	Review criterion partially met (reservations)	Drying and cracking of sediment is expected – may potentially increase and magnify PASS generation – seiching to amplify.	Potential (Not discussed)
1-3	Study 13	Acid generation	Review criterion partially met (observations)	If soils are completely dry then risk of oxidation is lower, although risk of sieching is still apparent	No (Not discussed in "Drawdown" option)
1-4	Study 16	Water (and Soil) salinity	Review criterion partially met	Increase in salinity of water via increased ET and lack of flushing. This may be apparent with and without	No (Not discussed in "Drawdown"

[4] Assessed with regards to Issue Decision Process.

			(observations)	weir action (Wellington).	option)
1-5	N/A	Return to freshwater status	Review criterion partially met (observations)	Relatively easy to return acid soil to status prior to oxidation although the sediment would potentially require localised neutralisation prior to input of 'natural freshwater via normal inflow from Murray'.	No (Pre neutralisation not discussed in any of the options)
1-6	Study 7	Acidity impacts upon fish	Review criterion partially met (observations)	Limited specific information of impacts on species found in Lake Albert to acidity	Yes (Fish species not discussed)
1-7	Study 7	Heavy metals in lower lakes	Review criterion partially met (observations)	Insufficient information regarding concentrations in lower lakes	Yes (Alton 2009 may have some information) (Not discussed)
1-8	Study 7	Drought/prolonged absence of water on fish species within Lake Albert (and Lower Lakes)	Review criterion partially met (reservations)	Commission a study to identify impacts upon fish should drying of system occur.	Yes (Not discussed)
1-9	Study 16	pH fatality fish impacts (<5, >10).	Review criterion partially met (reservations)	Drawdown approach resulting in acidic conditions below pH5 resulting in fish mortalities.	No (Not discussed)
1-10	N/A	Further decline in lake Albert levels leading to further acidity	Review criterion partially met (observations)	Likely further decline in lake levels leading to likely generation of acidity.	Scenario modelling of lake levels relative to climate and RM extraction (Not discussed)
1-11)	Study 12 as reviewed by Study	Uncertainty associated with acidification model, in terms of both its conceptualisation	Review criterion partially met (reservation)	Current version of acidification model considered by peer review (study 13) to be inadequate. Hence, it is uncertain how	Knowledge and data gaps currently being addressed in

	13	and its lack of calibration/validation		rapidly the Lower Lakes may acidify under the 'Drawdown' scenario.	alternative study (Stated)
1-12	Study 18 (Earth systems Lake Albert report)	Hydrology of Lake Bed sediments poorly understood, with simple (often uniform) representations in conceptual and numerical models of lower lake levels	Review criterion partially met (reservations)	As water levels decline, rate of oxidation and acid discharge will be dependent on hydrology of bed sediments – i.e. how quickly they drain, moisture content profiles, extinction depths, and oxygen diffusion rates. Spatial variability likely to be significant across the site	Hydraulic gradients, texture maps, permeability, transmissivity, ET, O_2 diffusion modelling (Not stated)
1-13	N/A	Further monitoring under this scenario will improve understanding of system and its response to changes in Lake Level	Review criterion partially met (reservation)	Oxidation rates, acid and metal flux rates and buffering capacity of system can be better understood	Potential (Discussed)
1-14	N/A	No provision of refuge habitat in Albert	Review criterion partially met (reservation)	Lakes will segregate under Drawdown option – i.e. there will be no pathway for fish to migrate	No (Not discussed under "Drawdown" scenario)

E.1 - Technically feasible and achievable in practice on the scale required

E.1.1 - Technically feasible (theoretically, will it work?)

A - Successful implementation of option is theoretically possible

Score: 'Probable' alignment with criteria, with a 'high' level of confidence in this score.
Justification: Theoretically, the 'Drawdown' option could be successful in mitigating the acidification of the Lower Lakes, assuming the following:

- that there was a sudden return to more normalised flow conditions;
- the generation of acidity was not as significant as forecast; or

- the buffering capacity of the system was such that any acidity generated could be naturally attenuated.

B– Theoretically viable on the scale (spatial) required

Score: 'Unlikely' alignment with the criteria, with a high level of confidence in this score.
Justification: Whilst the 'Drawdown' option may work on the local scale, increasing the spatial size will probably limit the effectiveness of this option. For instance, conditions in part of the system may be such that any acidity generated can be naturally attenuated, but due to the spatial variability in many environmental parameters, ideal conditions (i.e. effective inherent neutralisation capacity) are unlikely to occur across the entire system (based on the currently available information regarding heterogeneity of soils).

E.1.2 - Achievable in practice (has it been proven to work?)

A - Generic Proof of Concept established

Score: 'Probable' alignment with the criteria, with a medium level of confidence in this score.
Justification: In some cases, a 'Drawdown' approach has worked to treat environmental acidification. For instance, there are sites where acid discharge occurs (not necessarily from ASS), but natural processes are sufficient to treat the acidity generated (e.g. Sarmientoa et al., 2009; Ergas et al., 2006). It is possible that there are other cases where a 'Drawdown' option has worked, but they are not reported as no problem is evident.

B - Proof of Concept established in similar (representative) environments

Score: 'Unlikely' alignment with the criteria, with a moderate level of confidence in this score.
Justification: There is documented proof of some acid sulfate soils (in estuarine wetlands in Australia) having an inherently high Acid Neutralising Capacity, which exceeds their acid generation potential (McElnea et al. 2004). In such cases, a 'Drawdown' approach would be effective as there would be no net acid generation upon the oxidation and subsequent flushing of these sediments. However, most documented evidence throughout estuarine environments in Australia, suggests a 'Drawdown' approach to acid sulfate soils may result in subsequent acid generation and discharge.

C – Proof of concept established in Lower Lakes environments and environs

Score: 'No' alignment with the criteria, with a high level of confidence in this score.
Justification: There is no apparent proof of concept that indicates that doing nothing to manage acidification in the Lower Lakes and allowing lake levels to decline will not result in the generation of acidity. Indeed there is evidence to the contrary, with a significant generation of acidity already noted in the Finniss/Currency Creek region as water levels have declined (refer study 15).

E.1.3 - Implemented successfully before acidification of the Lakes occurs

A1 – on a large scale

Score: 'Unlikely' alignment with the criteria, with a low level of confidence in this score.
Justification: Current indications suggest the 'Drawdown' option will not be successful in treating the acidification from ASS (CSIRO, 2009). In addition, the 'Drawdown' option is currently the status quo, and increased evidence of acidification has been identified. Therefore it is unlikely that this option could be effective in terms of acidification mitigation prior to acidification of the system.

A2 – on a localised scale

Score: 'Unlikely' alignment with the criteria, with a moderate level of confidence in this score.
Justification: Current indications suggest the 'Drawdown' option will be unlikely to successfully treat the acidification from ASS (CSIRO, 2009). However, it is theoretically possible that the approach could work in some localised zones where conditions are conducive to minimal acidification (i.e. below predicted sulfuric content and / or presence of sufficient inherent buffering capacity).

E.2 - Costs to Government (State and Federal)

E.2.1 - Direct lifecycle costs (dollar costs directly apportioned to the entire lifecycle of the option.)

A - Capital / Establishment costs are minimal

Score: 'Yes' alignment with the criteria, with a high level of confidence in this score.
Justification: Assuming that the 'Drawdown' option is applied indefinitely, regardless of the effectiveness of the approach, then it is likely that its capital / establishment costs can be confidently predicted as minimal.

B – Operational / Maintenance costs are minimal

Score: 'Yes' - Maximum alignment with the criteria, with a high level of confidence in this score.
Justification: A 'Drawdown' approach will involve minimal operational and maintenance costs besides those costs required for environmental monitoring expenditure, which are applicable to other options regardless.

C – Decommissioning costs are minimal

Score: Maximum alignment with the criteria, with a high level of confidence in this score.
Justification: As no infrastructure or specific management plan is required, it is considered that the 'Drawdown' option would incur minimal decommissioning costs.

E.2.2 - Indirect or environmental costs & benefits (limited to impacts that Government may be liable for through the application of the option)

A - Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes region)

Score: 'Unlikely' alignment with the criteria, with a moderate level of confidence in this score.
Justification: Although the implementation of the option will involve no indirect costs to other environments in terms of environmental factors (i.e. the option has a relatively small carbon footprint and requires no raw materials – including water), there is a potential linked effect to other environments in terms of ecological contribution to other environments, should habitats be lost as a result of decreasing water levels and absence of specific management intervention. Accordingly, this criterion has been assessed as 'unlikely'.

B - Maximises the indirect benefits experienced in the wider Lower Lakes region (e.g. / tourism, agriculture, wine, lifestyle)

Score: 'No' – least alignment with the criteria, with a high level of confidence in this score.
Justification: It is difficult to identify where the implementation of this option might benefit the wider Lower Lakes region as whole. It is anticipated that some active management would be required in order to sustain indirect benefits.

E.3 - Adjustments

Preventative or Treatment: This option is regarded as a 'treatment' approach due to its non-preventative nature.
Risk of Negative Impacts: Even if it is assumed that the option is effective in treating the acidification of the Lower Lakes, there is a risk that the following adverse impacts could eventuate as a result of undertaking this option (See Issues 1-1 to 1-14 in Table I, Appendix E for further information):

- significantly lower lake levels (including a completely dry Lower Lakes environment);
- increased salinity due to a lack of flushing and evaporative concentration;
- dust generation and erosion of exposed lake beds;
- eutrophication as water levels recede; and
- anoxic conditions developing.

Therefore the option is regarded as having the following risk matrix inputs:

- **Likelihood:** Likely
- **Severity:** Dangerous

Resulting in an '**Extreme**' risk in terms of adverse impacts.

Additionally, the 'Drawdown' option does not remove the risk of pyrite oxidation and seiching of lake water over oxidised sediments (potentially the primary pathway for lake acidification) and / or rainfall events which may flush / export acidity and metals to the water bodies or discharge to the marine environment (Indraratna et al., 2002; Macdonald et al., 2007). The effect of sulfuric acid discharge to freshwater chemistry would be significantly detrimental to the environment (Russell and Helmke, 2002., Haraguchi, 2007). The 'extreme' risk rating reflects this consideration.

▪ Appendix F – Assessment of the Bioremediation Option

F – Bioremediation Option

The bioremediation option was assessed via the review of studies relating to the option, both specific to the Lower Lakes and from the wider research community (i.e. published research). Any identified potentially significant issues were recorded in the option's issue table, following assessment via the Issue Decision Process. The issue table for the option is presented in Table F1 (below), with the considerations derived from the review being presented against each metric (F.1 to F.3).

Table F1 – Summary of Issues and Consequence

Bioremediation Option

Issue	Parent Document	Summary	Consequence[5]	Comments	Potential Data Gap (Confidence)
2-1	Study 18	Applicability of subsurface micro-organisms	Review criterion met (observations)	Although sulphate reducing bacteria are very ubiquitous – the absolute presence and application of SrB in LL to the issue in hand has not been explicitly investigated.	Yes
2-2	Study 13	Mobilisation of acidity and metals from lake margins	Review criterion met (observations)	Bioremediation requires anoxic conditions – anoxic conditions achieved in subsurface (immediate depths) via mounding with groundwater – availability of groundwater or otherwise is unknown. Immediate and direct influx of water may flush acid into the water body. Pre-neutralisation may be required prior to sediment inundation.	Yes
2-3	Study 2	Mobilisation of acidity and metals from lake	Review criterion met	Bioremediation requires anoxic conditions – anoxic conditions achieved in	Potential gap relating to implementation

[5] Assessed with regards to Issue Decision Process.

		margins –acid spike	(observations)	subsurface (immediate depths) via mounding with groundwater – immediate application and drying out or migration of groundwater may cause localised WL variation and magnified oxidation – may require in-depth application of hot-spot mgt.	of option
2-4	Study 18	Resource - groundwater	Review criterion met (reservations)	Groundwater resource scarce and unlikely to supplement the lakes water budget, although may supply enough to inundate in terms of maintaining ASS saturation?	Potential
2-5	Study 18	Resource – groundwater	Review criterion met (reservations)	Ability to maintain groundwater supply once committed? Variation in inundation may lead to uncertainty in ASS management?	Potential
2-6	Study 18	Resource – volume required (as GW)	Review criterion met (reservations)	Unlikely that level maintenance waters could be sourced and applied. Inundation may work although infrastructure required and drawdown rates (see below) may be inhibitive.	Potential
2-7	Study 18	Resource – volume required (other)	Review criterion met (observations)	Unlikely that level maintenance waters could be sourced (e.g. Lake Bonney) that would meet or exceed required volume for lake level maintenance (e.g. circa 1GL required for Lake Albert alone – this target cannot be met).	Potential – relating to water availability
2-8	Study 18	Usage of Fe in bio-stimulation	Review criterion met (observations)	The use of Fe in this sediment system must be closely assessed and monitored – if Fe(III) is applied to a sediment with	No

				<pH 4.5 then oxidation of Fe(II) (and subsequent acid generation may occur) and so direct blanket application of Fe(III) without prior assessment may be detrimental.	
2-9	Study 18	Inhibition of Fe(II) oxidising bacteria	Review criterion met (observations)	Further application studies into co-inhibition may be useful to assess potential for limiting oxidation of pyrite by Fe(iii) during stimulation application.	Yes
2-10	Study 18	Conditions may not be suitable across the whole site	Review criterion met (observations)	Likely to be high spatial variability in environmental variables, which are key for sulphate reducing bacteria to work. Therefore, approach may work in places but not ubiquitously.	Potential – relating to implementation
2-11				Generally accepted that SRB oxidise products of fermentative bacteria such as lactate, fatty acids, alcohols, some aromatic acids, a few amino acids and hydrogen.	Not outlined in the above.

F.1 - Technically feasible and achievable in practice on the scale required

F.1.1 - Technically Feasible (theoretically, will it work?)

A - Successful implementation of option is theoretically possible.

Score: 'Yes' – maximum alignment with criteria, with a 'high' level of confidence in this score.
Justification: It is considered that theoretically, the 'bioremediation' option could be successful in mitigating the acidification of the Lower Lakes, with a number of successful studies undertaken in this field. Study 18 by Earth Sciences, provides supporting information with respect to the implementation of this option in the Lower Lakes environs (Appendix D).

The microbially mediated reduction of sulfate is a technique often employed in the rehabilitation of acid mine lakes and also in the treatment of acid mine drainage. The process can be limited by the availability of carbon, and thus treatment using this option requires the addition of organic matter. A wide variety of organic matter sources have been used to treat environmental acidity with various degrees of success (Neculita et al., 2007).

Equations 1 – 4 below outline the reactions of importance with respect to pyrite oxidation and reduction of sulfate (H_2SO_4 associated) to sulfide. The oxidation of pyrite can be represented as follows (1), note that the associated products with respect to pyrite oxidation are acidity, sulfate and ferric Fe.

- **$FeS_2 + 3.75O_2 + 3.5H_2O \rightarrow Fe(OH)_3 + 2SO_4^{2-} + 4H^+$ (1)**

Microbes maybe actively encouraged to alter the sulfate to sulfide, which has an associative effect of removing acidity (as H^+) from solution outlined as follows (shown here with H_2 as the donor):

- **$4H_2 + SO_4^{2-} + H^+ \rightarrow HS^- + 4H_2O$ (2)**

And can also generate alkalinity when considering the organic substrate required (CH_2O is used here to simplify organic matter):

- **$2CH_2O + SO_4^{2-} \rightarrow H_2S + 2HCO_3^-$ (3)**

The sulfide produced is then partitioned into the sediment as pyrite (FeS_2) or lesser iron mono-sulfides (FeS, e.g. mackinawite or greigite) which form much more rapidly than pyrite.

Sulfate is highly soluble and is delivered to the microbial community via groundwater flow or from dissolution of sulfate bearing minerals (e.g. $CaSO_4$). Sulfate may also be produced from the oxidation of sulfidic material or minerals (e.g. FeS, as described above). Note that this generally occurs where dewatering or exposure of previously anoxic sediment has occurred, and that for sulfate reduction to occur, these sediments (or more accurately, the pore water) must return to a suitably negative redox (i.e. reducing conditions).

Note that the transfer of electrons to sulfate, culminating in reduction to sulfide, theoretically occurs when all other Terminal Electron Acceptors (TEAs; such as nitrate, manganese, Fe(III)) have been exhausted, and results in an increased sulfide concentration in pore water (Konhauser et al., 2002).

Sulfate reducing bacteria (SRB) are a specialised group of anaerobes that are responsible for the dissimilatory reduction of sulfate to sulfide. They are important in the anaerobic degradation of organic matter in most aquatic habitats, where they are situated at the bottom of the anaerobic food chain. Following the process of reduction, SRB are also a major contributor to sulfide formation, which is highly reactive and geochemically important. Sulfide reaction with extra-cellular Fe (and concomitant formation of insoluble FeS) is a common detoxification mechanism for the microbes (O'Flaherty et al., 1998) while partitioning the sulfide into an insoluble form. With respect to electron donors, it is generally accepted that SRB oxidise products of fermentative bacteria such as lactate, fatty acids, alcohols, some aromatic acids, a few amino acids and hydrogen. The suite of substrates varies among microbial genera (Postgate, 1984; Skyring, 1987; Odom and Singleton, 1993; Wawer and Muyzer, 1995; and Minz et al., 1999).

The SRB are widely distributed in nature, and are regular components of both natural and engineered systems including, for example, petroleum reservoirs and oil production facilities. SRB are currently subject to extensive genomic studies, which are yielding new understanding of their basic biochemical mechanisms, and aiding in the development of novel techniques for the analyses of their environmental roles. Barton (1995) provides an in-depth review of the SRB in terms of taxonomy, physiology and ecology.

It is worth noting that certain genera of SRB can also reduce Fe(III) to Fe(II) prior to sulfate reduction (Coleman et al., 1993), which with respect to the bioremediation option, would increase the partition of sulfide as $FeS_{(s)}$, and may reduce the requirement for Fe addition.

B – Technically feasible on the scale required.

Score: 'Unlikely' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification: The area (whole system) that requires bioremediation will probably introduce a number of issues relating to optimising conditions suitable for bioremediation to occur (Study 18). Whilst such issues may technically be addressed, they introduce a further degree of complexity to this option, which is captured in our assessment by a significantly reduced alignment with the criteria and a corresponding lower confidence weighting.

A groundwater (or introduction of other water source) resource would be required in order to keep sediments saturated and incur sub-oxic conditions. The volumes of groundwater potentially required to achieve this are considerably lower than attempting to maintain levels within the entire lake system (using groundwater). However, additional engineering is required either using some form of irrigation system or another method to trap the water to prevent the soils from drying out. It is anticipated given the aquifer properties and groundwater quality, that in order to sustain an operation of this type for any significant period of time is likely to have significant impacts on the groundwater system that could be irreversible given that natural recharge is very low (SKM, 2009).

F.1.2 - Achievable in practice (Has it been proven to work?)

A - Generic Proof of Concept established

Score: 'Yes' alignment with the criteria, with a 'high' level of confidence in this score.
Justification: Actively managed bioremediation technologies have become well established methods in the treatment of contaminated land issues (Environment Agency, 1999), with numerous successful projects undertaken (e.g. see www.cl:aire.org.uk). The managed application of microbes to reduce sulfate as a preventative measure / treatment for acid sulfate soil has not yet been fully realised; however the occurrence of such processes in the natural environment are reasonably well documented. Several studies have identified the presence of SRB and active reduction of sulfate in saline and hyper-saline environments (Jakobsen et al., 2006; Foti et al., 2007 and Porter et al., 2007).

Sulfate reduction has been documented in meromictic lakes (Tonolla et al., 2004) and oligotrophic lakes (Bak and Pfennig, 1991). It is considered that where anaerobic conditions exist (e.g. sediments and appropriate lake depths), then sulfate reduction can occur.

B - Proof of Concept established in similar (representative) environments

Score: ''Probable' alignment with the criteria, with a moderate level of confidence in this score.
Justification: It is worth noting that SRB are ubiquitous in nature, and given the onset of the appropriate conditions, are expected to become prevalent in such environments similar to the Lower Lakes system. Previous research undertaken in a similar environment has indicated the possibility of sulfate reduction via microbial mediation (Wright, 1999). The extrapolation of this work to the Lower Lakes system or an environment representative of this system is achievable at a high level, although confidence in the proof of concept in the actual Lakes system cannot be currently absolutely maximised due to the lack of site specific information (see below). Previous research was undertaken in highly saline water bodies characterised by high pH and elevated concentrations of carbonate, which may not be the case for the Lakes proper (i.e. lower pH and low carbonate concentrations).

C – Proof of concept established in Lower Lakes environments and environs

Score: 'Probable' alignment with the criteria, with a moderate level of confidence in this score.
Justification: In the absence of a comprehensive desktop analysis, proof of concept in this technology applied in Lower Lakes circumstances is considered to be probable (taking into account the discussion presented above in base criteria B and C. However a potential data gap relating to the bioremediation potential within the Lower Lakes exists, due to the absence of information relating to the presence of suitable microbes (the SRB) available within the respective soil systems. In addition, there may also be other associative limitations in terms of in-situ carbon (organic substrate). Note that some species can utilise H_2 as an electron donor (Smith and Klug, 1981), although the capacity for this would need to be assessed.

As discussed above, another factor that may require consideration is the source water required for inundation (i.e. to achieve sub-oxic conditions). Assuming a groundwater source is preferred (note Earth Systems preliminary acid flux results indicate continuity between sediments and underlying Bridgewater Aquifer) then the yield available versus required will need careful consideration. The current understanding of the available groundwater yield in the majority of the Lower Lakes is that it is insufficient for supporting large scale bioremediation (SKM, 2009). However, the inundation of sediments with freshwater (i.e. via buy-backs and or environmental allocations would assist in creating sub-oxic environments in the same manner as using a groundwater source).

Note that it is possible that pre-neutralisation of the sediments would also be required in order to ensure optimum pH conditions for bioremediation (i.e. circum-neutral, although some species of microbes can function in extreme pH environments, e.g. acidophiles) assuming this option is implemented post oxidation of sediments.

F.1.3 - Implemented successfully before acidification of the Lakes occurs.

A1: On large scale

Score: 'Unlikely' alignment with the criteria, with a low level of confidence in this score.
Justification: Whilst the option is theoretically possible, the absence of proof of concept reduces the confidence attributed to its successful implementation for the entire Lower Lakes system. It is also possible that active management of groundwater levels would be required to ensure sufficient redox environments. This may not be achievable over a large scale. In addition, if neutralisation of sediments is required, the potential requirement for large scale neutralisation of the Lakes may decrease the feasibility of bioremediation as a practical and cost effective option.

A2: On a localised scale.

Score: 'Yes' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification: On a smaller scale, optimising the conditions to provide a suitable environment (namely elevated water table to encourage negative redox suitable for sulfate reduction to occur) would be more achievable, and thus this option lends itself to treatment of hotspots, rather than a blanket approach to the entire system. This is also true of the potential requirement for pre-neutralisation of sediments, which is significantly more achievable over a localised scale than a large scale approach.

This maximum alignment with the localised scale criteria is based on an assumed use of freshwater from sources other than groundwater, with respect to in-sufficient groundwater yields that would be required to inundate hotspots over the required period of time.

F.2 - Costs to Government (State and Federal)

F.2.1 - Direct lifecycle costs (dollar costs directly apportioned to the entire lifecycle of the option.)

A - Capital / Establishment costs are minimal

Score: 'Unlikely' alignment with the criteria, with a high level of confidence in this score.
Justification: This option is likely to be a reactive approach, in respect to optimising conditions over a large scale, suitable for bioremediation – the strength of this option is likely to be associated with small scale / localised implementation in and around 'hotspots'. As such, this prevents an accurate costing profile to be identified (large vs. small scale), with only minimal assumptions possible regarding infrastructure. However, it is considered that a significant level of infrastructure would be required (e.g. bores, well permits / licenses, pumps, distribution networks and possibly telemetry / monitoring systems). This would therefore result in some capital costs being required.

B – Operational / Maintenance costs are minimal

Score: 'Probable' alignment with the criteria, with a low level of confidence in this score.
Justification: Knowledge gaps (as discussed above) reduce the confidence attributed to this score, relating to capital expenditure. This includes unknown costs relating to optimising conditions (e.g. pumps and pipelines for inundation). Relocation of pumps may also be required to address changes in system as this is a reactive approach. The absence of detailed cost estimates introduces a significant data gap into the assessment of this option. However, in terms of orders of magnitude, this option's acceptance is considered probable. A moderate confidence has been attributed due to the large scales involved in successfully implementing this option.

C – Decommissioning costs are minimal

Score: 'Probable' alignment with the criteria, with a high level of confidence in this score.
Justification: Based on the assessment undertaken in A and B of this criterion, it is evident that some infrastructure would be required in order to achieve appropriate conditions for bioremediation. The decommissioning costs identified (based on the limited information associated with commissioning) are associated with removal of pumps and distribution network, noting that the pumps may well have a resale value. Therefore the costs have been awarded a probable alignment.

F.2.2 - Indirect or environmental costs & benefits (limited to impacts that Government may be liable for through the application of the option)

A - Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes region)

Score: 'Probable' – moderate alignment with the criteria, with a moderate level of confidence in this score.
Justification: No significant impacts upon environments external to the Lower Lakes environment have been identified, with the exception of increasing water table drawdown due to over extraction for inundation purposes. However, it is considered that if sufficient information is obtained concerning the localised and regional hydrogeology, that the drawdown can be managed in a sustainable manner.

B - Maximises the indirect benefits experienced in the wider Lower Lakes Region (e.g. tourism, agriculture, wine, lifestyle)

Score: 'Probable' – moderate alignment with the criteria, with a moderate level of confidence in this score.
Justification: It is considered that the successful implementation of this option would have some indirect benefits (i.e. primarily the maintenance of a steady state system), with the contribution of the groundwater resource potentially adding to the lake volume in certain locations, which could be

actively managed to increase ecological and associated benefits. No significant impacts upon environments external to the Lower Lakes environment have been identified.

F.3 - Adjustments

Preventative or Treatment: This option is regarded as a ‘treatment’ approach, based on the fact that it actively targets sulfate for reduction to sulfide (i.e. the oxidation of sulfide has already occurred and therefore the action is not preventative). However, the inundation of sediments with groundwater with a view to encouraging bioremediation may act as a preventative measure in some locations, depending on site specific pyrite oxidation rates.

Risk of Negative Impacts: The reduction and partition of sulfate as a mono-sulfide is dependent on maintaining suitable redox conditions, which would likely be managed by water level. If redox conditions cannot be maintained, then re-generation of acid may become likely, with flushing via rainfall / seiching becoming increasingly likely (Macdonald et al., 2007). The application of Fe in order to encourage partition of sulfide as FeS may initially cause increased oxidation of pyrite if applied incorrectly to sediments with a pH <3.5. Initial neutralisation may be required.

The addition of too much mulch (if chosen as the source of organic matter) could lead to anoxia in the water column which in turn can lead to adverse environmental outcomes (Baldwin et al., 2001). The nutrient content of the organic matter source should also be considered so as to avoid the significant release of nutrients to the water column under low oxygen conditions (Baldwin and Mitchell, 2000). However, the likelihood of over addition of such material with development of widespread anoxia and further eutrophication of the water column is not expected to be significant.

Therefore the option is regarded as having the following risk matrix inputs:

- **Likelihood:** Possible
- **Severity:** Slight

Resulting in a ‘**Moderate**’ risk in terms of adverse impacts.

Appendix G - Assessment of the Vegetation Option

G - Vegetation Option

The vegetation option was assessed via the review of studies relating to the option, both specific to the Lower Lakes and from the wider research community (i.e. published research). Any identified potentially significant issues were recorded in the option's issue table, following assessment via the Issue Decision Process. The issue table for the option is presented in Table G1 (below), with the considerations derived from the review being presented against each metric (G.1 to G.3).

Table G1 – Summary of Issues and Consequence

Vegetation Option

Issue	Parent Document	Summary	Consequence[6]	Comments	Potential Data Gap (confidence)
3-1F	Study 14 (Reid)	Window of opportunity for plant colonisation	Review criterion partially met (observations)	Window of opportunity for plant colonisation as solubilisation of Aluminium is considered likely to occur at <pH 4.5. This window is dependant on oxidation rates, which may be estimated from system modelling although would be difficult to determine in situ (time and expense?) unless field monitoring for pH was undertaken to determine the pH prior to seeding – i.e. <ph 4.5 may exclude seeding.	No
3-2F	Study 14 and 6	Boundary around pH 4.5	Review criterion partially met (observations)	Potential boundary (margin) around pH 4.5 for aluminium toxicity i.e. what is colonisation time of chosen species (species depth) and can growth and colonisation occur over a time that would arrest decrease in pH. Prior neutralisation of acidity may	Potential – risks need to be captured in implementation study (building upon Study 6)

[6] Assessed with regards to Issue Decision Process.

				be required.	
3-3F	- Study 14 and 6	Colonisation time management	Review criterion partially met (observations)	Can colonisation time be actively managed?	Potential (see above: 3-2)
3-4F	- Study 14 and 6	Evapo-transpiration	Review criterion partially met (observations)	Role of evapo-transpiration requires better understanding with respect to large scale application of biomass, especially over summer months. Current DENR trials may provide more insight into this if they run over summer.	Potential
3-5F	- Study 14 and 6	Biomass and ET	Review criterion partially met (reservations)	The mass of biomass may increase ET and lower water table while still regulating some portion of soil moisture which may increase ASS oxidation. This may occur as drawdown the water table which is recharged via rainfall (cyclical action) which may exacerbate oxidation.	Potential (some discussion in Study 14)
3-6F	N/A	Biomass and adjacent soil	Review criterion partially met (observations)	Not clear what role the biomass may have on adjacent (horizontal) water levels and may induce a certain level of cracking in adjacent soils which may then increase further oxidation.	Potential
3-7F	Study 14 Pg 6	Role of dead / decaying biomass	Review criterion partially met (reservations)	Not clear as to the role that the increase in dead / decaying biomass may have – it may be possible that the biomass may increase anoxic conditions directly beneath and increase MBO production (See study 2).	Potential

3-8F	Study 14 Pg 6	Rampant colonisation	Non significant issue	The chosen species may be invasive	No (Study 6 identifies weed management requirements)
3-9F	Study 14 Pg 6	Soil Type	Review criterion partially met (observations)	Success of chosen / selected species may be associated with the soil type so that any particular species may not be suitable for a site wide application.	Potential (basic soil mapping undertaken in Study 6)
3-10F	Study 14 Pg 6	Water level fluctuation	Review criterion partially met (reservations)	Water level fluctuation is a variable that may influence uncertain biomass colonisation success.	Potential
3-11F	Study 14 Pg 6	Salinity	Review criterion partially met (reservations)	Soil salinity increases may disrupt biomass growth / colonisation success	Yes – identify salinity tolerances of selected plants (building on Study 6)
3-12F	Study 14 Pg 6	Theoretical evidence	Review criterion partially met (reservations)	No apparent theoretical evidence for application of plant species in acid soil management.	Yes. Definitive results of trial required.
3-13F	Study 14 Pg 7	Bacterial optimum pH	Review criterion partially met (observations)	Optimum ph for *T ferrooxidans* may be higher at around 3.5 – implications for application of plant remediation	No
3-14F	Study 14 Pg 9	Experimental data – soil pH	Review criterion partially met (observations)	Soil pH in the experiment is not related to root presence – i.e. no uptake of oxygen (see figure 1, sample S1) and pH as S2 (low / no vegetation) generally higher than S1 (good stand of grass).	No
3-15F	Study 14 Pg 9	Experimental data – replication	Review criterion partially met (reservations)	No replication / duplicate / triplicate on experimental data	Yes. Definitive results of trial required, as a minimum.)

3-16F	Study 14 Pg 10	Experimental data – heavy metals	Review criterion partially met (reservations)	Aluminium not assessed – key pH sensitive metal – toxicity would be a key factor here.	Yes
3-17F	Study 14 Pg 11	Soil type and pH	Review criterion partially met (reservations)	Sandy soil is generally more acidic (ASS) as it has little buffering capacity compared to clay soils - therefore plant and pH results could be skewed by soil type rather that plant performance.	Yes
3-18F	Study 14 Pg 11	Plants vs no plants	Review criterion partially met (reservations)	No significant difference in surface soil pH between plants versus no plants	Potential
3-19F	Study 14 Pg 11	Relationship to moisture content	Review criterion partially met (observations)	The role of plant roots on soil moisture content is unclear	Yes
3-20	-Study 6	Implementation of planting	Review criterion partially met (reservations)	Limited discussion of complexities associated with establishing vegetation on a large scale, ie, no consideration for falling and rising water levels or periodic inundation where establishing plants will be difficult. This may not be a significant issue as water levels likely well away from lake edges already where plantings proposed	Yes/possible (Further information available from the DENR trials)
3-21	Study 6	Number of study sites	Review criterion partially met (observations)	800 study sites visited (very brief assessment)	No
3-22	Study 6	Weed control	Review criterion partially met (reservations)	General absence of discussion and reasoning	Yes
3-23	Study 6	Planting implementation	Review criterion partially met (observations)	Unclear if organisations recommended to undertake planting have given support/approval in	Potential

				timeframes required	
3-24	Study 6	Planting implementation	Review criterion partially met (observations)	Absence of detailed timeframes	Yes
3-25	Study 6	Addition of iron to system	Review criterion partially met (observations)	Science behind this reasoning unclear	Potential
3-26	Study 14 and Study 6	Confidence associated with success of re-vegetation to maintain soil moisture and reduce soil acidification	Review criterion partially met (observations)	Statement made that the approach is "likely" to be successful. Poor confidence associated with this statement and lack of evidence to support this assumption.	Yes.
3-27	Study 6	Limited/no discussion of risk	Review criterion partially met (reservations)	Absence of discussion regarding potential risks, (such as weed establishment, impacts following re-flooding of system etc). Only mentions water draw down in brief.	Potential (Risks discussed in Study 14)
3-28	Study 6	Weed control	Review criterion partially met (observations)	Lack of specific information regarding techniques, timings	Potential
3-29	Study 6	Extent of re-vegetation	Review criterion partially met (observations)	Study identifies plan to solely re-vegetate borders of the lake (possibly where hot spots occur), not whole system	Potential
3-30	Study 6	Implementation (timing of planting)	Review criterion partially met (observations)	No timeframes proposed or discussed for planting	Yes (DENR trials may provide further information)
3-31	Study 6	Implementation of planting	Review criterion partially met (reservations)	Logistics of planting in timeframes required appear unlikely.	Potential
3-32	Study 6	Scientific rigour associated with	Review criterion partially met	Relative lack of scientific justification for approach,	Potential

		Study 6	(reservations)	including a lack of references in main body of document.	
3-33	Study 6	Water balance model	Review criterion partially met (observations)	Water balance model recommended in study in relation to water consumption of proposed large scale planting	Yes (water balance model for the system incorporating planting approach required)
3-34	Study 6	Species selection and locations	Review criterion partially met (observations)	Limited information restricted to broad areas. May need further clarification and mapping	Yes/Potential
3-35	Study 6	Implementation (sourcing plant materials)	Review criterion partially met (observations)	Unclear if plant seed and tube stocks can be sourced in timeframes required.	Yes/Potential
3-36	Study 14	Risk of acidification inhibiting plant growth	Review criterion partially met (observations)	No plant specific assessment – Need for specific acidic tolerances for proposed plant species	Yes
3-37	Study 14	Risk identified relating to practicalities of planting	Review criterion partially met (reservations)	Small window present where plants can establish following partial drying, yet prior to acidification process occurs.	Yes – in relation to a detailed specific planting schedule needs to be developed in line with current predictions
3-38	Study 14	Implementation of planting	Review criterion partially met (observations)	Risk of ability to establish plants in different soil types present within Lower Lakes. Need to identify specific soil requirements for proposed plant species in relation to Lower Lakes.	Yes/Potential (building upon Study 6)
3-39	Study 14	Implementation of planting	Review criterion partially met	Risk of plants to establish and survive in fluctuating	Yes – identify water requirements

			(reservations)	water levels	and inundation ranges for plant species
3-40	Study 14	In relation to flooding the system and existing stands of *P. australis*.	Review criterion partially met (reservations)	Risk of saltwater inundation of *P. australis* and production of Monosidic black ooze	Yes
3-41	Study 14	Implementation of planting	Review criterion partially met (observations)	Limited evidence that plants can reduce acidity in their own right	Yes
3-42	Study 14	Data Gap	Review criterion partially met (observations)	pH profiles of ASS for established plants	Yes
3-43	Study 14	Data Gap	Review criterion partially met (observations)	pH requirements and tolerances for plant species proposed for lower lakes re-vegetation	Yes
3-44	N/A	Water Balance model	Review criterion partially met (reservations)	Plants will lower soil oxygen diffusion rates and dampen variability in soil moisture contents, but trade-off is higher ET to potentially lower the watertable. Not clear yet as to whether plants will improve or exacerbate acid generation	Yes – Water balance model required for Lake Albert under this option

G.1 -Technically feasible and achievable in practice on the scale required

G.1.1 - Technically feasible (theoretically, will it work?)

A - Successful implementation of option is theoretically possible.

Score: ‘Unlikely’ alignment with criteria, with a ‘moderate’ level of confidence in this score. **Justification:** Theoretically, the ‘vegetation’ option could be successful in mitigating the acidification of the Lower Lakes, as discussed in Study 14 (Appendix D). As these studies have not been subjected to scientific rigour, a ‘moderate’ confidence has been allocated to this score.

A variation on the theme of the use of vegetation in such an environment as a management option is the use of aerobic wetlands, which are one of the most commonly used passive treatment techniques for acid soils (where disturbed through anthropogenic activities) and acid mine drainage. They are simple to construct and can be used to develop public amenities and wildlife sanctuaries in areas where soil and water have become acidified. They consist of a large area of reeds (often *Typha* or *Phragmites* species are used) planted in an organic-rich substrate. Their role is to provide sufficient oxygen and residence time to allow iron and some other metals to be precipitated as oxyhydroxides. These systems are most effective for water that has high iron content but a low acidity. Often, drainage is first passed through settling ponds to precipitate some iron before discharge to aerobic wetlands to ensure that the wetland is not rapidly smothered with precipitates. Reeds and sludge have to be periodically harvested from aerobic wetlands to maintain their effectiveness.

Compost wetlands have also been used to treat acidic drainage, and differ from aerobic wetlands in having very thick (> 30 cm) substrates of various forms of organic matter. The substrate encourages bacterial activity which reduces sulfate to sulfide, generating alkalinity in the process. This process is more akin to bioremediation than the actual vegetation undertaking neutralisation of acidity. Additional alkalinity can be generated by mixing crushed limestone with the organic substrate. Iron and some other metals are removed from solution by the formation of insoluble sulfide minerals within the organic matter. Aluminium accumulates as a precipitate of aluminium hydroxide on the top of the compost material.

The organic sludge in the wetlands has to be periodically removed to maintain the effectiveness of the system. As the material accumulates sulfide minerals, it needs to be handled and treated as ASS.

It should be noted however that wetlands as described above are generally used to treat drainage as a flow through process and not as a management option for large scale management of acidic sediments.

B– Technically feasible on the scale required.

Score: 'Unlikely' alignment with the criteria, with a 'high' level of confidence in this score.
Justification: Significant knowledge gaps have been identified in relation to the success of vegetation techniques within a similar environment to the Lower Lakes (Study 14). There may be an apparent window of opportunity for plant colonisation as solubilisation of aluminium is considered likely to occur at <pH 4.5. This window is dependent on oxidation rates, which may be estimated from system modelling although this would be difficult to determine in situ unless field monitoring for pH was undertaken to determine the pH prior to seeding – i.e. <pH 4.5 may exclude seeding.

In addition, the role of evapo-transpiration (ET) requires better understanding with respect to large scale application of biomass, especially over summer months. Current trials by the Department for Environment and Natural Resources (DENR) may provide more insight into this if they run over summer. The mass of biomass may increase ET and lower the water table while still regulating some portion of soil moisture which may increase ASS oxidation. This may occur as drawdown of the water table which is recharged via rainfall (cyclical action) which may exacerbate oxidation.

G.1.2 - Achievable in practice (has it been proven to work?)

A - Generic Proof of Concept established

Score: 'No' alignment with the criteria based on the assumption that the plants themselves are not the agent, but rather the accompanying substrate (i.e. bioremediation).
Justification: Study 14 (Appendix D) discusses the generic proof of concept for this technology (plant uptake of acidity), however, there is no apparent theoretical evidence for direct application of plant species in acid soil management.

A proof of concept for the use of compost wetlands (i.e. organic substrate) has been shown to have potential for the reduction of sulfate to sulfide (Piramid, 2003).

B - Proof of Concept established in similar (representative) environments

Score: 'No' alignment with the criteria.
Justification: A number of data gaps have been identified to clarify this assumption, which is consistent with the literature review undertaken as a component of Study 14. However, Johnston et al., (2005b) report that the type of vegetation used can have large differences in the quality and lability of carbon, which strongly influenced decay/redox processes and the chemical composition of surface waters. Grass species had more labile carbon. Sites with grass stands had surface waters which displayed rapid sustained O_2 depletion and sustained low redox potential (Eh, ~0 mV), high dissolved organic carbon (DOC), and moderate pH (5-6). Their soil acidity was partially neutralised, sulfides were re-formed, and reductive dissolution of Fe(III) led to the generation of stored acidity in the water column as $Fe^{2+(}$aq). In contrast, sites which had *M. quinquenervia* litter was high in decay-resistant compounds. Its surface waters had lower DOC and low pH (<4) and only underwent a short period of low O_2/Eh. Soluble Al caused *M. quinquenervia* surface waters to have higher titratable acidity (assumed to be as a reflection of total acidity) and soil pH remained consistently low (~3.8-4.0). Concentrations of Cl^- and Al in surface waters appeared to be strongly correlated to initial soil contents, whereas the behaviour of Fe and SO_4^{2-} varied according to pH and redox status. This demonstrates that changes in vegetation communities in ASS environments that substantially alter either: (a) the pool of labile vegetative organic carbon; or (b) the concentration of acidic solutes in surface soil can have profound implications for the chemical characteristics of surface waters.

C – Proof of concept established in Lower Lakes environments and environs

Score: 'No' alignment with the criteria.
Justification: A number of data gaps have been identified to clarify this assumption, which is consistent with the literature review undertaken as a component of Study 14. However, it is

acknowledged that more focussed studies are underway and thus this score should be revisited after review of these studies.

G.1.3 - Implemented successfully before acidification of the Lakes occurs

A1: On a large scale

Score: 'Unlikely' alignment with the criteria, with a high level of confidence in this score.
Justification: Whilst the option is theoretically possible, the absence of proof of concept reduces the confidence attributed to its successful implementation for the entire Lower Lakes system. A number of risks have also been identified in Study 14 relating to practicalities of establishing vegetation in ASS and PASS on a large scale. It is noted that the results of Lower Lakes vegetation trials are not available at this time.

A2: On a localised scale

Score: 'Probable' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification: On a smaller scale, vegetation is likely to reduce acidification of the Lower Lakes, as discussed in Study 14. However, the absence of a proof of concept reduces the confidence attributed to its success.

G.2 - Costs to Government (State and Federal)

G.2.1 - Direct lifecycle costs (dollar costs directly apportioned to the entire lifecycle of the option.)

A - Capital / Establishment costs are minimal

Score: 'Yes' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification: Study 6 presents cost estimates associated with vegetation and associated preparatory and management works required for Lake Alexandrina and Lake Albert.

B – Operational / Maintenance costs are minimal

Score: 'Probable' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification: Study 6 presents costs associated with vegetation and associated preparatory and management works required for the Lower Lakes. As risks are associated with successful establishment of vegetation on the scale required within PASS and ASS environments (as detailed in Study 14), re-seeding may be required. Therefore, a moderate confidence has been attributed to this score. Managing water levels over a 5-10 year period may also introduce risks associated with establishing and maintaining vegetation within the entire Lower Lakes environment.

C – Decommissioning costs are minimal

Score: 'Yes' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification: It is considered likely that decommissioning costs would be minimal for this option.

G.2.2 - Indirect or environmental costs & benefits (limited to impacts that Government may be liable for through the application of the option)

A - Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes region)

Score: 'Yes' alignment with the criteria, with a high level of confidence in this score.
Justification: No significant impacts upon environments external to the Lower Lakes environment have been identified.

B - Maximises the indirect benefits experienced in the wider Lower Lakes region (e.g. tourism, agriculture, wine, lifestyle)

Score: 'Probable' alignment with the criteria, with a moderate level of confidence in this score.
Justification: It is considered possible that the application of this option would have some benefit to the wider Lakes region in terms of increasing amenity value, although these benefits may not be passed on to all stakeholders in the region (i.e. water extraction will still be poor).

G. 3 - Adjustments

Preventative or Treatment: Option is regarded as a 'preventative' approach.
Negative Impacts: Moderate impacts have been identified for this option. These relate to:

- loss of freshwater environment and associated flora and fauna impacts and significant species loss;
- salinisation of lake basin as water levels recede;
- potential for eutrophication to occur as water levels recede;
- ecological disturbance impacts during installation of infrastructure and ongoing management and monitoring; and
- Potential disturbance of PASS and ASS environments which may create acidification issues.

Therefore the option is regarded as having the following risk matrix inputs:

- **Likelihood:** Unlikely
- **Severity:** Slight

Resulting in a '**LOW**' risk in terms of adverse impacts.

Appendix H - Assessment of the Neutralisation Option

H - Neutralisation Option

The neutralisation option was assessed via the review of studies relating to the option, both specific to the Lower Lakes and from the wider research community (i.e. published research). Any identified potentially significant issues were recorded in the option's issue table, following assessment via the Issue Decision Process. The issue table for the option is presented in Table H1 (below), with the considerations derived from the review being presented against each metric (H.1 to H.3).

Table H1 - Summary of Issues and Consequence

Neutralisation Option

Issue	Parent Document	Summary	Consequence[7]	Comments	Potential Data Gap (Confidence)
4-1	Study 9	Cannot be applied effectively everywhere	Review Criterion Partially Met (Reservations)	Parts of the Lake system may be inaccessible or require too much disturbance	Yes – Relating to implementation of this option
4-2	Study 9	De-oxygenation issues	Review Criterion Partially Met (Observations)	May not be able to treat problems associated with de-oxygenation?	Yes/Potential
4-3		Volumes required for whole systems treatment?	Increase costs	Data gaps for actual costs for long term operation	Yes
4-4		Availability of neutralising agent	Although costs could not be an issue – what is the availability of raw materials in the area? May have negative feedback loops for : • Sustainability • Costs • Reaction time (i.e. time taken	Assumptions required for availability but will have to reflect in indirect stream or in practicality assessment?	Yes/Potential

[7] Assessed with regards to Issue Decision Process.

			for management to be applied)		
4-5		Flora impacts?	Impacts to system from dosing.	Review external literature? no long term system data available	Yes/Potential
4-6		Fauna impacts?	Impacts to system from dosing.	Review external literature? no long term system data available	Yes/Potential

H.1 - Technically feasible and achievable in practice on the scale required

H.1.1 - Technically feasible (theoretically, will it work?)

A – Successful implementation of option is theoretically possible.

Score: 'Yes' alignment with criteria, with a 'high' level of confidence in this score.
Justification: Theoretically, the 'neutralisation' option could be successful in mitigating the acidification of the Lower Lakes, as discussed in Study 9, with a number of neutralisation schemes undertaken, including successful limestone addition in acidic lakes within Northern Europe (Anderson, 2006). On a global basis, treatment of acid soils using limestone technology appears to have yielded promising results (Green et al., 2008a; Green et al., 2008b).

B– Technically feasible on the scale required.

Score: 'Yes' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification: Some knowledge gaps exist when treating a large area, such as ability to treat deep acidification within the soil profile (also, there are no known documents that report mass neutralisation across the area in question). This has been captured by a moderate confidence score.

Previous research has indicated that a firm understanding of both water and sediment chemistry is vital to treatment (Young et al., 1986).

H.1.2 - Achievable in practice (has it been proven to work?)

A – Generic Proof of Concept established

Score: 'Yes' alignment with the criteria, with a 'high' level of confidence in this score.
Justification: Study 9 identifies a number of successful cases where neutralisation has been implemented. Green et al., (2008a) and Green et al., (2008b) provide some interesting reports on investigations into practical application, one of these being the use of a closed tank reactor (CTR, Green et al., 2008b) which although increased solution pH and reduced metal loading, was considered to present operational problems due to accumulation of aluminium inside the CTR. This would not really affect the Lower Lakes treatment scenario as it is unlikely that reactor based treatment would be utilised, but such tank reactor technology may be limited in application to many coastal acid sulfate soil systems. However, the example of neutralisation (generic) exists.

B – Proof of Concept established in similar (representative) environments

Score: 'Yes' alignment with the criteria, with a 'high' level of confidence in this score.
Justification: Study 9 identifies a number of successful cases where neutralisation has been implemented. However, fine limestone slurry was found to remove acidity to varying degrees of effectiveness (from 12 to 100%) in trials at Clothiers Creek, NSW (Green et al., 2006). The efficiency decreased as the pH of the water approached neutrality due to calcite saturation and the slow reaction rate of limestone at high pH. Hydrated lime powder was also mixed with drain water in a rotating drum though most mixing occurred once the slurry entered the drain where efficiencies ranging from 67 to 89% were observed. A powdered mixture of $MgCO_3$ and $CaCO_3$ was only 11% effective in treatment of drainage water due to the slow rate of reaction of $MgCO_3$.

Investigations into open limestone channels have indicated that the accumulation of sediment over the limestone, preventing contact of limestone with acidic water, was the greatest problem impacting the treatment in its first year of operation. Removal of metals from the water was due to the increase in pH produced by limestone dissolution in addition to sorption reactions of the existing coating which had natural microbial activity (Green et al., 2008a). It is considered that such an operation (i.e. channel treatment) would be unlikely within the Lakes setting, although the study demonstrates that at a geochemical level, the neutralisation and water quality adjustment can be achieved.

C – Proof of concept established in Lower Lakes environments and environs

Score: 'Probable' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification: Neutralisation trials have been conducted within the tributaries of the Lower Lakes using limestone addition to neutralise acid soils. This was undertaken over several months and comprised the following:

- Limestone addition in the form of three temporary barriers in mid and lower Currency Creek;

- Application of limestone slurry to dose pooled acidic water in Currency Creek; and
- Aerial dispersal of limestone via aircraft between Currency Hill and Currency Creek.

Water monitoring of the tributaries following addition of limestone was considered to have addressed much of the acid formed, and the majority of the tributaries have a pH within a suitable range, with the exception of one or two area that remain a high risk (DENR, 2009b).

Whilst preliminary results suggest a positive outcome, the definitive results are currently not available and, as such, a lower score has been attributed to this criterion.

H.1.3 - Implemented successfully before acidification of the Lakes occurs.

A1: On large scale

Score: 'Probable' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification: Potential complexities identified for neutralisation to be successfully implemented on a large scale and the general reactive nature of this technology to achieve a suitable pH. Data gaps exist in relation to sourcing of sufficient quantities of material to neutralise the entire Lake Albert environment. For example, whilst active treatment systems have been noted to be capable of treating a large acidity flux (particularly using hydrated lime) the treatment system may require regular addition of reagent and the dosing of hydrated lime may be particularly difficult to control (Green et al., 2006), in addition to the logistical difficulties associated with such an application. Treatment should be closely managed to prevent adverse aquatic impacts due to overdosing. However, trials of distribution via aircraft indicate that large scale application of this technique may be applicable to large areas.

A2: On a localised scale.

Score: 'Yes' alignment with the criteria, with a ''high' level of confidence in this score.
Justification: As discussed in Study 9 and through a number of examples where neutralisation has been successfully implemented, a high degree of certainty has been attributed that this option can successfully be implemented on a localised scale. It is considered that small scale localised dosing is much more operationally manageable.

H.2 - Costs to Government (State and Federal)

H.2.1 - Direct lifecycle costs (dollar costs directly apportioned to the entire lifecycle of the option.)

A - Capital / Establishment costs are minimal

Score: 'Unlikely' alignment with the criteria, with a 'high' level of confidence in this score.
Justification: A number of data gaps exist in relation to actual costs of implementing this option.

There is a need to commission a study to estimate costs associated with the 'neutralisation' option for Lake Albert (and the Lower Lakes environment) to clarify this score.

Aglime is the cheapest neutralising agent and is generally not harmful to plants, livestock, humans and most aquatic species. The limitation of its application is its insolubility in water, although it is more soluble in strongly acid water. Using aglime to increase the pH of water can be slow and costly.

B – Operational / Maintenance costs are minimal

Score: 'Probable' alignment with the criteria, with a 'low' level of confidence in this score.
Justification: A number of data gaps exist in relation to actual costs of maintaining this option, or the requirement for maintaining the option i.e. is follow-up work required over time after initial treatment? This component could be assessed more accurately following spatial heterogeneity investigation results. Also, the additional costs such as agency project management would need to be factored into the costings.

C – Decommissioning costs are minimal

Score: 'Probable' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification: It is considered probable that decommissioning costs may be minimal. However, it is worth noting that some infrastructure may be recommended depending on the delivery process. Earth Systems have previously suggested that slurry could be added to the water, via select process points. This infrastructure would require decommissioning.

Indirect or environmental costs & benefits (limited to impacts that Government may be liable for through the application of the option)

A - Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes region)

Score: 'No' alignment with the criteria.
Justification: Obtaining sufficient neutralising agents to successfully implement this option on the scale required for Lake Albert is likely to result in impacts external the Lower Lakes environment. An example includes the need to quarry and transport sufficient limestone material (reuse of non-renewable resource) and the carbon footprint associated with transportation and processing of neutralisation agent into the system. Some data gaps exist in relation to sources and required quantities of neutralising agents, which has been captured by a moderate confidence weighting to this score.

B - Maximises the indirect benefits experienced in the wider Lower Lakes region (e.g. tourism, agriculture, wine, lifestyle)

Score: 'Unlikely' alignment with the criteria, with moderate confidence.
Justification: It is considered unlikely that this option would benefit the wider region on an indirect basis, and is not considered likely to improve amenity value or resource value of the system.

H.3 - Adjustments

Preventative or Treatment: this option is regarded as a 'treatment' approach.
Risk of Negative Impacts: Data gaps have been identified relating to a full identification of the potential impacts associated with the addition of large volumes of limestone to an environment. However, the following impacts are likely to occur with an unknown extent of severity:

- Flora impacts associated with addition of large volumes of neutralising agents, including smothering inhibition of photosynthesis; and
- Fauna impacts, primarily aquatic species, associated with addition of large volumes of neutralising agents, including increased turbidity and associated impacts to fish and invertebrate populations.

Additionally, the following impacts would be anticipated:

- loss of freshwater environment and associated flora and fauna impacts and significant species loss;
- salinisation of lake basin as water levels recede;
- potential for eutrophication to occur as water levels recede; and
- ecological disturbance impacts during neutralisation material addition and ongoing management and monitoring.

Note that Study 9 (Appendix D) provides an in-depth review of potential impacts to the environment from liming and indicates that overall, the impacts are predominately positive, given the alternatives, although the study also states that further knowledge in this area is required with respect to the Lakes systems.

Therefore the option is regarded as having the following risk matrix inputs:

- **Likelihood:** Possible
- **Severity:** Moderate

Resulting in a '**HIGH**' risk in terms of adverse impacts.

Appendix I - Assessment of the Freshwater (buy-backs) Option

I - Option: Provision of Freshwater Flows (via buy-backs)

The use of freshwater to inundate sediments as an alternative option to the proposed action was assessed via the review of studies relating to the option, both specific to the Lower Lakes and from the wider research community (i.e. published research). Any identified potentially significant issues were recorded in the option's issue table, following assessment via the Issue Decision Process. The issue table for the option is presented in Table I1 (below), with the considerations derived from the review being presented against each metric (I.1 to I.3).

Table I1– Summary of Issues and Consequences

Freshwater Buy-backs Option

Issue	Parent Document	Summary	Consequence[8]	Comments	Potential Data Gap (Confidence)
5-1		Treatment of currently oxidising lake margins	Review criterion partially met (reservations)	As a stand alone option, this treatment may not be sufficient to treat (neutralise) acidic sediments. The treatment may disperse via evaporation before treatment occurs.	Potential (Discussed)
5-2	Aquaterra study	Inundation effectiveness	Review criterion partially met (reservations)	The rate of inundation must at least match evaporation (the lower pump rates associated with the more available pumps may not meet evaporation). Inundation must be constant, accurate and effective, a fluctuating inundation may be worse than no inundation at all, and may exacerbate pyrite oxidation (via increase in optimum moisture for oxidation via Fe(III)) and flushing. Lake seiching may then amplify and transport	(Discussed)

[8] Assessed with regards to Issue Decision Process.

				acidification to water body.	
5-3	Study 2	Mobilisation of acidity and metals from lake margins	Review criterion partially met (observations)	Immediate and direct influx of water may flush acid into the water body. Pre-neutralisation may be required prior to sediment inundation.	Potential (Not Discussed)
5-4		Resource - groundwater	Review criterion partially met (reservations)	Groundwater resource scarce and unlikely to supplement the lakes water budget, although may supply enough to inundate in terms of maintaining ASS saturation?	Potential (Discussed)
5-5		Resource – groundwater	Review criterion partially met (reservations)	Ability to maintain groundwater supply once committed? Variation in inundation may lead to uncertainty in ASS management?	No (Discussed)
5-6		Resource – volume required (as GW)	Review criterion partially met (observations)	Unlikely that level maintenance of waters could be sourced and applied. Inundation may work although infrastructure required and drawdown rates (see below) may be inhibitive.	No (Volumes not discussed)
5-7		Resource – volume required (other)	Review criterion partially met (reservations)	Unlikely that level maintenance waters could be sourced (e.g. Lake Bonney) that would meet or exceed required volume for lake level maintenance (e.g. circa 1GL required for Lake Albert alone – this target cannot be met).	Potential (Not discussed)
5-8	Study 14	Return to status	Review criterion partially met (observations)	Ability of soil re-inundation to reverse oxidation	Yes/Potential (Not discussed)

5-9	Study 12 as reviewed by Study 13	Uncertainty associated with acidification model, in terms of both its conceptualisation and its lack of calibration/validation	Review criterion partially met (reservation)	Current version of acidification model considered by peer review (study 13) to be inadequate. Hence, it is uncertain how the Lower Lakes may respond to changes in water level associated with provision of freshwater.	Knowledge and data gaps currently being addressed in alternative study (Not discussed)
5-10	Study 18 (Earth systems Lake Albert report)	Hydrology of Lake Bed sediments poorly understood, with simple (often uniform) representations in conceptual and numerical models of lower lake levels	Review criterion partially met (reservations)	Effectiveness of targeted applications of freshwater dependent on accurate understanding of hydrology of bed sediments – i.e. how quickly they recharge, moisture content profiles, extinction depths, and oxygen diffusion rates. Spatial variability likely to be significant across the site	Hydraulic gradients, texture maps, permeability, transmissivity, ET, O_2 diffusion modelling (Not discussed)

I.1 - Technically feasible and achievable in practice on the scale required

I.1.1 - Technically feasible (theoretically, will it work?)

A – Successful implementation of option is theoretically possible.

Score: ‘Yes’ alignment with criteria, with a ‘high’ level of confidence in this score.
Justification: Re-instatement of water levels to submerge PASS and ASS has been identified in a number of studies to be a feasible option (Study 18). However as a stand-alone option, this treatment may not be sufficient to treat (neutralise) acidic (oxidised) sediments. The treatment may disperse via evaporation before treatment occurs in the summer months, and it is unlikely that freshwater would have requisite buffering capacity. Also, it is considered that the rate of inundation must at least match evaporation (the lower pump rates associated with the more available pumps may not meet evaporation). Inundation must be constant, accurate and effective, a fluctuating inundation may be worse than no inundation at all, and may exacerbate pyrite oxidation (via increase in optimum moisture for oxidation via Fe(III)) and flushing. Lake seiching may then amplify and transport acidification to the water body (Macdonald et al., 2007).

B– Technically feasible on the scale required.

Score: ‘Yes’ alignment with criteria, with a ‘low’ level of confidence in this score.
Justification: Re-instatement of water levels to submerge PASS and ASS has been identified in a

number of studies to be a feasible option. However freshwater resource is potentially scarce (low confidence) and potentially unlikely to supplement the Lakes water budget, although may supply enough to inundate in terms of maintaining ASS saturation.

I.1.2 - Achievable in practice (has it been proven to work?)

A – Generic Proof of Concept established

Score: 'Yes' alignment with the criteria, with a 'high' level of confidence in this score.
Justification: Generic proof of concept known from numerous studies into ASS and provision of freshwater flows. The current state of thinking in the ASS research area is that avoidance of disturbance of ASS, followed by inundation is perhaps the most effective method of prevention.

B – Proof of Concept established in similar (representative) environments

Score: 'Yes' alignment with the criteria, with a 'high' level of confidence in this score.
Justification: Generic proof of concept known from numerous studies into ASS and provision of freshwater inundation (DEC, 2009).

C – Proof of concept established in Lower Lakes environments and environs

Score: 'Yes' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification: Proof of concept accepted from specific studies into ASS and provision of freshwater flows within Lower Lakes. However it is potentially less likely that level maintenance of waters could be sourced and applied. Inundation may work although the acquisition of the freshwater resource required may be challenging.

I.1.3 - Implemented successfully before acidification of the Lakes occurs.

A1: On large scale

Score: 'Unlikely' alignment with the criteria, with a 'low' level of confidence in this score.
Justification: Under the current climatic conditions, and in light of political pressures with regards to water allocations and quotas, the volumes of water required to inundate the Lakes are considered unlikely within the timeframes proposed. However, a low level of confidence has been attributed to this score, due to the unknown political pressures involved in securing adequate water allocations. To some extent, the unknown climatic conditions in the short to medium term have also reduced the confidence attributed to this score.

A2: On a localised scale.

Score: 'Probable' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification: Partial inundation of system, whereby sufficient water is secured without completely

inundating the Lakes is considered probable, as lesser volumes of water would need to be purchased. A moderate level of confidence has been attributed to this score due to some unknowns concerning the volumes of water required, and unknown political drivers in securing sufficient water allocations.

I.2 - Costs to Government (State and Federal)

I.2.1 - Direct lifecycle costs (dollar costs directly apportioned to the entire lifecycle of the option.)

A - Capital / Establishment costs are minimal

Score: 'No' alignment with the criteria.
Justification: The purchase of large volumes of water allocations for the Lakes is currently in the high order of capital magnitude. Whilst the anticipated costs associated with this option are considered in the high order of magnitude, a number of data gaps exist in relation to the level of acceptable costs associated with addressing acidification. Political pressures are anticipated to play an important role in defining acceptable costs associated with this option. As such a low confidence has been attributed to this score as political drivers surrounding Lake Albert are unknown at this time.

B – Operational / Maintenance costs are minimal

Score: 'Unlikely' alignment with the criteria, with a 'high' level of confidence in this score.
Justification: A number of variables are associated with securing sufficient water to inundate the Lakes and maintain water levels over time. These include data gaps relating to the duration of drought conditions and the availability of water within the River Murray, commodity rises and potential fluctuations in purchasing water allocations and political issues concerning the acceptability of purchasing large volumes of water for Lake Albert.

C – Decommissioning costs are minimal

Score: 'Yes' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification: This option is not considered to be unduly infrastructure heavy. The costs relate more to assumed costs with respect to water purchase, and the agreements required therein.

I.2.2 - Indirect or environmental costs & benefits (limited to impacts that Government may be liable for through the application of the option)

A - Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes region)

Score: 'Unlikely' alignment with the criteria, with a' high' level of confidence in this score.
Justification: Potential impacts to environments in the Murray-Darling Basin, including the River Murray and associated wetlands in South Australia may occur. These may result due to the water

allocation purchase for Lake Albert limiting the availability of environmental flows in other areas of the Murray-Darling Basin.

B - Maximises the indirect benefits experienced in the wider Lower Lakes region (e.g. tourism, agriculture, wine, lifestyle)

Score: 'Yes' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification: Potentially, the increased flow of freshwater into the Lakes is considered to warrant a maximum score for indirect benefits associated with the Lakes as a resource.

I.3 - Adjustments

Preventative or Treatment: This option is regarded as a 'preventative' approach.
Negative Impacts: Low impacts have been identified for this option. Whilst there are potential issues relating to:

- the mobilisation of acidified sediments;
- initial turbidity increases; and
- salinisation (in the medium to long term through evaporation), these are considered to be relatively low at this time.

Of key importance is the retention/re-establishment of a freshwater environment within Lake Albert.

Also, as mentioned previously, if inconsistent inundation is undertaken, leading to wildly varying water levels, this may exacerbate the oxidation of pyrite and generation of acidity. Consideration may be given to prior neutralisation of oxidised sediments to prevent export of acidity and metals via flushing during re-flooding (e.g. Study 4, Macdonald et al., 2007).

Therefore the option is regarded as having the following risk matrix inputs:

- **Likelihood:** Unlikely
- **Severity:** Moderate

Resulting in a '**Moderate**' risk in terms of adverse impacts.

- **Appendix J - Assessment of the Freshwater (Environmental Allocations)**

J - Provision of Freshwater (environmental allocations) Option

The use of freshwater to inundate sediments (but sourced from environmental allocations) as an alternative option to the proposed action was assessed via the review of studies relating to the option, both specific to the Lower Lakes and from the wider research community (i.e. published research). Any identified potentially significant issues were recorded in the option's issue table, following assessment via the Issue Decision Process. The issue table for the option is presented in Table J1 (below), with the considerations derived from the review being presented against each metric (J.1 to J.3).

Table I1– Summary of Issues and Consequences

Freshwater Allocations Option

Issue	Parent Document	Summary	Consequence[9]	Comments	Potential Data Gap (Confidence)
6-1	N/A	Treatment of currently oxidising lake margins	Review criterion partially met (reservations)	As a stand-alone option, this treatment may not be sufficient to treat (neutralise) acidic sediments. The treatment may disperse via evaporation before treatment occurs.	Potential (Discussed)
6-2	Aquaterra study	Inundation effectiveness	Review criterion partially met (reservations)	The rate of inundation must at least match evaporation (the lower pump rates associated with the more available pumps may not meet evaporation). Inundation must be constant, accurate and effective, a fluctuating inundation may be worse than no inundation at all, and may exacerbate pyrite oxidation (via increase in optimum moisture for oxidation via Fe(III)) and flushing. Lake seiching may	(Discussed)

[9] Assessed with regards to Issue Decision Process.

				then amplify and transport acidification to water body.	
6-3	Study 2	Mobilisation of acidity and metals from lake margins	Review criterion partially met (observations)	Immediate and direct influx of water may flush acid into the water body. Pre-neutralisation may be required prior to sediment inundation.	Potential (Not Discussed)
6-4	Study 2	Resource - groundwater	Review criterion partially met (reservations)	Groundwater resource scarce and unlikely to supplement the lakes water budget, although may supply enough to inundate in terms of maintaining ASS saturation?	Potential (Discussed)
6-5	Study 2	Resource – groundwater	Review criterion partially met (reservations)	Ability to maintain groundwater supply once committed? Variation in inundation may lead to uncertainty in ASS management?	No (Discussed)
6-6	Study 2	Resource – volume required (as GW)	Review criterion partially met (observations)	Unlikely that level maintenance of waters could be sourced and applied. Inundation may work although infrastructure required and drawdown rates (see below) may be inhibitive.	No (Volumes not discussed)
6-7	Study 2	Resource – volume required (other)	Review criterion partially met (reservations)	Unlikely that level maintenance waters could be sourced (e.g. Lake Bonney) that would meet or exceed required volume for lake level maintenance (e.g. circa 1GL required for Lake Albert alone – this target cannot be met).	Potential (Not discussed)
6-8	Study 14	Return to status	Review criterion partially met	Ability of soil re-inundation to reverse oxidation	Yes/Potential (Not discussed)

			(observations)		
6-9	Study 12 as reviewed by Study 13	Uncertainty associated with acidification model, in terms of both its conceptualisation and its lack of calibration/validation	Review criterion partially met (reservation)	Current version of acidification model considered by peer review (study 13) to be inadequate. Hence, it is uncertain how the Lower Lakes may respond to changes in water level associated with provision of freshwater.	Knowledge and data gaps currently being addressed in alternative study (Not discussed)
6-10	Study 18 (Earth systems Lake Albert report)	Hydrology of Lake Bed sediments poorly understood, with simple (often uniform) representations in conceptual and numerical models of lower lake levels	Review criterion partially met (reservations)	Effectiveness of targeted applications of freshwater dependent on accurate understanding of hydrology of bed sediments – i.e. how quickly they recharge, moisture content profiles, extinction depths, and oxygen diffusion rates. Spatial variability likely to be significant across the site	Hydraulic gradients, texture maps, permeability, transmissivity, ET, O_2 diffusion modelling (Not discussed)

J.1 - Technically feasible and achievable in practice on the scale required

J.1.1 - Technically feasible (theoretically, will it work?)

A – Successful implementation of option is theoretically possible.

Score: 'Yes' alignment with criteria, with a 'high' level of confidence in this score.
Justification: Re-instatement of water levels to submerge PASS and ASS has been identified in a number of studies to be a feasible option (Study 18). However as a stand-alone option, this treatment may not be sufficient to treat (neutralise) acidic (oxidised) sediments. The treatment may disperse via evaporation before treatment occurs in the summer months, and it is unlikely that freshwater would have requisite buffering capacity. Also, it is considered that the rate of inundation must at least match evaporation (the lower pump rates associated with the more available pumps may not meet evaporation). Inundation must be constant, accurate and effective. A fluctuating inundation may be worse than no inundation at all, and may exacerbate pyrite oxidation (via increase in optimum moisture for oxidation via Fe(III)) and flushing. Lake seiching may then amplify and transport acidification to the water body (Macdonald et al., 2007).

B– Technically feasible on the scale required.

Score: 'Yes' alignment with criteria, with a 'low' level of confidence in this score.
Justification: Re-instatement of water levels to submerge PASS and ASS has been identified in a number of studies to be a feasible option. However freshwater resource is potentially scarce (low confidence) and potentially unlikely to supplement the Lakes water budget, although enough freshwater may be supplied to inundate in terms of maintaining ASS saturation.

J.1.2 - Achievable in practice (has it been proven to work?)

A – Generic Proof of Concept established

Score: 'Yes' alignment with the criteria, with a 'high' level of confidence in this score.
Justification: Generic proof of concept known from numerous studies into ASS and provision of freshwater flows. The current state of thinking in the ASS research area is that avoidance of disturbance of ASS, followed by inundation is perhaps the most effective method of prevention.

B – Proof of Concept established in similar (representative) environments

Score: 'Yes' alignment with the criteria, with a 'high' level of confidence in this score.
Justification: Generic proof of concept known from numerous studies into ASS and provision of freshwater inundation (DEC, 2009).

C – Proof of concept established in Lower Lakes environments and environs

Score: 'Yes' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification: Proof of concept accepted from specific studies into ASS and provision of freshwater flows within Lower Lakes. However it is potentially less likely that level maintenance of waters could be sourced and applied. Inundation may work although the acquisition of the freshwater resource required may be challenging.

J.1.3 - Implemented successfully before acidification of the Lakes occurs.

A1: On large scale

Score: 'Unlikely' alignment with the criteria, with a 'low' level of confidence in this score.
Justification: Under the current climatic conditions, and in light of political pressures with regards to water allocations and quotas, the volumes of water required to inundate the Lakes are considered unlikely within the timeframes proposed. However, a low level of confidence has been attributed to this score, due to the unknown political pressures involved in securing adequate water allocations. To some extent, the unknown climatic conditions in the short to medium term have also reduced the confidence attributed to this score.

A2: On a localised scale.

Score: 'Probable' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification: Partial inundation of system, whereby sufficient water is secured without completely inundating the Lakes is considered probable, as lesser volumes of water would need to be purchased. A moderate level of confidence has been attributed to this score due to some unknowns concerning the volumes of water required, and unknown political drivers in securing sufficient water allocations.

J.2 - Costs to Government (State and Federal)

J.2.1 - Direct lifecycle costs (dollar costs directly apportioned to the entire lifecycle of the option.)

A - Capital / Establishment costs are minimal

Score: 'Yes' alignment with the criteria, with a 'high' level of confidence.
Justification: The re-allocation of large volumes of water for the Lakes is currently not considered to be high in the order of capital magnitude. Re-allocation of existing quotas / volume is not considered to potentially incur significant establishment costs, due to the majority of infrastructure likely to be already present.

B – Operational / Maintenance costs are minimal

Score: 'Yes' alignment with the criteria, with a 'high' level of confidence in this score.
Justification: Although a number of variables are associated with securing sufficient water to inundate the Lakes and maintain water levels over time, it is assumed that these technical and physical obstacles are surmountable. Thus the operational / maintenance costs are considered to be not necessarily significant, given that the majority of the infrastructure required to maintain flow / input is present, and the re-allocation is effectively a return to 'normal' operating conditions.

C – Decommissioning costs are minimal

Score: 'Yes' alignment with the criteria, with a 'high' level of confidence in this score.
Justification: This option is not considered to be infrastructure heavy. As discussed in the above parameter, the provision of re-allocation is likely to be a return to the status quo for the system and thus decommissioning should not be a significant issue.

J.2.2 - Indirect or environmental costs & benefits (limited to impacts that Government may be liable for through the application of the option)

A - Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes region)

Score: 'Probable' alignment with the criteria, with a' high' level of confidence in this score.
Justification: As with the buy-back option, there are potential impacts to environments in the Murray associated wetlands of South Australia with this option. These impacts may result due to the water re-allocation limiting the availability of environmental flows in other areas of the Murray-Darling Basin. However, it is SKM's current understanding that wetland specific risk assessments are likely to be undertaken by the SA Government, which would mitigate potential impacts associated with re-allocation.

B - Maximises the indirect benefits experienced in the wider Lower Lakes region (e.g. tourism, agriculture, wine, lifestyle)

Score: 'Yes' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification: Potentially, the increased flow of freshwater into the Lakes is considered to warrant a maximum score for indirect benefits associated with the Lakes as a resource.

J.3 - Adjustments

Preventative or Treatment: This option is regarded as a 'preventative' approach.
Negative Impacts: Low impacts have been identified for this option. Whilst there are potential issues relating to:

- the mobilisation of acidified sediments;
- initial turbidity increases; and
- salinisation (in the medium to long term through evaporation), these are considered to be relatively low at this time.

Of key importance is the retention/re-establishment of a freshwater environment within Lake Albert.

Also, as mentioned previously, if inconsistent inundation is undertaken, leading to wildly varying water levels, this may exacerbate the oxidation of pyrite and generation of acidity (with subsequent mobilisation to the aquatic environment). Consideration may be given to prior neutralisation of oxidised sediments to prevent export of acidity and metals via flushing during re-flooding (e.g. Study 4, Macdonald et al., 2007).

Therefore the option is regarded as having the following risk matrix inputs:

- **Likelihood:** Unlikely
- **Severity:** Moderate

Resulting in a '**Moderate**' risk in terms of adverse impacts.

- **Appendix K - Assessment of the Transfer of Seawater to Lake Albert**

K – Transfer of Seawater to Lake Albert Option

The transfer of seawater to inundate exposed sediments in Lake Albert was assessed via the review of studies relating to the option, both specific to the Lower Lakes and from the wider research community (i.e. published research). Any identified potentially significant issues were recorded in the option's issue table, following assessment via the Issue Decision Process. The issue table for the option is presented in Table K1 (below), with the considerations derived from the review being presented against each metric (K.1 to K.3).

Table K1 – Summary of Issues and Consequences

Transfer of Seawater Into Lake Albert Option

Issue	Parent Document	Summary	Consequence[10]	Comments	Potential Data Gap
7-1	Lake Albert Investigation -Tonkin April 2008	Lead in time for infrastructure acquisition and commission	Review criterion partially met (reservations)	Commencement of pumping not achievable for 7 – 11 months depending on power supply issues and acquisition of pumps. Detailed design requires commencement ASAP.	Potential (Discussed)
7-2	- Lake Albert Investigation -Tonkin April 2008	Pump acquisition earlier but with lower capacity.	Review criterion partially met (reservations)	Pumps could be acquired sooner than stated above in 7-1 but would not be capable of pumping required 1Gl of water (can achieve c.800 ML) although still envisaged to supply a net influx (yearly), it would be below net evaporation in Jan and Feb (c. 950ML).	Potential (Not discussed)
7-3	- Lake Albert Investigation -Tonkin April 2008	Coorong as Source - salinity	Review criterion partially met (reservations)	Water from Coorong would potentially have higher salinity than the Ocean option as Coorong is hyper saline in sections. Absence of ecological assessment relating to hypersaline	Yes (Discussed)

[10] Assessed with regards to Issue Decision Process.

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				inundation	
7-4	- Lake Albert Investigation -Tonkin April 2008	Coorong as Source – recharge of Coorong	Review criterion partially met (observations)	The report does not clearly state that there would be effective recharge of Coorong. The report ASSUMES that pumping from Coorong at >800 ML day would draw in water from ocean via Murray Mouth – would hydrodynamic modelling be required to determine this process can occur? The report ASSUMES that inflow via Murray Mouth is sufficient to recharge based on calculations not supported by a bathymetric model.	Yes (Discussed)
7-5	- Lake Albert Investigation -Tonkin April 2008	Coorong as Source – ecological implications	Review criterion partially met (reservations)	Report states that ecological implications on the Coorong are not considered within the report.	Yes (some discussion of potential impacts to fish within Lake Alexandrina in Study 16 (Not discussed in detail)
7-6	- Lake Albert Investigation -Tonkin April 2008	Coorong as Source – practicable land issues	Non-significant issue	Construction on preferred route may be hindered by agreement from landholder. Report states that construction space may be attainable on road reserve. It is possible that the road reserves are not wide enough.	Yes/Potential (Not discussed)
7-7	- Lake Albert Investigation	Coorong as Source – Practicable Environmental	Non-significant issue	Potential for air and noise pollution from generators, Best practise would need to	No (Not discussed)

	-Tonkin April 2008	Nuisance		be adopted.	
7-8	Lake Albert Investigation -Tonkin April 2008	Salinity modelling	Review criterion partially met (observations)	Absence of modelling data, as undertaken in Lake Alexandria	Yes (Not discussed)
7-9		Returning Lake Albert to freshwater Environment	Review criterion partially met (observations)	Detailed study and information of options not available. Clarification of how the closed system can be flushed	Yes (Discussed)
7-10		Increase in salinity through evaporation	Review criterion partially met (observations)	Hypersaline conditions expected to develop with Lake Albert	No - detailed salinity models required (Discussed)
7-11		Refuge habitat for freshwater fauna (primarily fish)	Review criterion partially met (observations)	Study to identify refuge habitat not undertaken. Practicalities of segregating Lake Albert would likely prevent this being explored further	Yes (Discussed)
7-12		Potential benefits to Coorong through removal of hypersaline water	Review criterion partially met (reservations)	The report does not clearly state that there would be effective recharge of Coorong. The report ASSUMES that pumping from Coorong at >800 ML day would draw in water from ocean via Murray Mouth – would hydrodynamic modelling be required to determine this process can occur? The report ASSUMES that inflow via Murray Mouth is sufficient to recharge based on calculations not supported by a bathymetric model.	Yes (Not discussed)

7-13		Absence of fish passage into Lake Alexandrina	Review criterion partially met (observations)	Re-connection of Lake Albert to Lake Alexandrina temporarily as saltwater pumped into system may allow fish to enter Lake Alex and prevent mass fish mortality.	Yes: Issue not discussed or raised in documents reviewed. (Not discussed)
7-14	Lake Albert Investigation -Tonkin April 2008	Coorong water into Lake Albert – Treatment of currently oxidising lake margins	Review criterion partially met (observations)	As a stand-alone option, this treatment may not be sufficient to treat (neutralise) the oxidising margins of the lake. Previous research (Ahern et al., 2009) indicate that re-flooding of sediments is less effective furthest from marine source (i.e. northern edge of lake) and on slightly higher elevations. This issue is more relevant when considering the current pumping rates were given in April 2008. The water level is now lower within the lake and therefore more water maybe required inundating the margins and maintaining a higher level.	No (See Tonkin study
7-15	- Lake Albert Investigation -Tonkin April 2008	Coorong into Lake Albert - Inundation effectiveness	Review criterion partially met (observations)	The rate of inundation must at least match evaporation (the lower pump rates associated with the more available pumps may not meet evaporation). Inundation must be constant, accurate and effective, a fluctuating inundation may be worse than no inundation at all, and may exacerbate pyrite oxidation (via increase in optimum moisture for oxidation via Fe(III)) and flushing. Lake seiching may then amplify and transport	No (See Tonkin study) (Discussed)

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				acidification to water body.	
7-16	- Lake Albert Investigation -Tonkin April 2008	Coorong into Lake Albert – Mobilisation of acidity and metals from lake margins	Review criterion partially met (observations)	Immediate and direct influx of water may flush acid into the water body. Pre-neutralisation may be required prior to sediment inundation.	Yes
7-17	- Lake Albert Investigation -Tonkin April 2008	Seawater into Lake Albert – Neutralisation time frames	Review criterion partially met (observations)	Previous research (Ahern et al., 2009) has indicated significant time lags associated with sediment pH increase and actual acidity increases with respect to se	Potential
Tonkin report discounts the pumping of seawater from the ocean option. However, issues identified are detailed below for information.					
7-18	- Lake Albert Investigation -Tonkin April 2008	Ocean as Source – Practicable construction	Review criterion partially met (observations)	Construction would be difficult in sand dunes.	Potential (Not discussed)
7-19	- Lake Albert Investigation -Tonkin April 2008	Ocean as Source – increased plant size	Review criterion partially met (observations)	Increased plant may be required to deliver increased pumping rates (over that of Coorong as source) which would increase footprint.	No (See Tonkin study) (Discussed)
7-20	- Lake Albert Investigation -Tonkin April 2008	Ocean as Source – Potential NES Matters	Review criterion partially met (reservations)	Potential impact on NES matters as Young Husband Peninsula is a National Park – a referral to DEWHA may be required which would increase time criticality.	No (See Tonkin study) (Discussed)
7-21	Lake Albert Investigation -Tonkin April 2008	Ocean as Source – Risk to infrastructure	Review criterion partially met (reservations)	Potential risk to infrastructure from freak weather event (e.g. 1 in 100 year storm).	No (See Tonkin study) (Not discussed)

7-22	Lake Albert Investigation -Tonkin April 2008	Ocean as Source – Coast Dynamics and Intake	Review criterion partially met (observations)	Potential risk in terms of ongoing maintenance requirement of ocean intake due to silting up of intake and wear and tear due to dynamic wave action.	No (See Tonkin study
7-23	Lake Albert Investigation -Tonkin April 2008	Seawater into Lake Albert – Treatment of currently oxidising lake margins	Review criterion partially met (observations)	As a stand-alone option, this treatment may not be sufficient to treat (neutralise) the oxidising margins of the lake. Previous research (Ahern et al., 2009) indicate that re-flooding of sediments is less effective furthest from marine source (i.e. northern edge of lake) and on slightly higher elevations. This issue is more relevant when considering the current pumping rates were given in April 2008. The water level is now lower within the lake and therefore more water maybe required inundating the margins and maintaining a higher level.	No (See Tonkin study) (Not discussed)
7-20	- Lake Albert Investigation -Tonkin April 2008	Seawater into Lake Albert - Inundation effectiveness	Review criterion partially met (observations)	The rate of inundation must at least match evaporation (the lower pump rates associated with the more available pumps may not meet evaporation). Inundation must be constant , accurate and effective, a fluctuating inundation may be worse than no inundation at all, and may exacerbate pyrite oxidation (via increase in optimum moisture for oxidation via Fe(III)) and flushing. Lake seiching may	No (See Tonkin study) (Discussed)

				then amplify and transport acidification to water body.	
7-21	- Lake Albert Investigation -Tonkin April 2008	Seawater into Lake Albert – Mobilisation of acidity and metals from lake margins	Review criterion partially met (observations)	Immediate and direct influx of water may flush acid into the water body. Pre-neutralisation may be required prior to sediment inundation.	Yes (Not discussed)
7-22	- Lake Albert Investigation -Tonkin April 2008	Seawater into Lake Albert – Neutralisation time frames	Review criterion partially met (observations)	Previous research (Ahern et al., 2009) has indicated significant time lags associated with sediment pH increase and actual acidity increases with respect to se	Potential (Discussed)

K.1 - Technically feasible and achievable in practice on the scale required

K.1.1 - Technically feasible (theoretically, will it work?)

A - Successful implementation of option is theoretically possible

Score: 'Probable' alignment with criteria, with a 'Medium' level of confidence in this score.
Justification: As discussed previously in Section 3.3 (see discussion therein), theoretically, the inundation of ASS with seawater can be an effective strategy in preventing acidification.

B– Theoretically viable on the scale (spatial) required

Score: 'Probable' alignment with criteria, with a 'medium' level of confidence in this score.
Justification: As discussed previously in Section 3.3, theoretically, inundation will be as effective on a large scale as on a local scale, assuming a significant environmental homogeneity. As noted in Section 3.3, should the option be used to treat localised extremities, then land-forming of the lake bed and / or construction of dams may be required to retain the water. However these costs have not been considered here due to the requirement of the option to maintain Lake levels at a static elevation (and in addition, other options may be more viable for localised treatment, depending on scale etc).

K.1.2 - Achievable in practice (has it been proven to work?)

A - Generic Proof of Concept established

Score: ‘Maximum’ alignment with the criteria, with a high level of confidence in this score.
Justification: The application of this option has proved to be effective in a number of settings, although it is worth considering that the generic proof of concepts are generally on a different scale – see below. Application of seawater to acidic sediments has generally proven successful at the East Trinity site (Martens et al., 2004; Ahern et al., 2009), and thus it is considered that a generic proof of concept is available, although the variation in environments and technique (i.e. East Trinity used lime assisted tidal exchange) must be considered.

B - Proof of Concept established in similar (representative) environments

Score: ‘Probable’ alignment with the criteria, with a ‘high’ level of confidence in this score.
Justification: Whilst the option has proven to be effective in estuarine acid sulfate soil environments throughout Australia (e.g. White et al., 1997; Indraratna et al., 2002, Johnston et al., 2005), there are no documented cases where saline water (with a salinity higher than seawater) has been used to inundate a previously freshwater environment (i.e. East Trinity was a previous brackish estuarine environment that was already totally environmentally degraded). See Section 3.3 for further discussion.

C – Proof of concept established in Lower Lakes environments and environs

Score: ‘Probable’ alignment with the criteria, with a ‘moderate’ level of confidence in this score.
Justification: In 2008 to 2009, water was pumped from Lake Alexandrina into Lake Albert, which was considered to successfully prevent any acidification of Lake Albert (Study 18). However it is noted that water sourced from the Coorong is vastly different water than that previously sourced from Lake Alexandrina and there may be unforeseen consequences in terms of its ability to prevent acidification. For instance, water from the Coorong is hyper-saline and has elevated levels of sulfate which may limit the potential for sulfide precipitation (with respect to available concentrations of Fe required for formation of FeS). Previous research has focussed on the application of seawater to already acidified sediments (Johnston et al., 2009b), therefore the buffering / neutralisation of sediments that are not fully oxidised would appear to be achievable, and the inundation in terms of preventing oxidation is certainly achievable as a preventative measure. However, previous inundation research has generally used un-diluted lime assisted seawater. The seawater applied to the Lakes water bodies may be diluted by the remaining freshwater and the current option does not include lime assistance with respect to dosing the inflow.

The influx of seawater and lack of flushing may lead to a hyper-saline environment in the Lake, due to undiluted inflow (no net outflow) of saline water plus evaporation over time.

K.1.3 - Implemented successfully before acidification of the Lakes occurs

A1 – on a large scale

Score: 'Unlikely' alignment with the criteria, with a 'low' level of confidence in this score.
Justification: A pre-feasibility study of pumping from the Coorong to Lake Albert indicated a 12-15 month lead time to acquire the necessary pumps (Tonkin, 2008). Such a timeframe suggests the option will not be operational and effective by December 2010. There is also uncertainty associated with pumping such a large volume of water from the Coorong – e.g. potential scouring issues and time delays associated with acquiring the necessary approvals to source water from a wetland of national significance. Additionally, previous studies have indicated that sediment buffering / neutralisation has occurred over a period of at least 17 months (depth and location dependant) (see Ahern et al., 2009) and therefore it is not clear that unassisted seawater (with potential for dilution) may effectively buffer / or neutralise acidic sediments. This is of specific focus to sediment that has undergone oxidation. Where the option is designed primarily to inundate as an anti oxidation measure, then a reasonable level of success could be expected.

A2 – on a localised scale

Score: 'Probable' alignment with the criteria, with a 'low' level of confidence in this score.
Justification: It is likely that lower rates of pumping may be more feasible to implement in the timeframe identified. Lower pumping rates could be used to saturate, but not necessarily inundate ASS. However there is still some uncertainty related to sourcing water from a wetland of national significance.

K.2 - Costs to Government (State and Federal)

K.2.1 - Direct lifecycle costs (dollar costs directly apportioned to the entire lifecycle of the option.)

A - Capital / Establishment costs are minimal

Score: 'No' - alignment with the criteria.
Justification: A potentially significant capital outlay of $20.9 million (ex. GST, +/- 30%) is required to implement the option (Tonkin, 2008).

B – Operational / Maintenance costs are minimal

Score: 'Unlikely' alignment with the criteria, with a 'high' level of confidence in this score.
Justification: The costs of the option are considered to be potentially significant although the majority of the expenditure is considered to be associated with the capital / implementation costs.

C – Decommissioning costs are minimal

Score: 'Unlikely' alignment with the criteria, with a 'high' level of confidence in this score.
Justification: The decommissioning costs are likely to be significant, therefore not minimal.

K.2.2 - Indirect or environmental costs & benefits (limited to impacts that Government may be liable for through the application of the option)

A - Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes region)

Score: 'Probable' alignment the criteria, with a 'moderate' level of confidence in this score.
Justification: There is likely to be a big carbon footprint associated with this option, and there may also be costs to the Coorong associated with water removal, hence the reduced alignment and moderate confidence.

B - Maximises the indirect benefits experienced in the wider Lower Lakes region (e.g. tourism, agriculture, wine, lifestyle)

Score: 'Unlikely' alignment the criteria, with a 'moderate' level of confidence in this score.
Justification: It is currently considered unlikely that this option would maximise indirect benefits to the wider region given the intrusive nature of the infrastructure required for pumping, and associated noise pollution.

K.3 - Adjustments

Preventative or Treatment: Option is regarded as a 'preventative' approach.
Negative Impacts: Even if it is assumed that the option is effective in treating the acidification of the Lake Albert, there is a risk that the following adverse impacts could eventuate as a result of implementing the option:

- The primary risk, as discussed previously in Section 3.3, is the risk of incorrectly timing the inundation of acidic sediments, using seawater. For the inundation to work effectively, it must be applied prior to the sediments turning acidic, otherwise there is a risk of mobilising both acidity and heavy metals;
- the salinisation of a freshwater resource (with the potential to become hyper-saline due to lack of flushing regime), which has no refuge habitat for fish;
- potential generation of hydrogen sulfide gas due to high quantities of sulfate in water from the Coorong that could result in an imbalance between sulphur and available iron; and

- risk of adverse impacts on the Coorong and Murray Mouth associated with altered flow dynamics.

It is also important to consider:

- Risk to infrastructure from adverse extreme drawdown increasing the possibility of air entrapment in pipework; and
- Sediment accumulation in pump outlet.

Therefore the option is regarded as having the following risk matrix inputs:

- **Likelihood:** Possible
- **Severity:** Critical

Resulting in an '**Extreme**' risk, in terms of adverse impacts based on the mis-application of seawater to oxidised sediments.

Appendix L - Assessment of the Proposed Action: Use of Seawater via Barrages

L- The Proposed Action – Transfer of Seawater via the Barrages

The transfer of seawater to inundate exposed sediments in the Lower Lakes was assessed via the review of studies relating to the option, both specific to the Lower Lakes and from the wider research community (i.e. published research). Any identified potentially significant issues were recorded in the option's issue table, following assessment via the Issue Decision Process. The issue table for the option is presented in Table L1 (below), with the considerations derived from the review being presented against each metric (L.1 to L.3).

Table L1 – Summary of Issues and Consequences

Proposed Action (transfer of seawater via the barrages)

Issue	Parent Document	Summary	Consequence[11]	Comments	Potential Data Gap (Confidence)
8-1		Salinity increase	Review criterion partially met (observations)	It is not clear what effect the increased water salinity would have on ecology but would likely change format?	Yes/Potential
8-2	-	Treatment of currently oxidising lake margins	Review criterion partially met (observations)	As a stand-alone option, this treatment may not be sufficient to treat (neutralise) the oxidising margins of the lake. Previous research (Ahern et al., 2009) indicate that re-flooding of sediments is less effective furthest from marine source (i.e. northern edge of lake) and on slightly higher elevations. This issue is more relevant when considering the current pumping rates relate to April 2008. The water level is now lower within the lake and therefore more water may be required to inundate the margins and maintain a higher	

[11] Assessed with regards to Issue Decision Process.

				level.	
8-3	-	Inundation effectiveness	Review criterion partially met (observations)	The rate of inundation must at least match evaporation (the lower pump rates associated with the more available pumps may not meet evaporation). Inundation must be constant, accurate and effective, a fluctuating inundation may be worse than no inundation at all, and may exacerbate pyrite oxidation (via increase in optimum moisture for oxidation via Fe(III)) and flushing. Lake seiching may then amplify and transport acidification to water body.	Potential
8-4	Study 2	Mobilisation of acidity and metals from lake margins	Review criterion partially met (observations)	Immediate and direct influx of water may flush acid into the water body. Pre-neutralisation may be required prior to sediment inundation.	Potential
8-5	Ahern et al 2009 (not in technical reports)	Neutralisation time frames	Review criterion partially met (observations)	Previous research (Ahern et al., 2009) has indicated significant time lags associated with sediment pH increase and actual acidity increases with respect to seawater inundation *note different site – high level metric*	Potential
8-6	-	Acidity Neutralisation effectiveness	Review criterion partially met (observations)	Previous seawater flooding options have used hyrdrated lime as a dose to seawater, with lime added into the seawater on tidal influx. Would be difficult to dose seawater on tidal influx? Actual alkalinity benefit of seawater on sediments of unknown titratable actual acidity (and potential acidity)	Potential

				is tenuous.	
8-7	Study 14	Return to status	Review criterion partially met (observations)	Ability of soil re-inundation to reverse oxidation	Yes (may be covered n ASS studies)
8-8	Study 14	Flooding with seawater option	Review criterion partially met (observations)	Identify salinity tolerances for plant species should saline inundation option occur	Yes. Information desktop study required.
8-9	Study 7	Influence of seawater on fish species	Review criterion partially met (observations)	Commission study to identify impacts on fish should lower lakes be flooded with seawater. Study needs to identify refuge habitats and connectivity between these environments. Length of time species can exist under stressed environments. Ability of system to recover in terms of re-colonisation.	No -see Risk assessment study
8-10	Study 16	Provision of refuge habitat to protect fish and provide source population upon re-establishment of freshwater environment in Lower Lakes.	Review criterion partially met (observations)	Program unknown.	Yes/Potential
8-11	Study 16	Loss of fish species	Review criterion partially met (observations)	Severe negative impact resulting from Saltwater intrusion to lower lakes	No
8-12	Study 16	Creation of refuge habitat through weir construction at Clayton.	Review criterion partially met (observations)	Provision of freshwater refuge environment	Partial – absence of salinity modelling in refuge environment
8-13	Study 16	Impact on vegetation	Review criterion partially met	Loss of vegetation for spawning and feeding	No

			(observations)	opportunities	
8-14	Study 16	Disconnection of lower lakes from EMLR tributaries	Review criterion partially met (observations)	Important life cycle implications for diadromous fish species.	No

L.1 - Technically feasible and achievable in practice on the scale required

L.1.1 - Technically feasible (theoretically, will it work?)

A - Successful implementation of option is theoretically possible

Score: 'Probable' alignment with criteria, with a moderate level of confidence in this score.
Justification: Theoretically, the inundation of ASS with saltwater can be an effective strategy in preventing acidification.

The shift to reducing conditions initiated by inundation of ASS may favour sequestration of iron-sulfide minerals and the in-situ transformation of soil acidity (Burton et al., 2008). Pyrite formation can be rapid in natural inter-tidal environments (Howarth, 1979), although it is likely that due to generally sluggish pyrite kinetics, that FeS minerals would preferentially exist (e.g. mackinawite, griegite). Both pyrite and mono-sulfides are known to reform in coastal acid sulfate soil landscapes due to seasonal shifts in hydrology or the formation of localised, highly reducing sub-environments (Bush and Sullivan, 1997; Rosicky et al., 2004; Burton et al., 2006, 2007). Portnoy and Giblin (1997a) demonstrated that saturating a drained and acidified former saltmarsh with seawater stimulated both Fe(**III**) and SO_4^{2-} reduction. However, there are few examples of field-based investigations in acid sulfate soil landscapes which demonstrate the effectiveness of re-establishing tidal inundation (or application of seawater) at either ameliorating acidity or sequestering Fe(**II**)-sulfide minerals such as pyrite (see Powell and Martens, 2005).

Previous research (Ahern et al., 2009) undertaken at the East Trinity Site, Queensland, has indicated significant time lags (>17 months) associated with sediment pH increase and total actual acidity (TAA) decreases with respect to seawater inundation. These experiments also used hydrated lime dosing of the seawater, although the quantities of lime used is not provided. Additionally, the study by Ahern et al.,(2009) indicated that mixing of freshwater with the saline inundation source may effectively dilute the neutralisation capacity of the marine source, and therefore additional volumes may be required (increasing the lake water salinity). However, it should be noted that the East Trinity test sediments were initially acidic (c. pH 2.5) and so the inundation was originally handicapped in terms of buffering the sediment.

The inundation at East Trinity can be viewed as a success based on the 'before' and 'after' scenario, whereby the initially acidic environment was returned to a circum-neutral environment, with associative environmental betterment in terms of vegetation. Therefore a 'probable' score has been recorded with a medium level of confidence. The application of seawater as a preventative measure is, in theory, relatively different, although the neutralisation of acidity may be expected depending on the mixing status of the source.

B– Theoretically viable on the scale (spatial) required

Score: 'Probable' alignment with criteria, with a 'moderate' level of confidence in this score. **Justification:** Theoretically, inundation will be as effective on a large scale as on a local scale, assuming significant environmental homogeneity with respect to the sediments across the system. As discussed above, there may well be differences in neutralisation time scales, based on the initial TAA and pH, and depth of sediment. The landform may also be an issue. Where land elevation exceeds the height of inundation, a cyclical wetting and drying scenario may develop, which can increase TAA and Fe content in pore water over time (Ahern et al., 2009).

Furthermore, as a standalone option, this treatment may not be sufficient to treat (neutralise) the oxidising margins of the lake, and would thus leave these areas vulnerable to seiching, with subsequent transport of acid to waters. Previous research (Ahern et al., 2009) indicates that re-flooding of sediments is less effective furthest from the marine source (i.e. northern edge of lake) and on slightly higher elevations. This issue is more relevant when considering the current pumping rates were given in April 2008. The water level is now lower within the lake and therefore more water may be required to inundate the margins and maintaining a higher head. Alternatively, if the marginal sediments were completely dry then the risk of acid export would be lower, however a significant acid spike may still occur following extreme rainfall events (Indraratna et al., 2002).

L.1.2 - Achievable in practice (has it been proven to work?)

A - Generic Proof of Concept established

Score: 'Maximum' alignment with the criteria, with a high level of confidence in this score. **Justification:** The application of this option has proved to be effective in a number of settings, although it is worth considering that the generic proof of concepts are generally on a different scale under different environments – see below. Application of seawater to acidic sediments has generally proven successful at the East Trinity site (Martens et al., 2004; Ahern et al., 2009), and thus it is considered that a generic proof of concept is available.

B - Proof of Concept established in similar (representative) environments

Score: 'Probable' alignment with the criteria, with a high level of confidence in this score. **Justification:** Whilst the option has proven to be effective in estuarine acid sulfate soil environments throughout Australia (e.g. White et al., 1997; Indraratna et al., 2002, Johnston et al., 2005), there are no documented cases where saline water (with a salinity higher than seawater) has been used to inundate a previously freshwater environment (i.e. East Trinity was a previous brackish estuarine environment that was already totally environmentally degraded). The use of water (saline or otherwise) for inundation would limit oxidation of previously exposed sediments, and may initiate diagenetic processes that are similar to those found in intertidal sedimentary environments such as mangroves (i.e. higher water tables, abundant sulfate and organic matter). Such conditions would stimulate upward migration of the redox boundary, favouring the reductive dissolution of Fe(III) minerals and the reduction of sulfate (as a function of Eh, Johnston et al., 2009a).

C – Proof of concept established in Lower Lakes environments and environs

Score: 'Unlikely' alignment with the criteria, with a moderate level of confidence in this score. **Justification:** In 2008 to 2009, water was pumped from Lake Alexandrina into Lake Albert, which was considered to successfully prevent any acidification of Lake Albert (Study 18). Previous research has focussed on application of seawater to already acidified sediments (Johnston et al., 2009b), therefore the buffering / neutralisation of sediments that are not fully oxidised would appear to be achievable, and the inundation in terms of preventing oxidation is certainly achievable as a preventative measure. However, previous inundation research has generally used un-diluted lime assisted seawater. The seawater applied to the Lakes water bodies may be diluted by the remaining freshwater and the current option does not include lime assistance with respect to dosing the inflow.

The influx of seawater and lack of flushing may lead to a hyper-saline environment in the Lake, due to evaporation and to some extent limited flushing of the system, depending upon barrage operating rules. This would be particularly evident with Lake Albert. A moderate level of confidence has been attributed to this score, due to the large scale of the environment involved, whereby unforeseeable risks may occur.

L.1.3 - Implemented successfully before acidification of the Lakes occurs

A1 – on a large scale

Score: ''Yes' alignment with the criteria, with a moderate level of confidence in this score. **Justification:** Operation of the barrages to allow seawater to inundate Lake Alexandrina (and assuming subsequently Lake Albert) is assumed to be achievable within the timeframes required (i.e. in the absence of specific barrage operating protocols for this procedure). Whilst data gaps exist in relation to specific timeframes associated with inundating the entire Lower Lakes environment, this is not anticipated to be of significant duration.

A moderate confidence has been attributed to address previous studies which indicate that sediment buffering / neutralisation has occurred over a period of at least 17 months (depth and location dependant) (Ahern et al., 2009) and therefore it is not clear that unassisted seawater (with potential for dilution) may effectively buffer / or neutralise acidic sediments. This is of specific focus to sediment that has undergone oxidation. Where the option is designed primarily to inundate as an anti oxidation measure, then a reasonable level of success could be expected.

A2 – on a localised scale

Score: 'Probable' alignment with the criteria, with a low level of confidence in this score.
Justification: The feasibility of inundating localised areas of the Lower Lakes, as part of a hot spot management approach has been allocated a probable score with low confidence. This addresses a number of data gaps concerning operational implementation of such an approach, and the inherent difficulties in transferring water (and maintaining water) to localised sections, on the large scale of the Lower Lakes.

It is considered that further developmental works may be required, e.g. land-forming that can retain localised bodies of seawater around the extremities of the lake bodies, should extremity hotspots require treatment via this method. However, the SMART appraisal of this option has determined that the inundation would be required to a level of -1.5 m AHD (Lake Alexandrina, i.e. the 'care and maintenance' approach), and therefore the review of this option does not consider the use of seawater as a 'hotspot' treatment for lake body margins. Subsequently, this approach to the seawater option does not reflect potential costs (section 3.3.5) associated with lake land-forming for the retaining of seawater, such as what may be required for localised (lake extremities) treatment.

L.2 - Costs to Government (State and Federal)

Direct lifecycle costs (dollar costs directly apportioned to the entire lifecycle of the option.)

A - Capital / Establishment costs are minimal

Score: 'Yes' alignment with the criteria, with a high level of confidence in this score.
Justification: Management of the barrages in their current state (as it has been assumed the Clayton regulator and proposed Weir at Pomanda Island are operational) is currently underway and requires minimal capital expenditure.

B – Operational / Maintenance costs are minimal

Score: 'Maximum' alignment with the criteria, with a high level of confidence in this score.
Justification: The ongoing maintenance costs can be forecast with a high level of confidence as being minimal.

C – Decommissioning costs are minimal

Score: 'Unlikely' alignment with the criteria, with a moderate level of confidence in this score.
Justification: The decommissioning costs can be forecast with a high level of confidence as being

minimal, with respect to infrastructure. However, in terms of completely decommissioning the option and removing the salinisation of the system (i.e. returning the system to pre-drought conditions), the alignment is 'unlikely' against cost criteria.

L.2.1 - Indirect or environmental costs & benefits (limited to impacts that Government may be liable for through the application of the option)

A - Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes region)

Score: 'Yes' alignment the criteria, with a high level of confidence in this score.
Justification: This option requires no significant infrastructure requirements (material input) and therefore has a relatively low carbon footprint. Impacts outside of the Lower Lakes environment, as defined by the SMART criteria are not anticipated.

B - Maximises the indirect benefits experienced in the wider Lower Lakes region (e.g. tourism, agriculture, wine, lifestyle)

Score: 'Probable' alignment the criteria, with a low level of confidence in this score.
Justification: The inundation of the area with seawater is considered to be beneficial in terms of maximising lifestyle (relatively, via return of amenity value) although this is tempered by the salinisation of the system and the potential impacts on agri / viticultural extraction and potential increased requirement for ion exchange of lake waters prior to use.

L.3 - Adjustments

Preventative or Treatment: This option is regarded as a 'preventative' approach. Note that if the option is used as a treatment, then potentially significant negative impacts to the environment may occur (see below).
Risk of Negative Impacts: Even if it is assumed that the option is effective in treating the acidification of the Lower Lakes, there is a risk that the following adverse impacts could eventuate as a result of implementing the option under the wrong conditions (i.e. post oxidation):

- salinisation of a freshwater resource (with the potential to become hyper-saline due to lack of flushing regime);
- The provision of a refuge environment within the AMLR tributaries (Currency Creek and Finniss Creek) presents significant ecological safeguards should the Lower Lakes become a saltwater environment. However, due to the large scale of freshwater environment potentially impacted, the risks have still been classified as extreme;
- potential generation of hydrogen sulfide gas due to high quantities of sulfate in water from the Coorong that could result in an imbalance between sulphur and available iron (attributable to high salinity and considered less likely using standard ocean water);

- risk of adverse impacts on the Coorong and Murray Mouth associated with altered flow dynamics;
- potential loss of freshwater connection to the Coorong and with particular impacts upon diadromous fish species;
- Disconnection of Murray mouth to River Murray, with particular impacts upon diadromous fish species (this assumes fish passage is not possible for the proposed weir at Pomanda Island); and
- Mobilisation studies have indicated that seawater mobilises a significant amount of acidity and heavy metals / nutrients during inundation, if sulfidic sediments have oxidised (Sullivan et al., 2009, Hicks et al., 2009). Recent indications from Loveday Bay in the south-east corner of Lake Alexandrina show that overlying water can decrease to approximately pH 2 following re-wetting of ASS.

Based on the above considerations and implicit timing issues, this option is regarded as having the following risk matrix inputs:

- **Likelihood:** Possible
- **Severity:** Critical

Resulting in an '**Extreme**' risk in terms of adverse impacts.

▪ Appendix M - Assessment of Option Combination 1

M - Option Combination 1: Enhanced Bioremediation and Freshwater Stabilisation to -1.5 m AHD

This option comprises the stabilisation of the water level to -1.5 m AHD using freshwater from either environmental allocations or buy-backs, with application of Enhanced Bioremediation around the peripheral areas according to risk prioritisation of areas and rehabilitation mapping. The option considers no active acidification preventative measure being undertaken to address acidification of the central areas of Lake Alexandrina only; would require pumping for Albert to be at or above -0.5m AHD.

M.1 - Technically feasible and achievable in practice on the scale required

M.1.1 - Technically feasible (theoretically, will it work?)

A - Successful implementation of option is theoretically possible –
Score - 'Yes' alignment with criteria, with a 'high' level of confidence in this score.
Justification - Theoretically, option combination 1 is considered likely to be successful in managing the acidification of the Lower Lakes, assuming the following:

- Required volume of freshwater can be sourced from either environmental allocations, buy-back or a combination of both;
- the establishment of vegetation can be undertaken across the areas required based on rehabilitation mapping; and
- the buffering capacity of the system is such that any residual acidity generated could be naturally attenuated.

B– Theoretically viable on the scale (spatial) required –

Score: 'Probable' alignment with criteria, with a 'medium' level of confidence in this score.
Justification: The ongoing risk assessment undertaken on the lakes environment (i.e. prioritisation of risk areas) based on risk area mapping, coupled to rehabilitation zone mapping / planning indicates that 'hotspot areas' are likely to be the format for acid soil presence, rather than a homogenous continual blanket of acidic sediments.

Therefore the scale of area requiring potential management is considered to be related to this hot spot arrangement. Subsequently, it is considered that the criteria would warrant a 'probable' alignment.

The use of water to inundate the lake bed to -1.5 m AHD (note Lake Albert to – 0.5 m AHD) should safeguard the predominant risk area (i.e. clay lithology) present in the central areas of Lake Alexandrina.

M.1.2 - Achievable in practice (has it been proven to work?)

A - Generic Proof of Concept established

Score: 'Yes' alignment with the criteria, with a 'high' level of confidence in this score.
Justification - As noted previously, the enhanced bioremediation component is considered to be appropriately adequate. Generic proof of concept with respect to inundation (stabilisation) using freshwater is available from numerous studies into ASS and provision of freshwater flows. The current state of thinking in the ASS research area is that avoidance of disturbance of ASS, followed by inundation is perhaps the most effective method of prevention.

B - Proof of Concept established in similar (representative) environments

Score - 'Yes' alignment with the criteria, with a 'high' level of confidence in this score.
Justification - Generic proof of concept known from numerous studies into ASS and provision of freshwater inundation (DEC, 2009).

C – Proof of concept established in Lower Lakes environments and environs

Score - 'Yes' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification - Proof of concept accepted from specific studies into ASS and provision of freshwater flows within Lower Lakes. However it is potentially less likely that level maintenance of waters could be sourced and applied. Inundation may work although the acquisition of the freshwater resource required may be challenging.

M.1.3 - Implemented successfully before acidification of the Lakes occurs

A1 – on a large scale

Score - 'Probable' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification - Water required to -1.5m AHD level in Lake Alexandrina which is potentially achievable via combination of buy-backs and allocations.

A2 – on a localised scale

Score - 'Probable' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification - Partial inundation of system, whereby sufficient water is secured without completely inundating the Lakes is considered probable, as lesser volumes of water would need to be purchased. A moderate level of confidence has been attributed to this score due to some unknowns concerning the volumes of water required, and unknown political drivers in securing sufficient water allocations.

M.2 - Costs to Government (State and Federal)

M.2.1 - Direct lifecycle costs (dollar costs directly apportioned to the entire lifecycle of the option)

A - Capital / Establishment costs are minimal

Score - 'Yes' alignment with the criteria, with a 'high' level of confidence (as opposed to 'medium' for option combination 1 due to increased required management area).
Justification - The re-allocation of large volumes of water for the Lakes is currently not considered to be high in the order of capital magnitude. Re-allocation of existing quotas / volume is not considered to potentially incur significant establishment costs, due to the majority of infrastructure likely to be already present.

B – Operational / Maintenance costs are minimal

Score - 'Yes' alignment with the criteria, with a 'high' level of confidence in this score.
Justification - Although a number of variables are associated with securing sufficient water to inundate the Lakes and maintain water levels over time, it is assumed that these technical and physical obstacles are surmountable. Thus the operational / maintenance costs are considered to be not necessarily significant, given that the majority of the infrastructure required to maintain flow / input is present, and the re-allocation is effectively a return to 'normal' operating conditions (costs noted for the pumping of water to Lake Albert).

C – Decommissioning costs are minimal

Score - 'Yes' alignment with the criteria, with a 'high' level of confidence in this score.

Justification - This option is not considered to be infrastructure heavy. As discussed in the above parameter, the provision of re-allocation is likely to be a return to the status quo for the system and thus decommissioning should not be a significant issue.

M.2.2 - Indirect or environmental costs & benefits (limited to impacts that Government may be liable for through the application of the option)

A - Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes region)

Score - 'Probable' alignment with the criteria, with a 'high' level of confidence in this score.
Justification - There may be potential impacts to environments in the Murray associated wetlands of South Australia with this option. These impacts may result due to the water re-allocation limiting the availability of environmental flows in other areas of the Murray-Darling Basin. However, it is SKM's current understanding that wetland specific risk assessments are likely to be undertaken by the Government, which may mitigate potential impacts associated with re-allocation.

B - Maximises the indirect benefits experienced in the wider Lower Lakes region (e.g. tourism, agriculture, wine, lifestyle)

Score - 'Yes' alignment with the criteria, with a 'moderate' level of confidence in this score.
Justification - Potentially, the increased flow of freshwater into the Lakes is considered to warrant a maximum score for indirect benefits associated with the Lakes as a resource.

Adjustments for Option Combination 1

Further Information on the perceived potential environmental impacts is presented in Appendix I.

Preventative or Treatment: This option is regarded as a 'semi-preventative' approach, given that stabilisation is considered only to elevations of -1.5 m AHD (Lake Alexandrina) and -0.5m AHD (Lake Albert). The ideal scenario to mitigate all risks is stabilisation to between 0.0 and 0.3 m AHD.
Negative Impacts: Generally, low impacts have been identified for this option. Whilst there are potential issues relating to:

- Minor mobilisation of acid and heavy metals from oxidised sediment following inundation (i.e. leaching) with freshwater;
- initial turbidity increases;
- some potential salinisation (in the medium to long term through evaporation of water body and leakage of seawater through the barrages); and
- inconsistency of water level management.

These risks are considered to be relatively low at this time.

Extensive research has been conducted into the effect of inundating exposed sediments with water (both freshwater and seawater) and a more detailed discussion on this issue is provided in Section 3.3.6.

Additionally, there may be some minor turbidity increases upon inundation although given the low dynamics of the system, any turbidity generated in the water column would be expected to decrease relatively quickly following inundation.

The 'semi' stabilisation of the water level to -1.5 m AHD may increase water column salinity in comparison to the 'full' inundation of the system (i.e. to 0.0 – 0.3 m AHD). This may occur through long term leakage of seawater through the barrages coupled to evaporation of the (predominantly fresh) water body. However, this may be managed by sporadic environmental flows that could have a flushing effect on the system.

A further potential issue is the potential inconsistency in water level management. Local fluctuation of water inundation may lead to local scale wetting / drying scenarios, which could in some instances exacerbate the oxidation of pyrite, generation and mobilisation of acidity. Consideration may be given to prior neutralisation of oxidised sediments to prevent export of acidity and metals via flushing during re-flooding (e.g. Fitzpatrick et al., 2008; Macdonald et al., 2007).

Therefore the option is regarded as having the following risk matrix inputs:

- **Severity of Environmental Impact:** Moderate
- **Likelihood of Environmental Impact:** Unlikely

A moderate though unlikely impact therefore results in a ‘**Moderate**’ risk of adverse impacts.

Appendix N - Assessment of Option Combination 2

N - Option Combination 2: Enhanced Bioremediation and Seawater Stabilisation to -1.5 m AHD

This option comprises the stabilisation of the water level to -1.5 m AHD using seawater with application of enhanced bioremediation around the peripheral areas according to risk prioritisation of areas and rehabilitation mapping. The option considers no active acidification preventative measure being undertaken to address acidification of the central areas of Lake Alexandrina only; would require pumping for Lake Albert to be at or above -0.5m AHD.

N.1 Technically feasible and achievable in practice on the scale required

N.1.1 - Technically feasible (theoretically, will it work?)

A - Successful implementation of option is theoretically possible

Score - 'Probable' alignment with criteria, with a moderate level of confidence in this score.
Justification - Theoretically, the inundation of ASS with saltwater can be an effective strategy in preventing acidification. The shift to reducing conditions initiated by inundation of ASS may favour sequestration of iron-sulfide minerals and the in-situ transformation of soil acidity (Burton et al., 2008). Pyrite formation can be rapid in natural inter-tidal environments (Howarth, 1979), although it is likely that due to generally sluggish pyrite kinetics, that FeS minerals would preferentially exist (e.g. mackinawite, griegite). Both pyrite and mono-sulfides are known to reform in coastal acid sulfate soil landscapes due to seasonal shifts in hydrology or the formation of localised, highly reducing sub-environments (Bush and Sullivan, 1997; Rosicky et al., 2004; Burton et al., 2006, 2007). Portnoy and Giblin (1997a) demonstrated that saturating a drained and acidified former saltmarsh with seawater stimulated both Fe(III) and SO_4^{2-} reduction. However, there are few examples of field-based investigations in acid sulfate soil landscapes which demonstrate the effectiveness of re-establishing tidal inundation (or application of seawater) at either ameliorating acidity or sequestering Fe(II)-sulfide minerals such as pyrite (see Powell and Martens, 2005).

Previous research (Ahern et al., 2009) undertaken at the East Trinity Site, Queensland, has indicated significant time lags (>17 months) associated with sediment pH increase and total actual acidity (TAA) decreases with respect to seawater inundation. These experiments also used hydrated lime dosing of the seawater, although the quantities of lime used is not provided. Additionally, the study by Ahern et al., indicated that mixing of freshwater with the saline inundation source may effectively dilute the neutralisation capacity of the marine source, and therefore additional volumes may be required (increasing the lake water salinity). However, it should be noted that the East Trinity test sediments were initially acidic (c. pH 2.5) and so the inundation was originally handicapped in terms of buffering the sediment.

The inundation at East Trinity can be viewed as a success based on the 'before' and 'after' scenario, whereby the acidic environment was returned to a circum-neutral environment, with associative environmental betterment in terms of vegetation. Therefore a 'probable' score has been recorded with a medium level of confidence. The application of seawater as a preventative measure is, in theory, relatively different, although the neutralisation of TAA may be expected depending on the mixing status of the source.

However it must be noted that the East Trinity site discussed above is a predominantly tidal environment and is not directly comparable to the Lower Lakes, which is a RAMSAR wetland.

B– Theoretically viable on the scale (spatial) required

Score - 'Probable' alignment with criteria, with a 'moderate' level of confidence in this score.
Justification - Theoretically, inundation (stabilisation) of the system using seawater is required to -1.5 m AHD and is considered to be theoretically viable across the system (large scale) and is perhaps more viable on a large scale than management on a local scale, due to the potential requirement for minor earthworks (dams, channels etc) on a local scale.
The bathymetry of the system may be an issue. Where land elevation exceeds the height of inundation, a cyclical wetting and drying scenario may develop, which can increase TAA and Fe content in pore water over time (Ahern et al., 2009). Previous research (Ahern et al., 2009) indicates that re-flooding of sediments is less effective furthest from the marine source (i.e. northern edge of lake) and on slightly higher elevations.

N.1.2 - Achievable in practice (has it been proven to work?)

A - Generic Proof of Concept established

Score - 'Yes' alignment with the criteria, with a high level of confidence in this score.
Justification – In a generic sense, the use of seawater as a method of sediment inundation to prevent oxidation of sulfidic material has been proven to be effective, although the generic proof of concept is generally on a different scale and in relation to a tidally inundated estuarine environment (Martens et al., 2004; Ahern et al., 2009). A key issue for the Lower Lakes with respect to this option is that the inundation of sediment using seawater is regarded as a method to prevent oxidation of sulfidic material and not as a method of acid neutralisation.

B - Proof of Concept established in similar (representative) environments

Score - 'Probable' alignment with the criteria, with a high level of confidence in this score.
Justification – There are few similar environments where seawater has been introduced to a freshwater environment. The use of seawater has been proven to be potentially effective in estuarine acid sulfate soil environments within Australia (see White et al., 1997; Indraratna et al., 2002; and Johnston et al., 2005). However these systems generally had brackish to saline waters initially, and therefore the transition from freshwater to seawater was not of concern. It is considered that for the purposes of this study, the use of seawater as an inundation 'source' (i.e, as a method of stabilisation and not as a neutralisation method) would limit the oxidation of sulfidic sediments and potentially initiate diagenetic processes leading to reductive dissolution of ferric iron (Fe^{3+}) and the reduction of sulfate (Johnston et al., 2009a). However the application of seawater

and its success as a means to mitigate acidity generation and retard acid mobilisation (and heavy metal / ammonia mobilisation) requires careful consideration as discussed in Section 3.3.6.

C – Proof of concept established in Lower Lakes environments and environs

Score – 'Unlikely' alignment with the criteria, with a moderate level of confidence in this score.
Justification – The use of seawater as a means of either inundation (i.e. to prevent oxidation) or neutralisation has not been trialled in the Lower Lakes environment. Previous research has focussed on the application of seawater to already acidified sediments (Johnston et al., 2009b), therefore the buffering / neutralisation of sediments that are not fully oxidised would appear to be achievable, and the inundation in terms of preventing oxidation is certainly achievable as a preventative measure. However as discussed previously, the influx of seawater and lack of flushing may lead to a hyper-saline environment in the Lake, due to evaporation and to some extent limited flushing of the system, depending upon barrage operating rules.

N.1.3 - Implemented successfully before acidification of the Lakes occurs

A1 – on a large scale

Score - 'Unlikely' alignment with the criteria, with a moderate level of confidence in this score.
Justification – The operation of the barrages to allow seawater to inundate Lake Alexandrina (and assuming subsequently Lake Albert) is itself assumed to be relatively achievable within the timeframes required (i.e. in the absence of specific barrage operating protocols for this procedure). However it is considered that there are two key issues that may affect the successful implementation of the use of seawater as a stabilisation methodology, as follows:

1. The key infrastructure that would be required to separate the River Murray and the saline Lake Alexandrina at Pomanda Island; and

2. The fine tuning and potential revision of coastal barrage operating procedures (i.e. Goolwa and Tauwitchere Barrage) that would be required to manage seawater transfer. The pumping of 'shandied' (i.e. fresh and seawater mixture) from Lake Alexandrina to Lake Albert would require revision of pumping strategies.

A2 – on a localised scale
Score - 'Probable' alignment with the criteria, with a low level of confidence in this score.
Justification – Some data gaps concerning operational implementation of such an approach, and the inherent difficulties in transferring water (and maintaining water) to localised sections, on the larger scale of the Lower Lakes. It is considered that further developmental works may be required, e.g. land-forming that can retain localised bodies of seawater around the extremities of the lake bodies, should extremity hotspots require treatment via this method.

N.2 - Costs to Government (State and Federal)

N.2.1 - Direct lifecycle costs (dollar costs directly apportioned to the entire lifecycle of the option)

A - Capital / Establishment costs are minimal

Score - 'Unlikely' alignment with the criteria, with a moderate level of confidence in this score.
Justification - Management of the coastal barrages would be required in their current state. Also, the commissioning of a Weir at Pomanda Island requires significant capital expenditure.

B – Operational / Maintenance costs are minimal

Score - 'Probable' alignment with the criteria, with a moderate level of confidence in this score.
Justification - The ongoing maintenance costs are considered to be known to decision makers. For the purposes of this assessment the costs are forecast as "probable', as the actual operational and maintenance costs are perceived to be not inhibitive in comparison with the likely capital (establishment) costs. The assigned level of confidence for this assessment is 'moderate'.

C – Decommissioning costs are minimal

Score - 'Unlikely' alignment with the criteria, with a moderate level of confidence in this score.
Justification - The decommissioning costs can be forecast with a high level of confidence as being moderate to high, with respect to infrastructure. However, in terms of completely decommissioning the option and resolving the salinisation of the system (i.e. returning the system to pre-drought conditions), the alignment is 'unlikely' against cost criteria.

N.2.2 - Indirect or environmental costs & benefits (limited to impacts that Government may be liable for through the application of the option)

A - Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes region)

Score - 'Yes' alignment with respect to the criteria, with a high level of confidence in this score.
Justification – Although this option is considered to require reasonably significant infrastructure requirements (material input) for potential infrastructure with respect to weirs etc, it is considered that the use of seawater would result in lower impacts (inputs) from the wider environment, with respect to freshwater, neutralising agents (in comparison to drawdown) and ongoing requirement for source of environmentally allocated water (i.e. impact on other wetlands in Murray-Darling system).

B - Maximises the indirect benefits experienced in the wider Lower Lakes region (e.g. / tourism, agriculture, wine, lifestyle)

Score - 'Probable' alignment with the criteria, with a low level of confidence in this score.
Justification - The inundation of the area with seawater is considered to be beneficial in terms of maximising lifestyle (relatively, via return of amenity value) although this is tempered by the salinisation of the system and the potential impacts on agri / viticultural extraction and potential increased requirement for treatment of lake waters prior to use. The probable alignment is given relative to the drawdown option.

N.3 - Adjustments for Option Combination 2

Further Information on the perceived potential environmental impacts is presented in Appendix I.

Preventative or Treatment: As with option combination 1, this option is regarded as a 'semi-preventative' approach. Note that if the option is used as a treatment (as discussed earlier in the report), then potentially significant negative impacts to the environment may occur (see below).
Risk of Negative Impacts: Even if it is assumed that the option is effective in treating the acidification of the Lower Lakes, there is a risk that the following adverse impacts could eventuate as a result of implementing the option under the wrong conditions (i.e. post oxidation):

- Depending on the timescale of implementation and availability of freshwater source (i.e. Murray-Darling flows) the salinisation of the freshwater body (with the potential to become hyper-saline due to lack of flushing regime) is likely to occur;
- The provision of a refuge environment within the tributaries (Currency Creek and Finniss Creek) presents significant ecological safeguards should the Lower Lakes become a saltwater environment. However, due to the large scale of freshwater environment potentially impacted, the risks have still been classified as extreme;
- potential generation of hydrogen sulfide gas due to high quantities of sulfate in water from the Coorong that could result in an imbalance between sulphur and available iron (attributable to high salinity and considered less likely using standard ocean water);
- risk of adverse impacts on the Coorong and Murray Mouth associated with altered flow dynamics;
- potential loss of freshwater connection to the Coorong and with particular impacts upon diadromous fish species;
- Disconnection of Murray mouth to River Murray, with particular impacts upon diadromous fish species (this assumes fish passage is not possible for the proposed weir at Pomanda Island); and

- Mobilisation studies have indicated that seawater mobilises a significant amount of acidity and heavy metals / nutrients during inundation, if sulfidic sediments have oxidised (Sullivan et al., 2009, Hicks et al., 2009). Recent indications from Loveday Bay in the south-east corner of Lake Alexandrina show that overlying water can decrease to approximately pH 2 following re-wetting of ASS.

Based on the above considerations and implicit timing issues this combination is regarded as having the following risk matrix inputs:

- **Severity of Environmental Impact:** Critical
- **Likelihood of Detrimental Environmental Impact:** Possible

The combination of a critical and possible impact to the environment results in an '**Extreme**' risk in terms of adverse impacts.

Appendix O - Assessment of Option Combination 3

O - Option Combination 3: Enhanced Bioremediation and Drawdown to -2.0 m AHD

This option comprises the drawdown of the water level to -2.0 m AHD with establishment of enhanced bioremediation around the peripheral areas according to risk prioritisation of areas and rehabilitation mapping. The option considers no active acidification preventative measure being undertaken to address acidification of the central areas which are likely to be comprised of intermittent shallow pooled areas. However it is noted that this option could be improved by the pre-addition of neutralising agent to the water column prior to drawdown, so that the sediments were pre-treated. This pre-addition has not been trialled or tested and therefore is not considered here as an integral component of the option.

O.1 - Technically feasible and achievable in practice on the scale required

O.1.1 - Technically feasible (theoretically, will it work?)

A - Successful implementation of option is theoretically possible

Score - 'Probable' alignment with criteria, with a 'high' level of confidence in this score.
Justification - Theoretically, option combination 1 could be successful in mitigating the acidification of the Lower Lakes, assuming the following:

- that there was a sudden return to more normalised flow conditions;
- the generation and mobilisation of acidity was not as significant as forecast; or
- the buffering capacity of the system was such that any acidity generated could be naturally attenuated.

B– Theoretically viable on the scale (spatial) required

Score - 'Unlikely' alignment with the criteria, with a 'high' level of confidence in this score.
Justification - Whilst option combination 1 may work on the local scale, increasing the spatial size will probably limit the effectiveness of this option. For instance, conditions in part of the system may be such that the mobilisation of any acidity generated can be naturally attenuated, but due to the spatial variability in many environmental parameters, ideal conditions (i.e. effective inherent neutralisation capacity) are unlikely to occur across the entire system (based on the currently available information regarding heterogeneity of soils).

O.1.2 - Achievable in practice (has it been proven to work?)

A - Generic Proof of Concept established

Score - 'Probable' alignment with the criteria, with a moderate level of confidence in this score.
Justification - In some cases, the drawdown approach has coped with environmental acidification, for example sites where acid discharge occurs (not necessarily from ASS), but natural processes are sufficient to treat the acidity generated (e.g. Sarmientoa et al., 2009; Ergas et al., 2006). It is

possible that there are other cases where a natural drawdown process has occurred, but is not reported as there is no apparent problem evident.

With respect to the enhanced bioremediation component of the option, actively managed 'bioremediation' technologies have become well established methods in the treatment of contaminated land issues (Environment Agency, 1999), with numerous successful projects undertaken (e.g. see www.cl:aire.org.uk). The managed application of microbes to reduce sulfate as a preventative measure / treatment for acid sulfate soil has not yet been fully realised; however the occurrence of such processes in the natural environment are reasonably well documented. Several studies have identified the presence of SRB and active reduction of sulfate in saline and hyper-saline environments (Jakobsen et al., 2006; Foti et al., 2007 and Porter et al., 2007). Sulfate reduction has been documented in similar freshwater environments such as meromictic lakes (Tonolla et al., 2004) and oligotrophic lakes (Bak and Pfennig, 1991). It is considered that where anaerobic conditions exist (e.g. sediments and appropriate lake depths), then sulfate reduction can occur.

The use of vegetation as an ongoing substrate, actively supplemented where necessary by additional organic matter (should in situ organic matter be < 3%) should be sufficient to provide required input to microbial processes (i.e. mediated reduction of sulfate to sulfide) and / or ensure establishment of sub-oxic to anoxic conditions.

B - Proof of Concept established in similar (representative) environments

Score - 'Unlikely' alignment with the criteria, with a moderate level of confidence in this score.
Justification - There is documented proof of some acid sulfate soils (in estuarine wetlands in Australia) having an inherently high Acid Neutralising Capacity, which exceeds their acid generation potential (McElnea et al. 2004). In such cases, drawdown would be an effective management option as there would be no net acidity upon the oxidation and subsequent flushing of these sediments. However, most documented evidence throughout estuarine environments in Australia, suggests drawdown and exposure of acid sulfate soils may result in subsequent acid generation and discharge.

C – Proof of concept established in Lower Lakes environments and environs

Score - 'No' alignment with the criteria, with a high level of confidence in this score.
Justification - There is no apparent proof of concept regarding drawdown as a management option to mitigate acidification in the Lower Lakes. Allowing Lake levels to decline may result in the generation / mobilisation of acidity (significant generation and transport of acidity already noted in the Finniss/Currency Creek region as water levels have declined and then rebounded).

O.1.3 - Implemented successfully before acidification of the Lakes occurs

A1 – on a large scale

Score - ‘Unlikely’ alignment with the criteria, with a low level of confidence in this score.
Justification - Current indications suggest drawdown will not be successful in treating the acidification from ASS (CSIRO, 2009). In addition, drawdown is currently the status quo, and increased evidence of acidification has been identified. Therefore it is unlikely that this option could be effective in terms of acidification mitigation prior to acidification of the system. Also, the increased exposed area of sediment resulting from drawdown would increase the area requiring enhanced bioremediation, as demonstrated in Figure F4. Therefore the implementation time relative to option combinations where exposure of sediments is less is likely to be higher.

A2 – on a localised scale

Score - ‘Unlikely’ alignment with the criteria, with a moderate level of confidence in this score.
Justification - Current indications suggest drawdown will be unlikely to successfully treat the acidification from ASS (CSIRO, 2009). However, it is theoretically possible that the approach could work in some localised zones where conditions are conducive to minimal acidification (i.e. below predicted sulfuric content and / or presence of sufficient inherent buffering capacity). The increased exposed sediment areas would be easier to address on a local scale, although could still represent a significant area (assuming a 16km^2 generic hotspot area).

O.2 - Costs to Government (State and Federal)

O.2.1 - Direct lifecycle costs (dollar costs directly apportioned to the entire lifecycle of the option)

A - Capital / Establishment costs are minimal

Score - ‘Yes’ alignment with the criteria, with a reduced (moderate) level of confidence in this score - to capture the increased treatment / management area for enhanced bioremediation.
Justification - Assuming that the drawdown option is applied indefinitely, regardless of the effectiveness of the approach, then it is likely that its capital / establishment costs can be confidently predicted as minimal. However, the increased surface area requiring attention may offset some of the ‘savings’ in outright planting costs. This increased cost may be offset by the benefits that increased planting brings to the local (and wider) community.

B – Operational / Maintenance costs are minimal

Score - ‘Yes’ - Maximum alignment with the criteria, with a reduced (moderate) level of confidence in this score to capture the increased treatment / management area for enhanced bioremediation.
Justification - The drawdown approach will involve minimal operational and maintenance costs besides those costs required for environmental monitoring expenditure, which are applicable to other options regardless. Confidence is adjusted to ensure that vegetation costs are relative to other options.

C – Decommissioning costs are minimal

Score - Maximum alignment with the criteria, with a high level of confidence in this score.
Justification - As no infrastructure or specific management plan is required, it is considered that this option combination would incur minimal decommissioning costs. However, it should be noted that significant cost / effort is likely to be required to manage a full-scale return to historical conditions once increased freshwater flows became available.

O.2.2 - Indirect or environmental costs & benefits (limited to impacts that Government may be liable for through the application of the option)

A - Minimises the extent of indirect costs in other environments (geographically distinct from Lower Lakes region)

Score - 'Unlikely' alignment with the criteria, with a moderate level of confidence in this score.
Justification - Although the implementation of the option will involve no indirect costs to other environments in terms of environmental factors (i.e. the option has a relatively small carbon footprint and requires no raw materials – including water), there is a potential linked effect to other environments in terms of ecological contribution to other environments, should habitats be lost as a result of decreasing water levels. Accordingly, this criterion has been assessed as 'unlikely'.

B - Maximises the indirect benefits experienced in the wider Lower Lakes region (e.g. / tourism, agriculture, wine, lifestyle)

Score - 'Unlikely' alignment with the criteria, with a moderate level of confidence in this score.
Justification - Based on the drawdown component, it is considered unlikely that the implementation of this option would provide benefit to the wider Lower Lakes region as whole, even considering the increased implementation of the peripheral management (i.e. enhanced bioremediation).

O.3 - Adjustments

Further Information on the perceived potential environmental impacts is presented in Appendix I.

Preventative or Treatment: This option is regarded as neither a 'treatment' or 'preventative' approach, and so the combined option has been assessed under each area.

Risk of Negative Impacts: Even if it is assumed that the option is effective in treating the acidification of the Lower Lakes (unlikely), it is considered that there is a risk that the following adverse impacts could eventuate as a result of implementing this option:

- significantly lower Lake levels (including a completely dry Lower Lakes environment);

- increased salinity due to a lack of flushing and evaporative concentration;
- dust generation and erosion of exposed Lake sediments;
- eutrophication as water levels recede;
- anoxic conditions developing; and
- a key factor: the drawdown option does not remove the risk of pyrite oxidation and seiching of Lake water over oxidised sediments exposed in the Lake basin following drawdown (potentially the primary pathway for lake acidification) and / or rainfall events which may flush / export acidity and metals to the water bodies or discharge to the marine environment (Indraratna et al., 2002; Macdonald et al., 2007). The effect of sulfuric acid discharge to freshwater chemistry would be significantly detrimental to the environment (Russell and Helmke, 2002; Haraguchi, 2007). The 'extreme' risk rating reflects this consideration.

Based on the above considerations, which are regarded as being potentially significantly detrimental to the Lakes system, and is also reasonably likely, option combination 3 is regarded as having the following risk matrix inputs:

- **Severity of Environmental Impact:** Dangerous
- **Likelihood of Environmental Impact:** Likely

The combination of a dangerous level of impact (as defined earlier in the report) coupled to a reasonable likelihood results in an '**Extreme**' risk in terms of adverse impacts.