Alternative Options Appraisal - Lower Lakes Acidification Management

STAGE 2: ASSESSMENT OF COMBINATION OF ALTERNATIVE OPTIONS

- Draft
- 14 June 2010

Alternative Options Appraisal - Lower Lakes Acidification Management

REPORT ON COMBINATION OF ALTERNATIVE OPTIONS

- Draft
- 14 June 2010

Sinclair Knight Merz
ABN 37 001 024 095
Level 5, 33 King William Street
Adelaide SA 5000 Australia
PO Box 8291
Station Arcade SA 5000 Australia
Tel: +61 8 8424 3800
Fax: +61 8 8424 3810
Web: www.skmconsulting.com

Contents

List of Tables, Figures and Appendices

Tables in Text

Figures In Text

Figures

Appendices

SINCLAIR KNIGHT MERZ
SKM

Document history and status

Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
.01					

Distribution of copies

Revision	Copy no	Quantity	Issued to
DRAFT	1	1 – pdf electronic	SKM Library (J Fox)
DRAFT	2	1 – pdf electronic	SA Water (Dr D Ferretti)

Printed:	14 June 2010
Last saved:	13 June 2010 12:04 AM
File name:	I:\VESA\Projects\VE23239\Deliverables\DRAFT - Report\Text\VE23239 - Lower Lakes Alternative Options Report (DRAFT.02).docx
Author:	J Fox / G Davidson / D Currie / A Harrison
Project manager:	James Fox
Name of	SA Water
Name of project:	Alternative Options Appraisal - Lower Lakes Acidification Management
Name of document:	Report on Alternative Options Scoring – Stage II (Option Combination)
Document version:	Draft
Project number:	VE23239

Executive Summary

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, as an alternative to the use of seawater to inundate potentially acid generating sediments.

The location and layout of the Lower Lakes system is presented in Figure F1. Previous investigations undertaken by CSIRO (Fitzpatrick et al., 2008) produced predictive GIS mapping that predicted the distribution of fourteen sub-types of acid sulfate soil (ASS) in the Lower Lakes and River Murray below Lock 1, according to the various water level scenarios.

As the water levels drop in the Lower Lakes system (including Lake Alexandrina, Lake Albert, the Coorong and associated tributaries) as a result of drought conditions, previously deep water soils may eventually become exposed and dewatered. Subsequently they may become 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.

A proposed action of last resort has been determined which comprises the opening of the barrages separating the lakes from the sea in order to allow seawater to flow into the Lower Lakes system. The seawater would then re-flood the lakes and inundate the acid generating sediments. This action 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.

A preliminary assessment of options alternative to the opening of the barrages has been undertaken by SKM as Stage I of a two stage process and was designed to bring together and review a large number of studies which have been completed that are relevant to the consideration of alternative management options for the Lower Lakes system.

As these studies were undertaken by a range of Government agencies and consultants, a key objective of Stage I of the Alternative Options Study (AOS) was to review and process the information presented in the various studies to assess the technical feasibility and practicality of alternate potential management options.

Stage II (reported here) is a more detailed assessment based on the findings and conclusions of Stage I and focuses on the technical and practicality of using a combination of three selected alternative option combinations as discussed and reviewed in Stage I, as follows:

1. Enhanced bioremediation with water drawdown to -2.0 m AHD;
2. Enhanced bioremediation with freshwater stabilisation to -1.5 m AHD; and
3. Enhanced bioremediation with seawater stabilisation to -1.5 m AHD.

Central to each option is the implementation of enhanced bioremediation around the periphery of the lake system to manage acid generation sediments around the margins.

Enhanced bioremediation is a combination of pre-treating (neutralising) acid sediments and then colonising the sediments with suitable vegetation which will provide organic carbon substrate to the in situ microbial population over the long term. The microbes may then actively transform any residual acidity to non acidic pyrite and maintain a suitable anoxic soil regime.

Following a qualitative literature based multi criteria assessment of each option, the findings of this assessment are that the option combination 2 (freshwater stabilisation) is the highest ranking option combination. It is considered to be technical and practically more feasible (and cost effective) than the other options and has the least negative environmental impact.

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, as an alternative to the use of seawater to inundate potentially acid generating sediments.

1.1. Background

Water levels in the Lower Lakes system (including Lake Alexandrina, Lake Albert, the Coorong and associated tributaries) are currently at all time lows and are likely to drop further if drought conditions continue as predicted. The location and layout of the Lower Lakes system is presented in Figure F1. Previous investigations undertaken by CSIRO (Fitzpatrick et al., 2008) produced predictive GIS mapping that predicted the distribution of fourteen sub-types of acid sulfate soil (ASS) in the Lower Lakes and River Murray below Lock 1, according to the various water level scenarios.

As the water levels drop, previously deep water 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 predictive GIS maps developed by CSIRO indicated that the oxidation (and consequential acid generation) of sulfidic materials in the shallow lower lakes is potentially significant.

Increased spatial variability assessment of acid sulfate soils within the Lower Lakes was undertaken in 2009 (Grealish et al., 2009) and 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.

Other areas were identified with low $pH_{soil:peroxide}$, net acidity and $pH_{incubation}$ that would indicate potential areas of concern (i.e. sulfidic material) if water levels continue to lower and the acid sulfate soils are oxidised. These areas include isolated locations throughout Lake Alexandrina and the majority of Lake Albert.

The spatial assessment indicates that there are several (generally marginal / peripheral) areas in both Lakes that are considered to exhibit < 0 mol H^+/t net acidity. These areas are largely associated with sand strata that have low sulfidic acidity and adequate acid neutralising capacity. The majority of sediments within both Lakes and the Finniss River and Currency Creek however demonstrate medium (25-50 mol H^+/t) to high (50 - >1,000 mol H^+/t) net acidity.

The areas of significantly high 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, and hence the propensity for higher net acidity in Lake Albert is increased (Table 1).

SINCLAIR KNIGHT MERZ SKM

- **Table 1 - Net Acidity Statistics: Lake Albert[1]**

Water Levels (m AHD)	Net Acidity Classes (mol H^+/t; area in hectares)							Total for each water level (ha)	Cumulative Total (ha)
	>1000	500-1000	100-500	50-100	25-50	0-25	<0		
>-0.5	3	513	1721	393	216	179	539	3564	3564
-0.75 to -0.5	0	496	1204	260	115	89	472	2636	6200
-1.0 to -0.75	71	1069	990	109	62	32	111	2444	8644
-2.0 to -1.0	112	2961	4805	296	77	51	191	8493	17137
<-2.0	0	2	9	4	2	3	3	23	17160

With respect to Lake Alexandrina, zonal statistics were used to determine potential net acidity ranges associated with bathymetry. 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 (Table 2).

- **Table 2 - Zonal Statistics on the Net Acidity (all values are mol H+/t unless otherwise stated)[2]**

ZONE	DEPTH RANGE	AREA (ha)	MIN	MAX	RANGE	MEAN	STD
1	<-2.3m	22190	-464.448	1321.5	1785.95	231.194	150.442
2	-2.3m to -2.0m	10097	-795.806	640.427	1436.23	92.5058	143.715
3	-2.0m to -1.5m	9511	-702.345	1274.27	1976.61	49.3756	147.680
4	-1.5m to -1m	7186	-773.249	890.602	1663.85	29.6113	133.378
5	>-1m	12797	-804.595	785.818	1590.41	85.0631	147.144

[1] Source: CSIRO (net acidity data) and DEH, November 2009
[2] Source: CSIRO (net acidity data) and DEH, November 2009

The net acidity data presented above highlights the principle risk to the environment of acid sulfate soils, which is the drawdown of water level to below -1.5 m AHD, with subsequent rebound of water level above this datum, which would leach a significant amount of acidity into the environment.

Some peripheral areas within the Lower Lakes environs have experienced water level drawdown and subsequent exposure of acid sulfate soils, with significant generation of acidity. Around 200 ha of acidic water has been reported in Loveday Bay, in the southern region of Lake Alexandrina. Monitoring of pH in Loveday Bay lake water reported values less than 3. Completely or partially dissolved mussel shells were identified in this area (DEH, 2009a).

It has been recognised that action is necessary as a means of preventing serious and permanent damage to the Lower Lakes system as a result of acidification. An option of last resort is of the introduction of seawater into the Lakes via the barrages. It is considered that the inundation of sulfidic sediments with seawater would prevent sediments from becoming oxidised and prevent subsequent generation of acid. This action is seen as an 'action of last resort' to minimise the environmental consequences of acidification of the Lower Lakes system.

The South Australian Government 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 under the provision of the *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act).

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;

- 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.

Given that the proposed opening of the barrages is considered to be an 'action of last resort', the assessment of impacts associated with alternative management options to that proposed is a key priority.

1.2. Alternative Options Assessment

The adopted assessment process was a two stage assessment, as follows:

- A preliminary assessment (Stage I) designed to bring together and review a large number of studies which have been completed that are relevant to the consideration of alternative management options for the Lower Lakes system. As these studies were undertaken by a range of Government agencies and consultants, a key objective of Stage I of the Alternative Options Study (AOS) was to review and process the information presented in the various studies to assess the technical feasibility and practicality of alternate potential management options.
- Stage II (reported here) is a more detailed assessment based on the findings and conclusions of Stage I and focuses on the technical and practicality of using a combination of selected alternative options discussed and reviewed in Stage I.

Stage II of the assessment is reported here.

1.3. Objectives of the Alternative Options Study

The primary objective of this study is to identify (and rank) possible combinations of alternative management options that may be used as an alternative to the use of seawater as an acid sulfate soil prevention / treatment option in the Lower Lakes environs, South Australia.

1.4. Scope of Work (Stage II)

The Scope of Works was developed from the Request For Tender (RFT, reference CS4582B), and in consultation with the Alternative Options Study Management Team (SMT), during the project inception workshop component of the project. The Scope of Works for Stage I of the project is summarised in SKM, 2010 and is not repeated here. The Scope of Works for Stage II of the project is detailed below:

1.5. Summary of Stage I Nominated Options

The options nominated for assessment were as follows:

1. Do Nothing;
2. Bioremediation;

3. Inundation of Lakes with Seawater (via barrages);
4. Re-vegetation;
5. Neutralisation;
6. Provision of Freshwater via buy-backs; and
7. Provision of Freshwater (environmental allocations).

In addition, the pumping of seawater direct into Lake Albert from the Coorong was also considered in relation to the above seven options. A summary of each option is provided below, with a more detailed description (SMART review) of each option provided in Appendix A[3].

[3] Note that freshwater (environmental allocations) is considered to be a mirror option to 'buy-backs' and so is not replicated in Appendix A.

2. Summary of Stage I

The general methodology applied in Stage I of the assessment of potential alternative options was based on Multi Criteria Analysis (MCA), which provided 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 generic sources, were translated into quantitative scores, so that each option could be assessed relatively.

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.

Sensitivity analysis of the effect of variation in contribution from each of the two broad criteria was also undertaken. The assessment indicated that the 'provision of freshwater via environmental allocations' option is generally ranked as the number 1 option across the majority of technical versus costs contribution ratios. The provision of freshwater (buy-backs) also shared the number 1 ranking when costs contribution was minimised (i.e. 0%). The re-vegetation option ranks at number 2 for certain contribution ratios. However, further analysis of the scores indicated that the re-vegetation option scored poorly on a technical basis (i.e. in terms of acidification management), but retained a high ranking due to high scores awarded on the costs contribution, coupled to a high multiplier for the perceived low environmental risks.

The ranking of the seawater inundation (via barrages) option increased when the cost contribution was increased, as it is a low cost option. It did not score significantly well on the technical contribution as a treatment measure, as it is was downgraded by its potentially high environmental risk, associated with inundating oxidised sediments. However, as the option scored a technical ranking of 4 (from 8), it was considered that there may be merit in using this option as a preventative measure under certain conditions, i.e. to safeguard certain areas of Lake Albert.

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 an adjustment factor, which produced an overall score for relative assessment. The high ranking options (i.e. provision of freshwater) were judged to have less environmental risks associated with implementation / operation than the option of last resort (i.e. use of seawater). Further, the majority of the alternative options were considered to have less environmental risk than the use of seawater to mitigate 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 should seawater be applied to oxidised sediments (assuming no preliminary liming – neutralisation – operation has occurred).

Local scale application of options for the management of 'hotspots' of net acidity were also assessed, based on a threshold action criteria of 50 mol H^+/t net acidity, and assuming a 16 km^2 hotspot area. The hotspot application of options was scored with respect to application to the areas of the lakes with significant net acidity (i.e. below -1.0m AHD) as a conservative measure that is also valid for areas above -1.0 m AHD. The soil type (e.g. sands, clays) was taken into consideration during the assessment of option feasibility, and the presence of clays in Lake Albert below -1.0m AHD was considered to have a potential effect on the effectiveness of those options dependent on a relatively high hydraulic conductivity (i.e. bioremediation). The local scale assessment resulted in the provision of freshwater (buyback) being ranked the highest option (1) where 50% to 100% technical contribution is considered. This ranking fell significantly to 5 at 100% cost contribution, reflecting the significant financial resources required to implement this option. This pattern is also evident at a large scale. The respective higher scores for 'buy-back' versus 'environmental allocation' were attributable to the increased confidence in obtaining the required volume via purchasing, over that of re-allocation from other sources.

The provision of freshwater (environmental allocation) was ranked as the number 2 option over each cost contribution. Provision of freshwater (allocation) was the most stable ranked option irrespective of cost contribution. A similar pattern is also evident for this option at a large scale, although scored one ranking lower at a local scale. This is due to significantly lower costs associated with provision of water through buyback at a local scale where lower water volumes are required.

It was considered that there is likely to be overlap between a number of options to achieve implementation, for example vegetation and bioremediation are intrinsically linked, and would require some freshwater inundation, and perhaps some pre-neutralisation to pre-increase sediment pH to optional levels. Therefore a combination of options was considered relevant for assessment in Stage II:

- Stabilisation of lakes using water (i.e. freshwater and / or seawater); and
- Use of enhanced bioremediation (vegetation supported bioremediation).

2.1. Parallel Studies

In addition, three baseline Alternative Management Options (Options 1, 2 and 3) will be generated using the computer-aided hydromodelling software package ELCOM/CAEDYM (University of Western Australia). It is envisaged that the model outputs for Options 1 to 3 will be used to form a key element of the full Ecological Risk assessments (ERA) process and the Multi Criteria Decision Analysis (MCDA). It was decided by the SMT that two other options (Alternative Options 4 and 5 and combinations thereof) would not be evaluated using ELCOM/CAEDYM, but would be assessed in the alternative options study and in terms of their potential ecological and socio-economic impacts. However, all options will be synthesized and summarised in the Draft EIS report.

The three Alternative Management Options and their subsets of scenarios being modelled using ELCOM/CAEDYM (including their general, underlying assumptions and boundary conditions) are described in the following paragraphs. The following basic assumptions and boundary conditions apply:

- A combined period of 15 years is applied to capture a time for when the ‘action’ occurs (until 2015), followed by a ‘recovery’ until 2025.
- Worst case, generalised, flow conditions of 350 GL at Wellington is assumed for the duration of the action (until 2015); a recovery period of 10 years follows (either at entitlement flow or long term average flow)
- The inflow time series for 2010 was adjusted to allow for environmental water purchased / acquired prior to execution of the simulations in February, 2010
- For all simulations, and for the duration of the full length of the simulations (15 years), the models were configured such that:
  - Average 2008 rainfall, wind and solar radiation (annual) time series were repeated every year;
  - Total annual net evaporation (rainfall – evaporation) from the surface of the Lakes was equal to that measured in 1982 (e.g, historical time series from 2008 were scaled to 80 % to represent 1982 conditions).
- Conceptual base flow acid flux rate used, averaged across similar soil types
- For all simulations, Lake Albert was managed as follows:
  - For options 1a, 2a and 3a (see below): Sufficient water was pumped across the blocking bank at Narrung to maintain the water level in Lake Albert at or above -0.5 m AHD
  - During recovery, once the water level in Lake Alexandrina reached -0.5 m AHD, additional water was pumped to ensure that Lake Albert rose to 0.0 m AHD at the same time as Lake Alexandrina
  - For all simulations, when the water level rose to 0.0 m AHD during recovery, the blocking bank at Narrung was removed, effectively reconnecting Lakes Albert and Alexandrina. Similarly, it was assumed that the Regulator at Clayton, and Weir at Wellington (if in place) were removed
- Following the management options that continue for 5 years as outlined above, there follows two potential recovery climate patterns
  - “Average”: whereby a time series of flows at Wellington, representing an “average” year of inflows to Lake Alexandrina is applied to the model boundary at Wellington. The time series of flows was supplied to us by DWLBC
  - “Entitlement”: whereby a time series of flows at Wellington, representing an “entitlement” situation is applied to the model boundary at Wellington. The time series of flows was supplied to us by DWLBC

During the initial 5 year period (the duration of the action, until 2015), three options (‘actions’) have been considered for management.

- Do Nothing: also known as the “drawdown” scenario; worst case flow (and climate) conditions persist; the Lakes are drawn down based on the observed volumetric deficits between inflows and evaporative losses.

- Freshwater Stabilisation: whereby the water level is allowed to fall to -1.5 m AHD in Lake Alexandrina initially, and then managed to maintain that water level throughout the duration of the action. In these simulations, the excess evaporative demand which would otherwise cause the water level to fall substantially below -1.5 m AHD is met through the purchase/delivery of additional freshwater and provision of that water over Lock 1.

- Seawater Stabilisation: whereby water levels are managed as per the freshwater stabilisation option. However the excess evaporative demand is met through managed opening of Tauwitchere Barrage, such that estuarine water from the Coorong is allowed to flow into Lake Alexandrina.
- For the seawater stabilisation option, it was assumed that Wellington Weir was installed before seawater was introduced. Similarly, Wellington Weir was removed once the water level rose to 0.0 m for those simulations where it was in place.

In particular, a total of 12 model runs are being conducted using ELCOM/CAEDYM (SA Water, 2010, See Appendix D).

However, Additional Alternative Management Options, to be addressed as per the EIS guidelines, have been evaluated using different assessment mechanisms in Stage I of this assessment:

Alternative Option 4 – Bioremediation Sensitivity Trial runs

This alternative option has been evaluated using a combination of the outcomes of the Alternative Options Study as well as model outcomes from initial sensitivity simulations using ELCOM/CAEDYM. The principle evaluation will primarily be relying on findings of the Alternative Options Study. However, initial information on the possibility to model bioremediation effects in the near future more accurately has been gained already through initial simulations, testing sensitivities of the model results to changes in parameters. A total of two sensitivity trial simulations have been prepared.

Alternative Option 5 – Liming

This alternative option has been evaluated using a combination of the outcomes from the Alternative Options Study (in preparation by SKM, 2010) and acid generation rate results from the do-nothing drawdown scenario runs (Alternative Option 1 ELCOM/CAEDYM model results). The potential for successful hotspot treatment by a hypothetical increase of alkalinity in the water body (to counteract acidity generation) will be assessed. A semi-quantitative method will be applied including the use of approximate calcite dosing rates.

Alternative Option 6 – Lake segregation

This option has been evaluated using the outcomes from the Alternative Options Study (in preparation, SKM 2010) and those ELCOM/CAEDYM simulations that specify that Lake Albert would not receive any flow after October 2010 (1ba, 1bb, 2ba, 2bb, 3ba, 3bb).

Combination of other options

Based on the outcomes of the ERA and using evaluation results from Stage I of the Alternative Options Study, additional, value-adding, combinations of options will be assessed (qualitatively) here to further refine the potential to supplement each other in the effort to avoid broadscale acidification of the Lakes.

2.2. Enhanced Bioremediation

Enhanced 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, vegetation (as ongoing organic substrate) and any associated infrastructure to enable this.

In addition to the perceived benefits obtained with respect to management of acidification, the use of vegetation colonisation across any newly exposed sediments has added benefits of soil stabilisation (i.e. from wind activity).

A conceptualisation of Enhanced Bioremediation is presented in Figure 1.

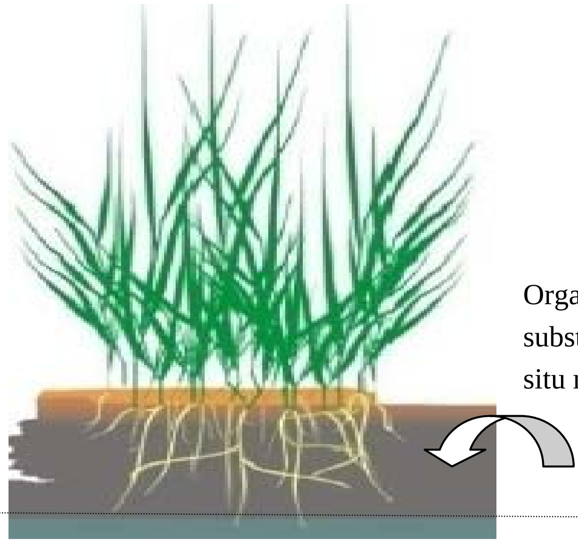
A detailed discussion of microbially mediated bioremediation (i.e. transformation of sulfate to sulfide) is presented in the Stage I Report (SKM, 2010).

In the context of this project *vegetation* is the term used for covering the soils affected by lack of water within the Lower Lakes system with vegetation.

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.

- **Figure 1 - Conceptual Enhanced Bioremediation**



3. Methodology

3.1. Overview

The general methodology applied in Stage II of this study to review potential combination of alternative options is as used in Stage I, i.e. a Multi Criteria Analysis (MCA) approach. 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 MCA approach for Stage II followed on from Stage I and the workshops held by the SMT to determine the most appropriate combination of options based on the conclusions of Stage I.

A detailed description and discussion of the MCA approach is provided in SKM, 2010.

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 3).

Table 3 - 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. MCA Development

The chosen criteria (as above) were then processed through a SMART review in order to fully define the exact interpretation of each criterion to sub-criteria level, as presented in Table 4.

Table 4 - 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 prescribed potential alternative options, in order to assess each option in the same 'currency' as the criteria, as presented in Table 5.

Table 5 - 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 resulting SMART review for the options is presented in Appendix A.

The determined criteria 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 3) 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 3 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 - Decision Confidence Assessment). 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

Based on the following standard risk assessment matrix (Table 6):

Table 6 - 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 7 and Table 8:

Table 7 - 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***.

SINCLAIR KNIGHT MERZ SKM

- **Table 8 - 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).

3.3. MCA scoring & reporting

The process culminates with 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.

3.4. Combination of Options

The combinations of options to be assessed qualitatively (i.e. not by ELCOM/CAEDYM) were defined by the SMT as follows:

1. Enhanced Bioremediation with Drawdown to -2.0 m AHD;
2. Enhanced Bioremediation with Freshwater Stabilisation to -1.5 m AHD; and
3. Enhanced Bioremediation with Seawater Stabilisation to -1.5 m AHD.

Enhanced Bioremediation is considered to represent the combination of the following components:

- Establishment of vegetation in order to provide a carbon substrate to the sediment;
- Addition of neutralising agent prior to vegetation establishment so as to develop optimal conditions for vegetation establishment;

- Onset of reduction of sulfate (as sulfuric acid) in the subsurface as a result of carbon substrate input and progressive anoxia of sediments.

A conceptual summary of the Stage II assessment is provided in Figure X.

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.

For the purposes of scoring each option combination (and to avoid unnecessary repetition), it is assumed that the concept of enhanced bioremediation (as defined in Section 2.2) is technically and practically achievable.

4. Scoring Assessment

The results and associated justification of the scoring assessment for each option is presented in this section. The Issues Registers providing the underpinning support to this section and completed during the review of each option are presented in Appendix D. The confidence determination is based on the parameter specific requirements presented in Appendix C.

The MCA scoring matrices for each option are presented as Tables T1 to T3 in Appendix D.

A conceptual schematic of each of the three options is presented in Figures F4 to F6.

4.1. Option Combination 1: 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. The issue register for this option is presented as Table A in Appendix D - . The MCA Scoring Assessment is presented as Table 001.

The SMART review for option combination 1 is presented in Appendix A.

The conceptual schematic is presented in Figure F4.

Heading	Sub Criteria	Base Criteria	Score	Justification
Technically feasible and achievable in practice on the scale required	**Technically feasible (theoretically, will it work?)**	**A - Successful implementation of option is theoretically possible**	'Probable' alignment with criteria, with a 'high' level of confidence in this score.	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 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	'Unlikely' alignment with the criteria, with a 'high' level of confidence in this score.	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 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).

	Achievable in practice (has it been proven to work?)	**A - Generic Proof of Concept established**	'Probable' alignment with the criteria, with a medium level of confidence in this score.	In some cases, the 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. With respect to the enhanced bioremediation portion 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 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	'Unlikely' alignment with the criteria, with a moderate level of confidence in this score.	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 acid generation 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	'No' alignment with the criteria, with a high level of confidence in this score.	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.

Implemented successfully before acidification of the Lakes occurs		**A1 – on a large scale**	'Unlikely' alignment with the criteria, with a low level of confidence in this score.	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	'Unlikely' alignment with the criteria, with a moderate level of confidence in this score.	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[4]).
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**	'Yes' alignment with the criteria, with a reduced (medium) level of confidence in this score to capture the increased treatment / management area for enhanced bioremediation.	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.

[4] As per Stage I, the generic hotspot area has been taken as approximately the size of Loveday Bay.

		B – Operational / Maintenance costs are minimal	'Yes' - Maximum alignment with the criteria, with a reduced (medium) level of confidence in this score to capture the increased treatment / management area for enhanced bioremediation.	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	Maximum alignment with the criteria, with a high level of confidence in this score.	As no infrastructure or specific management plan is required, it is considered that this option combination would incur minimal decommissioning costs.

	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)**	'Unlikely' alignment with the criteria, with a medium level of confidence in this score.	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)	'Unlikely' alignment with the criteria, with a medium level of confidence in this score.	Based on the drawdown component, 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.

Option Combination 1 Adjustments

Preventative or Treatment: This option is regarded as a 'treatment' approach due to the majority of the option (i.e. drawdown of water level) being non-preventative in 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 D 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 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.

4.2. Option Combination Two: Enhanced Bioremediation and Freshwater Stabilisation to -1.5 m AHD

This option comprises the stabilisation of the water level to -1.5 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. The issue register for this option is presented as Table B in Appendix D - . The MCA Scoring Assessment is presented as Table T2 in Appendix D.

The SMART review for option combination 2 is presented in Appendix A.

A conceptual schematic of the option is presented in Figure F5.

Heading	Sub Criteria	Base Criteria	Score	Justification
Technically feasible and achievable in practice on the scale required	Technically feasible (theoretically, will it work?)	**A - Successful implementation of option is theoretically possible**	'Yes' alignment with criteria, with a 'high' level of confidence in this score.	Theoretically, option combination 2 could 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 was such that any residual acidity generated could be naturally attenuated.
		B– Theoretically viable on the scale (spatial) required	'Probable' alignment with criteria, with a 'medium' level of confidence in this score.	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 should safeguard the predominant risk area of clay present in the central areas of Lake Alexandrina.

	Achievable in practice (has it been proven to work?)	**A - Generic Proof of Concept established**	'Yes' alignment with the criteria, with a 'high' level of confidence in this score.	As noted previously, the Enhanced Bioremediation component is assumed to be appropriately adequate. Generic proof of concept with respect to inundation (stabilisation) using freshwater 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	'Yes' alignment with the criteria, with a 'high' level of confidence in this score.	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	'Yes' alignment with the criteria, with a 'moderate' level of confidence in this score.	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.

Implemented successfully before acidification of the Lakes occurs		**A1 – on a large scale**	'Probable' alignment with the criteria, with a 'moderate' level of confidence in this score.	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	'Probable' alignment with the criteria, with a 'moderate' level of confidence in this score.	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.

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**	'Yes' alignment with the criteria, with a 'high' level of confidence (as opposed to 'medium' for option 1 due to increased required management area)	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	'Yes' alignment with the criteria, with a 'high' level of confidence in this score.	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	'Yes' alignment with the criteria, with a 'high' level of confidence in this score.	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.

	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)**	'Probable' alignment with the criteria, with a 'high' level of confidence in this score.	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 SA 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)	'Yes' alignment with the criteria, with a 'moderate' level of confidence in this score.	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 2

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. Fitzpatrick et al., 2008; 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.

4.3. Option Combination Three: Enhanced Bioremediation and Seawater Stabilisation to -1.5 m AHD

It is considered that this option would be as per option combination 2 with the difference being that seawater rather than freshwater is used. This option would not involve flooding the Lower Lakes with sea water, 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 (i.e. inundation).

This assessment has considered the option in the absence of specific information regarding operating rules for the barrages and means of delivering water via the barrages.

The MCA Scoring Assessment is presented as Table T3, Appendix D.

A conceptual schematic of the option is presented as Figure F6.

Heading	Sub-criteria	Base Criteria	Score	Justification
Technically feasible and achievable in practice on the scale required	**Technically feasible (theoretically, will it work?)**	**A - Successful implementation of option is theoretically possible**	'Probable' alignment with criteria, with a moderate level of confidence in this score.	Theoretically, the inundation of ASS with salt water 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 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 TAA may be expected depending on the mixing status of the source.
		B– Theoretically viable on the scale (spatial) required	'Probable' alignment with criteria, with a 'moderate' level of confidence in this score.	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).
	Achievable in practice (has it been proven to work?)	**A - Generic Proof of Concept established**	'Maximum' alignment with the criteria, with a high level of confidence in this score.	• Proved to be effective in a number of settings; • Generic proof of concepts are generally on a different scale under different environments; and • Seawater on acidic sediments has generally proven successful at the East Trinity site (Martens et al., 2004; Ahern et al., 2009).

		B - Proof of Concept established in similar (representative) environments	'Probable' alignment with the criteria, with a high level of confidence in this score.	• 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); • However - no documented cases where saline water (with a salinity higher than seawater) has been used to inundate a previously fresh water environment; • 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	'Unlikely' alignment with the criteria, with a moderate level of confidence in this score.	• Previous pumping from Lake Alexandrina into Lake Albert was considered to be successful in preventing any acidification of Lake Albert. • 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.

Implemented successfully before acidification of the Lakes occurs		**A1 – on a large scale**	'Yes' alignment with the criteria, with a moderate level of confidence in this score.	• 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); • 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; • 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	'Probable' alignment with the criteria, with a low level of confidence in this score.	• 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; • 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.
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**	'Yes' alignment with the criteria, with a high level of confidence in this score.	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	'Yes' alignment with the criteria, with a high level of confidence in this score.	The ongoing maintenance costs can be forecast with a high level of confidence as being minimal.

		C – Decommissioning costs are minimal	'Unlikely' alignment with the criteria, with a moderate level of confidence in this score.	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.
	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)**	'Yes' alignment the criteria, with a high level of confidence in this score.	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)	'Probable' alignment the criteria, with a low level of confidence in this score.	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.

Adjustments for Option Combination 3

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 fresh water resource (with the potential to become hyper-saline due to lack of flushing regime);
- 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 fish 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.

5. Summary of Results

Complete tabulation of the scoring results along with sensitivity analysis on the results for the entire system assessment is presented as Table T4.

At the default setting of 50/50 contribution from each of costs and technical stream, and applying the adjustment parameters, option combination 2 (enhanced bioremediation with freshwater stabilisation) appears to be ranked as the highest scoring option. Table 9 below presents the 50/50 rankings when the adjustment parameters are applied.

Table 9 - Ranking of adjusted options at 50/50 costs vs. technical contribution – Entire system

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

When each of the following adjustment parameters is removed:

- Prevention vs. treatment
- Risk of negative impacts

the ranking does not change (although the scores between option combinations 2 and 3 become much closer). Table 10 below presents the 50/50 rankings when the adjustment parameters are removed.

SINCLAIR KNIGHT MERZ SKM

Table 10 - 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	634
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 broken down further to provide rankings based on the relative contributions of technical feasibility (Table 11) and costs (Table 12).

Table 11 - 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	238
3	enhanced bioremediation with drawdown	79

SINCLAIR KNIGHT MERZ
SKM

- **Table 12 - 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 seawater stabilisation	396
3	enhanced bioremediation with drawdown	303

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.

The MCA scores were developed across a sliding scale of variation 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 cost vs. technical / practical feasibility. This contribution scale based on option ranking is presented as Figure F7. 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 F8.

The variation in option ranking over this scale is based on the change in contribution from heading criteria and not the sub and base criteria weighting (Appendix B). The contribution ranking scale (Figure F4) indicates that there is no change to the ranking of options across all contribution ratios.

6. Discussion

6.1. Technical vs. Costs

Based on both adjusted and non adjusted assessments, the enhanced bioremediation with freshwater stabilisation combination is ranked as the number 1 option across all contribution ratios.

There is a marginal decrease in all scores as the costs contribution decreases. The most significant decrease is associated with option combination 1 (enhanced bioremediation and drawdown) which displays an approximate 74% decrease, compared to 31% for combination 2, and 40% for combination 3, indicating that the technical aspects of combinations 2 and 3 are more robust and higher scoring than combination 1.

6.2. Environmental risks

A summary of the potential environmental risks per option is presented in Table 13. Combination 2 has a significantly lower environmental risk (as indicated by the risk multiplier) than combinations 1 and 3, which have relatively similar risk multipliers:

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

The low multiplier for combination 3 (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.

Table 13 – Summary of potential environmental risks for each of the options

Negative	Positive
1 – Enhanced Bioremediation with Drawdown	
▪ 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.	▪ **Relative ease of returning Lower Lakes to pre-action state upon re-flooding.** ▪ **Less management required with respect to water levels.**

▪ Additional costs associated with increased requirement for vegetation across exposed areas.	
2 – Enhanced Bioremediation with Freshwater Stabilisation	
▪ Salinisation of a fresh water 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. ▪ 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.**
3 - Enhanced Bioremediation with Seawater Stabilisation	
▪ 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 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 fish 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 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**

7. Conclusions

The Stage II assessment indicates that option combination 2 (enhanced bioremediation with freshwater stabilisation) is the top ranking option combination.

There is no change in the order of option combinations (with respect to rank) across all technical / costs contribution, indicating that option combination 2 is a significantly robust option.

There is no significant variation in preferred ranking considering both adjusted and non adjusted assessments.

There is a marginal decrease in all scores as the costs contribution decreases. The most significant decrease is associated with option combination 1 (enhanced bioremediation and drawdown) which displays an approximate 74% decrease, compared to 31% for combination 2, and 40% for combination 3, indicating that the technical aspects of combinations 2 and 3 are more robust and higher scoring than combination 1.

Combination 2 has a significantly lower environmental risk (as indicated by the risk multiplier) than combinations 1 and 3, which have relatively similar risk multipliers:

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

The low multiplier for combination 3 (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 2 would have the following potential environmental benefits:

- Predominant factor is the maintenance of current ecological characteristics / regimes
- It is considered that 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).
- Some 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.
- Desired level could be achieved via managed water savings across basin.

8. References / Bibliography

Ahern, C.R., McElnea, A.E., Sullivan, L.A. 2004. Acid Sulfate Soils Laboratory Methods Guidelines. Queensland Department of Natural Resources, Mines and Energy, Indooroopilly, Queensland, Australia.

Ahern, C, Smith, D., McElnea, A., Finch, N., Wilbraham, S., Van Heel., S., Sullivan, L. 2009. Lime assisted tidal exchange reduces acidity of dyked acid sulfate soil at East Trinity, Northern Australia. pers note to J Fox from C Ahern.

Anderson, D.O. 2006. Labile aluminium chemistry downstream a limestone treated lake and an acid tributary: Effects of warm winters and extreme rainstorms. Science of the total environment 366, 739-749.

Barton L.L. 1995. *Sulfate Reducing Bacteria*. Biotechnology handbooks, volume 8. Plenum Press, New York.

Brandt, K.K., Vester, F., Jensen, A.N., and Ingvorsen, K. 2001. Sulfate Reduction Dynamics and Enumeration of Sulfate-Reducing Bacteria in Hyper saline Sediments of the Great Salt Lake (Utah, USA), *Microbial Ecology, **41**, 1-11.*

Bush, T.T., and Sullivan, L.A. 1997. Morphology and behaviour of greigite from a Holocene sediment in Eastern Australia. *Australian Journal of Soil Research* 35, 853-861.

Burton, E.D., Bush, R.T., Sullivan, L.A. 2006. Sedimentary iron geochemistry in acidic waterways associated with coastal lowland acid sulfate soils. *Geochimica et Cosmochimica Acta* 70, 5455-5468.

Burton, E.D., Bush, R.T., Sullivan, L.A., Mitchell, D.R.G. 2007. Reductive transformation of iron and sulphur in schwertmannite-rich accumulations associated with acidified coastal lowlands. *Geochimica et Cosmochimica Acta* 71, 4456-4473.

Bottrell, SH; Mortimer, R.J.G; Spence, M; Krom, M.D; Clark, J.M; Chapman, P.J. 2007. Insights into redox cycling of sulfur and iron in peatlands using high-resolution diffusive equilibrium thin film (DET) gel probe sampling, *Chemical Geology*, **244(3-4)**, pp409-420.

Burton, E. D., Bush, R. T., Sullivan, L. A., Johnston, S. G., Hocking, R. K. 2008. Mobility of arsenic and selected metals during re-flooding of iron- and organic-rich acid-sulfate soil. *Chemical Geology* 253, 64-73.

Coleman, M.L., Hedrick, D.B., Lovley, D.R., White, D.C., Pye, K. 1993. Reduction of Fe(III) in sediments by sulfate reducing bacteria. *Nature* 361,436-438.

DEC. 2009. *DRAFT Treatment and management of acid sulfate soils and water in acid sulfate soil landscapes* Department of Environment and Conservation, Government of Western Australia, Acid Sulfate Soils Guideline Series, January 2009.

DEH. 2009a. Murray Futures Community Update – Department of Environment and Heritage, 2 September 2009.
DEH. 2009b. Murray Futures Fact Sheet – Department of Environment and Heritage, September 2009. Accessed at:
http://www.murrayfutures.sa.gov.au/images/file_groups/193/limestone_trials_in_currency_creek_and_the_Finniss_river_to_manage_acid_sulfate_soils.pdf

Domenico, P.A., Schwartz, F.W. 2008. *Physical and Chemical Hydrogeology*. 2nd Edition. Wiley, Inc. New York.

Earth Systems. 2009. Quantification of Acidity Flux Rates to the Lower Murray Lakes: Final Report. Prepared for the South Australian Environment Protection Authority. December 2009.

Ergas, SJ, J Harrison, J. Bloom, K Forloney, DP Ahlfield, K Nüsslein and RF Yuretich. 2006. Natural attenuation of acid mine drainage by acidophilic and acidotolerant Fe(III)- and sulfate-reducing bacteria. A.C.S. symposium series. 2006, vol. 940, pp. 105-127.

Fetter, C.W. 2000. *Applied Hydrogeology*. 4th Edition. Prentice Hall, New Jersey.

R.W. Fitzpatrick, P. Shand, S, Marvanek, R.H Merry, M. Thomas, M.D. Raven, S.L. Simpson and S. McClure. 2008. 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.

Foti, M., Sorokin, D.Y., Lomans, B., Mussman, M., Zacharova, E.E., Pimenov, N.V., Kuenen, J.G, and Muyser, G. 2007. Diversity, Activity and Abundance of Sulfate Reducing Bacteria in Saline and Hyper saline Soda Lakes, Applied and Environmental Microbiology, 73(7), 2093-2100.

Freeze, A.R., Cherry, J.R. 1979. *Groundwater*. Prentice Hall, New Jersey.

Freolich, P.N., Klinkhammer, G.P., Bender, M.L., Luedtke, N.A., Heath, G.R., Cullen, D., Dauphin, P. 1979. Early oxidation of organic matter in pelagic coastal sediments of the eastern equatorial Atlantic: suboxic diagenesis. *Geochimica Cosmochimica et acta*. 68, 3261-3270.

Grealish, G., Fitzpatrick, R.W., Chappell, A., Marvanek, S. 2009. Spatial variability of subaqueous and terrestrial acid sulfate soils and their properties for the Lower lakes, South Australia (DRAFT). CSIRO Land and Water Science Report 49/09, December 2009.

Green R, Waite T.D, Melville M.D, Macdonald B.C.T. 2008a. Effectiveness of an open limestone channel in treating acid sulfate soil drainage. *Water Air and Soil Pollution* 191, 293-304.

Green R, Waite T.D, Melville M.D, Macdonald B.C.T. 2008b. Treatment of acid sulfate soil drainage using limestone in a closed tank reactor. *Water Air and Soil Pollution* 191, 319-330.

Haraguchi, A. 2007. Effect of sulfuric acid drainage on river water chemistry in peat swamps forests in central Kalimanton, Indonesia. *Limnology* 8, 175-182.

Hicks, W.S., Creeper, N., Hutson, J., Fitzpatrick, R.W., Grocke, S., and Shand, P. 2009. The Potential for Contaminant Mobilisation Following Acid Sulfate Soil rewetting: Field experiment. Final Report Version 1.13. November 2009. Prepared by CSIRO for the South Australian Environment Protection Authority.

Indraratna, B., Glamore, W.C., Tularam, G. 2002. The effects of tidal buffering on acid sulfate soil environments in coastal areas of New South Wales. *Geotechnical and Geological Engineering*. 20, 181-191.

Jakobsen, T. F., Kjeldsen, K. U., and Ingvorsen, K. 2006. *Desulfohalobium utaense* sp. nov., a moderately halophilic, sulfate reducing bacterium isolated from Great Salt Lake, *International Journal of Systematic and Evolutionary Microbiology*, **56**, 2063-2069.

Johnston, S.G., Slavicho, P.G., Hirst, P. 2005a. The effects of controlled tidal exchange on improving water quality in acid sulfate soil backswamps. *Agricultural Water Management* 73, 87-111.

Johnston, S.G., Slavich, P.G., Hirst, P., 2005a Changes in surface water quality after inundation of acid sulfate soils of different vegetation cover. *Australian Journal of Soil Science* 43, 1-12.

Johnston, S.G., Keene, A.F., Bush, R.T., Burton, E.D., Sullivan, L.A., Smith, D., McElnea, A.E., Martens, M.A. Wilbraham, S. 2009a. Contemporary pedogenesis of severely degraded tropical acid sulfate soils after introduction of regular tidal inundation. *Geoderma*, 149, 335-346.

Johnston, S.G., Bush, R.T., Sullivan, L.A., Burton, E.D., Smith, D., Martens, M.A., McElnea, A.E., Ahern, C.R., Powell, B., Stephens, L.P., Wilbraham, S.T., van Heel, S. 2009b. Changes in water quality following tidal inundation of coastal lowland acid sulfate soil landscapes. *Estuarine, Coastal and Shelf Science*, 81, 257-266.

Konhauser, K.O., Mortimer, R.J.G., Morris, K., Dunn, V. 2002. Biogeochemical cycles and re-mobilisation of the actinide elements. In: *Interaction of micro-organisms with radionuclides*. Eds M.J. Keith Roach & F.J. Livens. Elsevier, Oxford.

Lovley, D.R., and Chapelle, F. 1995. Deep subsurface microbial processes. *Rev. Geophysics* 33, 365-381.

Lovley, D.R., and Goodwin, S. 1988. Hydrogen concentrations as an indicator of the predominant terminal electron accepting reactions in aquatic sediments. *Geochimica Cosmochimica et acta*. 52, 2993-3003.

Macdonald B.C.T., White I, Astrom, M.E., Keene, A.F., Melville M.D., Reynolds, J.K. 2007. Discharge of weathering products from acid sulfate soils after a rainfall event, Tweed River, eastern Australia. *Applied Geochemistry* doi:10.1016/j.apgeochem. 2007.07.004, (accepted 09/2007).

Manning, P.G., Murphy, T. P., and Mayer, T. 1988. Effect of Copper Sulfate on Pyrite Formation in Reducing Sediments, *Canadian Mineralogist*, **26**, 965-972.

McElnea, A.E, Ahern, C.R., Manders, J.A., and Smith, C.D. 2004. Variability of acid sulfate soil chemistry at East Trinity Remediation Site, Far North Queensland, Australia. ISCO 2004 - 13th International Soil Conservation Organisation Conference – Brisbane, July 2004. Conserving Soil and Water for Society: Sharing Solutions Paper No. 689 page 1

Minz, D., Flax, J.L., Green, S.J., Muyzer, G., Cohen, Y., Rittman, B., Stahl, D. 1999. Diversity of sulfate reducing bacteria in oxic and anoxic regions of a microbial mat characterised by comparative analysis of dissimilatory sulfate reductase genes. *Applied Environmental Microbiology*. 65, 4666-4671.

Odom, J.M., and Singleton, R. 1993. *The sulfate reducing bacteria: contemporary perspectives*. Springer-verlag, New York.

O'Flaherty, V., Mahony, T., O'Kennedy, R., Colleran., E. 1998. Effect of pH and sulfide toxicity thresholds of a range of methanogenic, syntrophic and sulfate reducing bacteria. *Process Biochemistry*, 33, 555-569

Parkes, R.J., Gibson, G.R., Muelluer-Harvey, I., Buckingham, W.J., and Herbert, R.A. 1989. Determination of the Substrates for Sulfate-reducing Bacteria within Marine and Estuarine Sediments with Different Rates of Sulfate Reduction, *Journal of General Microbiology*, **135**, 175-187.

PIRAMID Consortium, 2003, Engineering Guidelines for the Passive Remediation of Acidic and/or Metalliferous Mine Drainage and Similar Wastewaters, European Commission 5th Framework RTD Project - no. EVK1-CT-1999-000021 "Passive *in-situ* remediation of acidic mine / industrial drainage" (PIRAMID). University of Newcastle Upon Tyne, Newcastle Upon Tyne UK. 166pp. Available at web site www.natural-resources.org/minerals/europe/docs/**PIRAMID**_Guidelines_v1.0.pdf.

Porter, D., Roychoudhury, A. N., and Cowan, D. 2007. Dissimilatory sulfate reduction in hypersaline coastal pans: Activity across a salinity gradient, *Geochimica et Cosmochimica Acta*, **71**(21), 5102-5116.

Portnoy, J.W., and Giblin, A.E. 1997. Biogeochemical effects of seawater restoration to diked salt marshes. *Ecological Applications* 7, 1054-1063.

Postgate, J.R. 1984. *The sulfate reducing bacteria*. 2nd edition. Cambridge university press, Cambridge.

Powell, B, and Martens, M. 2005. A review of acid sulfate soil impacts, actions and policies that impact on water quality in Great Barrier Reef catchments, including a case study on remediation at East Trinity. *Marine Pollution Bulletin* 51, 149-64.

Rosicky, M.A., Slavich, P.G., Sullivan, L.A. and Hughes, M. 2006. Techniques for the re-vegetation of acid sulfate soil scalds in the coastal floodplains of New South Wales, Australia: ridging, mulching, and liming in the absence of stock grazing. *Australian Journal of Experimental Agriculture*, 46, 1589–1600.

Russell, D.J., Helmke, S.A., 2002. Impacts of acid leachate on water quality and fisheries resources of a coastal creek in northern Australia. *Marine and Freshwater Research* 53, 19-33.

SA EPA. 2007. South Australian Environmental Protection Authority. EPA Guidelines – Site Contamination – Acid Sulphate Soil Material EPA Guideline 638/07. Issued November 2007.

Sarmientoa, AM, Olíasb, M., Olíasb, J.M., Cánovasb, M.B., and J Delgado. 2009. Natural attenuation processes in two water reservoirs receiving acid mine drainage. *Science of The Total Environment*. Volume 407, Issue 6, 1 March 2009, Pages 2051-2062.

SKM. 2009. Lake Alexandrina and Lake Albert Groundwater Investigations to Support EIS. Final Report Version 2, 11th December 2009.

Skyring, G.W. 1987. Sulfate reduction in coastal sediments. *Geomicrobiology Journal*, 5, 295-374.

Smith, R. L., and Klug, M. J., 1981. Electron Donors Utilized by Sulfate Reducing Bacteria in Eutrophic Lake Sediments, *Applied and Environmental Microbiology*, **42**(1), 116-121.

Sullivan, L.A., Bush, R.T., Ward, N.J., Fyfe, D.M., Johnston. M., Burton, E.D., Cheeseman, P., Bush, M., Mher, C., Cheetham, M., watling, K.M., Wong, V.N.L., Maher, R., and Weber, E. 2009. Lower lakes laboratory study of contaminant mobilisation under seawater and freshwater inundation (long term study). Southern Cross Geoscience Technical Report No. 1109 prepared for South Australian Environmental Protection Authority (EPA), Adelaide.

Tonolla, M., Peduzzi, S., Demarta, A., Peduzzi, R. and Hahn, D., 2004. Phototropic sulphur and sulfate-reducing bacteria in the chemocline of meromictic Lake Cadagno, Switzerland, *J. Limnol*, **63**(2), 161-170.

Ward, N.J., Sullivan, L.A., Bush, R.T. 2004a. The response of partially-oxidised acid sulfate soil materials to anoxia. *Australian Journal of Soil Research*, 42, 515-526.

Ward, N.J., Sullivan, L.A., Bush, R.T. 2004b. Soil pH, oxygen availability and the rate of sulfide oxidation in acid sulfate soil materials: implications for environmental hazard assessment. *Australian Journal of Soil Research*, 42, 509-514.

Ward, N.J., Sullivan, L.A., Fyfe, D.M., Bush, R.T., Ferguson, A.J.P. 2004. The process of sulfide oxidation in some acid sulfate soil materials. *Australian Journal of Soil Research*, 42, 29-37.

Wawer, C., and Muyzer, G. 1995. Genetic diversity of Desulfovibrio sp. In environmental samples analysed by denaturing gradient gel electrophoresis of hydrogenase gene fragments. *Applied Environmental Microbiology*, 61, 2203-2210.

White, I., Melville, M.D., Wilson, B.P., Sammut, J., 1997. Reducing acidic discharges from coastal wetlands in eastern Australia. *Wetlands Ecology and Management* 5, 55-72.

Wright, D. T. 1999. The role of sulfate –reducing bacteria and cyanobacteria in dolomite formation in distal ephemeral lakes of the Coorong region, South Australia, *Sedimentary Geology*, **126**(1-4), 147-157.

Young, T.C, Rhea, J.R., and McLaughlin, G. 1986. Characterisation and neutralisation of two acidic lake sediments. *Water, Air and Soil Pollution* 31, 839-846.

9. Limitations

This report has been prepared by Sinclair Knight Merz Pty Limited ("SKM") for the sole use of the SA Water ("the Client") and in accordance with the scope of services outlined in the proposal prepared for the client dated 16 June 2009.

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.

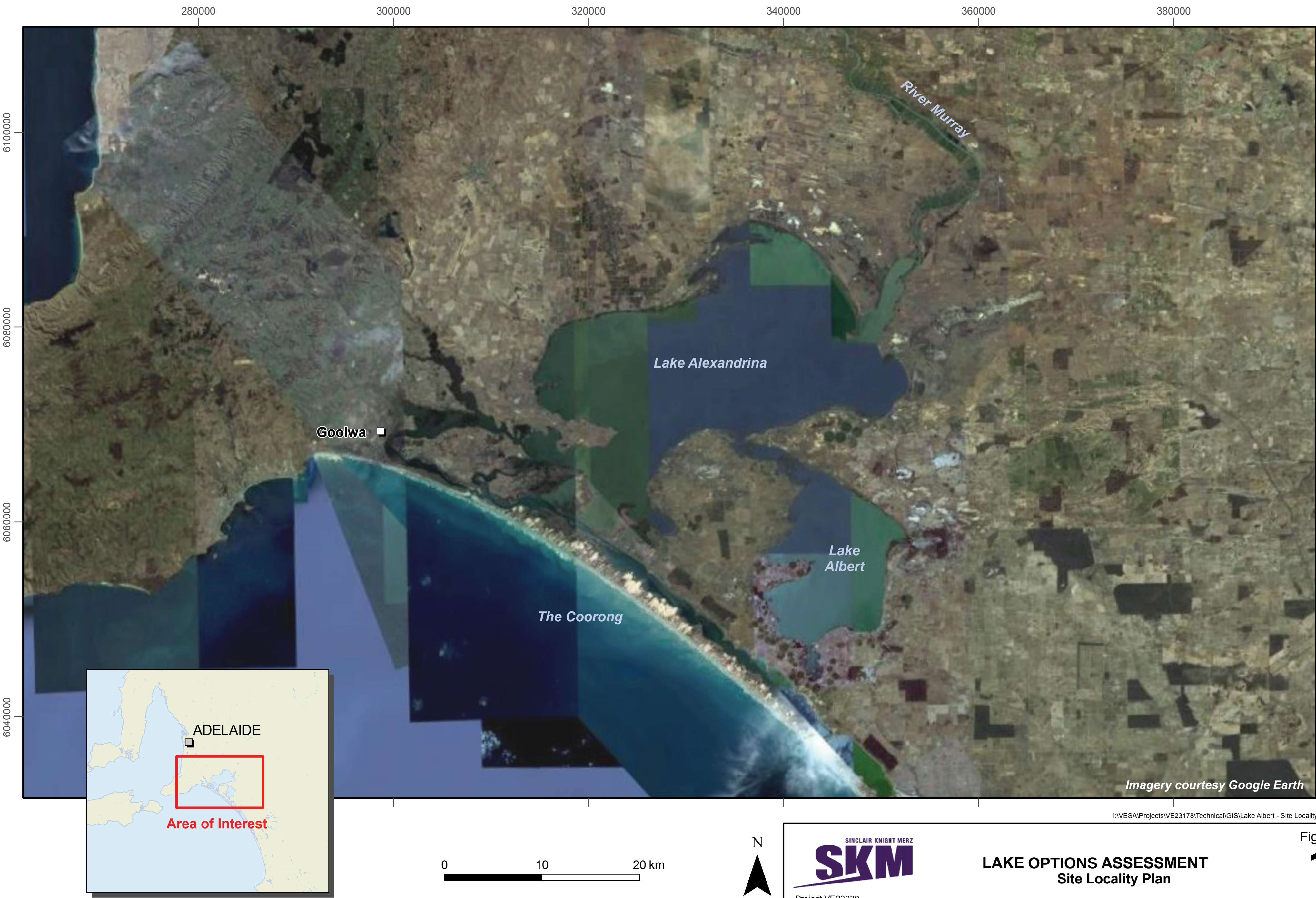
It is imperative to note that the Report only considers the site conditions current at the time of assessment, and to be aware that conditions may have changed due to natural forces and/or operations on or near the site. Any decisions based on the findings of the Report must take into account any subsequent changes in site conditions and/or developments in legislative and regulatory requirements. SKM accepts no liability to the Client for any loss and/or damage incurred as a result of a change in the site conditions and/or regulatory/legislative framework since the date of the Report.

The Report is based on an interpretation of factual information available and the professional opinion and judgement of SKM. Unless stated to the contrary, SKM has not verified the accuracy or completeness of any information received from the Client or a third party during the performance of the services under the Agreement, and SKM accepts no liability to the Client for any loss and/or damage incurred as a result of any inaccurate or incomplete information.

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.

Any reliance on this report by a third party shall be entirely at such party's own risk. SKM provides no warranty or guarantee to any third party, express or implied, as to the information and/or professional advice indicated in the Report, and accepts no liability for or in respect of any use or reliance upon the Report by a third party.

Figures

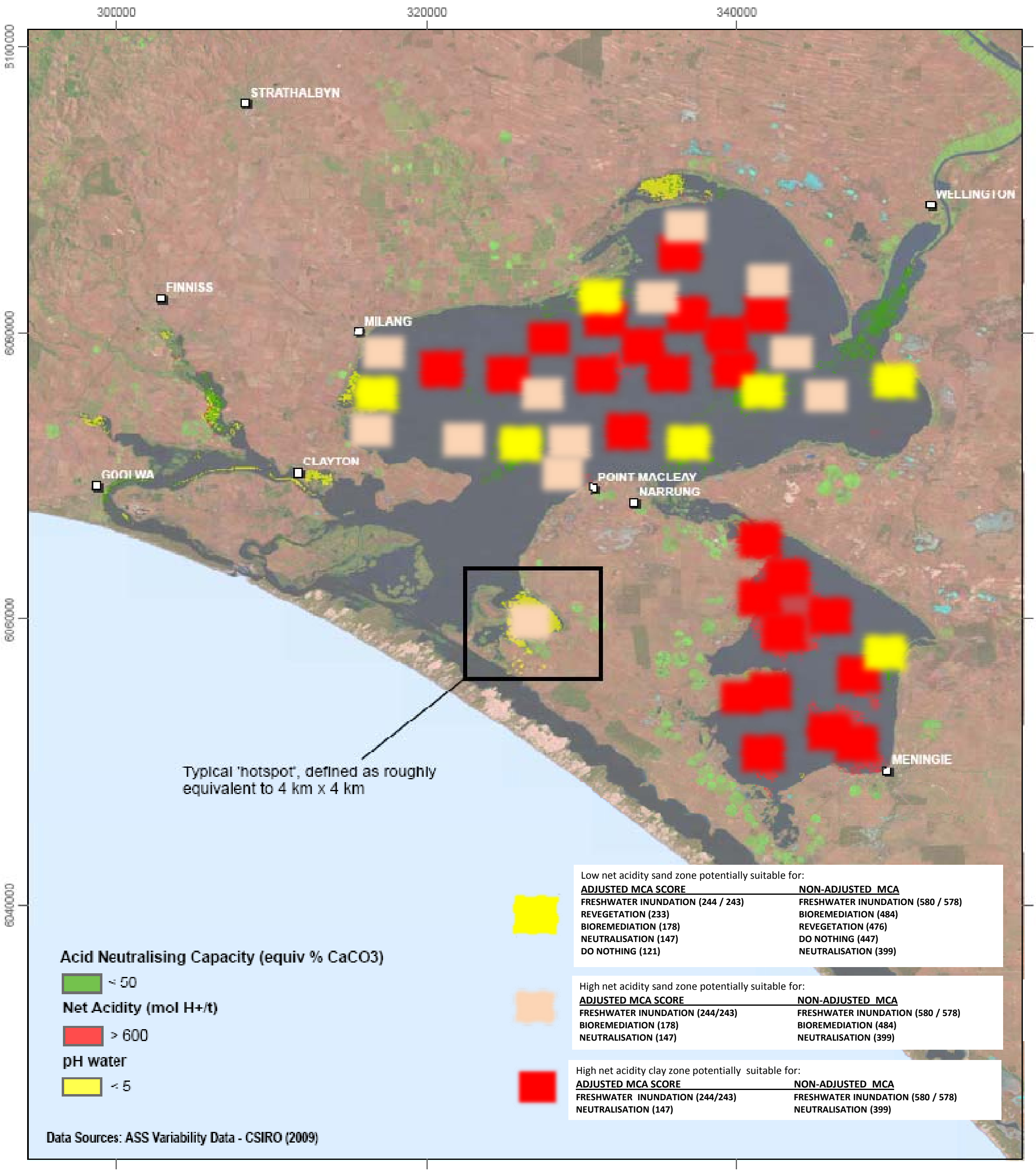


I:\VESA\Projects\VE23178\Technical\GIS\Lake Albert - Site Locality.mxd

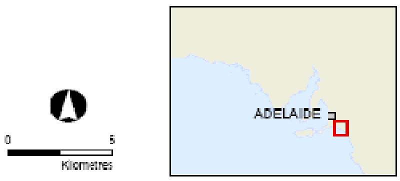
SINCLAIR KNIGHT MERZ
SKM
Project VE23239

LAKE OPTIONS ASSESSMENT
Site Locality Plan

Figure
1



Note that the options scores given are based on 50/50 technical / cost contribution. Inundation of sediments with seawater has not been included due to the considered risk of acid mobilisation following rewetting, based on numerous field and laboratory studies. This figure is provided as a summary only and should not be used out of context from the accompanying text. This figure should not be used for decision making purposes and is a result of preliminary assessment of options only.

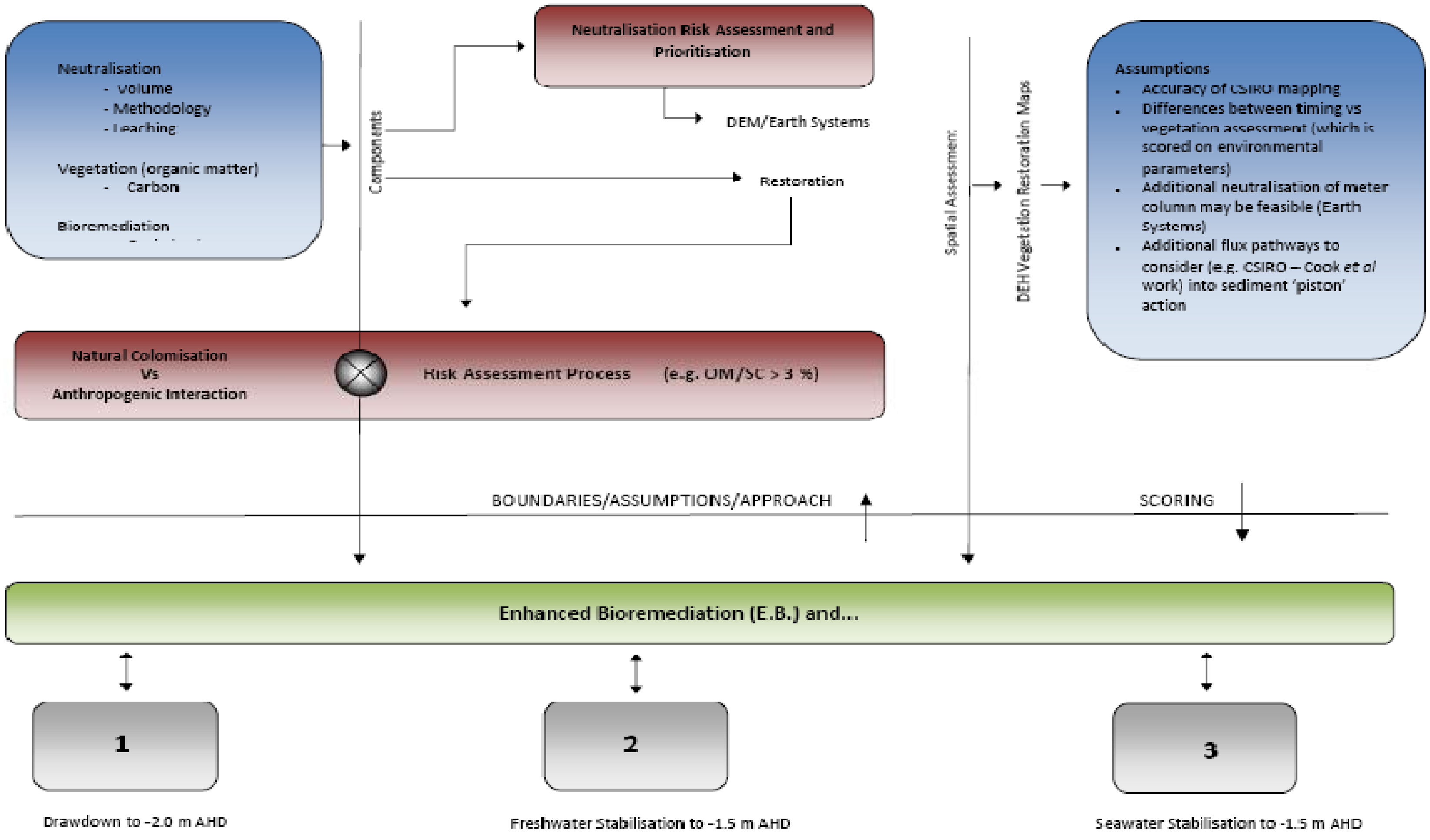


Lower Lakes Alternative Options Analysis
Hotspot Management - Potential Management Options

FIGURE F2

PROJECT VE23239

June-10



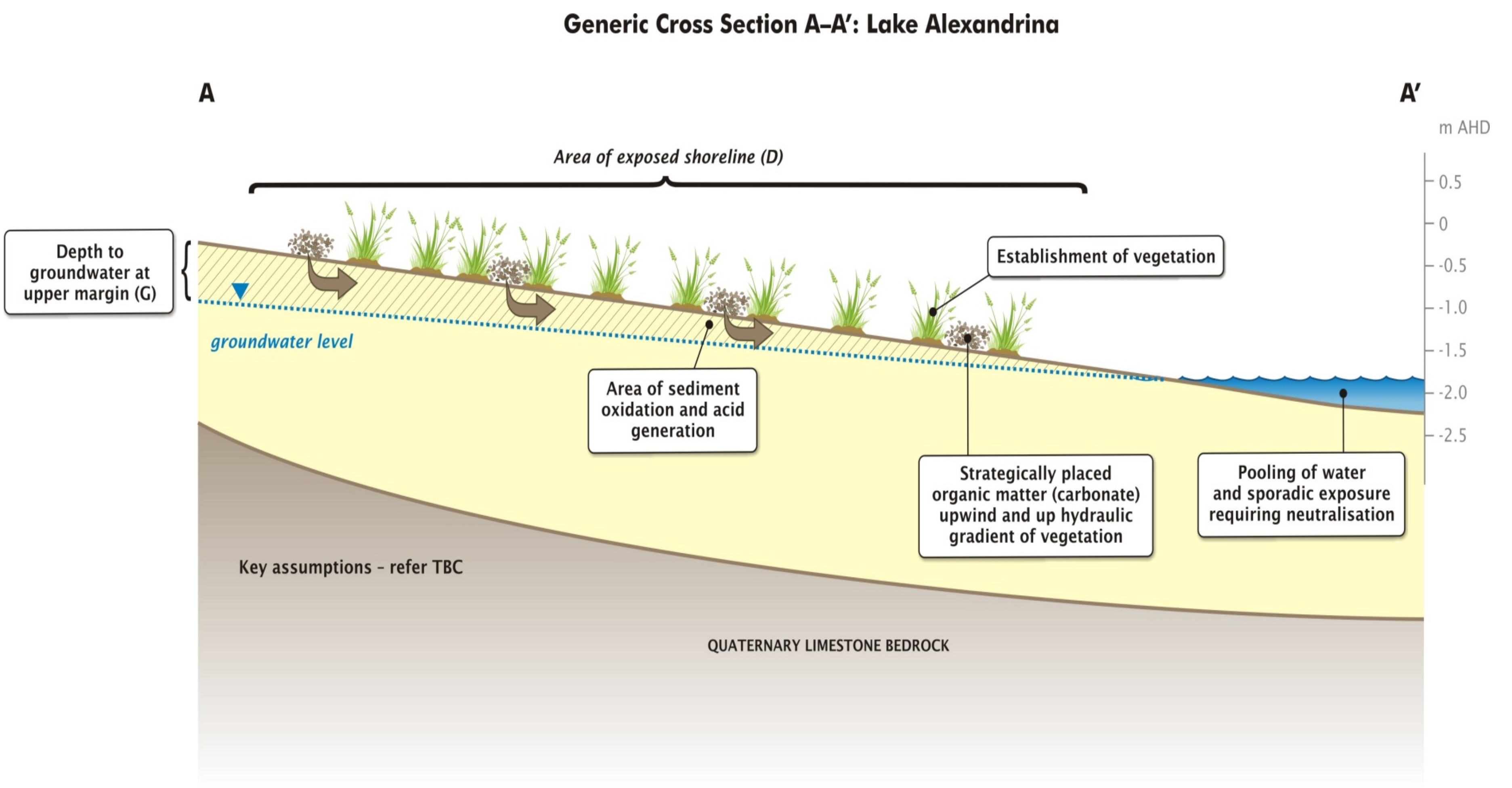
FIGURE

Lower Lakes Alternative Options Analysis - Stage II
Assessment Assumptions and Boundaries

F3

PROJECT VE23239

June-10



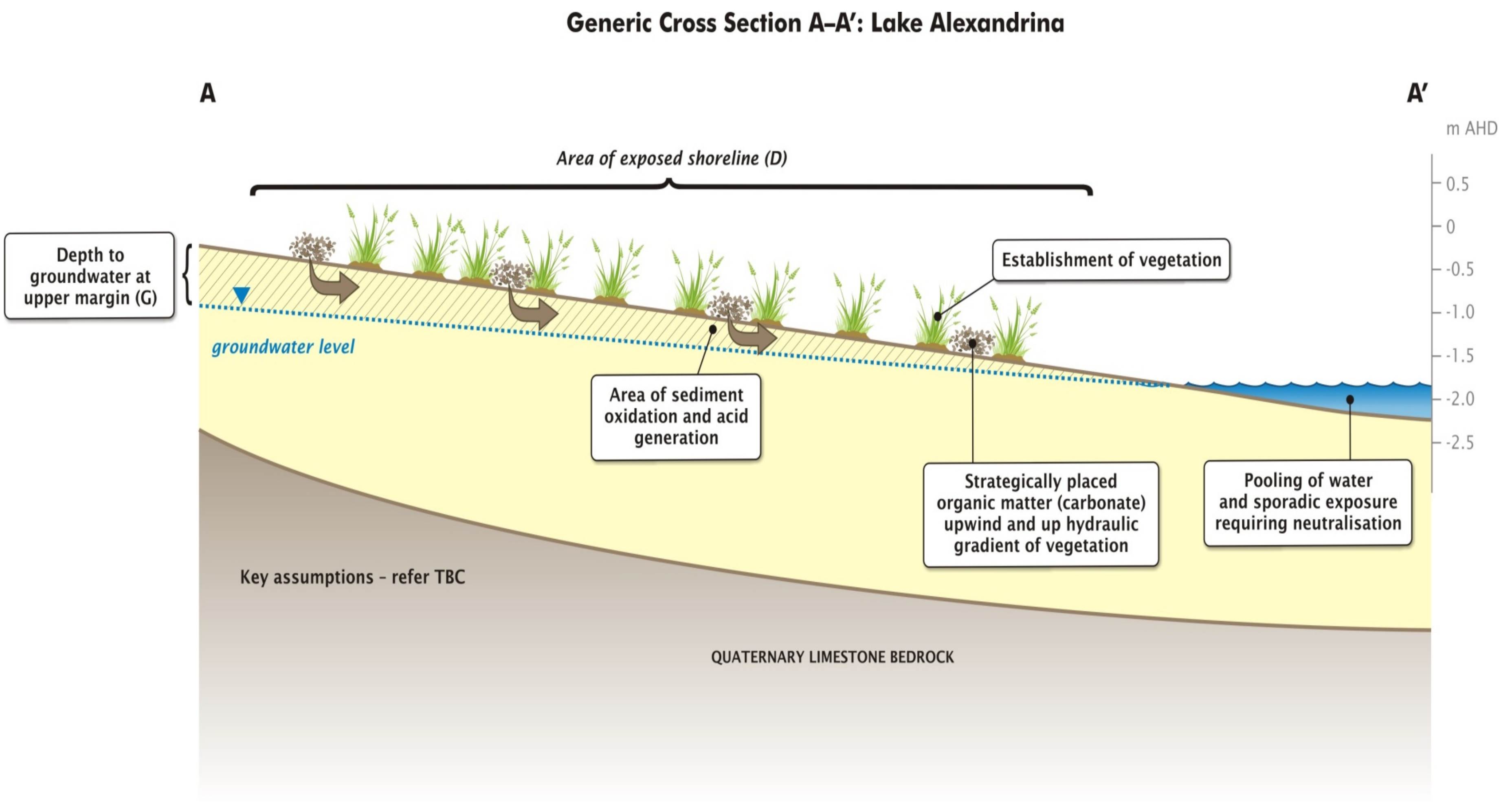
Lower Lakes Alternative Options Analysis -
Drawdown to -2.0 m AHD with Enhanced Bioremediation on Boundaries

FIGURE

F4

PROJECT VE23239

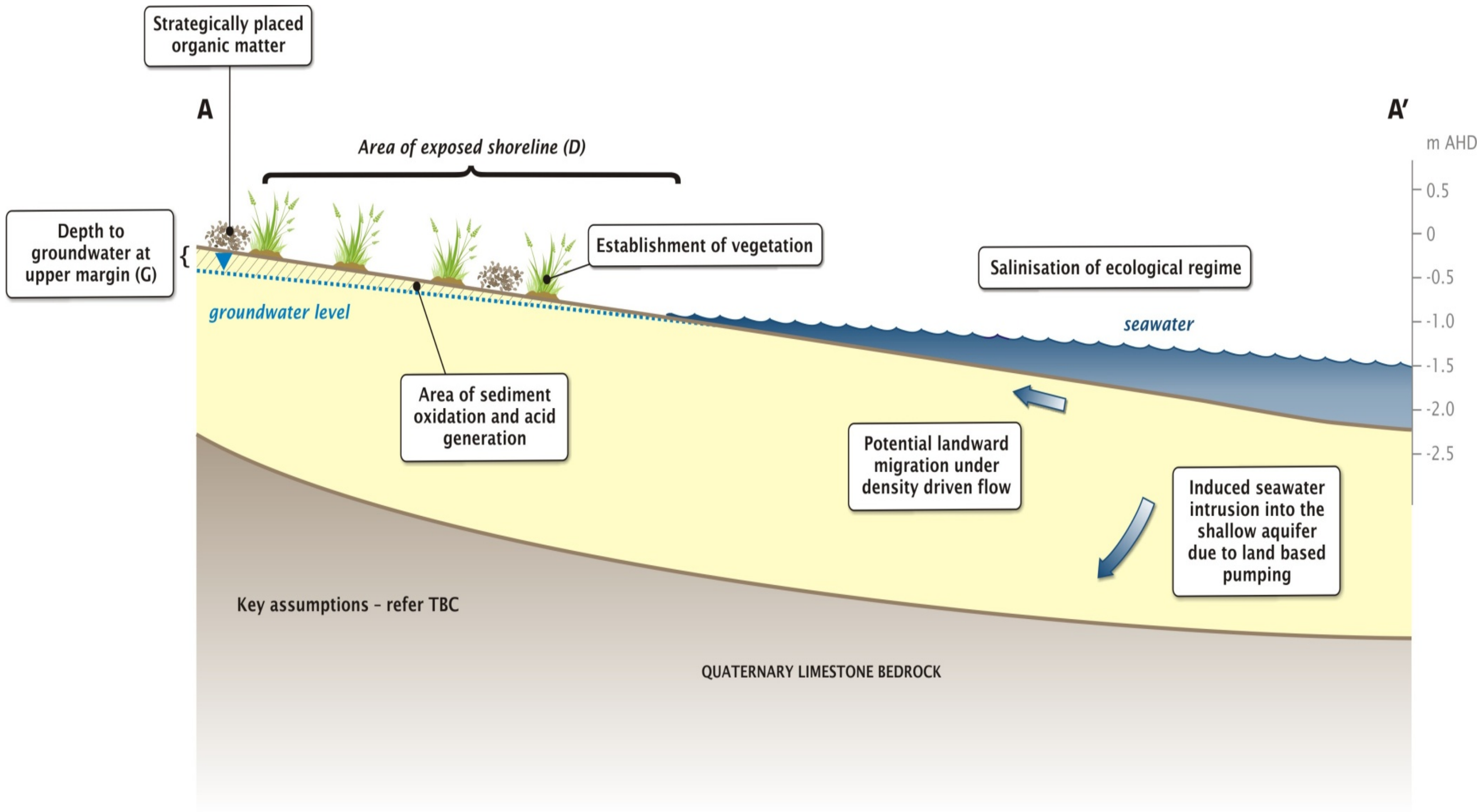
June-10



Lower Lakes Alternative Options Analysis -
Freshwater stabilisation to -1.5 m AHD with Enhanced Bioremediation on Boundaries

FIGURE **F5**

PROJECT VE23239 June-10



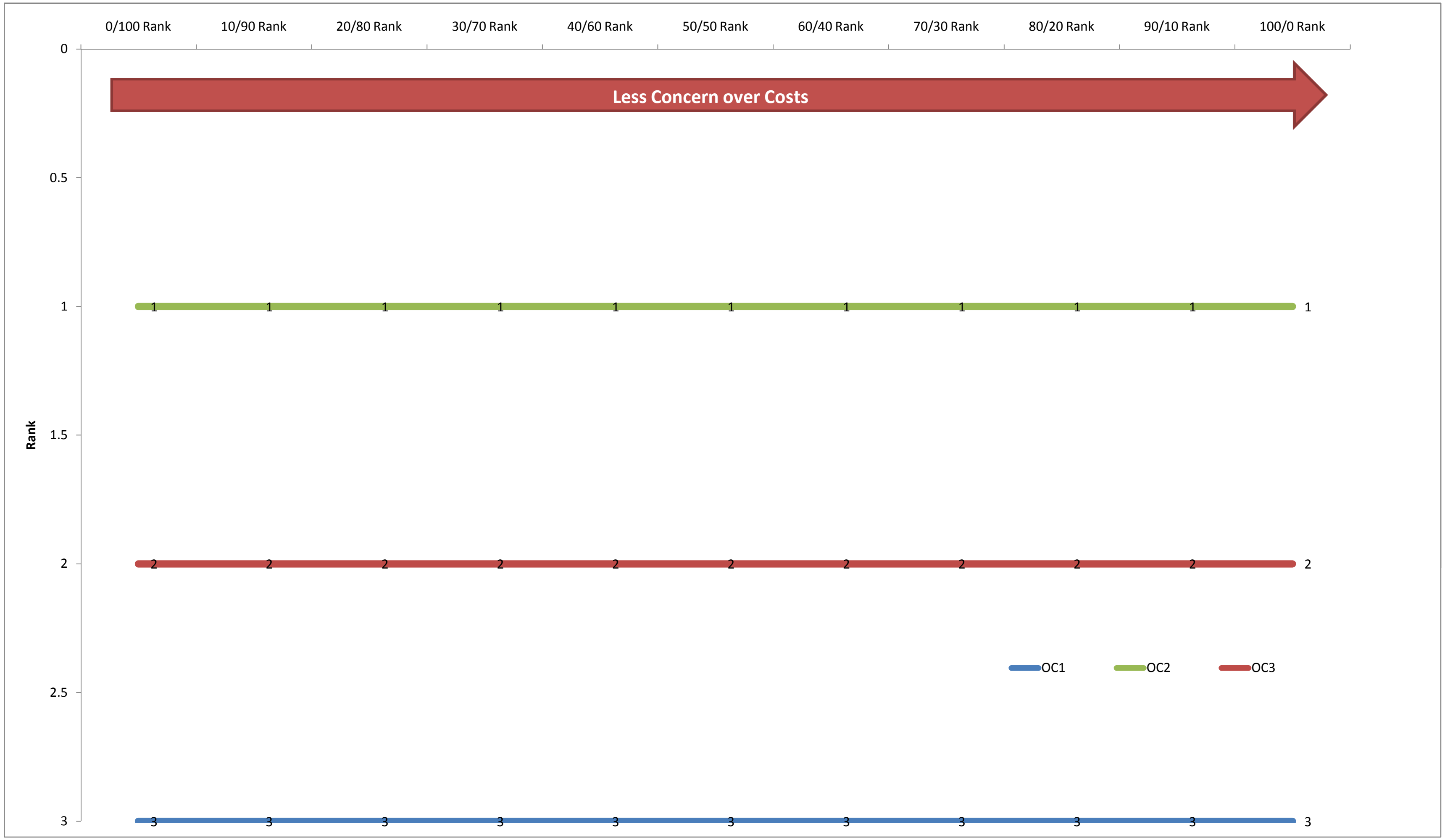
SKM SINCLAIR KNIGHT MERZ

Lower Lakes Alternative Options Analysis -
Seawater stabilisation to -1.5 m AHD with Enhanced Bioremediation on Boundaries

FIGURE
F6

PROJECT VE23239

June-10



Please note that this figure is provided as a summary only and should not be used out of context from the accompanying text. This figure should not be used for decision making purposes and is a result of preliminary assessment of option s only.

Illustration Purposes Only

SKM SINCLAIR KNIGHT MERZ

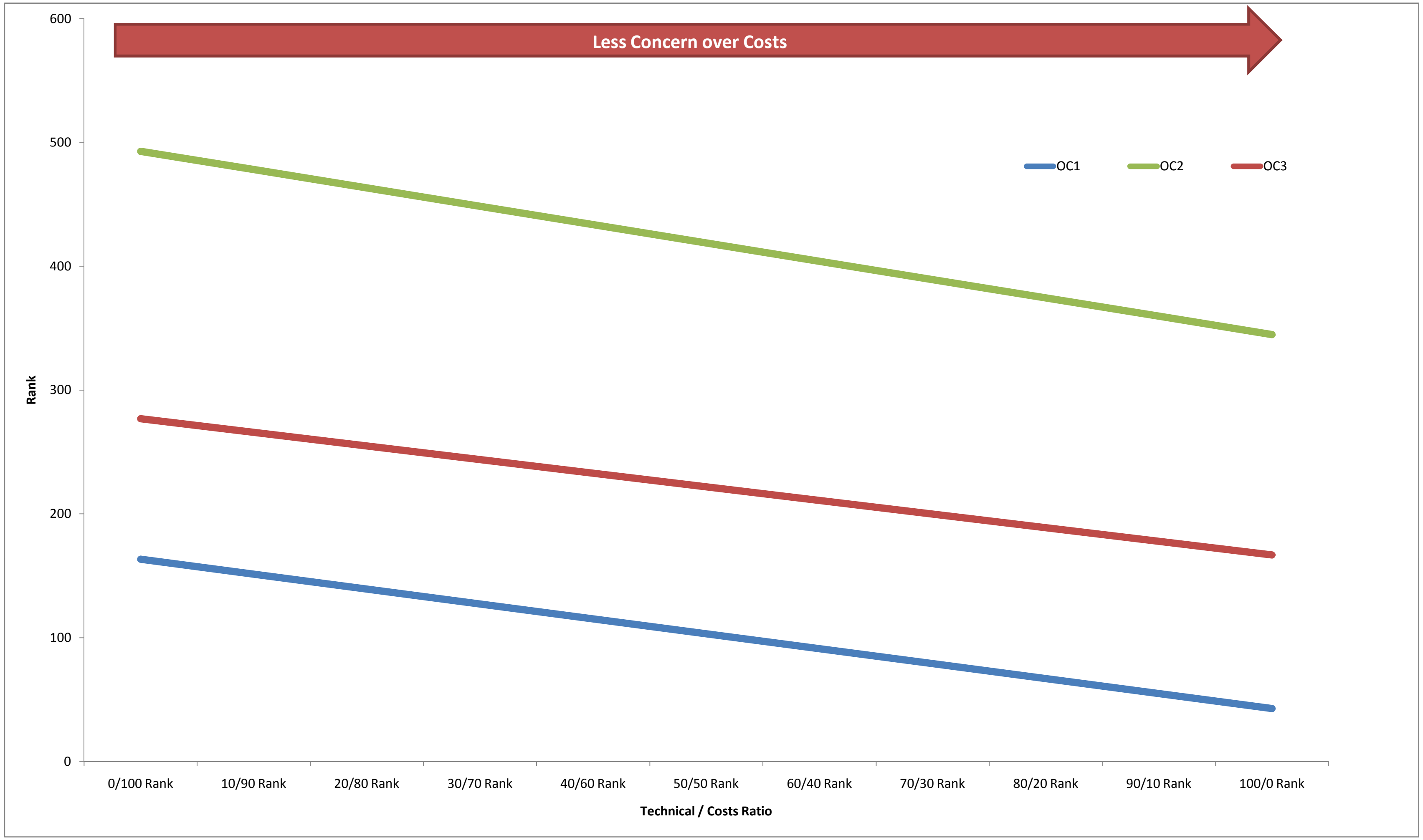
Lower Lakes Alternative Options Analysis - Contribution Ranking Scale of Options based on technical / practical feasibility and high level cost assumptions - Entire System

FIGURE

F7

PROJECT VE23239

June-10



Please note that this figure is provided as a summary only and should not be used out of context from the accompanying text. This figure should not be used for decision making purposes and is a result of preliminary assessment of option s only.

Illustration Purposes Only

SINCLAIR KNIGHT MERZ SKM

Lower Lakes Alternative Options Analysis - Contribution Ranking Scale of Options based on technical / practical feasibility and high level cost assumptions - Entire System

FIGURE

F8

PROJECT VE23239

June-10

Appendices

- **Appendix A - SMART Interpretation of Options**

SMART Options Interpretation

Option	Team Discussion Points	SMART
Option Combination 1		
Specific	• Assumes no remedial action is taken; • Barrage operations continue as normal (under current operating rules for the drought conditions); • 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 (lake health) • Soil pH
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) Clarify extent of study area – To include Lake Alexandria, Lake Albert to the extent of the Barrages. Does not include the Coorong. Does it include Finniss and Currency Creek?	This is considered a control option and therefore is relevant to the environment.
Time bound	Should this take into account the D Day when acidification occurs?	Option span is indefinite here as no active management is being considered.

SMART Options Interpretation

Option Combination 2		
Specific		
Measureable	Is there a quantity we need to cover off on? 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 sulphate 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; • Re-allocation of current licenses not required / used; • Provision of groundwater resources to provide saturation.
Achievable		Assumed to be achievable
Relevant	Clarify extent of study area	Assumed to be relevant
Timebound	Should this take into account the D Day when acidification occurs?	Proof of effectiveness prior to determined date of system acidification.

SMART Options Interpretation

Option Combination 3		
Specific	Define extent of inundation and process of managing the barrages	Although the intent is to maintain fresh water in the Lower Lakes, if water levels and water quality drop below a critical point and acidification is imminent then allowing sea water into the Lower Lakes will need to be considered. This would not involve flooding the Lower Lakes with sea water, 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		Assumed to be relevant
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).

SMART Options Interpretation

- **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.

SKM

- **Appendix C - Decision Confidence Assessment**

Appendix C. - Summary of Confidence Determination

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	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	• Proof of concept established within a similar environment, such as a large shallow large, within a relatively comparable climatic region.

	terrestrial environment. • Study not identified, yet reasonable possibility it may have been undertaken and has not been sourced (as deemed by the study team).	different climatic region (e.g. acidic lakes in Scandinavia).	• 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 - System MCA Matrices

Table	1	**Sponsor / Owner**	SA Water	**Major Dependencies**	See Text
Option Name	OC1	**Current Status**	Draft	**Issues Register Reference**	Table A

Specific	Enhanced Bioremediation with drawdown to -2.0 m AHD
Measurable	Measure of: • Lake water alkalinity (>25 mg/L) • Lake water elevation (>1.5m AHD) • Lake water salinity (EC< 1500 EC)
Achievable	• Volume FW resource required? • Volume FW available? • Long term availability?
Relevant	Is the option relevant to the Lower Lakes environment? (can the option be practicably implemented?)
Timebound	• When do we expect to see results? • What is the effective lifespan of the treatment? • How long are we measuring for?

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	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

Table	2	Sponsor / Owner	SA Water	Major Dependencies	See Text
Option Name	OC2	Current Status	Draft	Issues Register	Table B
Specific	Enhanced Bioremediation with stabilisation of water level to -1.5 m AHD using freshwater				
Measurable	• Porewater geochemistry • Groundwater quality And • Lake water alkalinity (>25 mg/L) • Lake water elevation (>1.5m AHD) • Lake water salinity (EC< 1500 EC) • Trophic state (oligotrophic) • Ecological component – impact on NES matters (Part 3 EPBC Act)				
Achievable	• Volume FW resource required? • Volume FW available? • Long term availability? • Theoretically possible? • Is there proof of concept, trials etc				
Relevant	Is the option relevant to the Lower Lakes environment? (can the option be practicably implemented?)				
Timebound	• When do we expect to see results? • What is the effective lifespan of the treatment? • How long are we measuring for?				

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, lifestyle)	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**

Table	3	**Sponsor / Owner**	SA Water	**Major Dependencies**	See Text
Option Name	OC3	**Current Status**	Draft	**Issues Register**	Table C
Specific	Enhanced Bioremediation with stabilisation of water level to -1.5 m AHD using seawater				
Measurable	• Porewater geochemistry • Groundwater quality And • Lake water alkalinity (>25 mg/L) • Lake water elevation (>1.5m AHD) • Lake water salinity (EC< 1500 EC) • Trophic state (oligotrophic) • Ecological component – impact on NES matters (Part 3 EPBC Act) Plus • Sediment salinity				
Achievable	• Volume FW resource required? • Volume FW available? • Long term availability? • Theoretically possible? • Is there proof of concept, trials etc				
Relevant	Is the option relevant to the Lower Lakes environment? (can the option be practicably implemented?)				
Timebound	• When do we expect to see results? • What is the effective lifespan of the treatment? • How long are we measuring for?				

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	**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, lifestyle)	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**

Table 009 - Summarised Results

	Technically feasible and achievable		Cost and transpancy		Adjustments						Combined @ 50/50	
Option	**Sub-total**	**Rank**	**Sub-total**	**Rank**	**Preadjustment scores**	**Rank**	**PM or T?**	**Likelihood of Negative**	**Severity**	**combined adj**	**Total**	**Rank**
OC1	79	3	303	3	**382**	3	0.75	0.6	0.6	0.36	103	3
OC3	238	2	396	2	**634**	2	1	0.7	0.5	0.35	222	2
OC2	308	1	440	1	**748**	1	1	0.8	0.7	0.56	419	1