Department of Energy Environment and Climate Action &
Corangamite Catchment Management Authority

Anglesea River Management Options Investigation

21 November 2023

CDM Smith

Executive Summary

Background

CDM Smith undertook this study, on behalf of the Department of Energy, Environment and Climate Action (DEECA) and the Corangamite Catchment Management Authority (CCMA), to identify and assess options to address water acidity issues experienced in the Anglesea River. The river is known by the Wadawurrung Traditional Owners as Kuarka Dorla, place of fishing mullet.

The key source of acidity in the Anglesea River is understood to be acid sulfide soils (ASS). Acid sulfate soils are naturally present in a wide range of coastal and inland settings. Oxidation of sulfide minerals contained in ASS can cause acidification of waterways and management of ASS oxidation in coastal environments is a challenge in Australia and around the world.

Periods of water acidity in the Anglesea River, in particular the estuary, have in the past resulted in fish death events, degradation of habitat such as sea grass and water quality conditions that have not supported recreational use of the waterway. This has resulted in observed impacts on the estuary ecosystem, social, cultural, and potentially economic values supported by the Anglesea River. Management of low pH in coastal waterways including estuaries is often a complex issue requiring thorough assessment to determine the most appropriate technology or combination of technologies for a particular setting (Thomas, Fitzpatrick, Merry, & Hicks, 2003).

Objective, scope and methodology

The objective of the project was to identify and assess the feasibility of options to address acidity issues experienced in the Anglesea River estuary. This will inform decision making on future management options that can meet expectations for multiple values and provide expert responses to questions raised by the community through this process.

The project involved the following scope and methodology:

Stage 1

- Consolidation of an understanding of the issue through a review of previous studies and publicly available information.
- Identification of potential options to treat, manage or avoid low pH conditions, through review of literature, case studies and previous studies completed in Anglesea.
- Screening and shortlisting of identified management options against a developed assessment framework through a two-stage process:
  - preliminary screening to identify options that have potential to influence pH (acidity) in the Anglesea estuary or catchment (i.e. potentially feasible options).
  - multicriteria analysis of potentially feasible options against criteria to establish a shortlist for more detailed assessment. The multicriteria analysis was adopted as a method for considering a range of factors to shortlist options.

Stage 2

- Detailed evaluation of shortlisted options including:
  - Evaluation of pH and flow conditions experienced in the Anglesea River, and assessment of pH and flow conditions required for each management option to be effective.
  - Estimation of feasibility-level costs
  - Consideration of siting options

  - Identification of permit and approval requirements
  - Identification of environmental, economic, social and cultural risks and limitations
  - Identification of additional information that would be required to inform further refinement or implementation of the option.

Throughout the project at key stages a community and stakeholder reference group was consulted to provide input and feedback. An Expert Panel was also established to provide independent advice to CDM Smith on various aspects of the project, as needed. within their technical area of expertise, as follows:

- Honorary Associate Professor John Sherwood (Deakin University and Austral Consulting) – Estuarine hydraulics and water quality
- Professor Robert Fitzpatrick (The University of Adelaide) – Acid sulfate soil (ASS) and rehabilitation of acidic waterways
- Professor Vincent Pettigrove (RMIT University) – Risk to ecosystems and aquatic environmental stress
- Dr Carolyn Brumley (Arcadis) – Human and ecological health and communication of risk

The expert panel members were consulted for specific advice and inputs to the project throughout related to their area of expertise.

Issue overview

The Anglesea River catchment is a complex dynamic system, where marshlands, rainfall, surface water flows, estuary entrance state and tidal exchange interact to transport and influence acidity. Two main potential or actual sources of acidity have been identified: ASS containing sulfidic material in the upper and mid catchment, and ASS containing hypersulfuric material at Coogoorah Park.

Since pH monitoring started in 1969, water quality data collected by Alcoa, DEECA and EstuaryWatch has indicated that the Anglesea River estuary has experienced periods of acidic or low pH conditions. Measurements of pH in the upper and mid catchment tributaries indicate acidic conditions occur the majority of the time. Longer periods of low pH conditions have been recorded in the estuary in recent years, most significantly from 2019 until the end of October 2022, and environmental values including ecosystem health and recreational amenity have been impacted.

The pH and flow conditions in the Anglesea River, prior to 1969, are not known. Therefore, it is difficult to understand how the long-term factors (described in subsequent sections) likely contribute to water quality conditions in the catchment.

The following presents a summary of the key aspects of the issue, with further details and discussion provided in Section 3 of the report:

- The source of acidity in the Anglesea River is oxidised ASS and geology containing acidic minerals. Previous studies have identified significant acid potential in the extensive marshlands in the upper and mid catchment (along ephemeral tributaries Salt and Marshy Creeks) and at Coogoorah Park in the upper estuary. ASS in the catchment is both labile and retained acidity. ASS at Coogoorah Park is predominantly potential ASS (hypersulfidic soil) that is thought from previous studies to have not yet been oxidised to form acid (Sullivan, Reeves & Trewarn, 2016).
- A range of previous studies have identified that climate (rainfall patterns, temperature, evapotranspiration) is the predominant influence on formation of acid through wetting and drying (oxidation) of marshlands in the upper and mid catchment, and of transport of acid via surface water flows in the catchment.
- Other potential causes of ASS being oxidised have been raised, including the potential interaction of shallow groundwater that supports the marshes and regional Upper Eastern View Formation groundwater aquifer that was extracted from between the 1970s and 2016.

- Acidity is transported in the catchment by surface water flows downstream to the estuary, and by tidal influences when the estuary mouth is open.
- There have been a range of anthropogenic influences on catchment hydraulics that have potentially influenced the formation and transport of acid in the Anglesea catchment, as well as the ability for the river to regulate and return to neutral conditions following an acid event. These include:
  - Excavation of the Anglesea Open Cut Coal Mine Pit;
  - Diversion of Salt Creek around the former Alcoa mine pit in a 3 km open concrete channel;
  - Excavation of channels at Coogoorah Park in the upper estuary in 1983, which is estimated to represent approximately 14 – 20% of the total estuary volume; and
  - Discharge of approximately 4.5 ML of fresh water per day to the river during operation of the Alcoa power station (1969 – 2015), representing between 50 % and nearly the entire flow of the river at times (Maher, 2011; GHD, 2021; Pope, 2006). This influenced the lower catchment by maintaining water levels, the morphology of the estuary entrance berm and likely masking and regulating the naturally low pH flows from the upper and mid catchment.

Management area and objective

The priority area for options to address acidity is within the Anglesea River estuary, where previous periods of low pH water have resulted in the most significant impacts on environmental values. Actions may be implemented in other parts of the catchment to influence conditions in the estuary; therefore, the entire catchment was identified as the relevant management area.

The objective is to regulate acidity within the Anglesea River estuary to protect environmental, cultural, social and economic values to the extent reasonably practicable.

Broadly, the goals are:

- A river that supports a balance of aquatic and terrestrial life as well as social and economic activities such as swimming, fishing and active tourism
- low pH events are occasional and minimise fish deaths to the extent possible.

In order to meet the overall objective, management of acidity from both the upper and mid catchment and ASS at Coogoorah Park is recommended in order to meet the objectives of a functioning estuary and environment that supports a range of values.

It is acknowledged that no management or remediation strategy will be ‘ideal’, nor will it be likely to fully restore the environment to its original state. Given the complexity of the system, catchment characteristics and issue drivers, the strategy is also unlikely to completely avoid acidic water being present, particularly during high flow episodes. It is also unlikely that any outcome will meet the objectives of all stakeholder groups and maintain all values, as each bring their own priorities and viewpoint on risks or benefits. Nevertheless, the options assessment process has been considerate of these elements and aims to ultimately lead to the shortlisting of the most appropriate and effective options that balances the greatest number of values.

Stage 1 Options assessment and shortlisted options

Thirty potential options for management and minimisation of acidity were identified of which 21 were considered potentially feasible to address the issue in the context of the Anglesea River catchment. Broadly these aligned with strategies proven to treat, avoid or manage ASS or acidic runoff.

A multicriteria analysis (MCA) used relative scoring to compare feasible options against criteria. Adopted criteria considered technical aspects and practicability, as well as a quadruple bottom line approach considerate of environmental, cultural, social and economic aspects:

- Technical: relative effectiveness, timeframe for being effective and long-term flexibility
- Practicability: logistical and supply constraints, legislative and regulatory requirements and timeframes, ongoing maintenance requirements
- Environmental: energy, resource and waste, climate resiliency, potential effects on the broader environment and risks to aquatic or terrestrial organisms
- Cultural: potential effects on cultural significance and acceptance by Traditional Owners
- Economic: relative capital and ongoing costs, potential effects on local economy
- Social/stakeholder: acceptance by stakeholders, potential effects on recreational values or amenity.

To address acidity from ASS in the upper and mid catchment, options that treat low pH surface water flowing downstream were identified as the most appropriate in the context of the Anglesea catchment, in preference of in-situ soil treatment methods, predominantly due to the extensive area of ASS and acidic soils and to minimise significant impacts to other values in the heathland.

Ideally it would be possible to identify one option that is feasible for managing acidity sourced from both the upper and mid catchment and Coogoorah Park, however generally options identified were not able to achieve this simultaneously. Options to address both acid sources were considered.

The following options were shortlisted for further detailed assessment as part of the next stage of the project. These were based on the top scoring options from the MCA and additional options agreed as part of the stakeholder workshop. As noted in the table below, some shortlisted options would need to be paired for effective management of all aspects of acidity risk; both acidity sourced from the upper and mid catchment and potential acidity at Coogoorah Park.

A sensitivity analysis was undertaken to understand the influence of weighting or grouping categories on the outcomes. This identified the same six options with the highest scores through the MCA, however there was some variability in the next four options that scored in the top ten options.

Other options that were identified as part of the project but not carried forward for shortlisting have the potential to be effective under the right conditions but were considered to have less likelihood of success for the Anglesea River or were assessed as having a greater number of trade-offs through the multicriteria analysis.

Table 1 Shortlisted options

ID	Option	Description
12	Treat low pH water in the estuary by shallow artificial entrance openings or berm grooming	Introduce sea water to the estuary system by artificially opening the channel at the entrance or maintaining berm height and allowing seawater into the estuary via tides. The objective of this option is to dilute and buffer low pH water that flows into the estuary from the upper and mid catchment.
13	Treat low pH water in the estuary by deep artificial entrance openings	As for Option 12, with a deeper channel excavated to increase the opportunity for tidal exchange in the estuary.
14	Treat low pH catchment flows by introducing sea water to the estuary via offshore pump and pipe	Introduce sea water to the estuary system by pumping via a pipe upstream. The objective of this option is to maintain water levels and avoid oxidation of ASS at Coogoorah Park, and to dilute and buffer low pH water that flows into the estuary from the upper and mid catchment. Design could include for example construction of a pipeline and pumping system from the ocean to a point in the river.

ID	Option	Description
20	Install passive alkaline berms for treatment of acidic flows in-situ within river / open limestone drains	This option involves installation of passive alkaline treatment materials to increase the pH of water within the river. This would involve placement of alkaline beaching or berms throughout catchment / river, or limestone drain beds. For example, this could involve placement of limestone gravel treatment beds within stream beds in the upper and mid catchment, and/or placement of limestone rock within the estuary.
23	Constructed wetland (reducing and alkalinity producing type) to neutralise low pH flows	Construction of a managed wetland that captures flow through the catchment, regulating water levels and providing capacity to manage and treat acidic water from the upper and mid catchment. Wetlands can be aerobic, anaerobic, or reducing and alkalinity producing. If combined with another passive treatment option, aeration and settling wetlands could be used. A range of designs could be applied within each wetland type. Processes within a constructed wetland to improve water quality include (depending on wetland design): oxidation, reduction, precipitation, sedimentation, filtration, adsorption, complexation, chelation, active metal uptake by plants and microbial conversion/immobilisation mechanisms. Assumes existing basins/channels could be repurposed for construction of the wetland (e.g., part of Alcoa site during rehabilitation or Coogoorah Park channels)
24	In-situ passive permeable reactive barrier to neutralise low pH flows	Option involves construction of a permeable barrier within the river or creek bed, similar to berms however with greater treatment capacity due to capturing and treating all flow. PRB contains treatment materials (alkaline material such as limestone, and/or organic matter). As water passes through the barrier it is treated to increase the pH.
28	In-situ dosing with alkali materials to neutralise low pH flows	Involves direct addition of materials such as calcium hydroxide (“lime”), sodium hydroxide, potassium hydroxide, magnesium hydroxide or carbonate salts to the river when the river pH is low. Dosing stations could be located at multiple points along the river in the upper and mid catchment and/or estuary.
5	Manage ASS at Coogoorah Park by maintaining water levels with a weir system	Involves installing a hydraulic barrier / weir between Coogoorah Park channels and Anglesea River estuary, with the aim of maintaining an area of suitable water quality. The barrier could be permanent or temporary. Isolating channels would also aim to provide a refuge where water quality is maintained, and environmental values are protected. Water level would need to be maintained in Coogoorah Park channels via redirecting stormwater and catchment flows, or via pumping into the channels.

Stage 2 Detailed options assessment

Further investigation of shortlisted options was undertaken to understand in more detail how options could be implemented and their potential effectiveness specific for the Anglesea catchment.

Due to the complexity of the issue of acidity in the Anglesea River catchment and nature of the dynamic system, no management or remediation strategy will be ‘ideal’, nor will it be like to fully restore the environment to its original state.

The Anglesea catchment and estuary is a highly dynamic system (GHD, 2021; Pope, 2006). Rainfall and thus run-off is highly variable, with Anglesea River experiencing both periods of no flow and floods exceeding 100ML/day. Long-shore sand transport continuously delivers sand to the estuary entrance and sea states (tidal range, wave height) are variable. The degree of marine influence in the estuary is a function of mouth condition (open/perched/closed) and the interplay of sea state and river flow. Large floods can flush all saltwater from the estuary for extended periods (days to weeks).

To be the most practical and effective at responding when pH conditions require, management approaches should ideally be adaptable and functional in a range of different conditions.

Options should also be in-line with existing recommendations and management approaches for the river, and established acid sulfate soil management guidelines (Section 2.1).

A summary of findings and recommendations from Stage 2 of the project are:

- The options considered most suitable for managing acidity from catchment flows are treatment by dosing with alkali materials (Option 28) or treatment by buffering with seawater via a pump and pipe (Option 14). These options were identified as likely being more effective than the other options assessed, at managing pH in the greatest range of flow conditions, which is an important success factor given the ephemeral and dynamic nature of the system.
- The options above however still have a range of other factors and risks requiring consideration. Both options will require the consideration of the mixing location, water quality, reaction speed and specific ecosystem, as the mixing of alkaline material or saline and fresh waters could lead to the precipitation of metallic compounds. In-situ dosing does not directly manage the risk from oxidation of acid sulfate soils at Coogoorah Park; alternatively, the seawater pump and pipe option could manage water levels and address this risk however has a greater number of stakeholder, amenity, marine environment and cultural heritage considerations.
- Other shortlisted options were considered to have less ability to meet the objectives and manage acidity in the river if implemented in isolation. In some cases, however – for example in-situ permeable reactive barriers and limestone channels – these options have fewer environmental and stakeholder considerations or represent a lower cost than the options considered most suitable for effective acid management. Some assessed options – notably artificial estuary openings – could be considered but are likely to be effective only under specific conditions (limited success). They also should be carefully implemented to maintain a healthy functioning ecosystem and physical dynamics of the estuary (Alluvium, 2014; GHD, 2021).
- Management of ASS containing hypersulfidic material at Coogoorah Park is recommended to avoid oxidation and formation of sulfuric acid, which would exacerbate the issue. ASS in the lower catchment represents a potential hazard based on extensive soil sampling across Coogoorah Park. The most viable options that will effectively manage ASS and provide the most balanced approach across all assessment criteria involve maintenance of water levels using weirs (Option 5) or by introducing seawater via a pump and pipe (Option 14). It is recognised that both options represent trade-off's regarding usability of the area for recreational and business purposes, environmental and cultural values.
- Further investigation of a range of factors such as timeframe for soil drainage and ASS oxidation at Coogoorah Park, and assessment of geochemistry and potential for flushing of acidity is recommended before progressing options further. Recommendations for each option are presented within Section 7 of the report and general overall recommendations are summarised in Section 8.
- Future activities in the catchment that could potentially influence pH conditions in the river (e.g., activities related to surface water runoff and flow, groundwater, soil in the upper catchment, or estuary entrance conditions) should consider this study and related previous studies to understand and minimise potential influence on the issue.

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Acknowledgement of Country

We acknowledge the Wadawurrung as Traditional Owners of the Country where this project took place. We also pay our respects to all other Aboriginal and Torres Straight Islander peoples of this nation. We recognise their continued connection to land, skies, seas and waters, including the importance of kuarka dorla (Anglesea River).

Section 1 Introduction

CDM Smith has undertaken this study, on behalf of the Department of Energy, Environment and Climate Action (DEECA) and the Corangamite Catchment Management Authority (CCMA), to identify and assess options to address acidity issues experienced in the Anglesea River.

Acid sulfate soils (ASS) are naturally present in a wide range of coastal and inland settings. Oxidation of ASS can cause acidification of waterways and management of ASS oxidation in coastal environments is a challenge in Australia and around the world.

Periods of low pH water in the Anglesea River, particularly in the estuary, have resulted in degradation of environmental values including ecosystem health and recreational use of the waterway. Specifically, a number of fish death events have occurred, and degradation of aquatic habitat including sea grass during extended periods of low pH have been observed. This has resulted in observed or potential impacts on the estuary ecosystem, social, cultural, and economic values supported by the Anglesea River. Management of low pH in coastal waterways including estuaries is often a complex issue requiring thorough assessment to determine the most appropriate technology or combination of technologies for a particular setting (e.g. Fitzpatrick et al. 2008; 2012; Thomas, Fitzpatrick, Merry, & Hicks, 2003).

This report presents the findings of the project. Further details on the project scope and stages are provided in Section 1.2.

1.1 Objective

The objective of the project was to identify and assess the feasibility of options to address acidity issues experienced in the Anglesea River estuary. This will inform decision making on future management options that can meet expectations for multiple values and provide expert information in responses to questions raised by the community through this process.

1.2 Project scope

The scope of the project was developed to identify potential short to medium term remediation options for the low pH conditions in the Anglesea River catchment and review these against developed criteria.

Stage1 of the project included the following:

1. Consolidation of an understanding of the issue based on existing studies and information.
2. Identification of potential options to treat, manage or avoid low pH conditions in the Anglesea River
3. Development of an assessment framework for screening potential options
4. Screening and shortlisting of potential options using a multi-criteria analysis, to provide a recommendation for which options should progress to Stage 2 of the project (detailed assessment)

Stage 2 of the project involved further detailed assessment of options that were shortlisted as part of Stage 1.

The project also involved engagement with a community and stakeholder representative group at key points to inform aspects of the assessment related to social and stakeholder values. This is further described in Section 1.3.

This project was completed based on the current knowledge including conceptual understanding of the catchment and the potential divers of the acidity issue that was formed from previous studies and based on the current catchment setting and available management technologies. A number of potential future changes to the catchment have been identified that were not able to be quantified and considered in the project. These are detailed in Section 3.8.

Future activities in the catchment that have the potential to influence pH conditions in the Anglesea River should be assessed and managed appropriately to avoid or minimise the risk of harm to environmental values, in accordance with State legislation and guidance. Management of activities with potential to influence pH should consider recommendations made through the extensive previous studies, including those summarised throughout this report with relation to pH, ASS, water quality and estuary health.

This project considered known and potential drivers of acidity in Anglesea River. Further investigation, specifically into the influence of historic groundwater extraction on surface water acidity was not part of this scope, however for the purpose of this assessment it was assumed that this could have influenced the issue.

1.3 Stakeholder engagement and collaborative approach

A collaborative approach has been adopted to assist in developing project visions and objectives that are relevant to the community, aligned with the expectations of different stakeholders and technically sound.

To assist in this engagement and consultation process, a project stakeholder reference group was established to provide inputs and feedback to the project for consideration. The group comprised representatives from:

- Surf Coast Shire
- Barwon Water
- Great Ocean Road Coast and Parks Authority
- Business and Tourism Anglesea Association
- Friends of Anglesea River
- EstuaryWatch
- Local residents and business representatives

Engagement with the stakeholder reference group took place during the project at the following points:

1. A site visit at the commencement of the project to understand values and concerns held by the group and provide local context to the issue understanding.
2. During finalisation of the issue understanding to obtain feedback and seek alignment from the group, as well as to get inputs from the group on the key values and objective of the project.
3. Following identification of management options, to understand whether options would likely be acceptable to stakeholders or meet expectations, understand key concerns and inform the stakeholder component of the options assessment.
4. At the conclusion of Stage 1 to present the draft list of shortlisted options, understand key concerns, and gain any further information to inform the investigation.
5. At the conclusion of Stage 2 to present the findings of the detailed assessment.

A community open house was held after completion of the draft Stage 2 assessment to share information about the project and gather feedback or questions to consider during future steps.

Feedback and information provided by the stakeholder representative group was incorporated into the study and this report where relevant.

DEECA, CCMA and the Wadawurrung Traditional Owners Aboriginal Corporation also formed the project steering committee who were consulted as part of the stakeholder reference group.

An Expert Panel was also established to provide independent advice to CDM Smith on various aspects of the project as needed within their technical area of expertise, as follows:

- Honorary Associate Professor John Sherwood (Deakin University and Austral Consulting) – Estuarine hydraulics and water quality
- Professor Robert Fitzpatrick (The University of Adelaide) – Acid sulfate soil (ASS) and rehabilitation of acidic waterways
- Professor Vincent Pettigrove (RMIT University) – Risk to ecosystems and aquatic environmental stress
- Dr Carolyn Brumley (Arcadis) – Human and ecological health and communication of risk

The expert panel members were consulted for specific advice and inputs to the project throughout related to their area of expertise.

Section 2 Legislation, guidelines and management framework

2.1 Management principles

2.1.1 Current estuary management

The management of the Anglesea River catchment is a partnership between different agencies and groups including:

- Corangamite Catchment Management Authority (CCMA);
- Local Government (Surf Coast Shire);
- Department of Energy, Environment and Climate Action (DEECA);
- Victorian Environment Protection Agency (EPA);
- Parks Victoria (PV);
- Great Ocean Road Coast and Parks Authority (GORCAPA);
- Barwon Water; and
- Wadawurrung Traditional Owners

Other regulatory bodies with specific jurisdictions also manage natural resources within the catchment, such as Southern Rural Water who are responsible for groundwater extraction licensing.

The estuary is currently managed based on a collaborative approach with the groups above, and range of recommendations made in previous studies and plans. With relation to this project, this includes:

- Seasonal capture of water during winter wetter months that is released during dry periods to provide a base flow of 0.75-1 ML/day between the months of December and March. This is done in order to maintain water levels in the estuary and reduce the potential for activation of ASS in Coogoorah Park. This was an interim solution to manage ASS in the estuary following cessation of artificial discharge by Alcoa in 2016, following an options assessment (GHD, 2016).
- Artificial estuary entrance openings are currently undertaken by Surf Coast Shire in consultation with the CCMA when high water levels threaten human assets on the floodplain, such as the Great Ocean Road.

A range of other management recommendations have been made for the river to maintain environmental health which should be considered as part of any activity. In particular, an Environmental Flows Study (GHD, 2021) identifies several recommendations for the river. These are further discussed in Section 4.4.

2.1.2 Acid sulfate soil and acid runoff management principles

Several sources of information related to the: 1) standard nomenclature and definitions used for acid sulfate soil (ASS) materials in Australia, and 2) management and remediation of ASS impacts have been reviewed to support preparation of this options assessment, including:

- National and interstate best practice guidance on the management of ASS issues in inland and coastal landscapes.
- Technical publications describing technologies for the treatment of acid mine drainage, which presents several similarities with ASS issues.
- Selected papers presenting case studies and technology performance reviews of ASS remediation techniques.

- Online resources, such as the Interstate Technology and Regulatory Council (ITRC) Mining Waste Treatment Technology Selection (www.itrcweb.org/miningwaste-guidance/) and the Global Acid Rock Drainage (GARD) Guide (www.gardguide.com).

Acid sulfate soils may be acidic (i.e., contain sulfuric material) or may have the potential to generate sulfuric acid when exposed to oxygen because of the presence of sulfide minerals, principally pyrite (i.e., they contain hypersulfidic or hyposulfidic materials). The following nomenclature and definitions used for acid sulfate soil materials are defined in the third edition of the Australian Soil Classification (Isbell and National Committee on Soil and Terrain [NCST] 2021):

- Hypersulfidic material: sulfidic material that had a field pH ≥4 and the pH dropped by at least 0.5 units to <4 when incubated at field capacity for at least 8 weeks.
- Hyposulfidic material: sulfidic material that had a field pH ≥4 and the pH dropped by at least 0.5 units to not less than 4 when incubated at field capacity for at least 8 weeks.
- Sulfuric material: soil material that has a pH <4 (1:1 by weight in water, or in a minimum of water to permit measurement) when measured as a result of the oxidation of sulfidic materials.
- Monosulfidic material: soil material containing ≥0.01% acid volatile sulfide.

When acid sulfate soils with hypersulfidic materials are exposed to oxygen (e.g., due to drainage or drying), oxidation of metal sulfides may cause acidification and formation of sulfuric material. ASS oxidising reactions can be minimised or potentially reversed under the right conditions over time (which can take months to years). If soils are resaturated or reflooded, microbial catalysed reaction in the presence of organic matter may reduce dissolved sulfate to hydrogen sulfide and precipitate Fe^{3+} to Fe^{2+} due to the activity of sulfate-reducing bacteria, which also require available organic carbon (Blunden, 2000).

The terms ‘potential acid sulfate soils’ (PASS), ‘active [or actual] acid sulfate soils’ (AASS) are used in Victorian Guidance for assessment and management of ASS (EPA Publication 655.1), but they are not defined or used in national or international soil classification systems.

The *National Strategy for the Management of Coastal Acid Sulfate Soils* (National Working Party on Acid Sulfate Soils, 2000) identifies the following main approaches to management of issues arising from ASS:

1. Where possible leaving ASS with hypersulfidic and hyposulfidic materials undisturbed
2. If disturbance is required, mitigate impacts
3. Rehabilitate disturbed ASS with sulfuric material and acid drainage to improve water quality and mitigate adverse impacts.

The hierarchy identified in the *National guidance for the management of acid sulfate soils in coastal and inland aquatic ecosystems (*Fitzpatrick et al. 2011, 2017; Sullivan et al. 2018a,b,c) further expands on these:

1. Minimising the formation of ASS with sulfuric material.
2. Preventing oxidation of ASS with hypersulfidic material if they are already present in quantities of concern; or controlled oxidation to remove ASS if levels are a concern but the water and soil has adequate neutralising capacity.
3. Controlling or treating acidification if oxidation of ASS with hypersulfidic material does occur.
4. Protecting connected aquatic ecosystems/other parts of the environment if treatment of the directly affected aquatic ecosystem is not feasible.
5. Limited further intervention.

Appendix C provides a brief overview of common approaches for management of ASS. In most cases, several management strategies are required in order to effectively control ASS issues.

2.2 Options assessment process guidelines

The general process outlined in the National Remediation Framework (CRC CARE, 2018) was adopted for identifying and assessing options to address acidity issues in the Anglesea River Catchment. The structure of the Australian National Water Quality Management Framework was also generally followed for reaching an agreed outcome.

2.2.1 National Remediation Framework

The Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) National Remediation Framework – Guideline on performing remediation options assessment (Version 0.1: August 2018) defines the stages of a remediation options assessment as shown below in Figure 2-1, with this process being a precursor to the design and implementation stage of a remediation process.

The NRF states that the first stage of developing a management or remediation strategy and action plan is to establish clear and measurable end point objectives and criteria to form the requirements against which options are assessed. These are then used to select technology and management or remediation options that have the potential to treat acidic conditions and apply management controls as necessary so that the objectives are achieved, and no unacceptable risk is posed by low pH conditions in the context of the estuary's use and values.

A key element to this process is engagement with regulators (where relevant) and stakeholders.

2.2.2 Australian National Water Quality Management Framework (2017)

The Australian National Water Quality Management Framework (NWQMF) provides a structure for agreeing on appropriate water management strategies to achieve objectives and management goals, including protection of community values. This is through an iterative process considering cultural, ecological, economic and social implications or benefits, with open and robust stakeholder engagement at its core. The NWQMF identifies 10 iterative and continuous steps towards water and sediment quality decisions, similar to that outlined in the NRF.

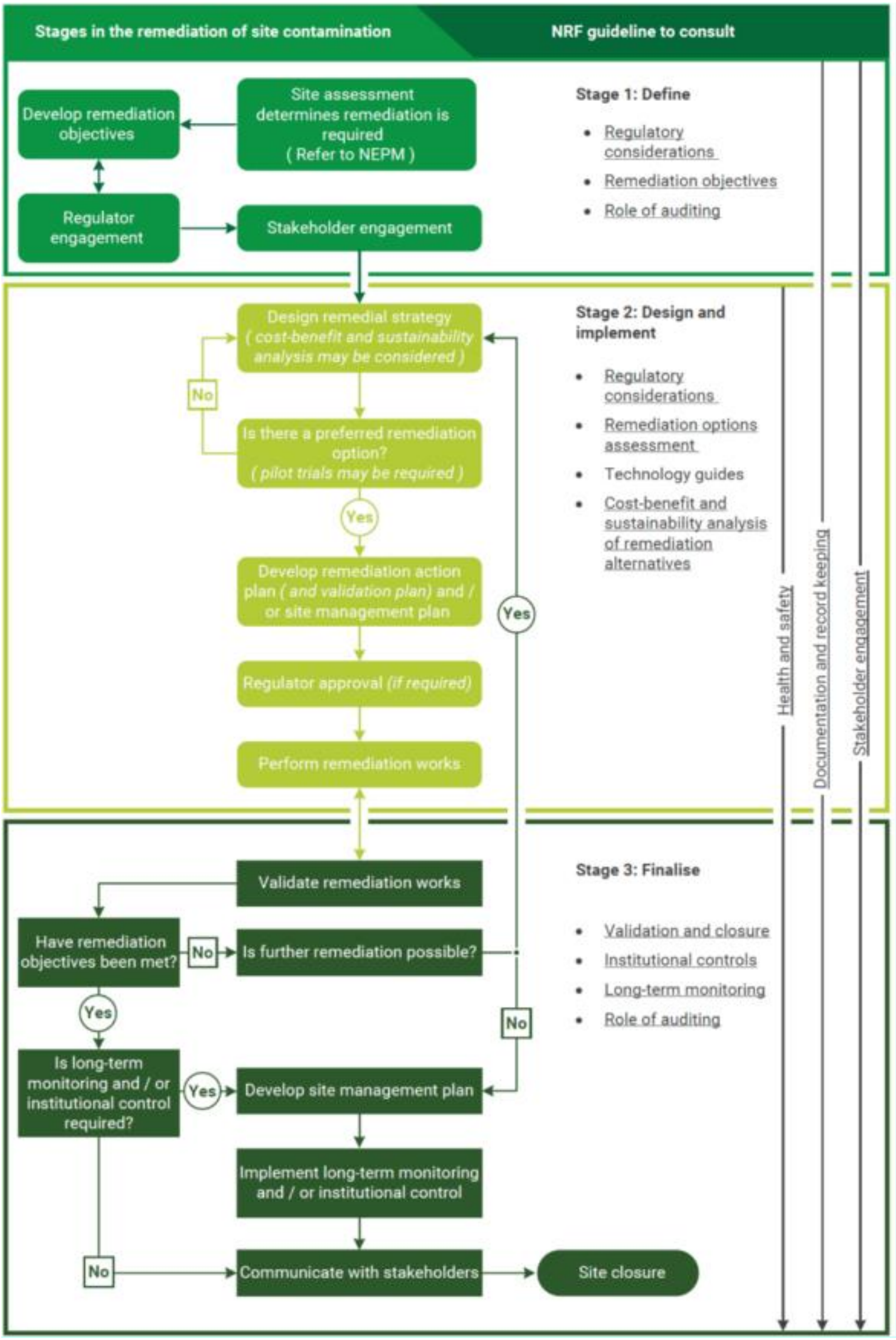


Figure 2-1 National Remediation Framework stages of remediation options assessment

2.3 Victoria Environment Protection Act 2017

Under the Environment Protection Act 2017 (updated 2021), management and remediation regulatory requirements must be adhered to. The most relevant aspects of regulatory policies and guidelines are detailed below.

2.3.1 General Environmental Duty (GED) and Duty to Manage

As part of the Environmental Protection (EPA) Act 2017 (updated 2021), the requirement of General Environmental Duty has been developed and applies to all Victorians. The GED requirement ensures the reduced risk from activities potentially harming the environment or human health through pollution or waste. GED is the requirement for anyone to manage activities to avoid the risk of environmental damage, ensuring that emissions from contaminated land don’t threaten the environmental values of the surrounding land.

Duty to Manage (s.39) is a requirement under the EPA Act 2017 (Updated 2021) and requires risks to human health and the environment from contaminated land, both on and offsite to be minimised so far as reasonably practicable.

2.3.2 Reasonably practicable

The term *‘reasonably practicable’* under the Environment Protection Act 2017 relates to the level of effort expected to prevent harm to human health or the environment.

This involves proportionate measures to eliminate or minimise risks of harm, with a higher level of expectation to manage greater risks of harm. ‘Controls’ can range from:

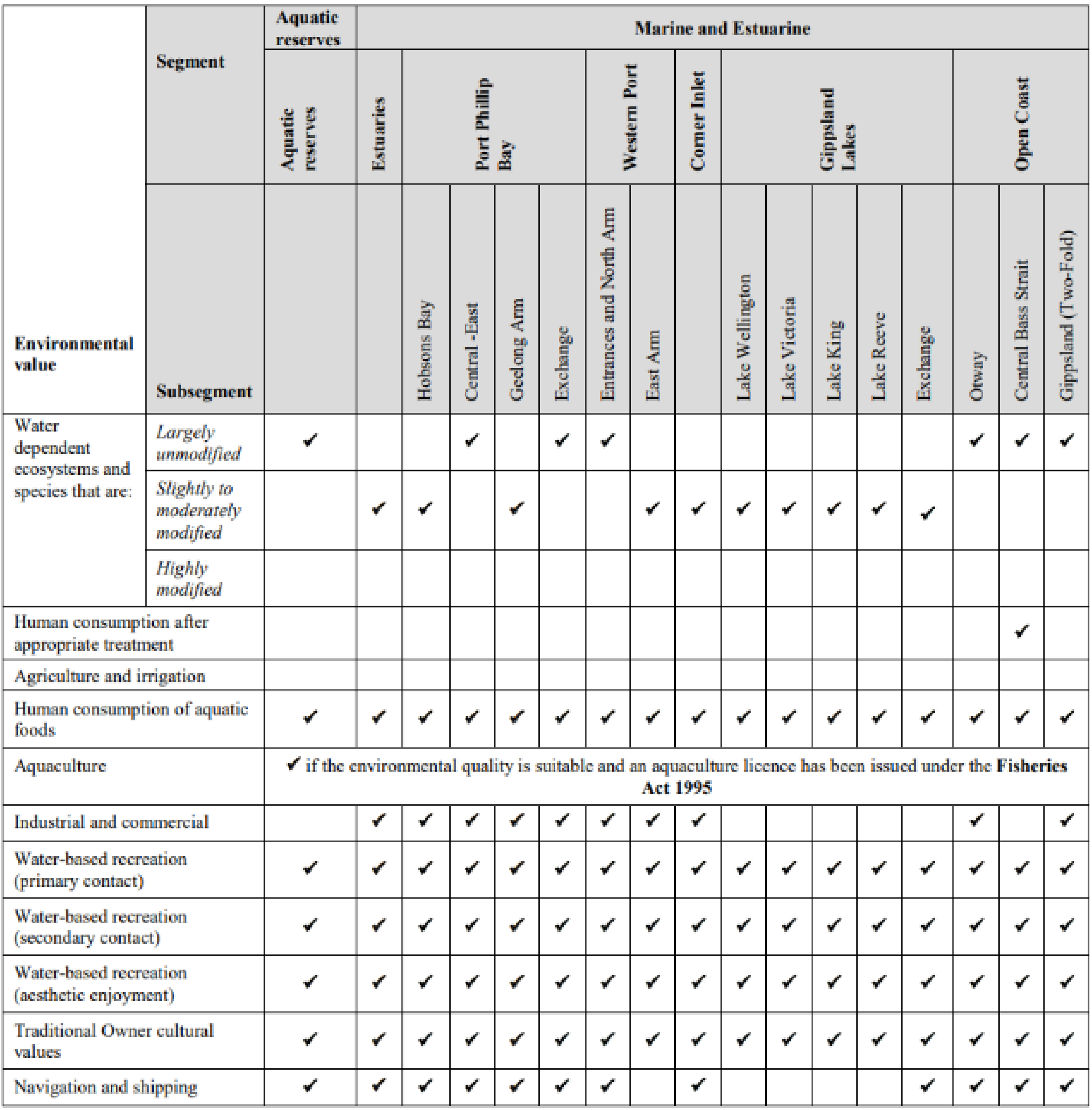
- eliminating or changing the source of the risk
- engineering or building controls
- training and safe site practices
- a combination of any of the above.

Identifying reasonably practicable measures for managing risks of harm should consider:

- Whether risks can be eliminated, or reduced if not reasonably practicable to eliminate
- What the likelihood of harm occurring is
- The severity or degree of harm to human health or the environment
- The current state of knowledge about the risks
- Availability and suitability of technologies, processes or equipment to control the risk
- Cost of putting controls in place to reduce risks to human health or the environment.

2.3.3 Environmental Reference Standard

The Environmental Reference Standard sets out the outcomes that Victorians want to achieve and maintain. Figure 2-2 below identifies the environmental values of estuarine waters as per the Environmental Reference Standard (ERS) 2017 (Victoria Government Gazette, 2021), including those applicable to the estuaries like at Anglesea.



	Segment	Aquatic reserves	Marine and Estuarine															
		Aquatic reserves	Estuaries	Port Phillip Bay				Western Port		Corner Inlet	Gippsland Lakes					Open Coast		
Environmental value	**Subsegment**			Hobsons Bay	Central -East	Geelong Arm	Exchange	Entrances and North Arm	East Arm		Lake Wellington	Lake Victoria	Lake King	Lake Reeve	Exchange	Otway	Central Bass Strait	Gippsland (Two-Fold)
Water dependent ecosystems and species that are:	*Largely unmodified*	✔			✔		✔	✔								✔	✔	✔
	Slightly to moderately modified		✔	✔		✔			✔	✔	✔	✔	✔	✔	✔			
	Highly modified																	
Human consumption after appropriate treatment																	✔	
Agriculture and irrigation																		
Human consumption of aquatic foods		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Aquaculture		✔ if the environmental quality is suitable and an aquaculture licence has been issued under the **Fisheries Act 1995**																
Industrial and commercial			✔	✔	✔	✔	✔	✔	✔	✔						✔		✔
Water-based recreation (primary contact)		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Water-based recreation (secondary contact)		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Water-based recreation (aesthetic enjoyment)		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Traditional Owner cultural values		✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
Navigation and shipping		✔	✔	✔	✔	✔	✔	✔		✔					✔	✔	✔	✔

Figure 2-2 **Environmental values of marine and estuarine waters from ERS. Anglesea estuary is in the Otway Open Coast group.**

Section 3 Conceptual model

This section presents an overview of the Anglesea River catchment setting and a summary of the issue which options aim to address. The information has been sourced from a range of references listed in Section 7 including previous studies, a site visit completed by CDM Smith, publicly available data and the stakeholder representative group consulted as part of this project.

A summary of previous studies reviewed as part of this project is provided in Appendix A.

Figure 3-1 presents a summary of the catchment features as well as acidity sources, fate and transport mechanisms and environmental values. A timeline of catchment activities as well as factors potentially influencing acidity is presented in

Figure 3-5.

3.1 Catchment and estuary overview

The Anglesea River is located on Wadawurrung Country and is known traditionally as Kuarka Dorla, place of fishing mullet.

Anglesea River estuary is 2.6 km long, and the river catchment has an area of 116 sq. km (Pope, 2006) which includes ephemeral tributaries Salt Creek (including tributary Breakfast Creek) and Marshy Creek (Upper Anglesea River). Marshes are present in the upper catchment, with more extensive areas along Marshy Creek compared to Salt Creek.

The upper catchment is predominantly within Crown Land managed as the Anglesea Heath Flora and Fauna Reserve. Within this area is the Alcoa open cut coal mine and power station which operated from 1969 – 2016. Decommissioning, rehabilitation and closure of the Alcoa sites are under way; investigations to support finalisation and implementation of the mine closure plan are ongoing and once under way will need to be considered in future review of the Anglesea River management actions.

A heavy-vehicle driver-training complex is located in the upper part of the Marshy Creek sub-catchment, at the site of the former Roche Coal Mine that operated in the 1950s and 1960s.

The Anglesea Heathland supports a range of social and environmental values. This includes recreational activities such as four-wheel driving, camping, birdwatching, walking and horse riding. The forest is predominantly intact native vegetation, including heathland and open sclerophyll forest. Portions of the catchment were historically used for pine plantations and a former rifle range was located in the middle of the catchment adjacent to Marshy Creek. The heathland also holds significant cultural importance to the Wadawarrung Traditional Owners.

The upper Anglesea estuary is approximately 15 m wide near Coalmine Road, approximately 1km below where the tributaries meet. Downstream the estuary widens through Coogoorah Park (within a series of constructed channels), then to a variable 110 m near the mouth after flowing through the centre of Anglesea township. The estuary is generally highly stratified, predominantly upstream of the Great Ocean Road (Pope 2006, Maher, 2011; CCMA, 2012; Water Technology, 2010).

Land in the Anglesea River catchment is owned and managed by a range of parties, including state government departments and agencies, local government, as well as private companies. Community groups are active in management of the estuary and have been involved in previous studies as well as this project to provide their input and feedback on the impacts to values that acidification of the estuary presents. Wadawurrung Traditional Owners are also actively involved in caring for country and a range of projects related to the estuary. Management of the health of the estuary therefore is a complex arrangement between parties with a range of interests and responsibilities.

Figure 3-1: Anglesea River catchment conceptual model overview

Service Layer Credits: World Topographic Map: Vicmap, Esri, HERE, Garmin, FAO, NOAA, USGS
World Imagery: Maxar
World Hillshade: Esri, USGS

Figure 3-1: Anglesea River catchment conceptual model overview

1 Kuarka dorla, place of fishing mullet. Wadawurrung Traditional Owners have a continued connection to country, having lived, hunted and foraged in the area. Wadawurrung Traditional Owners continue to work towards healing, restoring and continuing to care for important Cultural waterways such as kuarka dorla.

2 Marshy Creek: Ephemeral flow. Marshes provide range of ecosystem services and regulate water flow. Shallow groundwater likely supports marshes (groundwater dependent ecosystems). Acid sulfate soils and soluble metals have been identified. pH typically indicates acidic water conditions.

3 Anglesea landfill. Previous studies have identified this as a potential minor source of acidity, however considered unlikely to be a significant contributor

4 Groundwater extraction from Upper Eastern View Formation: 1969 - 2016 to support Alcoa coal mine and power station. Interaction between shallow groundwater and UEVF is not fully understood. Community have raised groundwater extraction as potential cause of acidity, however the effects of the groundwater extraction have not been confirmed.

5 Groundwater extraction from Lower Eastern View Formation intermittently since 2009 by Barwon Water for water supply. Studies suggest little to no connection between UEVF and LEVF.

6 Salt Creek diversion channel: 3km section of lower Salt Creek modified and diverted around Alcoa mine. This potentially influences surface water flow through the catchment.

7 Former Alcoa power station: Ceased operation in 2016.

8 Discharge into Anglesea River: From 1969 - 2016 Alcoa discharged ~4 ml/day of pH neutral water. Since 2016, storage throughout winter-spring and seasonal release during drier summer periods has occurred to maintain water levels in the estuary.

9 Salt Creek: ephemeral flow. Marshes provide range of ecosystem services and regulate water flow. Shallow groundwater likely supports marshes (groundwater dependent ecosystems). Acid sulfate soils and soluble metals have been identified. pH typically indicates acidic water conditions.

10 Coogoorah Park: channels created following 1983 fires; acid sulfate soil present. Previous studies suggest water levels need to be maintained ~1.3 - 1.5 mAHD to avoid oxidation and release of acid.

11 Economic values: reflected with recreational camps, boat hire and other businesses reliant on tourism.

12 Former Alcoa coal mine (1969 - 2015): rehabilitation plan and supporting studies are ongoing. Change in vegetation and hydraulics of catchment following opening of the mine. Potential future changes to the hydrology of the catchment dependent on the rehabilitation plan. Community concern regarding potential overburden in upper catchment.

13 pH monitoring: fluctuation between neutral and acidic conditions since monitoring began in the 1970s. Unknown conditions prior to this time. Low pH conditions can increase the toxicity of some metals, and was the likely cause of previous fish deaths.

14 Environmental values: changes to estuarine fish species and presence, seagrass beds and habitat or available food for other species including frogs and waterbirds during extended acidic periods.

15 Rock wall: built 1975, majority removed late 1970s-80s with additional remnants removed in the 2010's. Previous studies indicate unlikely to influence estuary mouth dynamics.

16 Estuary mouth: classified as intermittently open/closed estuary. Opening and berm driven by rainfall and flow through catchment, offshore reefs and longshore drift in Bass Straight.

17 Climate (rainfall patterns, evaporation and evapotranspiration). Suggested to influence formation and transport of acid in the estuary where acid sulfate soils present. Studies suggest changes in rainfall patterns are not observed equally in stream flow (typically amplified).

18 Former Roche coal mine (1950s - 60s): potential disturbance of ASS and coal and release of acid, backfilled with ash and capped.

19 Estuary is highly stratified particularly upstream of the GOR bridge, influenced by fresh water inflows and marine exchange. Mixing saline and fresh water can cause flocculation of dissolved metals. Sea water can provide buffering capacity for low pH water.

20 Erosion of recreational 4WD tracks in the upper catchment has resulted in sediment transport in the catchment.

🟢 Acidity sources

🟠 Potential acidity formation drivers

🟡 Potential acidity transport mechanisms and regulators

🔵 Catchment activities and features

⚪ Environmental, social, cultural and economic values

3.2 Issue understanding

The Anglesea River estuary is a dynamic system resulting from the interplay of marine and upstream flows. Measurements of pH in the catchment tributaries of Salt Creek and Marshy Creek indicate acidic conditions most of the time. During such times, acidic conditions persisted in general for short to medium periods before returning to neutral conditions (Pope, 2006, 2011; EstuaryWatch, 2022; DELWP, 2022). Longer periods of low pH conditions have been recorded in the estuary in recent years, most significantly from 2019 until the end of October 2022. Figure 3-2 Figure 3-3 and Figure 3-4 present pH monitoring data in the estuary as well as in upstream tributaries.

Water pH conditions in the Anglesea River, prior to 1969 when Alcoa started monitoring as part of their mine operations are not known. It is difficult therefore to make links to the long-term factors described in subsequent sections that could contribute to water quality conditions in the catchment.

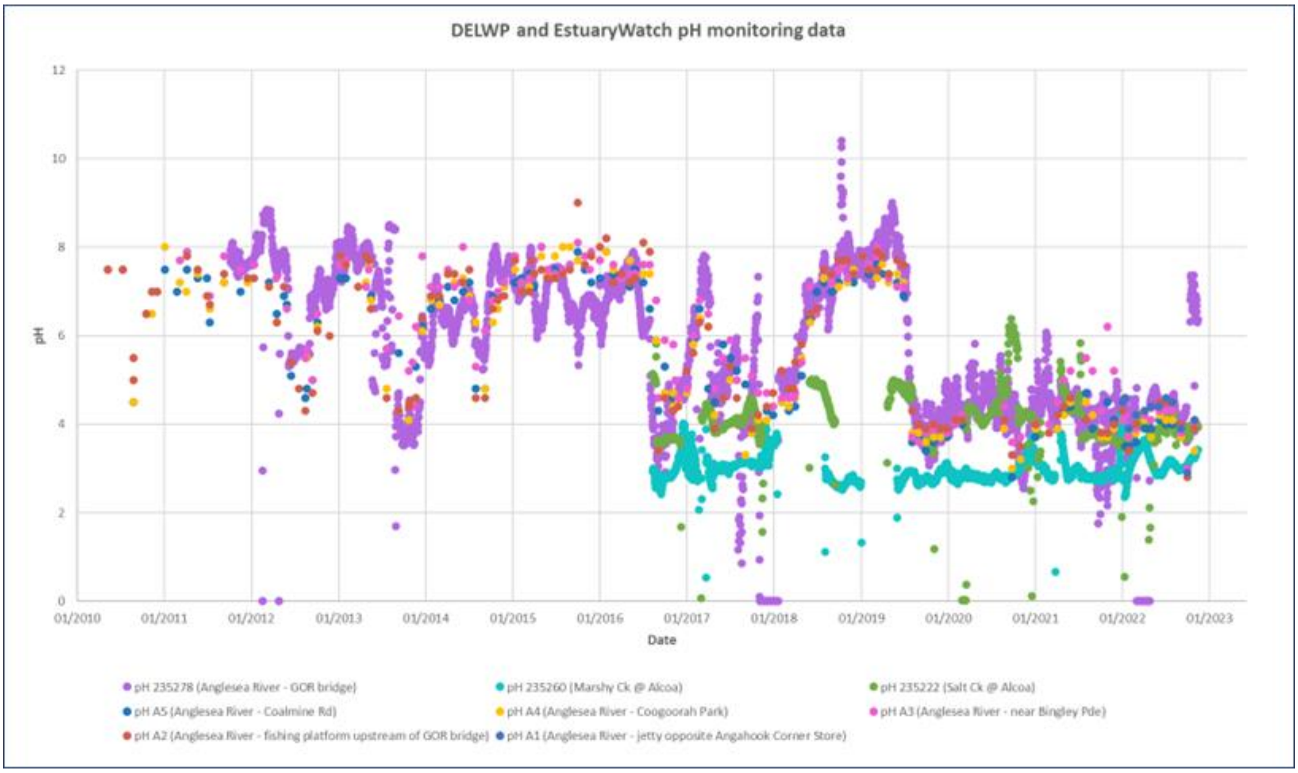


Figure 3-2 WMIS and EstuaryWatch pH monitoring data 2010 – Jan 2023

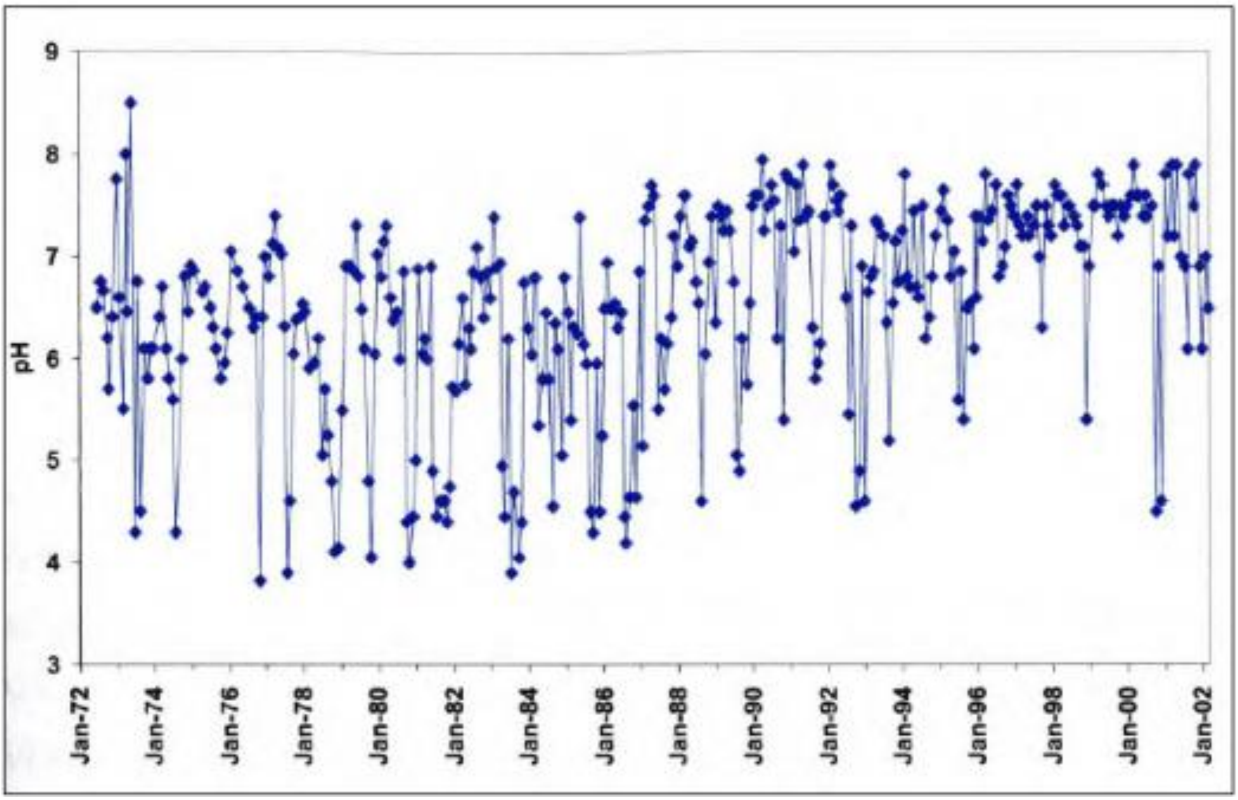


Figure 3-3 Estuary (mid) surface water pH (originally sourced from Alcoa, extracted from Pope, 2006)

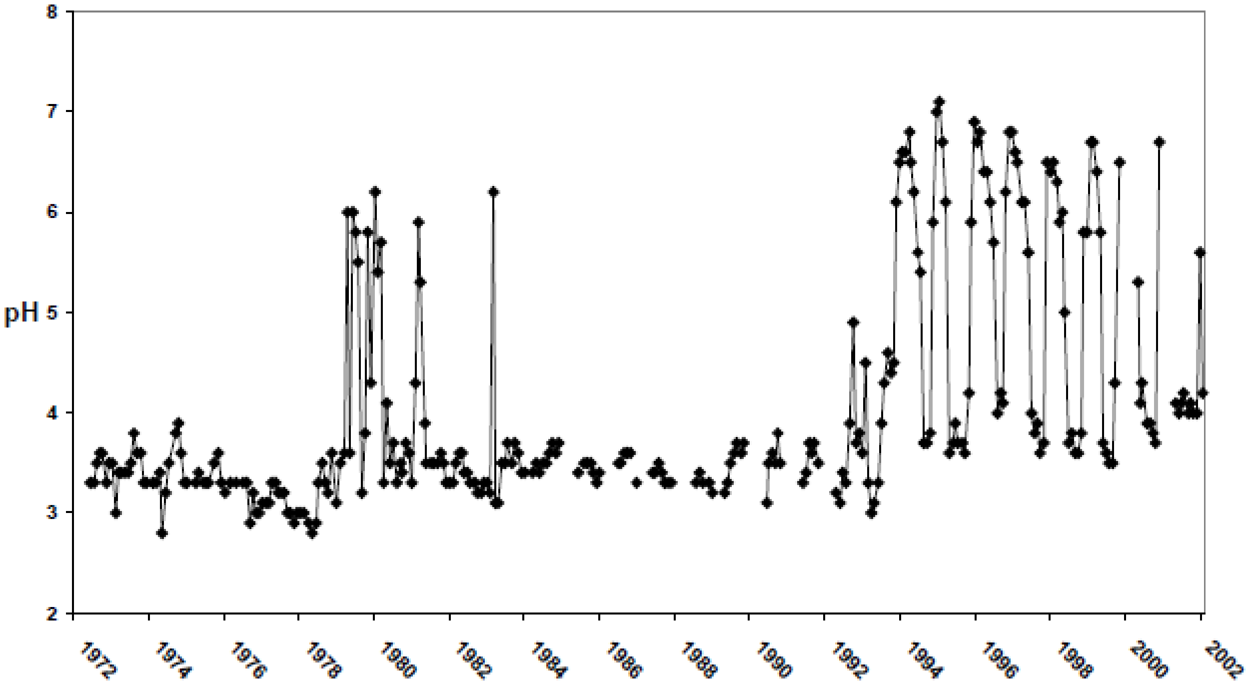


Figure 3-4 Long term monthly pH of the Anglesea River upstream of Alcoa (extracted from Pope, 2006; data from Alcoa)

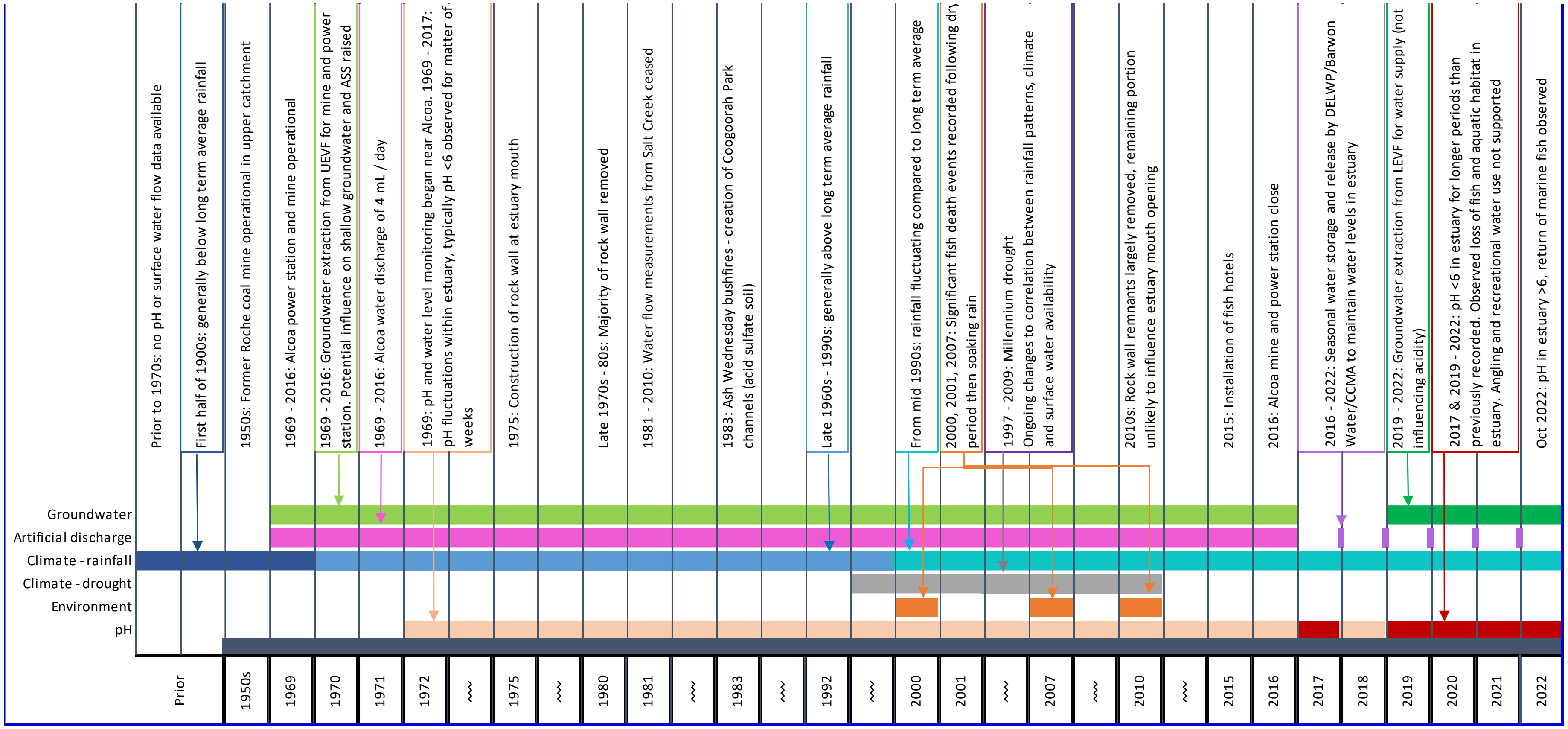


Figure 3-5 Timeline of catchment activities and factors potentially influencing acidity in recent decades

3.3 Environmental setting

3.3.1 Climate

Climate (rainfall patterns, evaporation and evapotranspiration) is proposed to be one of the main drivers resulting in formation of acid, influencing flow conditions in the catchment and transport of acid into the estuary (Maher, 2011; Wong, 2011).

The longest continuous rainfall record available nearest to Anglesea are from Wensleydale near the headwaters of the river in the upper catchment from 1965. The Wensleydale data indicates that below average rainfall occurred during the Millennium Drought between 1997 and 2010, with slightly wetter years from the 1970s to 1990s (GHD, 2021).

The report, Victoria's Water in a Changing Climate (DELWP et al, 2021) looked at long term historic trends in Victoria's climate and how it is changing. The report identified that rainfall is highly variable, and that rainfall patterns have changed over recent decades. This has included changes in seasonal rainfall (e.g., a decreasing trend in winter rainfall volumes) and increases in intense rainfall events.

3.3.1 Surface water flow

Salt Creek and Marshy Creek are highly ephemeral, with flow gauging measurements indicating they flowed only 35% and 50% of the time respectively between 2009 – 2020 (GHD, 2021). Measurements during recent years are shown on Figure 3-9 and Figure 3-10 (Section 3.4), demonstrating the level of fluctuation in daily surface water flow. Flow from the Marshy Creek and Salt Creek catchments to the estuary have decreased significantly over time as a result of the drier climate since the Millennium Drought (GHD, 2021; Water Technology, 2010). Historic flow conditions prior to Alcoa commencing operations (1969) in the catchment are not recorded.

Studies suggest that swamps in the upper catchment must become saturated before flow contributes to downstream reaches, with the swamps acting to attenuate water flow (GHD, 2021). As indicated by Pope (2006), factors such as soil type, temperature, humidity, vegetation type, connectivity of surface water and groundwater and geographic aspect, as well as anthropogenic influences, affecting the relationship between rainfall and runoff.

The Long-Term Water Resource Assessment for the Otway Coast Basin (DELWP, 2020) which includes the Anglesea River catchment, indicates that all rivers in the Basin have experienced a decline in surface water availability compared to historical availability). This is inferred to be primarily a result of climate, with other factors such as dams, large scale land-use changes (such as forestry) and groundwater extraction also potential contributors.

Streamflows over the past decades have also been the lowest on record, with many catchments experiencing significantly greater declines than expected based on past rainfall– runoff relationships. Streamflow is likely to continue to decline over coming decades (Potter et al. 2016). This is driven mostly by declines in future cool-season rainfall, along with increasing temperatures and potential for evapotranspiration (the transfer of water vapour to the air directly from the soil, from open water or through plants).

Changes to rainfall patterns shown in long term data suggest that rainfall is not directly linked to an equivalent change in surface water availability (DELWP et al, 2020; Fowler, 2022). Victoria's Water in a Changing Climate (DELWP et al, 2020) suggests that changes to streamflow volumes in Victoria are amplified compared to rainfall. Changes to temperature and atmospheric conditions also influence evaporation and runoff. An example of this is the change in rainfall to runoff ratios, where it is established that stream hydrology has shifted post the millennium drought within southern Australia, such that the stream flow of catchments has had a time step change (Fowler, 2022). Previous existing relationships therefore no longer can explain trends.

3.3.2 Anthropogenic influences on surface water and estuary flow

Lower reaches of the catchment have undergone anthropogenic changes that have altered surface water flow regimes and estuary functioning, including:

1) Development of an open cut coalmine from the 1970s with its associated land clearing, altering surface water drainage and infiltration as well as cone of depression in regional groundwater.
2) Construction of a 3 km diversion of the lower reaches of Salt Creek around the Alcoa open cut brown coal mine via an open concrete channel;
3) Coogoorah Park was created following the 1983 Ash Wednesday Bushfire from excavation of a series of channels to let water from the river extinguish peat fires. Studies have found surficial soil and sediment at Coogoorah Park would likely be subject to acidification if the water level is lowered (i.e., by ~1m), whereas if the area remains saturated there will be lower potential for release of acid sulfate soil acidity (Maher, 2011; GHD, 2016a; GHD 2016b; Sullivan, Reeves, Trewarn, 2016; GHD, 2016c). This is discussed further in subsequent sections. Pope (2006) modelled the volume of Coogoorah Park as containing between 14 – 20 % of the total estuary volume (at water levels of 1.05 – 1.8 m AHD). It was acknowledged that this was likely to be an underestimate due to assumptions in the model.
4) Artificial discharge into the river:
   - during operation of the Alcoa power station (1969 – 2015), approximately 4.5 ML per day of pH neutral to alkaline water was discharged under an EPA license. At times this represented between 50% and nearly the entire flow of the river [Maher 2011; GHD, 2021; Pope, 2006]. This had a significant influence on the lower catchment, maintaining discharge into the estuary when it would previously have ceased seasonally, as well as influencing the morphology of the entrance berm and its location [GHD, 2021; Water Technology, 2010). Discharges from Alcoa therefore have likely masked the acidity of naturally low flows from the upper and mid catchment in recent decades through dilution and buffering; and
   - since 2016, DEECA together with other agencies has undertaken seasonal water management, comprising storage from the upper or mid estuary during winter-spring, then release during summer periods to maintain water levels within the estuary including at Coogoorah Park to minimise oxidation of ASS (GHD 2021). This was adopted after a range of previous studies, which included consultation with the community, that investigated options for avoiding exposure of ASS at Coogoorah Park (GHD, 2016a; GHD, 2016b; Firelight Consulting, 2016; Mosaic Lab, 2016; GHD, 2016c). Seasonal water storage and release was selected as the option to implement in the short term.

3.3.3 Estuary mouth dynamics

The Anglesea River Estuary is classified as a wave-dominated intermittently open/ closed estuary. Prior studies have determined that whether the Anglesea estuary is open or closed is a function of the relative balance between wave and fluvial energy at the entrance (Ranasinghe & Pattiaratchi, 1999; McSweeney et al., 2018; GHD, 2021; Water Technology, 2011). These two competing forces dictate the net direction of sediment transport at the entrance, and thus the entrance condition. During periods of low river flow, wave processes dominate, and the net direction of sediment transport is onshore. Thus, two natural mechanisms of entrance opening operate at the Anglesea River estuary when water flow across the sand bar at the entrance erodes a channel creating an open entrance:

- Overtopping from the catchment side; and
- Overtopping from the marine side.

The dominant estuary opening process at Anglesea in recent times has been through human intervention, with artificial estuary openings occurring to protect public infrastructure and built assets from inundation (CMA, 2012) (Alluvium, 2014).

The most common natural mechanism of opening is overtopping from the catchment side. This occurs when high river flow enters the estuary and raises the water level to overtop the berm and incise a channel seaward. Once the estuary drains and hydraulic head is reduced, the opening duration becomes a function of wave vs fluvial processes (i.e., which control the net direction of sediment transport at the entrance). Overtopping from the marine side is more common during spring tides and above average wave heights. As the nearshore sea level is higher, waves are more likely to overtop the berm and add water to the estuary.

To initiate an estuary opening via this process, the estuary must already be full (i.e., high hydraulic head) and the seaward edge of the lagoon, close to the ocean. If this is not the case, wave over-wash is unlikely to reach the estuary or contribute sufficient water to result in an opening (GHD, 2021).

The variability of flow conditions over several months in 2017 to illustrate the fluctuation in the estuary are detailed in Figure 3-6 below.

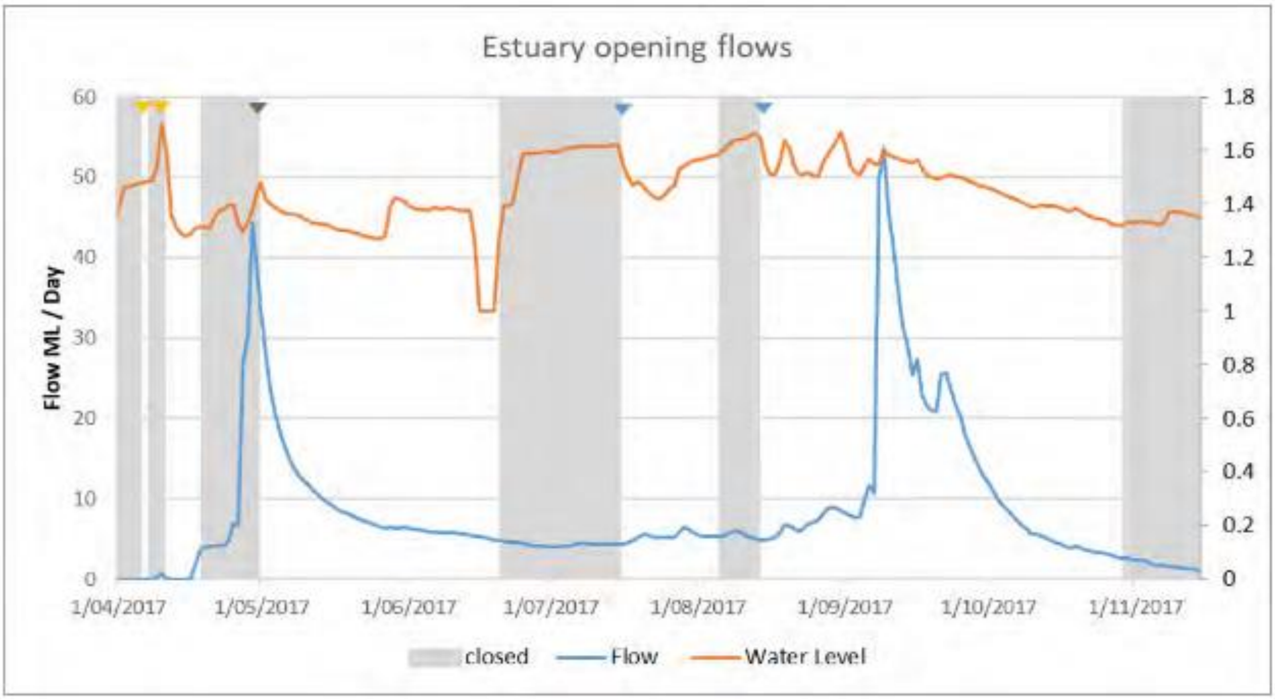


Figure 3-6 Estuary opening flows shown by triangles. Estuary flow on primary y axis and water level (m) on secondary axis (Source GHD Anglesea River and Estuary Environmental Flow Study, 2021)

Build-up of sand at the estuary entrance is predominantly a result of sand accumulating in the lee of the offshore reefs and the deposition pattern is determined by longshore drift. Bass Straight wave dynamics are suggested to be the primary cause of erosion/accretion of the dunes and upstream sedimentation (Water Technology, 2010; Pope, 2011). Incoming waves transport sand into the entrance and as water velocity decreases the sand is deposited in a structure known as a flood tide delta.

Pope (2006) identified three broad states for the Anglesea estuary:

- Closed: sand berm is highest relative to sea level and estuary is essentially isolated from tidal influence. Typically, water levels in the estuary were higher than sea level (~1.5 m AHD).
- Perched: sand berm is at an intermediate level, with tidal exchange only occurring during high tides via a channel to the sea. Typically, water levels in the estuary were higher than sea level, but lower than in a closed state.
- Tidal: a deep channel present with tidal exchange with the sea. Lower water levels in the estuary (~0.9 m AHD) with large daily fluctuations in depth.

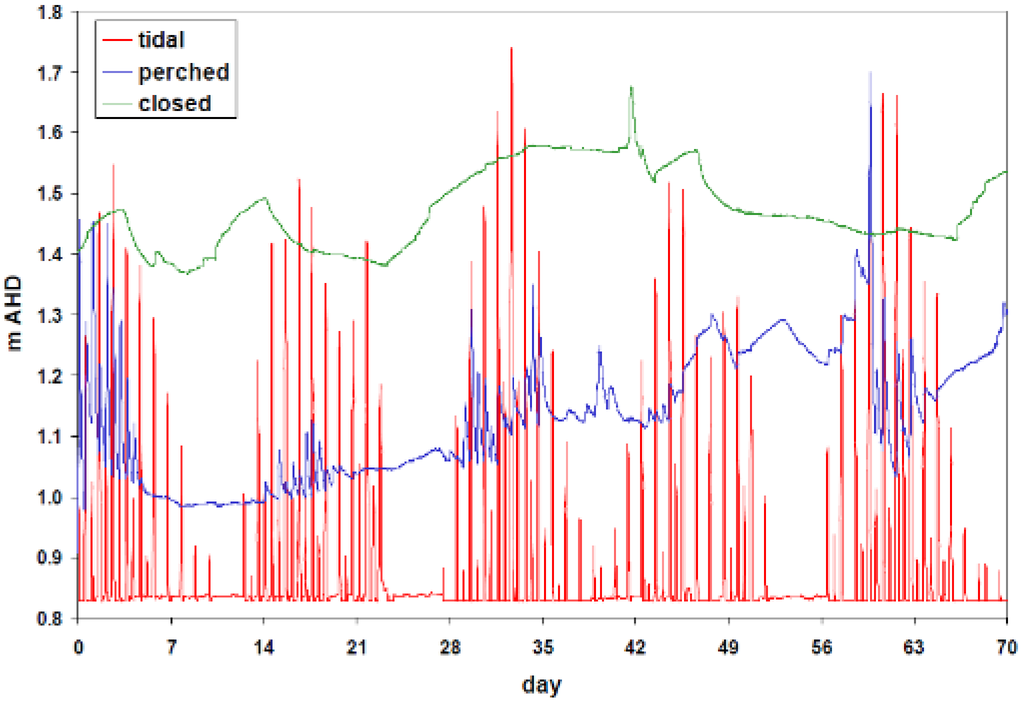


Figure 3-7 Logged water levels from Anglesea for three ten-week periods illustrating patterns of variation in water level during three hydrological states. Tidal: 25/4/2001 – 3/7/2001, Perched: 11/2/2001 – 21/4/2001, Closed: 15/11/1999 – 24/1/2000 (Source: Pope, 2006)

A rock wall was built in the entrance channel in 1975. The majority of the rock wall was removed in late 1970s and early 1980s, with the remains almost completely removed by Surf Coast Shire in the late 2010s. Studies have suggested that no changes to the river bank or entrance channel are associated with the rock wall and that the remaining section of rock wall is not likely to influence the build-up of the sand berm at the entrance (Water Technology, 2012; Water Technology, 2010).

Climate and anthropogenic factors in the catchment also likely influence the frequency and duration of estuary mouth opening due to changes in the volume of water flowing into the estuary (GHD, 2021; Water Technology, 2010). Since discharges by Alcoa ceased in 2016 the entrance sand berm has increased in height (from ~1.5m to ~1.9m AHD and migrated inland by 2-300m (GHD, 2021).

Increasing height and length of the berm will change the flow requirements for natural openings (GHD, 2021): water levels in the estuary will need to be higher or the tide lower to counter the lengthening of the berm for sufficient hydraulic head and energy for the opening to occur. Artificial estuary openings will also likely need to be deeper to maintain a channel. As water levels in the estuary increase, risks to infrastructure and flooding will increase. A key finding of the Anglesea River Environmental Flow Study (GHD, 2021) was that natural estuary openings should be encouraged, but artificial openings should be avoided, where possible, when sea conditions are unsuitable (i.e., spring tides, combined with high offshore waves, adverse south-westerly weather conditions), estuary oxygen levels are low, catchment flows are low (<5–7 ML/day) and will have limited impact on maintaining an open estuary.

3.3.4 Groundwater

3.3.4.1 Groundwater aquifers

The Upper Eastern View Formation (UEVF) and Lower Eastern View Formation (LEVF) aquifer systems underly the Anglesea River catchment. The UEVF surface is around 20 – 25m below the ground level, and the unit is 200 – 250 m in thickness. It consists of clay, silty clay, silt and fine to medium grained sand sequences with gravel and coal lenses [18]. Groundwater from the UEVF aquifer has historically been extracted by Alcoa between 1969 and 2016, resulting in drawdown of groundwater levels in the UEVF within the vicinity of the mine by up to 60 m (DELWP, 2022). There is currently no groundwater extraction from the UEVF occurring, and it is anticipated that water levels in the aquifer will recover over time. As this happens the mine pit will fill with water creating an acid lake without management action (Tutt, 2008).

The LEVF is around 200 m in thickness and separated from the UEVF by an aquitard of approximately 40 – 60 m thickness (GHD, 2021). The LEVF consists of micaceous silts, carbonaceous clays, silty clays, coal seams, sands and gravels. Barwon Water has extracted from the Lower Eastern View aquifer intermittently since 2009 for water supply (Maher, 2011; Wong et al, 2020)

Shallow groundwater has also been observed in the Anglesea catchment which is thought to support groundwater dependent ecosystems in the marshes in the upper catchment (GHD, 2021). The potential for interaction between shallow groundwater and the EVF is not fully understood. The Demons Bluff Formation overlies the UEVF in the lower catchment adjacent to the coast.

3.3.4.2 Groundwater and surface water interactions

Studies indicate that there are some marshes in the upper catchment along Salt and Marshy Creeks that are supported by shallow groundwater (Maher, 2011; Wong et al, 2020; GHD, 2021; Pope, 2011). These studies also suggest that-shallow groundwater systems and the underlying UEVF and LEVF aquifers are variably connected throughout the catchment.

There is some indication that in the upper catchment there is more connection between shallow groundwater and the UEVF than in the lower catchment where they are generally hydraulically disconnected (as summarised in GHD 2021, from GHD, 2008 and GHD, 2013).

Changing water levels in the UEVF may influence water levels in shallow groundwater that supports the swamps in some parts of the catchment, where these are connected. This connection and subsequently the influence that reduced groundwater levels in the UEVF could have had on ASS and acidity is not fully understood. For the purposes of this investigation, it has been assumed that changing groundwater levels in the regional UEVF could have influenced the issue.

Further technical studies are underway to support the mine rehabilitation and closure plan for Alcoa's coal mine, including further groundwater and hydrology studies. The data from these investigations will improve the understanding of any potential connection of groundwater aquifers and potential impacts this may have on the Anglesea River.

3.3.5 Soil and geology

The Anglesea catchment is located on the western edge of the Torquay Basin and eastern edge of the Otway Ranges High. The waterway cuts through various Tertiary sedimentary strata (EVF). Pleistocene and recent alluvial formations are associated with the creek and estuary beds comprising of quartz sand and gravel, clayey silt, carbonaceous clay and brown coal. Figure 3-8 illustrates the Pleistocene and recent alluvial formations associated with the creek and estuary beds. The Anglesea estuary and tributary streams are shown as the eastern R2 River alluvium deposit (in yellow).

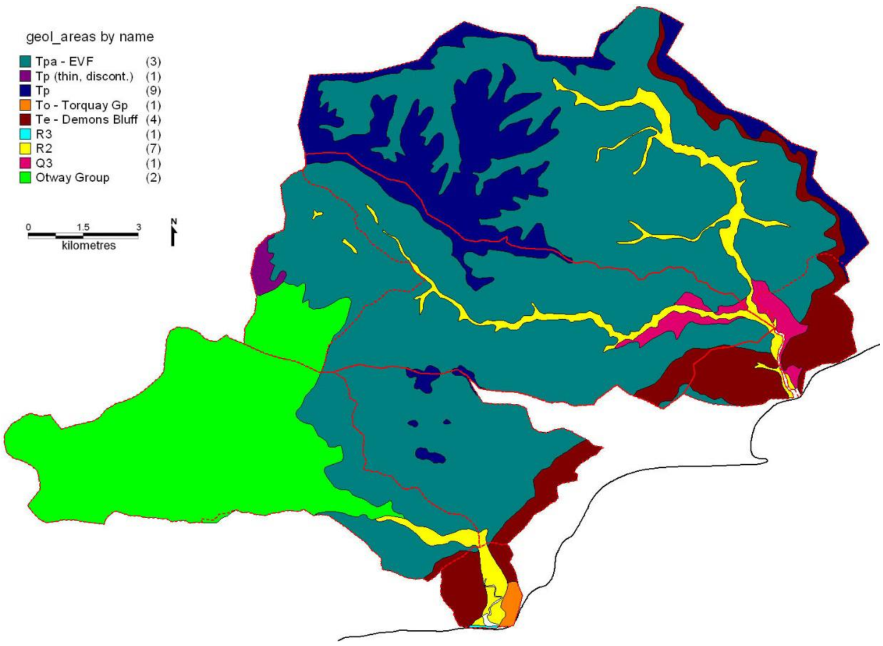


Figure 3-8 Outcropping geological strata in the Anglesea and Painkalac catchments (Pope, 2006). Data from (Abele, 1979)

The Anglesea Catchment resides within the Eastern View Formation, with substantial accumulations of organic peat material and sulfidic materials, including sulfidic coal materials. These sulfidic materials have the potential to oxidise and generate acidity and mobilise trace metals when exposed to the atmosphere (Wong et al, 2020). Further description of the acid generation process is detailed in section 3.4 below.

3.4 Acidity generation processes

3.4.1 General

ASS sulfidic minerals (of which the most prevalent is pyrite, FeS_2) are stable under waterlogged, anaerobic (no oxygen) conditions.

Hypersulfidic materials in ASS hold the potential to generate acidity from the sulfides they contain. In ASS with hypersulfidic material the sulfides are not reactive and have a pH ≥4 as this is the pH above which active bacterial sulfate reduction occurs, the process generating sulfide formation.

However, disturbances of hypersulfidic material (i.e., drought, excavation, dewatering or lowering of the water tables) causing exposure to both air (oxygen) and water can lead to the formation of sulfuric acid and to the generation of acidic conditions. These ASS are defined as having sulfuric material and have a pH ≤4.

Simplified geochemical reactions relevant to the processes involved in the release of acidity from soils include:

- $FeS_2 + 7/2^{\circ}_2 + H_2O \rightarrow Fe^{2+}\ 2SO_4^{2-} + 2H^+$ (1)

  (Conversion of pyrite to ferrous iron, sulfate and sulfuric acid.)

- $Fe^{2+} + ¼O_2 + H^+ \rightarrow Fe^{3+} + ½\ H_2O$ (2)

  (Oxidation of ferrous iron to ferric iron, consuming acid.)

- $Fe^{3+} + 3H_2O \rightarrow Fe(OH)_3\downarrow + 3H^+$ (3)

  (Hydrolysis of ferric ion, precipitation of ferric hydroxide and acid generation, at pH>4.)

- $FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO4^{2-} + 16H^+$ (4)

(Microbially mediated oxidation of pyrite by ferric iron, and production of soluble ferrous iron and sulfuric acid, at pH<4.)

The soluble ferrous iron produced by reactions (1) or (4) can be transported significant distances downstream of the ASS source, where it can be oxidised to form insoluble iron oxyhydroxides consuming oxygen and producing acid:

- $Fe^{2+} + \frac{1}{4}°_2 + 3/2H_2O \rightarrow FeO.OH \downarrow + 2H^+$ (5)

(Oxidation of ferrous iron and precipitation of goethite).

Other precipitates associated with iron oxidation include jarosite, natrojarosite and schwertmannite (retained acidity). Jarosite is a yellow mineral that is formed under strongly oxidising and highly acidic conditions (a pH of less than 3.7 units is required).

These minerals slowly decompose (usually by hydrolysis) leading to formation of iron precipitates, sulfate and acid. For example, in the case of jarosite:

- $Kfe_3(SO4)_2(OH)_6 + 3H_2O \rightarrow 3Fe(OH)_3 \downarrow + 2SO_4^{2-} + 3H^+ + K^+$ (6)

Similar reactions occur during oxidation of monosulfidic material (or monosulfidic black oozes (MBOs)) comprising monosulfide minerals (FeS):

- $FeS + 2O_2 \rightarrow Fe^{2+} + SO_4^{2-}$ (7)

(monosulfidic material or MBO oxidation consuming oxygen and releasing sulfate and acidity as ferrous iron; ferrous iron has then the potential to oxidise to ferric iron (reaction (2)) and hydrolyse (reaction (3)), generating acid)

ASS reactions can be minimised or potentially reversed under the right conditions over time, if soils are resaturated or reflooded, microbial catalysed reaction in the presence of organic matter may reduce dissolved sulfate to hydrogen sulfide and precipitate Fe^{3+} to Fe^{2+} due to the activity of sulfate-reducing bacteria, which also require available organic carbon (Blunden, 2000). This can take months to years to reverse the reactions, depending on the specific conditions.

Resaturation of oxidised ASS may also result in a flush of acidity into the waterway.

3.4.2 Terminology

Acidity is caused by the presence of high concentrations of the hydrogen ion (H^+). Neutral (non-acidic) water contains very low hydrogen ion concentrations. The following Acid Base Accounting (ABA) terms are generally used to describe the complex acidity and neutralising capacity associated with acid sulfate soils (ASS):

- **Actual Acidity**: the soluble and exchangeable acidity already present in the soil and readily available for reaction, including that in pore waters containing metal species capable of hydrolysis (e.g., Fe^{2+}, Fe^{3+} or Al^{3+} ions). It is this acidity that is typically readily mobilised and discharged following a rainfall event.
- **Retained Acidity**: the less available acidity retained from sparingly soluble and insoluble sulfur compounds (other than sulfides) that slowly produce acid (e.g., jarosite and natrojarosite).
- **Existing Acidity**: collective term that includes actual and retained acidity.
- **Potential Acidity**: The latent acidity in ASS that will be released if the sulfide minerals they contain (i.e., pyrite) are fully oxidised by exposure to air and water through drying or disturbance.
- **Net Acidity**: The result obtained when the acid neutralising capacity is subtracted from the sum of the total sources of acidity (Equation 1).

$$\text{Net Acidity} = \text{Potential Sulfidic Acidity} + \text{Actual Acidity} + \text{Retained Acidity}^{\#} - \text{Acid Neutralising Capacity}^{*}$$

Net Acidity Equation Notes: Where: # Retained Acidity must be determined when pH KCl < 4.5 or where jarosite has been visually observed in the soil material; * Acid Neutralising Capacity (ANC) can only be included in Net Acidity calculation if its effectiveness has been corroborated by other data (e.g. pH incubation data) that demonstrate acidification is not experienced by the soil material during complete oxidation under field conditions.

3.4.3 Sources of acidity

The primary sources of acidity in the Anglesea River catchment are ASS and the underlying geology. It is likely that there are a range of complex conditions contributing to this acid being formed and transported resulting in low pH conditions in the Anglesea River Estuary.

Geological units containing acid forming material (coal deposits, pyritic shale and siltstone) and ASS are present throughout the catchment. ASS containing both hypersulfidic material (i.e., potential acidity) and sulfuric material (i.e., existing acidity) have been identified in previous sampling in the Anglesea River estuary floodplain including at Coogoorah Park and extensively in the ephemeral tributaries Salt Creek and Marshy Creek in the upper Anglesea River catchment (Cheng Yao, 2014; Roussety; 2014; Sullivan, Reeves & Trewarn, 2016; Wong, Claff & Driscoll, 2020).

Previous studies have quantified the Acid Base Accounting e.g., of sulfuric and hypersulfidic materials in the catchment and found the following:

- Upper catchment (swamps) (from Wong, Claff & Driscoll, 2020):
  - Substantial volumes of readily mobile actual acidity are present in swamps along Salt and Marshy Creeks.
  - Marshy Creek contains high concentrations of actual (readily mobilised) acidity, as well as being saline and having high concentrations of soluble metals. Net acidity values up to 7168 mol H^+/t were measured. An ASS management plan is triggered when net acidity is > 18 mol H^+/t.
  - Salt Creek contains high concentrations of retained (slowly released) acidity, with net acidity values up to 609 mol H^+/t measured, as well as high concentrations of soluble metals. More extensive evidence of historical oxidation was present than in Marshy Creek.
  - In the surface 10 cm of soil within swamplands, the following preliminary estimates of net acidity and liming rates for neutralisation (including a 1.5 safety factor) was made:
    - Marshy Creek: 2.58 x 10^8 mol H^+, liming rate up to 76 t/ha
    - Salt Creek: 6.18 x 10^8 mol H^+, liming rate up to 100 t/ha
- Estuary (from Sullivan, Reeves & Trewarn, 2016):
  - Acidification hazard from ASS in the lower estuary is predominantly located at Coogoorah Park. Low lying land south of the Great Ocean Road bridge indicated low potential for the occurrence of ASS.
  - Lowering of water levels by ~1 m below recent historical levels (i.e., those maintained since excavation of Coogoorah Park in the 1980s) would result in oxidation of hypersulfidic material and the rapid formation of sulfuric material.
  - The majority of soil within Coogoorah Park was found to be ASS with hypersulfidic material. Sulfuric material in the top 70 cm of soil was found to have a mean net acidity of 1,188 mol H^+/t, and 2,717 mol H^+/t for soil deeper than 70 cm. Sulfidic material (not yet oxidised) was the dominant type of ASS and was found to have a mean net acidity of 803 mol H^+/t in the upper 70 cm and 3,795 mol H^+/t deeper than 70 cm.
  - Since excavation of channels at Coogoorah Park during Ash Wednesday in the 1980s, water levels were maintained at an average height of 1.5 mAHD from daily discharge of mine water from Alcoa. During operation of the Alcoa power station (1969 – 2015), EPA licensed discharges of pH neutral

process water at times contributed nearly the entire flow of the river (Maher, 2011; GHD, 2021). Since 2016, DEECA together with agencies has undertaken seasonal watering comprising storage from the estuary during winter-spring, then release during summer periods to maintain water levels within the estuary including at Coogoorah Park to avoid oxidation of ASS (GHD 2021). The exposure of ASS with hypersulfidic material in the area and potential release of acidity to the estuary remains an ongoing risk.

- Upper Catchment (soils outside of low lying swamps) (from CDM Smith 2023, summarised in Appendix D):
  - Targeted sampling of a representative area of soil erosion from recreational 4Wding indicated the presence of acidic soil with a net acidity up to 8.1 mol H+/t, significantly lower than ASS in the marshes. Given the catchment context (consisting of a large source of acidity, particularly within Salt and Marshy Creek), the localised areas of erosion of acidic soils, and potential increased oxidation of soils as a result of recreational 4WD activities, is unlikely to be significantly contributing to lower pH water conditions in Anglesea River to the extent that restricting this activity would influence acidity in the river.

The relative contributions of acidity from within the entire catchment area is currently unknown. While estimates of the acid generating potential have been made for various specific areas (e.g., Salt Creek marshes, Marshy Creek marshes, Coogoorah Park), the widespread occurrences of the various types of ASS across the catchment and complexity of the natural and human-influenced system makes the total acid potential of the catchment unknown. Mass balance approaches for determining the provenance of acidity (as recognised by Maher (2011)), is constrained at present by a lack of detailed understanding of the often complex potentially acid-contributing processes occurring across these landscapes, and consequently, there is a lack of reliable estimates of the magnitudes of the contributions of acidity by the various potentially acid-contributing processes.

Typically, pH in Marshy Creek is lower than in Salt Creek, with surface water flow in Salt Creek more variable. Figure 3-9 and Figure 3-10 show measurements from the WMIS sites in Salt and Marshy Creek in the mid-catchment, upstream of the confluence and estuary.

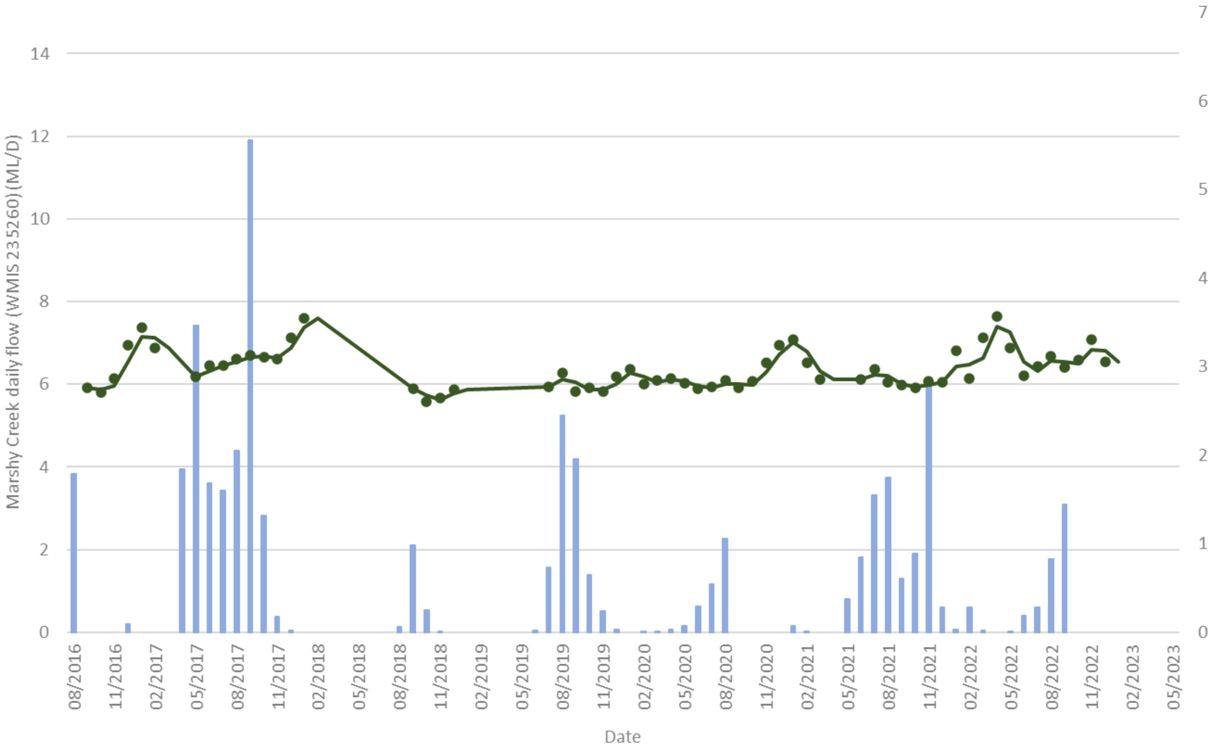


Figure 3-9 pH and average daily flow for Salt Creek @ Alcoa (WMIS site 235222)

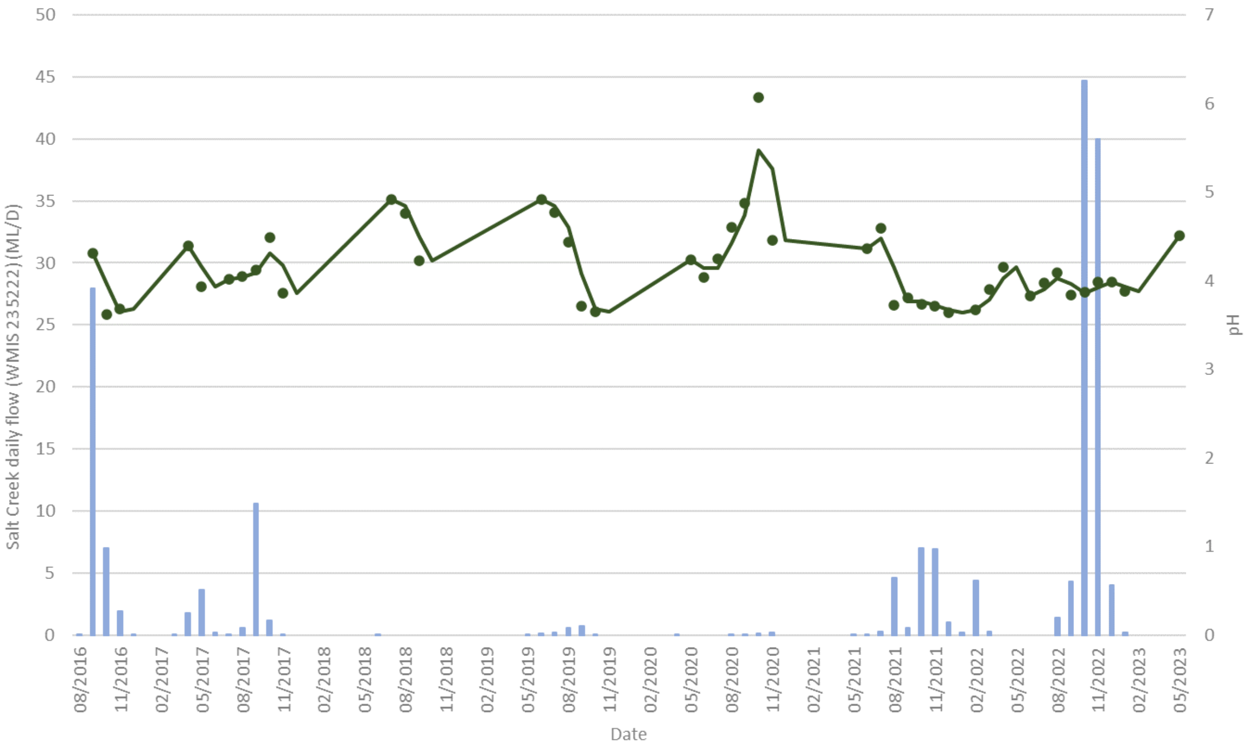


Figure 3-10 pH and average daily flow for Marshy Creek @ Alcoa (WMIS site 235260)

Given the scale of ASS in the upper and mid catchment, a treatment or management approach that aims to protect the receiving waters rather than treat the source is likely to be most practical and effective. Additionally, options that involve treatment or maintaining saturation of ASS are less likely to be practical and able to be maintained, as well as likely having greater impacts on existing environments. This is further discussed in later stages of this report related to identified options.

Other potential sources of acidity in the catchment were considered by Maher (2011). These potential sources were considered likely to be insignificant or unlikely to be contributing to acidity in the Anglesea River estuary.

- emission of sulfur dioxide from the former Alcoa Power Station;
- backfill of the historic Roche Mine in the 1950s and 60s; and
- leachate from the Anglesea Landfill.

It is important to note that the degree to which anthropogenic activity has contributed to acidity in the catchment is unknown. Sullivan (2013) for example, recognised that "commonly relied-upon indicators of human activity-accelerated sulfide oxidation – such as the use of depressed chloride:sulfate ratios, pH, and acidity in drainage or soil waters – will be less reliable when applied in landscapes such as those of the Anglesea region where iron sulfide oxidation driven by natural processes has occurred throughout significant proportions of the landscape in the past (as evidenced by the widespread occurrence of abundant natrojarosite in the Demons Bluff Formation) and indeed may still be occurring in this formation and the underlying Eastern View Formation both of which (especially the Eastern View Formation) drain into the Anglesea catchment".

3.4.4 Acid Generation in the Anglesea River catchment

A summary on the potential occurrence of acid generation processes in the Anglesea River catchment, based on a review of available previous studies and information, is provided below:

- Climate (rainfall patterns, evaporation and evapotranspiration) is suggested to be the predominant influence on formation and transport of acid in the Anglesea River catchment, with studies indicating that acid forms during extended dry periods, when catchment water tables and water levels in swamps in the upper catchment are lower, allowing oxidation of ASS (Maher, 2011; Wong, Claff & Driscoll, 2020; GHD, 2021; Water Technology, 2010).

- The potential for hypersulfidic material to have been oxidised as a result of groundwater extraction from the UEVF and drawdown of the aquifer has been raised (Maher, 2011; GHD, 2021; Haese, 2022; Pope, 2011). This has not been fully investigated, however further technical studies are under way to support rehabilitation and closure of the Alcoa coal mine, including groundwater and hydrology studies. Studies completed in the 2000s note that the health of vegetation and ecosystems within the marshes in the upper catchment do not appear to have been degraded however longitudinal studies have not been completed and historic information is generally not available (Maher, 2011).
- Fire and land clearing results in changes to vegetation and evapotranspiration rates, which can affect surface water runoff and infiltration, and as a result can change the wetting and drying of ASS materials. Organic matter (vegetation) can also control the formation hypersulfidic/hyposulfidic materials. The influence of changes in vegetation in the catchment has not been investigated in detail however may be a factor in controlling the oxidation of hypersulfidic material (Kölbl et al. 2022; 2021, 2019).
- Other factors of concern have also been raised as potentially contributing to acidity within the Anglesea River, such as erosion of soil from recreational four-wheel driving in the upper catchment. This has not been investigated as part of previous studies, however targeted sampling was undertaken in one representative area to inform this project. The results are presented in Appendix D. Effects are likely to be localised and minor compared to other catchment sources.

3.5 Transportation and regulation of acidity

The Anglesea Estuary is highly dynamic with many competing and complementing systems that both produce or transport acidic flows and regulate pH conditions. The figure below displays various surface water parameters (pH, dissolved oxygen and electrical conductivity (salinity)) and the variable water level in the estuary since 2011. This captures a period when Alcoa was discharging to the river and supplementing water levels, and a period (since 2016) when flows have represented a combination of natural conditions with some seasonal capture of water during winter and release in summer to manage ASS at Coogoorah Park.

Figure 3-11 displays periodic correlations between pH, water level and salinity, indicating that when there were significant surface water flows through the catchment in late 2022, the estuary berm was able to remain open and allowed marine exchange and buffering of pH conditions (increase in conductivity and lower water levels). The surface water flows, and marine exchange also correlated with an increase in pH.

Figure 3-11 also depicts times when heavy rainfall (not enough to open the estuary berm and allow marine exchange, with a decrease in conductivity associated with the catchment flows) proceeded by a dry period resulted in an acidic event such as in August 2019 leading to a fish death event.

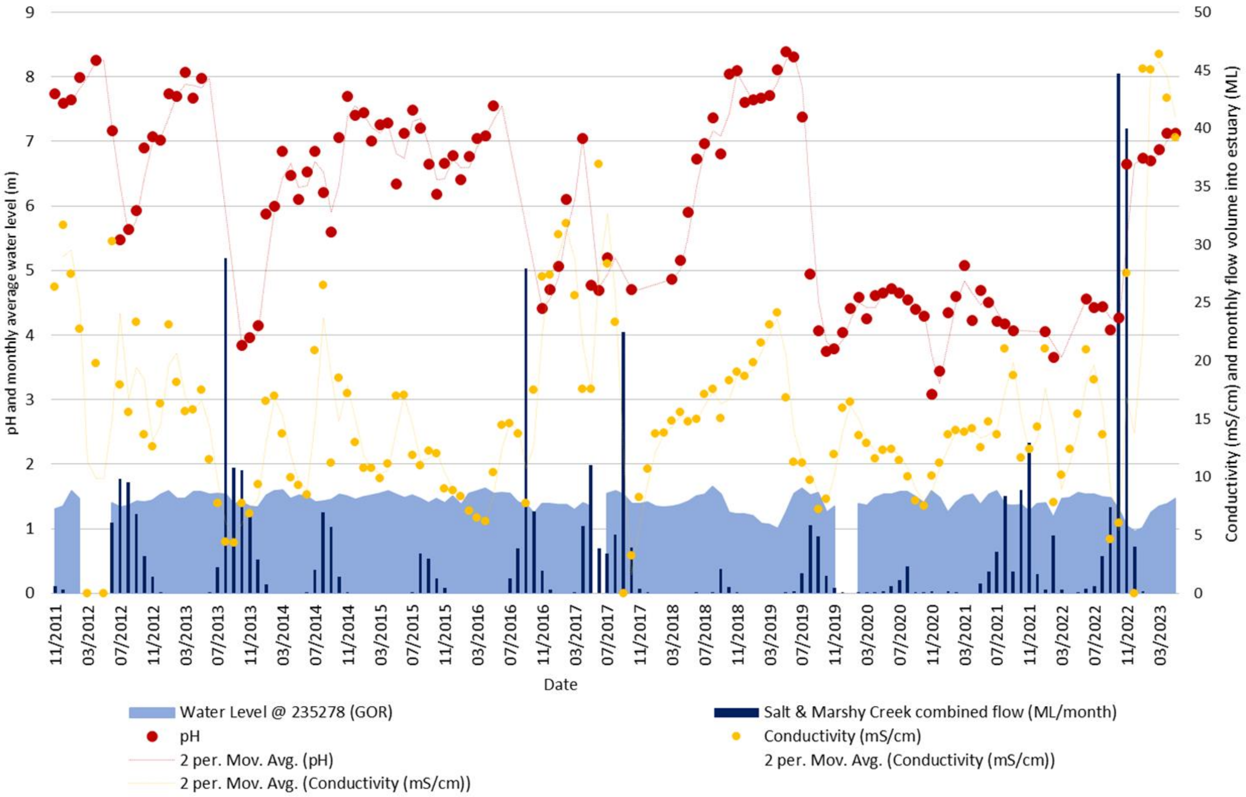


Figure 3-11 Estuary water quality and level 2011 – 2023 (measured at Great Ocean Road Bridge, WMIS site 235278)

Accumulation of actual acidity in the soil profile occurs as a result of ASS oxidation. Movement of acid into the estuary from sources in the upper catchment is by rainfall resulting in groundwater recharge and surface water flow. Studies have indicated that the most significant acid events resulting in fish deaths have occurred after extended dry conditions which allow acid to accumulate in the upper catchment, followed by prolonged saturating rainfall and higher flow conditions in Salt and Marshy Creeks rapidly mobilised acid into the river (Pope 2006, Tutt 2008, Maher, 2011; Wong, Claff & Driscoll, 2020).

Anthropogenic influences including artificial discharge and infrastructure have historically and currently affect flow in the catchment and the natural functioning of the estuary, for example the channels excavated at Coogoorah Park have likely altered how the estuary water quality regulates due to the additional volume.

Following low pH conditions or significant acid events, the estuary pH has historically recovered without intervention, most likely through changes in flow volumes through the catchment and/or opening of the estuary mouth, allowing flushing or buffering of low pH water with seawater (Pope 2006, Sharley, Amos & Pettigrove, 2012). The timeframe for natural recovery however has not always been acceptable to all stakeholders and has resulted in degradation of aquatic habitats.

Figure 3-12 depicts natural and human drivers and stressors in the system that are the key factors for acidity generation and regulation.

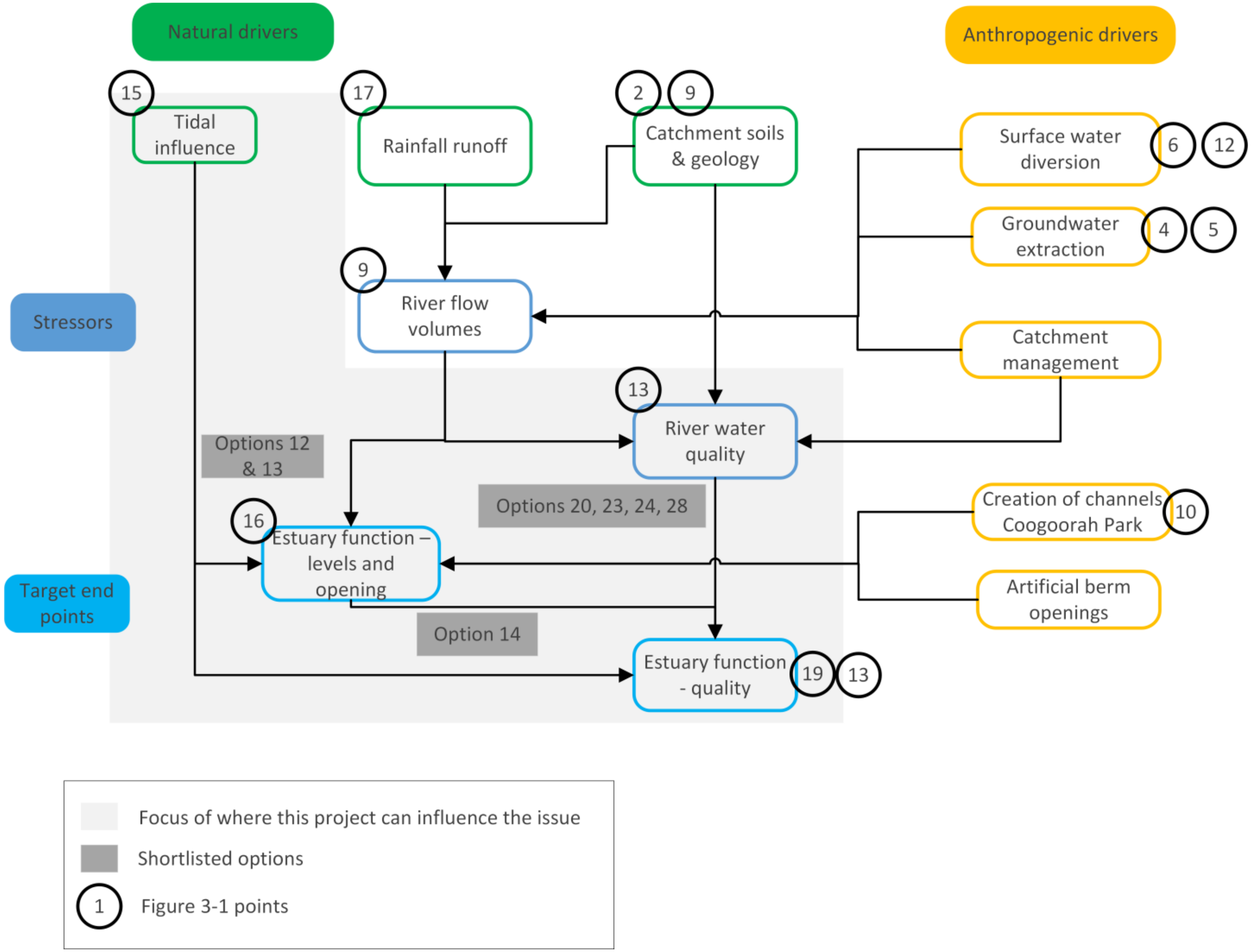


Figure 3-12 Driver-stressor diagram

3.6 Acidity and metal toxicity

Impacts to ecosystems from metals (in particular aluminium) are common in surface water flows from ASS. The toxicity of aluminium to aquatic organisms increases with lower pH (higher levels of acidity), and flocculation of aluminium can clog the gills of some fish and smother other aquatic life (Pope, 2010).

Aluminium speciation in water changes based on pH, with different aluminium species typically present in seawater (pH 8 – 8.3) compared to acidic fresh waters. The solubility of metals under different pH levels (i.e. point at which metals will precipitate) is shown in Figure 3-13. This varies based on kinetic and thermodynamic factors. Precipitation of aluminium (as aluminium hydroxide) can occur when acidic tributary waters meet neutral or alkaline water (for example in water previously discharged from the former Alcoa mine pit), and where saline and freshwater mix (Maher, 2011; Pope, 2010).

Dissolved aluminium and other metals that are bioavailable can also represent a potential risk of harm to aquatic organisms if concentrations are above criteria established in Australian New Zealand Water Quality Guidelines.

Aluminium, iron and other metals are naturally present in surface waters from soils, rock, coal seams and swamps. At lower pH levels, metals are more easily dissolved, such as the environments in the marshy areas in the upper catchment. During dry periods, metals can concentrate on the surface of marshes (Pope, 2010).

Fish deaths have been documented in 2000, 2007, spring 2010 and early 2011 during acid periods. In 2010, EPA-licenced discharge from Alcoa power station into the estuary was measured just above 7, with the estuary pH measured as 4 or lower in upstream tributaries. Previous investigations into the cause of fish death events have found that there was likely to have been a combination of factors that caused the event: pH, aluminium toxicity and suffocation due to precipitation of aluminium. This has typically occurred after a dry period where acid is formed in the marshes and aluminium is concentrated, followed by a saturating period of rain which flushes the acidic water and aluminium downstream.

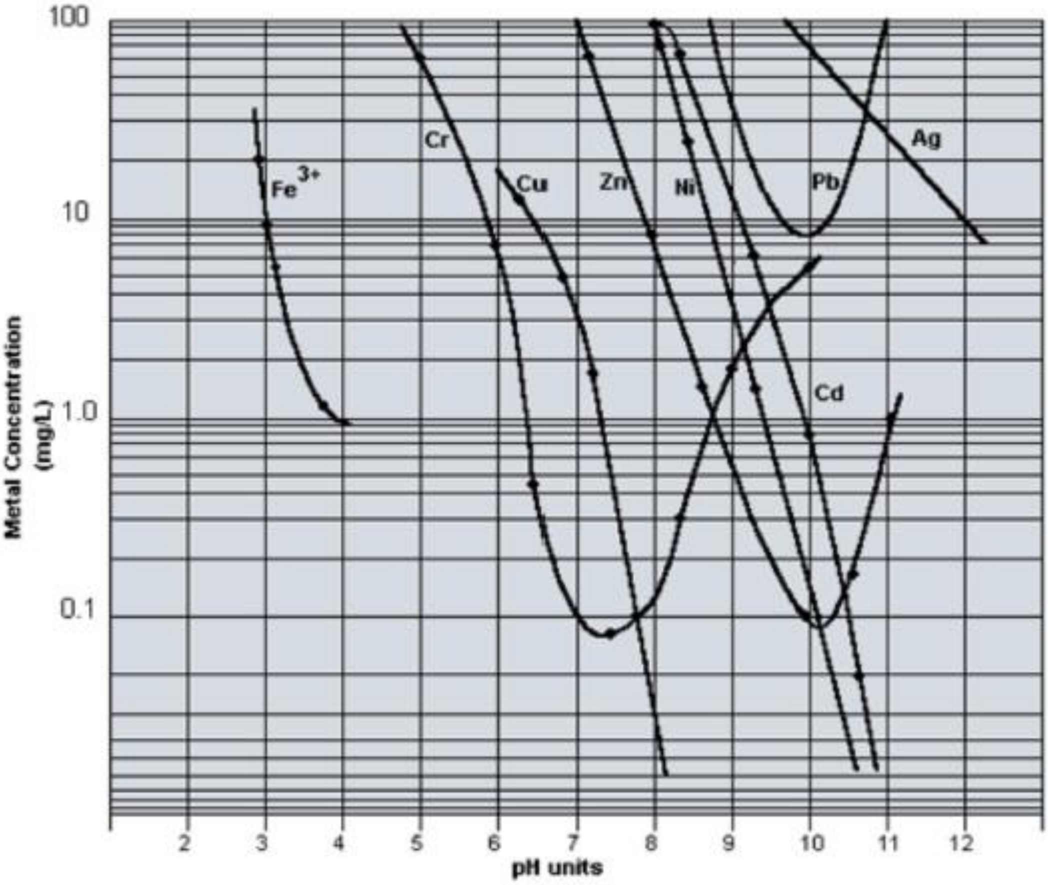


Figure 3-13 Solubility of metals at various pH levels (Smith, 1999)

3.7 Impacts on values

An Environmental Flow Study was undertaken in 2021 by GHD which identified the water dependent environmental values for the Anglesea River and Estuary. These are summarised in Table 3-1.

Table 3-1 Water dependent environmental values for the Anglesea River catchment and estuary (GHD, 2021)

Value Type	Specific Environmental Values
Vegetation	Range of high-valued (e.g., listed) Ecological Vegetation Classes (EVCs) and individual plants species including Broad Leaf Bog-sedge (*Schoenus laevigatus*), Salt Lawrencia (*Lawrencia spicata*), Lizard Orchid (*Burnettia cuneate*) and estuarine seagrass (*Zostera sp.* And *Ruppia sp.*).
Aquatic and amphibious fauna	Southern pygmy perch (*Nannoperca australis*), Common Galaxias (*Galaxias maculatus*), Flathead gudgeon (*Philypnodon grandiceps*), Shortfinned eel (*Anguilla australis*), Otway cray (*Geocharax gracilis*), Estuarine fish community (e.g., Black bream [*Acanthopagrus butcheri*]), Macroinvertebrate communities, Frog communities (e.g., Southern toadlet [*Pseudophryne semimarmorata*]).
Terrestrial vertebrates	Swamp Antechinus (*Antechinus minimus*), Swamp Skink (*Lissolepis coventryi*), White-footed Dunnart (*Smitnthopsis leucopus*), Rufous Bristlebird (*Dasyornis broadbenti caryochrous*), Spot-tailed Quoll (*Dasyurus maculatus*), Southern Brown Bandicoot (*Isoodon obesulus obesulus*).
Water quality	Suitable physico-chemical conditions for vegetation, aquatic and amphibious fauna, and terrestrial vertebrates, and issues associated with acid sulfate soils.

Value Type	Specific Environmental Values
Habitat	Diversity and complexity of habitat areas maintained by geomorphological and other physical processes, the nature of which are influenced by environmental variables such as geology, climate, vegetation, and human influences.

The following specific values set out in the Environmental Reference Standard (ERS) that are applicable for estuaries have been identified which may be impacted by extended periods of low pH. The potential impacts are based on previous studies and inputs from the project stakeholder reference group.

Table 3-2 ERS – Anglesea specific values

Value	Potential impact to:
Water dependent ecosystems	Refer to Table 3-1
Human consumption of aquatic foods	Loss of edible aquatic foods such as fish during low pH conditions
Water based recreation (primary and secondary contact, aesthetic enjoyment)	Public health from recreational use of the waterway for swimming or boating due to pH conditions below recreational water use guidelines Amenity due to loss of habitat and changes to the natural environment Recreational angling, swimming, boating, birdwatching and other passive recreation
Economic	Local tourism industry heavily supported by recreation and education Recreational fishing Degradation of infrastructure and landscape features.
Traditional Owner cultural values	Local plant and animal resources of the Wadawurrung People Spiritual connection with the river due to intervention and environmental degradation
Industrial and commercial	Industrial value not realised currently Commercial enterprises including recreational camps and angling
Navigation and shipping	Not impacted by pH

3.8 Potential future uncertainties

This assessment is based on current conceptual understanding of the acidity issue formed from previous studies and is based on the current catchment setting and available remediation technologies.

Potential future risks and changes in the catchment that have been identified are listed below. Should these situations eventuate, the appropriateness of remedial solutions identified and implemented will require review.

- **Changes to the catchment hydrology or hydrogeology following rehabilitation of the Alcoa open cut coal mine and power station**. Options for the rehabilitation of the Alcoa mine and power station which ceased operation in 2016 are currently being explored by other parties. The current plan for rehabilitation of the mine void involves filling of the pit with water, with water sources currently being investigated by Alcoa. Depending on the selected rehabilitation and management option for the mine there is potential future change to the catchment hydrology and hydrogeology. There is currently uncertainty regarding the details of the rehabilitation plan and an unknown timeframe for implementation. The focus of this project is on a short to medium term option for managing low pH conditions in the Anglesea River. Future monitoring to assess the effectiveness of the selected option once implemented should consider changes to the broader catchment, including whether any changes to the management approach are warranted. Options identified as part of this investigation may be independent of the Alcoa rehabilitation, or there may be options that could potentially be integrated into the rehabilitation of the Alcoa site if mutually agreeable.

- **Climate change**. A changing climate may influence pH conditions in the Anglesea River.
  - **Changes to surface water availability and flow.** Climate change has the potential to result in long term changes to temperature and rainfall patterns which has been observed as already occurring across Victoria (DEECA et al, 2021; Tholhurst et al, 2022). These, in turn, may alter vegetation types and extents, habitats, foraging and breeding areas, as well as catchment hydrology. Changes to the latter may lead to changes in catchment water tables and to the rates of exposure and drying of acid sulfate soil in the Salt and Marshy Creek and Coogoorah Park swamps. Resulting changes may also influence the suitability of the estuary for marine and estuarine fish (GHD, 2016c; GHD, 2021).
  - **Changes to the estuary berm** are also predicted due to climate change, with Water Technology 2011 estimating that the upper berm height will increase from 1.5 – 1.6 m AHD (as observed in 2011) to 2.3 – 2.4 m AHD by 2100. The profile is expected to change such that the crest of the berm shifts upstream.
  - **Changes to sea levels and water levels in the estuary** are predicted due to climate change. Water Technology (2011) has modelled what a predicted change of 0.8 m mean sea level and rise in berm height will mean for the estuary volume and water level in 2100. This results in inundation of low-lying areas with sea water, including the areas of Coogoorah Park, Lions Park Reserve and Caravan Park, western margin of the estuary and along River Reserve Road. The Water Technology study notes that this assumes an open entrance channel and any entrance closures would result in a higher water level in the estuary.
- **Episodic events such as bushfire.** Widespread bushfire or other episodic events may occur that influence surface water runoff, flow and acid generation.
- **Change in pH trends.** Given the complexity of the issue, it is possible that future trends in the generation and transport of acid in the catchment change and the issue either no longer requires management or requires additional interventions to protect environmental values.

Monitoring of water quality as part of an adaptive management strategy for the estuary and its catchment would allow early detection of future changes due to these factors.

3.9 Examples of other coastal waterways with acidity issues

Examples of remediation techniques employed or studied at other locations across Australia include:

Barker Inlet, SA

In 2002, CSIRO undertook studies that assessed the potential effectiveness of remediation technologies through a series of remediation trial experiments at Gillman, Barker Inlet, SA (Fitzpatrick et al. 2008; 2012; (Thomas, Fitzpatrick, Merry, & Hicks, 2003):

1. Re-flooding
   a. Seawater re-flooding (neutralization) — an open system, in which tidal and fluvial inputs occur and are then flushed to the estuary
   b. Water table management (containment and neutralisation)— a closed pondage system of saline groundwater/storm water and sea water where inputs are not exported to the estuary.

   c. Freshwater wetlands (neutralization and dilution) – storm-water contaminant treatment trapping and water table management.

2. Leaching/aging and containment of acid in the soil profile (requires chemical neutralisation)
3. Bioremediation (neutralisation and containment)
4. Lime Slotting (Chemical neutralisation of ASS with sulfuric material)

Shoalhaven Floodplain, southeast NSW

In 2006, the first pilot subsurface permeable reactive barrier (PRB) using recycled concrete for the remediation of acidic groundwater (~ pH 3) was employed in ASS terrain. Monitoring has confirmed the successful neutralisation of the acidic groundwater (~ pH 7.3) following installation of the reactive barriers. This solution proved a cost-effective remedy to the acidic groundwater conditions; however, uncertainty remains as to the longevity of the concrete used in this technology (Banasiak & Indraratna, 2012).

Trinity Inlet, QLD

Following sugarcane production that failed at East Trinity in the 1970's, the soils and waters became highly degraded due to construction of a bund wall in the early 1970's to exclude tidal seawater flushing (Hicks et al. 1999; Bowman et al. 2000; Smith et al. 2016; East Trinity Case Study, 2022). These investigations showed that areas of the site recorded pH readings of as low as 2.5 resulting in approximately 3,000 tonnes of sulfuric acid being leaked from the soil into Trinity Inlet every year along with large quantities of iron, aluminium and other metals. This resulted in many fish kills and the death of the mangrove forests. In 2000, it was estimated that it would cost approximately $78 million in lime alone to treat East Trinity this way (i.e., equated to 21,000 truckloads of lime to be taken on to the site). The limestone dosing method would also have been very destructive, as the earthworks to apply and mix the lime into the soil would have required the entire site to be cleared and dug up. Even if this money was invested in the property, it still did not guarantee a successful remediation. Lime-assisted tidal exchange was successfully used. This form of treatment involved reintroducing the tide to the site, by re-engineering the floodgates that had originally been used to stop the tide from entering. The aim was to stop the soils from drying further and continuing to produce acid. Seawater contains dissolved carbonate and bicarbonate and has the ability to neutralise acid. Hydrated lime (also known as slaked lime, or calcium hydroxide) dosing was added to the tidal waters to help neutralise the acidity.

In areas of the site that tidal waters had regularly reached over several years, the lime-assisted tidal exchange has been very effective. It has raised the pH of water leaving the site to above 6. Many areas of the site no longer need the daily lime addition to the tidal water as the seawater alone contains enough capacity to manage the small amount of acid generated from the site (Smith et al. 2016; East Trinity Case Study, 2022).

Section 4 Management objectives

4.1 Problem statement

The key issues that this project is seeking to address are:

- Low pH conditions are the result of naturally occurring ASS within the Anglesea River and tributaries in the upper and mid catchment that have historically oxidised to form acid which is transported downstream. This is driven by a complex range of natural conditions as well as anthropogenic changes to the catchment and estuary functioning.
- Sudden or prolonged periods of acidity in the Anglesea River, in particular the estuary, presents a risk to environmental and human health as well as other values and infrastructure.
- The natural system is able to regulate pH conditions through surface water flow and estuary mouth dynamics, however timeframes for returning to neutral pH conditions may not be acceptable to maintain environmental values unless a remediation or management option is implemented.
- Ongoing management of ASS with hypersulfidic material at Coogoorah Park is required to avoid oxidation of the hypersulfidic material and formation of sulfuric material with additional forms of acidity (Sullivan, 2016). The most appropriate method for managing Coogoorah Park is likely to be separate to the recommended options for remediating or managing ASS with sulfuric material or low pH water in the remainder of the catchment.

4.2 Management area

The priority area for options to address acidity is within the Anglesea River estuary, where previous periods of low pH have resulted in the most significant impacts on environmental values. It is noted that actions may be implemented in other parts of the catchment to influence conditions in the estuary, therefore the entire catchment has been considered to be the management area.

Specific areas of acidic soils include actual and potential ASS in the swamps along Salt and Marshy Creeks in the upper and mid catchment and potential ASS at Coogoorah Park.

4.3 Stakeholder reference group feedback

During the second engagement point, at a workshop held on the 2 November 2022, members of the project stakeholder reference group were asked to write down their top success factors for what a rehabilitation option would achieve. These are listed below grouped by theme.

Environmental

- Diversity of aquatic wildlife and a means of mitigating impacts of acid events
- Water quality that supports aquatic life
- A healthy functioning estuary
- A good variety of native fish in the estuary
- Salt and Marshy Creek have at least intermittent connection to sea (eels)

- Return of aquatic biodiversity
- Improve the imbalances in water quality driving algal growth and mosquito breeding
- Ongoing fish sustainable estuary – no fish kills
- Total healthy ecosystem – grasses, birds, invertebrates
- Restore natural inflows – pH neutral, only occasional acid events from Marshy (not continuous)
- Upper catchment without erosion of soils
- Establish causes, inputs and outputs that contribute to a) an unhealthy estuary and b) a healthy and thriving estuary
- Create a healthy, functioning estuary system that supports equally healthy ecosystems, habitats, flora and fauna
- Establish clear, effective remediation options in short and long term

Social

- Confidence from the community that we have done everything possible – community survey?
- Assessment of greenhouse gas flux to/from the river – can we make the river draw down
- Natural control of mosquito populations
- Community has 'ownership' of project final recommendations and supports them
- Safe swimming and recreation
- Level to allow recreation
- Have confidence that the estuary water quality is good enough to allow kids to swim without risk.

Cultural

- Return of the traditional name to the creek
- As for environmental

Economic

- Maintain and expand 'active tourism' on the river
- Whole catchment environment keeps 'pristine' reputation
- Promotable natural asset

4.4 GHD 2021 Environmental Flows Study – Relevant Social and Environmental Objectives

An Environmental Flows Study for the Anglesea River was completed in 2021 and established a range of conditions that future management actions of the Anglesea River would need to maintain to uphold the existing values of the river (GHD, 2021).

The study identified that higher catchment flows are required to promote natural openings, sustain the berm height and length, bed scouring and marine exchange, which assist in supporting values of the estuary including its visual amenity, recreational use, and environmental values. Higher magnitude flow events are required to naturally erode berm sediments and incise a channel that is deep enough to permit the entry of tides into the estuary (GHD, 2021).

Environmental objectives are related to vegetation, water quality and habitat (geomorphology and processes) (GHD 2021):

- Promote the rehabilitation of healthy beds of seagrasses in the estuary lagoon;
- Minimise the activation of ASS in swamplands and Coogoorah Park channels;
- Promote natural estuarine water quality conditions; and
- Promote natural regime of deep openings of the estuary entrance with marine exchange.

A variety of fish and other species have been recorded in the estuary (GHD 2016, GHD 2021). Estuarine species are tolerant of a wide range of salinity conditions and often have life cycles attuned to the natural hydrological cycles of the estuary. Environmental flow recommendations are designed to establish estuarine conditions to support life stages of these organisms and others that require an open entrance for migration into or out of the estuary (Lloyd et al 2012).

Flow requirements suggested by GHD focused on promoting natural regime of deep openings and a return to more favourable estuarine water quality conditions. This would support recovery of seagrass, development of haloclines associated with stratification and minimisation of the impacts of acid from the upper catchment and Coogoorah Park channels (GHD, 2021). The study however did state that this is unlikely to be possible under current and predicted conditions due to declines in rainfall and surface water flows from climate change, as well as cessation of Alcoa's EPA licenced discharge that supplemented natural flows. It also identified that the system is transitioning to a new normal, including that the estuary is moving from an intermittently open/closed system to a near permanently closed freshwater lagoon with a longer and higher berm.

Several recommendations for management of the river were made, including the following with relation to this study:

- Further extraction of surface water from Salt Creek and Marshy Creek is not supported. Significant reductions in river flows have impacted the estuary and will continue to limit its ecological and physical functioning
- Flows should be prioritised and prolonged periods of the estuary water levels being below 1.3 mAHD should be avoided to reduce the risk of activating ASS at Coogoorah Park
- Future alternative water sources should be investigated to maintain water levels in the estuary both to manage ASS at Coogoorah Park and support ecological and physical functioning
- Artificial estuary openings should be avoided and natural functioning promoted.

4.5 Objectives

The objective of the options assessed through this project is to regulate acidity within the Anglesea River estuary to protect environmental, cultural, social and economic values to the extent reasonably practicable.

Specifically, the broad goals are:

- A river that supports a balance of aquatic and terrestrial life as well as social and economic activities such as swimming, fishing and active tourism
- low pH events are occasional and minimise fish death events to the extent possible

As identified in Section 3.4.3, in order to meet the overall objective, two acid sources require management. The first is ASS in the upper and mid catchment that has formed sulfuric material and is the source of low pH flows into the estuary. The second is Coogoorah Park, where ASS with hypersulfidic material is present but has not yet formed acid. The management of ASS at Coogoorah Park would aim to avoid formation of acid due to exposure to oxygen which could exacerbate the issue (GHD, 2016; Federation University 2016).

Ideally it would be possible to identify one option that is practicable and acceptable for managing acidity sourced from both the upper and mid catchment and Coogoorah Park. It is noted that not all options are applicable for managing both ASS with hypersulfidic material and ASS with sulfuric material, and in some cases may be practicable or effective for one source but not the other. Options have been considered that manage the dual purposes simultaneously, could be applied separately to each potential acid source, and that would only apply for one source. Where options apply to one source only, these would need to be paired with a second option. This is further discussed through subsequent sections of this report.

It is acknowledged that no management or remediation strategy will be 'ideal', nor will it be likely to fully restore the environment to its original state. Given the catchment characteristics and issue drivers, the strategy is also unlikely to completely avoid acidic water being present within the catchment, particularly during high flow episodes. It is also unlikely that any outcome will meet the objectives of all stakeholder groups, as each bring their own priorities and viewpoint on risks or benefits. Nevertheless, the options assessment process has been considerate of these elements and aims to ultimately lead to the shortlisting of the most appropriate and effective options to meet the greatest number of priorities.

Section 5 Methodology

5.1 Stage 1: Identification of options

This task involved a comprehensive compilation of available options for management and remediation of the various types of ASS and acidification of waterways. This was generated from a range of sources including a literature review for initial identification of a broad spectrum of available options, research and applied experience from the appointed panel of independent experts, CDM Smith's experience, published technology performance data and guidance from national and international sources. Options that had been raised as part of previous studies and by the stakeholder reference group were also considered where these applied to the project objective.

5.2 Stage 1: Preliminary feasibility screening

Options that were identified were passed through an initial screen to consider whether they could address the critical objective of avoiding, treating, or managing acidity, in the context of feasibly being implemented in the Anglesea River catchment. The purpose of the preliminary feasibility screening was to allow a more site-specific assessment against detailed criteria only for those options considered to be potentially feasible for meeting the objectives.

The preliminary screening was conducted at a high level by qualitatively considering whether the option:

- Management or treatments of the source of acidity in the upper and mid catchment or treatments of acidic water, and/or
- Management of ASS with hypersulfidic material at Coogoorah Park to avoid further formation of ASS with sulfuric material

The following were also considered but did not influence whether the option was carried forward to multicriteria analysis:

- Whether the option protects or improves environmental, social, cultural, and economic values, external to pH levels
- Whether the option is likely to achieve acceptance by stakeholders, based on initial feedback from the project stakeholder reference group in a workshop held on the 14 December 2022.

The outcome of this task was identification of 21 options for a more detailed analysis and shortlisting (Section 5.3). Of these:

- 15 options would potentially be applicable to support remediation or management of acid sourced from upper and mid catchment as well as for the management of ASS with hypersulfidic material at Coogoorah Park
- Four options would be applicable to remediation or management of acid sourced from the upper catchment only (and require a separate option to be identified for management of Coogoorah Park)
- Two options would be applicable to Coogoorah Park only (and require a separate option to be identified for remediation of acid from the upper and mid catchment)

It should be noted that studies completed in 2016 assessed options for management of ASS with hypersulfidic material at Coogoorah Park and identified management of water levels to be the preferred approach (GHD, 2016a; GHD2016b). Options have been reconsidered as part of this investigation in the context of the broader issue.

As part of the preliminary screening and shortlisting, information on technology application, governing principles, typical performances, advantages and limitations were also collected and summarised to provide the basis for relative ranking of technologies performed as part of multicriteria analysis.

5.3 Stage 1: Shortlisting - multicriteria analysis

5.3.1 Overall

A simple multicriteria analysis scoring system was applied to options considered technically feasible in order to shortlist options for the Stage 2 detailed assessment. This involved assigning each technology a relative score for each of the assessment criteria to qualitatively compare the cost and benefit in relation to each other. This method was used to allow a ready and visual comparison between identified options; scoring was applied relatively rather than as a quantitative measure.

The following scoring matrix was used:

Table 5-1 MCA relative scoring matrix

MCA score	Description
2	Highly positive
1	Positive
0	Neutral
-1	Negative
-2	Highly negative

The project specific assessment framework was developed based on the categories and process outlined in the NRF and NWQMF, as presented in 1.3.

A total category score was then calculated for each option as a proportion of the maximum category score to provide adjusted relative category scores. This was done so that categories with more criteria (and therefore greater possible total score) were not having a greater influence over the overall score than categories with less criteria. No weighting was applied to categories, so all were considered equal in determining the outcome.

Adjusted relative category scores were then summed to provide a total score for each option. The five options that returned the highest total scores were retained for detailed assessment as part of Stage 2.

5.3.2 Sensitivity analysis

A range of other potential approaches to the MCA were applied to test the sensitivity and identify any bias in the scoring method. The sensitivity analysis considered:

- The categories included in the assessment
- The weighting applied to categories

Table 5-3 summarises the scenarios tested.

Table 5-2 Assessment framework

Category	**Criteria**	**Minimum score (-2) rational**	**Maximum score (2) rational**	**Maximum category score**
Technical	Relative effectiveness in achieving and sustaining outcomes (related to acidity and management of ASS at Coogoorah Park)	A score of -2 reflects an ineffectiveness to influence the pH conditions of the estuary	A score of 2 reflects a relatively very effective technique for achieving and sustaining neutral pH conditions both for acidic water received from the upper and mid catchment and for ASS at managing Coogoorah Park	6
	Timeframe for achieving outcome	A score of -2 reflects a technology that will be relatively long period until pH conditions improve	A score of 2 reflects a technology that will result in near instant pH level change.	
	Flexibility to be implemented as long term solution	A score of -2 reflects a technology that is a short-term solution with elements that will require a complete redesign if implemented for a long term. Elements that could potentially limit the effectiveness of a design over a long term are equipment lifetimes, growing population in the Anglesea community and future changes to the estuary	A score of 2 reflects a technology which has a long lifetime and that is relatively capable at adapting to changes in the Anglesea River Catchment area.	
Cultural	Effects on areas of cultural significance	A score of -2 reflects a technology that has relatively large negative impact on areas of cultural significance to the traditional owners.	A score of 2 reflects a technology that has no impact on areas of cultural significance to the traditional owners.	4
	Acceptance by Traditional Owners	A score of -2 reflects a technology that will have a relatively negative impact on the values of the traditional owners. As summarised in Section 4.4.	A score of 2 reflects a technology that will have no negative impact on and will positively address the values of traditional owners.	
Economic	Relative capital cost	A score of -2 reflects a very high capital cost	A score of 2 reflects a relatively very low capital cost	6
	Relative operational cost	A score of -2 reflects a very high ongoing operational cost	A score of 2 reflects a relatively very low ongoing operational cost	
	Relative potential effects on local economy	A score of -2 reflects a technology that potentially has a net detrimental effect on the local economy (for example preventing recreational camps use of the river or tourism)	A score of 2 reflects a technology that has a net positive effect on the local economy	

Category	Criteria	Minimum score (-2) rational	Maximum score (2) rational	Maximum category score
Environmental	Energy and resource consumption	A score of -2 reflects a design that has a relatively high energy and resource consumption during construction and throughout the technology's lifecycle	A score of 2 reflects a design that has a relatively low energy and resource consumption during construction and throughout the technology's lifecycle	10
	Waste disposal requirements	A score of -2 reflects a technology that has large waste disposal requirements during construction and throughout the technology's lifecycle. Potential waste disposal requirements might include excavated spoil from construction or reaction by-products and/or waste streams.	A score of 5 reflects a technology that has a no or negligible waste disposal requirements during construction and/or throughout the technology's lifecycle.	
	Climate resiliency to predicted changes in the Anglesea region (and ability to be scaled up etc.)	A score of -2 reflects a design that is inflexible to the changing conditions of the estuary due to climate change. The technology may require significant modification or complete redesign in the future.	A score of 2 reflects a technology that can readily adapt to the changing conditions of the estuary due to climate change. The technology can be up or down scaled as appropriate to effectively manage the acidity in the estuary.	
	Potential effects on the broader environment	A score of -2 reflects a technology that has a net detrimental effect on the broader environment. Potential factors of the design that may have a negative effect on the broader environment include land clearing from construction, greenhouse gas emissions from construction or during the lifecycle of the technology and potentially toxic waste products requiring management.	A score of 2 reflects a technology that has no or very minimal effects on the broader environment.	
	Risks to aquatic and terrestrial ecosystems within remediation area	A score of 1 reflects a technology that will or has the potential to pose a risk to local aquatic and terrestrial ecosystems. This includes factors such as the overall footprint removing habit or access for fauna up or down the estuary, other potential effects to the estuary water quality other than pH.	A score of 2 reflects a technology that has little to no potential risk to aquatic and terrestrial ecosystems within the estuary.	
Social/stakeholder	Acceptance by community, regulators, DEECA, CCMA, Surf Coast Shire, GORCAPA, Barwon Water, community and other stakeholders	A score of -2 reflects an overall lack of acceptance by stakeholders (community, regulators, DEECA, CCMA, Surf Coast Shire, GORCAPA, Barwon Water, community and other stakeholders)	A score of 2 reflects an overall acceptance by stakeholders (community, regulators, DEECA, CCMA, Surf Coast Shire, GORCAPA, Barwon Water, community and other stakeholders)	6

Category	Criteria	Minimum score (-2) rational	Maximum score (2) rational	Maximum category score
	Effects on recreational values (swimming, fishing, water activities)	A score of -2 reflects a technology that does not restore the reactional values of the estuary as per Section 4.4 or will potentially limit the recreational amenity of the estuary in the future.	A score of 2 reflects a technology that will restore the reactional values of the estuary as per Section 4.4 does not pose any risk to recreational amenity of the estuary in the future.	
	Amenity impacts (dust, noise, footprint, visual, odour)	A score of -2 reflects a technology that reduces public amenity of the area due to dust, noise, footprint, visual, odour, etc.	A score of 2 reflects a technology that limits the effect on public amenity to a negligible extent.	
Practicability	Timeframe for effective implementation	A score of -2 reflects a technology that will be relatively time-consuming to be granted approvals/permits and construct.	A score of 2 reflects a technology that will be able to be granted approvals/permits and constructed in a relatively timely manner.	8
	Logistical constraints (access, availability of resource/facility)	A score of -2 reflects a technology that utilises resources/facilities that may during construction or in the future pose a risk to the effectiveness of the technology.	A score of 2 reflects a technology that utilises resources /facilities that are readily available throughout the lifetime of the technology.	
	Legislative, regulatory and permit requirements	A score of -2 reflects a technology that will be challenging to get legislative /regulatory permit approvals for.	A score of 2 reflects a technology that will have negligible legislative or regulatory permit requirements	
	Ongoing maintenance requirements	A score of -2 reflects a technology that will or has the potential to require ongoing maintenance that may add additional costs or limit the efficiency of the technology. For example, regular replacement of consumable materials.	A score of 2 reflects a technology that will has fewer moving or consumable components and can be constructed of hardwearing material to limit it's required maintenance requirements.	

Table 5-3 Sensitivity analysis scenarios

Scenario	Categories included and weighting						Rationale for testing scenario for sensitivity
	Technical	Cultural	Economic	Environmental	Social/stakeholder	Practicability	
1. Main approach (Section 5.3.1)							Considers relative technical & practicability + quadruple bottom line (social, cultural, economic, environmental) All categories equal.
	16.67%	16.67%	16.67%	16.67%	16.67%	16.67%	
2. Excluding technical	-						Technical feasibility part of pre-screening and all options likely to help the issue to some degree
	-	20%	20%	20%	20%	20%	
3. Excluding cultural, economic and stakeholder		-	-		-		Environment central to all stakeholder and cultural goals Discounts cost as a factor.
	33.3%	-	-	33.3%	-	33.3%	
4. Weighted categories							Environment central to all stakeholder and cultural goals, technical and practicability key to whether it realistically can be implemented in Anglesea and achieve a successful outcome. These categories therefore weighted the highest. Cost least significant factor.
	20%	15%	10%	20%	15%	20%	
5. Weighted categories excluding technical	-						As for scenario 4, however with technical excluded as all options broadly likely to help the issue to some degree.
	-	20%	10%	25%	20%	25%	
6. Unweighted categories, combined social and cultural		Combined with social					Cultural views and values overlap with environmental, stakeholder acceptance and impacts to social and cultural values.
	20%	-	20%	20%	20%	20%	

5.4 Stage 2: Detailed assessment

Further investigation of options that were shortlisted in Stage 1 was undertaken to understand in more detail the relative effectiveness of each option. The options considered as part of the shortlist were based on the outcomes of the MCA which recommended further investigation of the six highest scoring options (Section 5.3), including options to manage ASS at Coogoorah Park and acidic catchment flows, and based on consultation with the Stakeholder Representative Group Workshop held on the 27 April 2023. At this workshop it was agreed that two other options would be considered further as part of this stage of the project – Option 12 and 13 (shallow and deep estuary entrance dredging).

Stage 2 of the project considered the following aspects in greater detail for each of the shortlisted options:

- Further investigation into the effectiveness of the option based on specific input parameters, including:
  - a qualitative assessment of the effectiveness under different dynamic conditions (based on available published reports and relevant literature) including surface water flow rates, water levels, water quality parameters and seawater influence in the estuary, as well as future climate change predictions.
  - evaluation of surface water flow, pH measurements and calculation of daily acidic load reaching the estuary. This was done using data from February 2022 to January 2023, which was selected to provide a recent and complete dataset, that included a range of different conditions from dry to high flows, and acidic to neutral conditions in the estuary. Data from monitoring points in Salt and Marshy Creeks at Alcoa – upstream of the confluence - was used (monitoring points 235222 and 235260 respectively) and acid load from each tributary combined to obtain an estimate of the quantity entering the estuary.
  - Comparison of the historic flow, pH and calculated acidic load against published thresholds for typical effectiveness (from Earth Systems, 2005). This was used to provide an indication of the proportion of the year when the option would have met ideal conditions to be effective, specific to the Anglesea River.
- Potential siting options
- High level feasibility cost estimate, based on published construction costs, previous studies as well as CDM Smith and independent expert experience. Costs are indicative for the purpose of comparing options, based on conceptual options
- Further details regarding logistical constraints, legislative and permit requirements
- Environmental, economic, social and cultural considerations
- Identification of additional information required and/or further assessment necessary to inform the potential effectiveness or conceptual design of the option.

Section 6 Stage 1 Options Identification and Assessment

6.1 Remediation and management strategies

Appendix C presents an overview of typical strategies for managing acidic geology and soils at the source, or impacts from acidic water, and the theory behind each of these approaches. Overall, typically strategies try to avoid acid generation or runoff, treat acidic conditions if formation of acid is unavoidable, or are responsive management measures. General constraints associated with application of the strategies are also summarised.

The following table provides a summary of strategies and the specific options identified for Anglesea River. The current strategy for management of water levels in the estuary to reduce the risk of ASS at Coogoorah Park through seasonal capture and release has not been included in the assessed options given this is part of current activities.

Table 6-1 Summary of strategies and specific identified options

Strategy	ID	Specific options identified for this project	Applicable management area	
			Upper catchment/estuary	Coogoorah Park
Minimise or prevent further oxidation of hypersulfidic material in ASS	1	In fill Coogoorah Park channels		▨
	2	Restrict access to upper reach of the catchment to minimise soil erosion from recreational activities	▨	
	3	Managed aquifer recharge to restore water levels in UEVF aquifer	▨	
	4	Maintain water levels with weir system (upper catchment)	▨	
	5	Maintain water levels with weir system (estuary - Coogoorah Park channels)		▨
Inundation of already acidified areas	6	Introduce water to upper and mid catchment to saturate areas with sulfuric material in ASS and stream/ponded water acidity	▨	
Isolation of impacted areas	7	Physical capping of acid sources	▨	
	8	Diversion of low pH water from Salt and/or Marshy Creek	▨	
Dilution + minimise further oxidation	9	Introduce potable water to estuary	▨	▨
Dilution + passive instream treatment of acidic water	10	Introduce recycled water to estuary from Anglesea RWTP	▨	▨
	11	Introduce recycled water to estuary from Black Rock RWTP	▨	▨
	12	Introduction of seawater to estuary via dredging of shallow artificial openings	▨	
	13	Introduction of seawater to estuary via dredging of deep artificial openings	▨	
	14	Introduce sea water to estuary via pump and pipe, or via passive tidal pipe	▨	▨
	15	Introduce seawater to estuary through removal of rock wall remnants at estuary mouth	▨	
	16	Introduce water to estuary from stormwater harvesting	▨	▨

Strategy	ID	Specific options identified for this project	Applicable management area	
			Upper catchment/estuary	Coogoorah Park
Dilution	17	Introduce groundwater to estuary	▨	▨
Neutralisation of ASS with sulfuric material	18	In-situ addition of a neutralising agent (e.g., lime) to ASS with sulfuric material in marshes	▨	▨
	19	In-situ bioremediation of sulfuric material in marshes	▨	▨
Passive treatment of acidic water	20	Install passive alkaline berms for treatment of acidity in-situ within river / open limestone drains	▨	
	21	In-stream limestone sand	▨	
	22	Limestone diversion wells	▨	
	23	Constructed wetland	▨	
	24	In-situ passive permeable reactive barrier	▨	
Active ex-situ treatment	25	Ex-situ filtration and membrane water treatment system	▨	
	26	Ex-situ treatment by alkali material dosing	▨	
	27	Ex-situ active resin ion-exchange treatment system	▨	
Active in-stream treatment of acidic water	28	In-situ dosing with alkali materials	▨	
	29	In-situ bioremediation of water	▨	
Management response action	30	Construction of aquatic habitat refuges	▨	

6.2 Preliminary feasibility screening

The preliminary feasibility screening compared all potential options to the "do nothing" baseline condition. As part of baseline conditions, the following is expected:

- Continued groundwater recovery in the UEVF.
- Continued natural fluctuation of pH conditions sourced from ASS in the upper catchment.
- Continued reduction in surface water availability, changes to temperature and rainfall patterns, as well as rising sea levels (and subsequently estuary water levels) as a result of climate change.

6.2.1 Feasible options carried forward for MCA

Feasible options for multicriteria analysis were identified from the preliminary screening, as summarised in Table 6-2. Options that met the primary objective of addressing pH conditions and/or secondary objective of maintaining water levels at Coogoorah Park were carried forward.

Table A1 in Appendix B provides further discussion about why each option was considered feasible.

Table 6-2 Summary of options carried forward for MCA

ID	Option	Description of how it would work
1	In fill Coogoorah Park channels	Option identified previously to avoid exposure of ASS with hypersulfidic material at Coogoorah Park and formation of sulfuric material and resulting acidification of water bodies within the estuary if water levels were reduced (GHD, 2016). Would reduce potential for generation of acid from ASS with sulfuric material at Coogoorah Park and therefore negate need for maintaining water levels in the estuary.
4	Maintain water levels with weir system (upper catchment)	Option involves installation of weirs to maintain water levels in areas where ASS with hypersulfidic material is present, with the aim of reducing oxidation and release of acidic water. By maintaining saturation of acidified areas in the upper catchment, this would have the ability to regulate flows and contain acidity in the upper catchment. Ultimately this approach would reverse geochemical processes and reduce in-situ acidity – however the extent and timeframe of this is uncertain and could take months to years. Simplest way to manage these areas is to ensure that ASS with both hypersulfidic and sulfuric materials remain under sufficient depth of water. Weirs can have different levels of permeability, and be constructed from sandbags or more permanent structures, incorporating habitat protection measures such as fish ladders.
5	Maintain water levels with weir system (estuary - Coogoorah Park channels)	Involves installing a hydraulic barrier / weir between Coogoorah Park channels and Anglesea River estuary, with the aim of maintaining an area of suitable water quality. Barrier could be permanent or temporary. Isolating channels would also aim to provide a refuge where water quality is maintained, and environmental values are protected. Water level would need to be maintained in Coogoorah Park channels via redirecting stormwater and catchment flows, or via pumping into the channels.
6	Introduce water to upper catchment to saturate areas of acidity	Option involves introducing water to areas of ASS with sulfuric materials in the upper catchment, and continual maintenance to maintain water levels and saturation of these acidic soils. This approach would aim to minimise oxidation of hypersulfidic material and the release of acidic water, and ultimately reverse geochemical processes and reduce *in-situ* acidity.
7	Physical capping of acid sources	Involves placement of a cap over areas where acid forming materials present. This would avoid exposure of pyrites and hypersulfidic materials to oxygen and prevent formation of acid. A clay cap would also reduce rainfall infiltration and runoff of labile acidity (already formed acid).
10	Introduce recycled water to estuary from Anglesea RWTP	Introduce recycled water to the estuary system to maintain water levels and prevent exposure of hypersulfidic material within this portion of the catchment. Would likely provide some support for bioremediation (introduction of organic matter) of sulfuric material and to treat acidic water, further regulating the pH, depending on its composition. Would involve construction of a pipeline from Anglesea water recycling plant (Class B water) and a treatment facility. Could be combined with other options (e.g. lime slurry or bioremediation) to enhance treatment capacity.
11	Introduce recycled water to estuary from Black Rock RWTP	As for Option 10, with construction of a pipeline from Black Rock (Class A water). Treatment would not be required to meet quality for human health. Less likely to support bioremediation objectives as treatment is to a higher quality.

ID	Option	Description of how it would work
12	Introduction of seawater to estuary via dredging of shallow artificial openings, or by grooming berm to allow wave overtopping	Physically dredge the estuary berm to increase tidal flows and volumes through the estuary, or maintain height of berm to allow wave overtopping, with seawater providing buffering capacity to neutralise acidic water from the upper catchment.
13	Introduction of seawater to estuary via dredging of deep artificial openings	Physically dredge the estuary berm to increase tidal flows and volumes through the estuary, with seawater providing buffering capacity to neutralise acidic water from the upper catchment.
14	Introduce sea water to estuary via pump and pipe, or via passive tidal pipe	Introduce sea water to the estuary system by pumping via a pipe upstream. The objective of this option would be to maintain water levels and avoid oxidation of ASS at Coogoorah Park, and to dilute and buffer low pH water that flows into the estuary from the upper catchment. Design could include for example construction of a pipeline and pumping system from the ocean to a point in the river, or a system for passively harvesting seawater during high spring tides.
16	Introduce water to estuary from stormwater harvesting	This option involves harvesting of stormwater and addition to the estuary system to maintain water levels at Coogoorah Park and prevent exposure of acid sulfate soils within this portion of the catchment. Depending on volumes and composition, may provide some support for dilution and bioremediation (introduction of organic matter) to treat acidic water, further regulating the pH. Infrastructure required including storage basins, diversion of stormwater, pump station and a pressure or gravity pipeline.
18	In-situ addition of a neutralising agent (e.g., lime) to ASS in marshes	Involves addition of soil neutralising agents (e.g., lime) where acid forming materials present such as in the upper catchment and at Coogoorah Park. Could be targeted to "hotspots".
19	In-situ bioremediation of sulfidic material in marshes	This option would involve addition of organic material (through mulching or planting of additional vegetation) to areas with hypersulfidic material.
20	Install passive alkaline berms for treatment of acidity in-situ within river / open limestone drains	The option involves installation of passive alkaline treatment materials to increase the pH of water within the river. This would involve placement of alkaline beaching or berms throughout catchment / river, or limestone drain beds. For example, this could involve placement of limestone gravel treatment beds within stream beds in the upper catchment, and/or placement of limestone rock within the estuary.
23	Constructed wetland	Construction of a managed wetland that captures flow through catchment, regulating water levels and providing capacity to manage and treat acidic water from the upper catchment. Wetlands can be aerobic, anaerobic, or reducing and alkalinity producing. If combined with another passive treatment option, aeration and settling wetlands can be used. A range of designs can be applied within each wetland type. Processes within a constructed wetland to improve water quality include (depending on wetland design): oxidation, reduction, precipitation, sedimentation, filtration, adsorption, complexation, chelation, active metal uptake by plants and microbial conversion/immobilisation mechanisms.
24	In-situ passive permeable reactive barrier	Option involves construction of a permeable barrier within the river or creek bed, similar to berms however with greater treatment capacity due to capturing and treating all flow. PRB contains treatment materials (alkaline material such as limestone, and/or organic matter). As water passes through the barrier it is treated to increase the pH.

ID	Option	Description of how it would work
25	Ex-situ filtration and membrane water treatment system	Option involves construction of a treatment system at a selected point, pumping of water from the river through the treatment system then back into the river. Specific technology uses filters and membranes to filter out sulfates. The passing of acidic water through a filtration / membrane plant will produce two outlet streams. One stream will be purified (sulfate free water) that could be returned back to the river. The second stream would be a concentrated sulfate rich stream that would need to be diverted away from the river.
26	Ex-situ treatment by alkali material dosing	Option involves construction of a storage dam or series of dams or holding tanks designed to store or hold back acidic water, which could then be treated by dosing with alkali material (calcium hydroxide or calcium oxide) and released.
27	Ex-situ active resin ion-exchange treatment system	Option involves construction of a fixed-point treatment system which pumps diverted streamflow via cation exchange resin to remove acidity from water. Treated water with higher pH is then returned to the river. The passing of acidic water through a resin bed, or series of resin beds allows target ions such as sulfates to be fixed onto the resin, and depending on the types of resins, the sulfates would either be replaced with a more benign ion, or taken a step further, the water could be “demineralised.”
28	In-situ dosing with alkali materials	Involves direct addition of materials such as calcium hydroxide (“lime”), sodium hydroxide, potassium hydroxide, magnesium hydroxide and carbonate salts to the river when there is a detection of low pH. Dosing stations could be located at multiple points along the river in the upper catchment and/or estuary.
29	In-situ bioremediation of water	This option would involve addition of organic bioremediation amendments (e.g., oxygen, hydrogen peroxide, ozone, magnesium peroxide, calcium peroxide) directly into the river or creeks in upper catchment or the estuary. Organic material containing carbon promotes sulfate reduction, increased alkalinity and pH.

6.2.2 Options not considered further as part of this project

Following review of all available options, those which were not able to address the issue in the context of the Anglesea catchment based on the initial information reviewed were not considered further. See Table 6-3 below for options that were not considered further.

Table 6-3 Identified options not considered further based on current objective and understanding

ID	Option	Theoretical description of how it would work	Feasibility screening discussion
2	Restrict access to upper reach of the catchment to minimise soil erosion from recreational activities	If eroded soil was ASS, reducing soil erosion and sedimentation from recreational access to upper catchment could avoid low pH conditions in the creeks and river.	Soil erosion from recreational four-wheel driving is unlikely to be significantly contributing to low pH conditions in Marshy or Salt Creeks or the Anglesea River, based on previous studies to understand where ASS is present in the catchment. Targeted sampling undertaken as part of this project within an area representative of eroded tracks in the upper catchment identified some ASS with low potential for generation of further acidity. Results supported the existing understanding of regional geology and soils, as likely containing acid forming minerals. Samples were collected from exposed 4WD tracks outside the marshes where soil had eroded. Net acidity results were lower than measurements previously reported within the marshes of Salt Creek and Marshy Creek. The areas of erosion observed were relatively small in comparison to the extensive marshes where ASS with significant estimated acid generating potential have been identified. Further details relating to the sampling and results are provided in Appendix D. Erosion and sedimentation can result in other impacts water quality, such as risk of hypoxic black water which if combined with low pH conditions in particular results in fish deaths. Unlikely this option would provide significant improvement in pH conditions in river therefore not considered feasible to address the objectives. Erosion management will be addressed outside of this project.

ID	Option	Theoretical description of how it would work	Feasibility screening discussion
3	Managed aquifer recharge to restore water levels in UEVF aquifer	If there is connectivity between shallow groundwater supporting swamplands where ASS is present and the UEVF, theoretically the option would aim to reduce potential for further oxidation of ASS with hypersulfidic material s within the area of groundwater drawdown. If lowered groundwater levels in the UEVF had resulted in drying and oxidation of hypersulfidic material, theoretically restoring water levels could resaturate these areas and ultimately inundation would reverse geochemical processes and reduce in-situ acidity. Involves pumping into UEVF aquifer to reverse historic groundwater drawdown more rapidly than allowing levels to recover naturally, which is currently occurring. Would require construction of infrastructure and identification of a water source.	Extent to which shallow groundwater supporting marshlands with ASS is connected to the UEVF is variable and not fully understood (Maher, 2011; GHD, 2021). Previous studies indicate that in the area where groundwater levels have been historically drawn down (mid and lower catchment near the Alcoa mine) the shallow groundwater that supports the swamps (where ASS is present) and UEVF are hydraulically disconnected (GHD, 2021; GHD, 2013; GHD, 2008) Unknown therefore whether recovery of groundwater levels in the UEVF aquifer would result in changes to water levels where ASS is present, so unknown whether this option would manage acidity from thecatchment. Range of other contributors to formation and transport of acid in catchment, therefore would most likely not fully address issue and reduce severity of low pH events. MAR is complex to design, significant additional studies would be required. Water source would also need to be identified. Significant timeframe for studies and approvals prior to implementation. Not feasible for the objectives of this project and uncertain outcome related to addressing the issue.
8	Diversion of low pH water from Salt and/or Marshy Creek	Diverting and containing acidic water to avoid downstream low pH conditions.	Technically feasible as an option for minimising the volume of low pH water reaching the estuary however as a standalone option likely to exacerbate the issue, as water levels at Coogoorah Park would lower resulting in oxidation of ASS with sulfuric material. Likely that there would be insufficient downstream flow required for maintaining a functioning estuary and ecosystem, and is not aligned with current recommendations for managing the river. Would need to be paired with a water supply to maintain flow and support environmental and social values within the river, and to maintain water levels at Coogoorah Park and avoid exposure of ASS. Refer to constraints and benefits of water supply options (Options 10-12, 16, 17). Legislation in place to maintain sustainable natural flow volumes; significant regulatory barriers in place currently to avoid environmental impacts as a result of this. Likely in contradiction with Water Quality Management Frameworks that aim to improve water quality over time.

ID	Option	Theoretical description of how it would work	Feasibility screening discussion
9	Introduce potable water to estuary	Introduce potable water to the estuary system to maintain water levels and prevent exposure of ASS with hypersulfidic material within this portion of the catchment. Would involve construction of infrastructure including a pipeline and dechlorination plant.	The option would reduce the potential for formation of acid within estuary system (by maintaining saturation of ASS at Coogoorah Park) and may dilute acidic water from mid and upper catchment, however the volume required for dilution would be significant and unlikely to be feasible. Approximately 100 - 1000 times the volume of the system is required for dilution of acidic waters, depending on the waters buffering capacity and alkalinity. Less effective than maintaining water levels with sea water or recycled/storm water as provides no treatment. This option represents an unsustainable use of potable water that would have broader environmental implications and is not acceptable to stakeholders.
15	Introduce seawater to estuary through removal of rock wall remnants at estuary mouth	Remove remaining portion of rock wall at estuary mouth. This has been raised by the community as an option for reducing sand build up at the estuary mouth and subsequently increasing the instances of seawater entering the estuary to dilute and buffer low pH conditions.	Previous studies (Water Technology, 2012) have found that the remaining section of rock wall is unlikely to affect: - volume of water entering or leaving the estuary from tidal flushing - sand deposition at the estuary mouth or upstream - the frequency of naturally occurring openings Removal of the remaining portion of rock wall therefore is unlikely to influence pH conditions. Risks and considerations in additional to little technical viability to address issue include potential for disturbance of cultural heritage values, coastal ASS, safety, recreational and economic costs. Disturbance of coastal ASS from removal of the rock wall has the potential to result in acidification.
17	Introduce groundwater to estuary	This option involves pumping of groundwater from a regional aquifer to the estuary system to dilute low pH water. This would also support maintenance of water levels and prevent exposure of ASS with hypersulfidic material at Coogoorah Park. Would involve identification of suitable groundwater source, construction of infrastructure including a pipeline and potentially new production bores, depending on capacity of existing bores.	The option would reduce the potential for formation of acid within estuary system (e.g., from Coogoorah Park) and may dilute acidic water from mid and upper catchment, however the volume required for dilution would be significant and unlikely to be feasible. Further investigation to understand whether groundwater would provide buffering capacity would be required. Further groundwater extraction is not supported by stakeholders.
21	In-stream limestone sand	Option involves placement of limestone sand stockpiles within stream beds, increasing the pH and alkalinity of the water progressively.	Is a proven treatment option for low pH water, where limestone sand is gradually washed downstream from a stockpile. Unlikely to be effective in the Anglesea catchment as requires high gradient streams to wash limestone particles downstream as well as to minimise armouring to maintain treatment effectiveness. Less controlled than dosing or other alkaline treatment methods, so not adjustable for conditions.

ID	Option	Theoretical description of how it would work	Feasibility screening discussion
22	Limestone diversion wells	Option involves construction of a shallow, wide well containing crushed limestone aggregate, and diversion of water to be treated into the well via a pipeline. Limestone increases the pH and alkalinity of the diverted water.	Consist of in-ground wells (1.5-1.8 m in diameter and 2.0-2.5 m in depth) containing crushed limestone aggregates into which part of a fast-flowing stream flow is diverted, usually via a pipeline. Is a proven treatment option for low pH water, however unlikely to be effective in the Anglesea catchment as requires high velocity stream flow to maintain effectiveness.
30	Construction of aquatic habitat refuges	Option involves installing refuges to improve resilience during periods of low pH. This could include construction of a network of pools/branches or diversion channels in the river system that remain at a pH suitable for supporting aquatic organisms.	Will not improve pH conditions broadly and address the issue, however provides a potential measure for better protection of aquatic life when pH conditions change. High river flows, and extreme acidic conditions may also render refuge point ineffective. May not be effective at supporting environmental values for prolonged periods of low pH, depending on the scale of the refuge. Could involve construction of new channels or use of existing areas (e.g., Coogoorah Park). Excavation of channels if required would need to avoid potential formation of ASS with sulfuric material and subsequent release of heavy metals. Most appropriate to be applied in combination with other options as does not directly manage acidity.

6.3 Multicriteria analysis of feasible options

Table 6-4 summarises the feasible options for the Anglesea River and total scores following the MCA. The detailed MCA review table and discussion is provided in Appendix A.

Table 6-4 Summary of relative MCA scoring (equally weighted categories)

ID	Option	Upper catchment / estuary	Coogoorah Park	Total score
1	In fill Coogoorah Park channels		■	🔴-1.7
4	Maintain water levels with weir system (upper catchment)	■		🟡-0.4
5	Maintain water levels with weir system (estuary - Coogoorah Park channels)		■	🟢0.6
6	Introduce water to upper catchment to saturate areas of acidity	■		🔴-3.0
7	Physical capping of acid sources	■	■	🔴-4.8
10	Introduce recycled water to estuary - Anglesea WTP	■	■	🟡0.0
11	Introduce recycled water to estuary - Black Rock WTP	■	■	🟡-0.1
12	Introduction of seawater to estuary via dredging of shallow artificial openings	■		🔴-3.2
13	Introduction of seawater to estuary via dredging of deep artificial openings	■		🔴-3.4
14	Introduce sea water to estuary via offshore pump and pipe	■	■	🟢1.2
16	Introduce water to estuary from stormwater harvesting	■	■	🔴-2.8
18	In-situ addition of a neutralising agent (e.g. lime) to ASS in marshes	■	■	🔴-2.6
19	In-situ bioremediation of sulfidic material in marshes	■	■	🔴-3.2
20	Install passive alkaline berms for treatment of acidity in-situ within river / open limestone drains	■		🟢4.3
23	Constructed wetland (reducing and alkalinity producing type)	■		🟢4.5
24	Insitu passive permeable reactive barrier	■		🟢3.2
25	Ex-situ filtration and membrane water treatment system	■		🟡-0.3
26	Ex-situ treatment by alkali material dosing	■		🟡-0.3
27	Ex-situ active resin ion-exchange treatment system	■		🟡-0.6
28	In-situ dosing with alkali materials	■		🟢1.7
29	In-situ bioremediation of water	■		🟡-1.0

6.3.1 Sensitivity analysis

The sensitivity analysis returned the same six options with the highest scores in each scenario, with some variation in the specific scores. Variation between each scenario tested within the top ten scoring options was observed. The results are summarised below. The full MCA for each of the scenarios considered is provided in Table A3 in Appendix A.

Table 6-5 Summary of options with the top 10 relative MCA scores for each scenario considered in the sensitivity analysis

		Scenario - total MCA score					
ID	**Option**	**1 (base**	**2**	**3**	**4**	**5**	**6**
23	Constructed wetland (reducing and alkalinity producing type) (repurposing existing disturbed area)	🟢4.5	🟢4.1	🟢4.8	🟢4.6	🟢4.1	🟢4.9
20	Install passive alkaline berms for treatment of acidity in-situ within river / open limestone drains	🟢4.3	🟢3.9	🟢5.9	🟢4.5	🟢3.9	🟢5.2
24	Insitu passive permeable reactive barrier	🟢3.2	🟢2.5	🟢4.2	🟢3.3	🟢2.3	🟢3.9
28	In-situ dosing with alkali materials	🟢1.7	🟢0.4	🟢3.4	🟢2.2	🟢0.8	🟢2.1
14	Introduce sea water to estuary via offshore pump and pipe	🟢1.2	🟡-0.5	🟢2.8	🟢1.6	🟡-0.4	🟢2.0
5	Maintain water levels with weir system (estuary - Coogoorah Park channels)	🟢0.6	🟢0.4	🟢2.9	🟢0.9	🟢0.6	🟢0.7
10	Introduce recycled water to estuary - Anglesea WTP	🟡0.0	🔴-1.7		🟢0.1		🟢0.5
11	Introduce recycled water to estuary - Black Rock WTP	🟡-0.1	🔴-1.8	🟢0.7	🟢0.2	🔴-1.7	🟢0.4
4	Maintain water levels with weir system (upper catchment)		🟡-0.8	🟢1.5		🔴-1.1	🟢0.6
26	Ex-situ treatment by alkali material dosing	🟡-0.3		🟢1.9	🟢0.2	🔴-1.9	🟢0.1
25	Ex-situ filtration and membrane water treatment system	🟡-0.3			🟢0.2		
27	Ex-situ active resin ion-exchange treatment system						
29	In-situ bioremediation of water		🔴-1.5			🔴-1.4	
1	In fill Coogoorah Park channels						
18	In-situ addition of a neutralising agent (e.g. lime) to ASS in marshes			🟢1.4			

6.4 Shortlisted options

The following options are recommended to be shortlisted for further detailed assessment as part of Stage 2. These options are based on the highest scoring options from the MCA for management of Coogoorah Park and low pH water sourced from the upper catchment.

In additional to the highest scoring options from the MCA, two further options were shortlisted for further consideration based on feedback from the Stakeholder Reference Group and agreed with DEECA and CCMA (Options 12 and 13).

As identified in the remediation objectives, the preference for this project is to identify options that are practicable and acceptable for managing all aspects of the acidity risk, both acidity sourced from both the upper catchment and potential acidity at Coogoorah Park. It is noted that not all shortlisted options proposed for further assessment are applicable for managing both sources. Where options apply to one source only, these would need to be paired with a second option as noted below. Pairing of suitable options will be considered further as part of Stage 2.

Table 6-6 Shortlisted options for further investigation (not in particular order)

ID	Option	Notes
5	Manage ASS at Coogoorah Park by maintaining water levels with weir system	For management of ASS at Coogoorah Park only. Would require pairing with another option to address low pH conditions from upper catchment.
12	Introduction of seawater to estuary via dredging of shallow artificial openings or berm grooming to treat low pH water in estuary	For treatment of low pH water in the estuary.
13	Introduction of seawater to estuary via dredging of deep artificial openings to treat low pH water in estuary	For treatment of low pH water in the estuary.
14	Introduce sea water to estuary via offshore pump and pipe to treat low pH catchment flows and manage ASS at Coogoorah Park	Could address low pH from upper catchment and manage ASS with sulfuric material at Coogoorah Park.

ID	Option	Notes
20	Install passive alkaline berms for treatment of low pH catchment flows in-situ within river / open limestone drains	For treatment of low pH water from upper catchment source, would not manage ASS with hypersulfidic material at Coogoorah Park.
23	Constructed wetland (reducing and alkalinity producing type) to treat low pH catchment flows	For treatment of low pH water from upper catchment source, would not manage ASS with hypersulfidic material at Coogoorah Park.
24	In-situ passive permeable reactive barrier to treat low pH catchment flows	For treatment of low pH water from upper catchment source, would not manage ASS with hypersulfidic material at Coogoorah Park.
28	In-situ dosing with alkali materials to treat low pH catchment flows	For treatment of low pH water from upper catchment source, would not manage ASS with hypersulfidic material at Coogoorah Park.

Section 7 Stage 2 Detailed Options Assessment

7.1 Assessment parameters

7.1.1 Input parameters

Table 7-1 summarises a range of parameters that have been used to develop a more detailed understanding of how each of the shortlisted options could address the issue of low pH conditions in the Anglesea River specifically, and to assess the relative effectiveness more comprehensively. These are based on available published literature and reports of the existing estuary condition. Other estuary conditions that have informed the detailed options assessment are outlined in subsequent sections 7.1.2.

Table 7-1 Detailed assessment input parameters

Parameter	Adopted Value	Justification
Soil parameters – upper catchment (Salt and Marshy Creek)		
Area of ASS in upper catchment (marshes)	Salt Creek: 93 ha Marshy Creek: 224 ha	Source: Wong et al. 2020
Soil net acidity (marshes)	Salt Creek: net acidity was reported up to 609 mol H^+/t Marshy Creek: net acidity was reported up to 7,168 mol H^+/t	Source: Wong et al. 2020
Soil net acidity (broader catchment outside of marshes)	Not quantified, however acidic soils present across the region. Targeted soil sampling near indicates net acidity between 4.9 mol H^+/t (0.008 %S) to 8.1 mol H^+/t (0.013%S) in soils outside of the marshes in higher elevation areas.	Targeted sampling conducted by CDM Smith of eroded recreational 4WD tracks on or adjacent to Gum Flats Tanner Link Track 2. Refer to Appendix D for further details. Some geological sediments are sulfur bearing (Douglas and Ferguson 1988, Tutt 2008).
Depth of hypersulfidic material in ASS in marshes to be treated	10cm	Preliminary estimate of the approximate depth of hypersulfidic material requiring management to manage the acidity in the estuary from Wong et al. 2020. Note hypersulfidic material identified to maximum study depth of 1.4 m bgl.
Estimated alkalinity required for treatment of ASS with sulfuric material in marshes	Salt Creek: A preliminary estimate of up to 6.18 x 10^8 mol H^+ in net acidity in the surface 0 – 10 cm of soil. Marshy Creek: A preliminary estimate of up to 2.58 x 10^8 mol H^+ in net acidity in the surface 0 – 10 cm of soil.	Preliminary estimate from Wong et al. 2020. This value was calculated as the predicted addition of 44 million tonnes of $CaCo_3$ as alkalinity would be needed to neutralise the top 10cm of leaching sulfuric material and reduce acidity flowing into the estuary, not to completely remove the risk of the underlying hypersulfidic material oxidising in the upper catchment.
Soil parameters – Coogoorah Park		

<table>
<tr><th>Parameter</th><th>Adopted Value</th><th>Justification</th></tr>
<tr><td>Estimated area of ASS with hypersulfidic material in Coogoorah Park</td><td>26.6 ha</td><td>Area based on the 31.6 ha study area from Sullivan et al. 2016. The report identified a 5 ha area that “did not contain indications of ASS with sulfuric materials and had not been affected materially by the enhanced inundation over the past 30 years”.</td></tr>
<tr><td>Average soil net acidity</td><td>2,634 mol H$^+$/t (maximum of 3,795 mol H$^+$/t)</td><td>Based on data from Sullivan et al. 2016 “of the surface soil layers identified, 8.9% were comprised of ASS with sulfuric material and 86.7% contained hypersulfidic material, with the CRS content mean of 0.80%S (1,188 mol H$^+$/t) and 1.06%S (803 mol H$^+$/t) respectively” and “of the subsurface soil layers (>70cm) identified, 7.3% were sulfuric material and 92.7% were hypersulfidic material subsoil layers, with the CRS content mean of 3.69%S (2,717 mol H$^+$/t) and 5.81%S (3,795 mol H$^+$/t) respectively”.</td></tr>
<tr><td>Average depth of hypersulfidic material in ASS to be managed</td><td>1 m</td><td>Based on Sullivan et al. 2016 predicted water table decline of up to 1m in the Coogoorah Park area.</td></tr>
<tr><td>Total acidity</td><td>1.19 x 10^9 mol H$^+$</td><td>Assuming:
- maximum water level drop of 1 m;
- Entire area of study area identified in Sullivan et al. 2016; and
- Soil bulk density of 1.7 t/m^3.</td></tr>
<tr><td colspan="3">Water parameters</td></tr>
<tr><td>Estuary volume</td><td>157 ML</td><td>Volume is a function of water level. This estimate is for a level of 1.49m AHD (Pope 2006).
Ranges from 31.9 – 210 ML based on water heights of 0.2 m AHD (minimum recorded during study) to 1.8 m AHD (max recorded during study).</td></tr>
<tr><td>Coogoorah Park channels volume</td><td>Channel volume at different water heights:
<table>
<tr><th>Water Height</th><th>Coogoorah Park Volume (ML)</th></tr>
<tr><td>1.8 (max recorded)</td><td>41.9</td></tr>
<tr><td>1.65</td><td>35.4</td></tr>
<tr><td>1.49</td><td>28.4</td></tr>
<tr><td>1.05</td><td>13.8</td></tr>
<tr><td>0.2 (min recorded)</td><td>0.568</td></tr>
</table></td><td>From Pope 2006.</td></tr>
</table>

Parameter	**Adopted Value**	**Justification**
Salt Creek flow rate	Average annual flow*: 544 ML/year Maximum annual flow*: 2,656.34 ML/year (2022) Median zero flow days per year*: 251 Average daily flow rate: approx. 1.43 ML/day Maximum daily flow rate: 319.85 ML/day (15/9/2016)	At WMIS site 235222 upstream of the confluence of Salt and Marshy Creeks. Data from 2010 to July 2023. Note data from 1983-2009 not complete, historical data 1975-1982 excluded for the purposes of representing recent conditions. *Annual information calculated where full year of data available (Jan 2010 – Dec 2022). Note: Flow in both tributaries is highly ephemeral (refer to Section 7.1.2 for further details). 
Marshy Creek flow rate (refer to Section 7.1.2 for further details)	Average annual flow*: 671 ML/year Maximum annual flow*: 1,513 ML/year (2022) Median zero flow days per year*: 173 Average daily flow rate: approx. 1.79 ML/day Maximum daily flow rate: 57.97 ML/day (16/11/2022)	At WMIS site 235260 upstream of the confluence of Salt and Marshy Creek. Data from September 2009 to July 2023. *Annual information calculated where full year of data available (Jan 2010 – Dec 2022). Note: Flow in both tributaries is highly ephemeral (refer to Section 7.1.2 for further details).
pH range (refer to Section 7.1.2.2 for further details)	GOR Bridge (middle estuary): 3.08 - 8.39 pH units Marshy Creek: 1.11 – 4.63 (average 2.9) pH units Salt Creek: 1.17 – 6.38 (average 4.15) pH units	WMIS Site: 235278 (GOR Bridge) WMIS Site: 235222 (Salt Creek)* WMIS Site: 235260 (Marshy Creek) * *Data 2016 – July 2023. Excluding where WMIS data has been considered incomplete/an error (reported zero, 0.01 or 0.02)
Acidity- Lime required to neutralise acidity	Minimum: 0.13 $CaCO_3$ kg/day Maximum: 3,713 $CaCO_3$ kg/day Average: 212 $CaCO_3$ kg/day Median: 38 $CaCO_3$ kg/day 75th percentile: 172 $CaCO_3$ kg/day	Based on recent daily pH and flow measurements for Salt Creek and Marshy Creek 1/2/22 – 31/1/23. Daily acidity calculated for monitoring points upstream of confluence and combined to estimate total acidity reaching estuary (refer to Section 5.4). Conversion factor of: 1 mol H^+/ 19.98 = 1 kg $CaCO_3$ Assumes neutralisation value of 100% (ie treatment to pH of 7 pH units), no safety factor

7.1.2 Dynamic conditions

The Anglesea catchment and estuary is a highly dynamic system, in particular due to its scale and location (GHD, 2021; Pope, 2006). This is illustrated by the range of pH, flow and acidity conditions presented in Section 7.1.1. Rainfall and thus run-off is highly variable with periods of no flow common, and floods exceeding 100ML/day. Long-shore sand transport continuously delivers sand to the estuary entrance and sea states (tidal range, wave height) are variable. The degree of marine influence in the estuary is a function of mouth condition (open/perched/closed) and the interplay of sea state and river flow. Large floods can flush all saltwater from the estuary for extended periods (days to weeks).

To be the most practical and effective at responding when pH conditions require, management approaches should ideally be adaptable and functional in a range of different conditions.

Shortlisted options have been qualitatively evaluated under some key factors in the dynamic system, including a range of flow conditions, considering water quality and geochemistry, as well as seawater influence and future climate change as discussed below and in Section 3.

7.1.2.1 Flow conditions

As an indication of the variability of flow conditions in the catchment, the Environmental Flows Study for the catchment (GHD, 2021) summarises a range of flow conditions for Salt Creek and Marshy Creek based on 2009 – 2018 data:

- Freshes flow conditions: When the estuary is flowing above base flow conditions. Flow conditions are between 2 to 7 ML/day through Marshy Creek. Flow of this volume was observed approximately 30% of the time during the period of 2009-2018 (GHD, 2021).
- High flow/flood conditions: During high flow conditions in winter/spring, discharge can be in excess of 10ML/day through Marshy Creek. Flow of this magnitude was observed approximately 10% of the time during the period of 2009-2018.
- Very high flow or flood events have been observed with flow rates in excess of 100ML/day in Marshy Creek. Typically, Salt Creek generated higher peak with shorter duration when compare with Marshy Creek where flows lower but longer duration (GHD, 2021). High flow rates can promote a deeper opening of the estuary facilitating marine exchange and deep scouring.
- Low flow/cease to flow conditions: During low flow conditions following summer drying and in times of reduced rainfall, flow rates typically range between 0.1 to 2 ML/day. This is the most common flow rate through Marshy Creek, occurring 50% of the time (GHD, 2021). The tributaries, being highly ephemeral, cease-to-flow for a majority of the time with Salt Creek being observed to not flow 65% of the time and Marshy Creek 50% of the time.
- Times of Estuary Mouth Openings: Estuary mouth openings are often the result of times of high flow conditions of more than 10ML/day (GHD, 2021). The estuary mouth is open approximately 27% of the time and perched (estuary is open however berm is still present and retains water during low tides) 29% of the time. It is predicted that the estuary entrance is transitioning to a permanently closed system with a higher and longer berm.

Long term flow data is not available for the catchment (pre-Alcoa discharge); however, these conditions are used indicatively to consider a range of flow conditions in the river that options would ideally be effective in.

Typically fish death events have occurred after a period of low flow/cease to flow, followed by a high or very high flow event.

7.1.2.2 Water quality and geochemical parameters

Water monitoring data from 2011 to 2023 indicates a wide pH range for the freshwater entering the estuary from the tributaries, with pH recordings ranging from 2.60 to 6.07 (summarised from WMIS Stations 235222 and 235260). The data also indicates prolonged periods of reduced pH (below 4) during the periods of 2017-2018 and 2020-2022.

Other water quality parameters including dissolved oxygen concentration, salinity, and turbidity varied significantly, indicating the management option selected will need to be versatile and adaptable to the changing water conditions.

Water quality conditions influence the effectiveness and risks associated with acidic water management. For example, when low dissolved oxygen conditions are being experienced in the estuary, opening the estuary mouth and allowing surface water to flow out could result in significant detrimental effects on fish and other aerobic organisms in estuary due to anoxic conditions if there was not freshwater flow from upstream or tidal exchange. That is, some options could only be implemented under specific conditions.

Redox conditions and geochemical parameters including iron, aluminium and sulfate concentrations can influence the effectiveness, longevity and design of some treatment options.

These factors can also influence the risks that would need to be managed. Fish death events have typically occurred after an extended dry period when surface water flows in the catchment are low or zero, followed by a saturating rain event which flushes acidity and aluminium downstream (Pope, 2011). The toxicity of aluminium to aquatic organisms increases with lower pH (higher levels of acidity), and flocculation of aluminium can clog the gills of some fish and smother other aquatic life (Pope, 2010). Effects can be exacerbated if precipitation of aluminium occurs due to interaction between different water sources.

7.2 Detailed assessment of options

7.2.1 Treatment of low pH catchment flows in a constructed wetland (option 23)

Figure 7-1 Examples of constructed wetlands

7.2.1.1 Conceptual overview of technology

The primary source of acidity in the Anglesea River estuary is from ASS containing sulfuric materials in the upper catchment, from both Salt and Marshy Creeks. Treating this acidic water prior to it flowing downstream would aim to minimise low pH events in the estuary.

Constructed wetlands are a form of passive system for treatment of acidic discharges that rely on a combination of physical, chemical, microbial and plant-mediated processes for amelioration of water quality. These processes include (depending on wetland design): oxidation, reduction, precipitation, sedimentation, filtration, adsorption, complexation, chelation, active metal uptake by plants and microbial conversion/immobilisation mechanisms.

A range of different designs and ameliorants can be used, and a specific study and design based on the location, acidity loads, redox conditions, flow rates, available area and treatment boundaries would be required for Anglesea.

7.2.1.2 Effectiveness

Based on the typical pH of water from the upper catchment, a reducing and alkalinity producing type system (RAPS) would likely be the most effective. RAPS typically use a combination of limestone and organic matter to raise the pH of water, adsorb metals and minimise armouring (coating of limestone with an inert chemical such as iron or aluminium oxyhydroxides). Appendix C provides a discussion of the different wetland types, typical design parameters and their effectiveness in a range of conditions.

Amongst the passive systems for treating of acidified waters, RAPS are usually presented as the ones having the highest treatment efficiencies and expected lifetime.

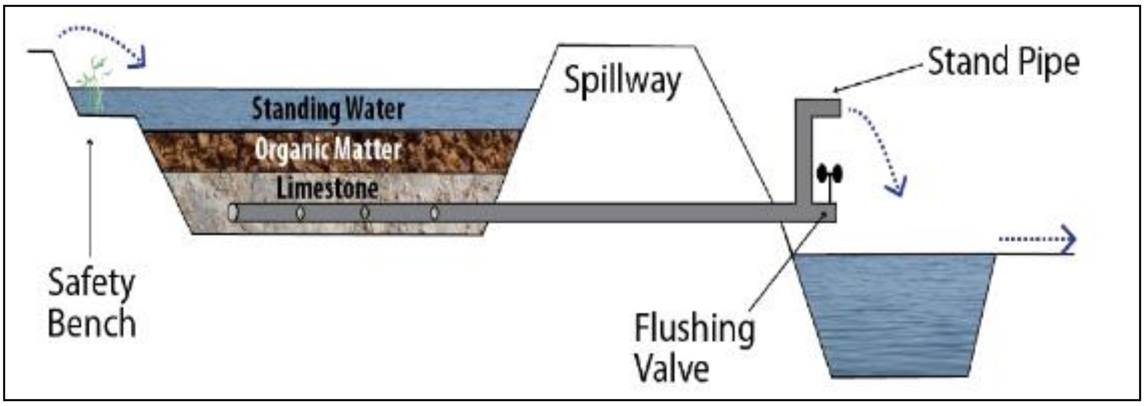


Figure 7-2 Typical RAPS cross section

Acidity removal rates are generally higher during the first year of operation (40-60 g H^+/m^2/day) when the compost layer has high reactivity and high permeability. Long term removal rates are reported in the range of 20-40 g H^+/m^2/day which would be adequate to treat a water flow of up to 4 ML/d. Typically pH levels between 6 – 8 can be achieved with a RAPS.

RAPS are generally more effective in lower flow environments as they rely on residence time within the wetland materials to increase pH. The specific effectiveness would be determined by the availability and topography of a site and selected substrate material.

This option could provide some benefit for managing ASS at Coogoorah Park if the proposed wetland also had storage capacity for retaining water during higher flow conditions and releasing treated water back into the river to maintain water levels when required during lower or zero flow periods.

- **High flow conditions**: During high flows of acidic water, the required pumping rate to redirect and treat all water from the upper catchment will not be feasible. Low pH water will still enter the estuary. Additionally, if high water volumes are pumped into the wetland during high flow conditions, the increased water volume would likely will result in decreased treatment efficiency (Turunen, 2019).
- **Low flow conditions**: During low flow conditions, wetlands would likely be effective at treating acidic water from the upper catchment. If flows were to decrease significantly in an anaerobic wetland and the wetland substrate is not saturated, sulfide solids may oxidize reversing the acid neutralisation effect, resulting in a pulse of acidity when water levels return (pulses in acidity are currently observed after low flow events).
- **Water quality:** This technology would be effective in a range of water quality conditions, if designed specifically for the water quality parameters experienced in the Anglesea catchment. With higher concentrations of metals and turbidity, substrate treatment material can decrease in effectiveness more quickly and require maintenance to remove sediment or substrate replacement.
- **Estuary entrance conditions**: The effectiveness of a wetland at treating pH conditions would not be affected by whether the estuary entrance berm is open or closed. A wetland however could reduce flow rates through the estuary if it stored significant water volumes for later release. In this situation this option could negatively impact the ability for natural openings.
- **Climate change**: Predicted future changes such as reduced surface water availability and increased extreme climate events (including floods) could reduce the effectiveness of this option in the long term.

As this option does not manage water levels in the estuary, it will not manage ASS risks at Coogoorah Park.

It should be also noted that RAPS wetlands require relatively intensive maintenance, including flushing of aluminium precipitates in the piping system and removal of sludges from the settling pond. Lack of proper maintenance is likely to result in progressive decrease of system performance and consequently, degradation of water quality in the river.

Typical characteristics (adopted from Earth Systems, 2005) for when a RAPS wetland would be effective have been compared to a subset of historical Anglesea Estuary data[1] (1/2/2022 to 31/1/2023) and are presented in Table 7-2 below. The acidity has been calculated using flow and pH conditions recorded in Salt and Marshy Creeks at Alcoa (monitoring points 235222 and 235260 respectively) to provide an estimate of the acidity reaching the estuary. Climate and flow vary significantly for the Anglesea catchment; this subset of data is used solely as an indication of the proportion of time conditions would have been within ideal thresholds for the option to work, and was selected to provide a recent and complete dataset, that included a range of different conditions from dry to high flows, as well as a period where acidic to neutral conditions were experienced in the estuary.

This is an assessment of the capacity of the selected option to neutralise the acidic load on any given day as given the highly ephemeral nature of the upper catchment tributaries, climate, flow rates and acidity can vary considerably day to day and over time. This assessment does not consider other estuary conditions such as turbidity, dissolved oxygen and geochemistry that will influence the effectiveness and design of the option.

Table 7-2 Summary of estimate effectiveness of RAPS wetland and percentage of days option could have met ideal conditions to effectively treat acidic load (February 2022 to January 2023).

Conditions where option is typically effective (Taylor, 2005)	Av. acidity range (kg $CaCO_3$/day)	Av. Flow rate (L/s)	Both acidity (kg $CaCO_3$/day) and flow rate (L/s)
	<100	<15	-
Anglesea river conditions (estimated at top of estuary, Feb 2022 – Jan 2023)	Av. 211 Max 3,713	Av. 132 Max 2,944	-
% days option would have met ideal conditions	68%	59%	47%

7.2.1.3 Potential location of wetland

The location of the wetland would preferably be hydraulically downgradient of the upper catchment and upgradient of the Anglesea Estuary to effectively intercept and treat the greatest proportion of low pH water from the catchment. There are no suitable in-stream locations that have been identified, without significant disturbance of the existing environment.

A potential siting option for the wetland would be on the former Alcoa site, such as in the Storage Pond (Figure 7-3):

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[1] Flow and pH conditions recorded in Salt and Marshy Creeks at Alcoa (DEECA monitoring points 235222 and 235260 respectively).

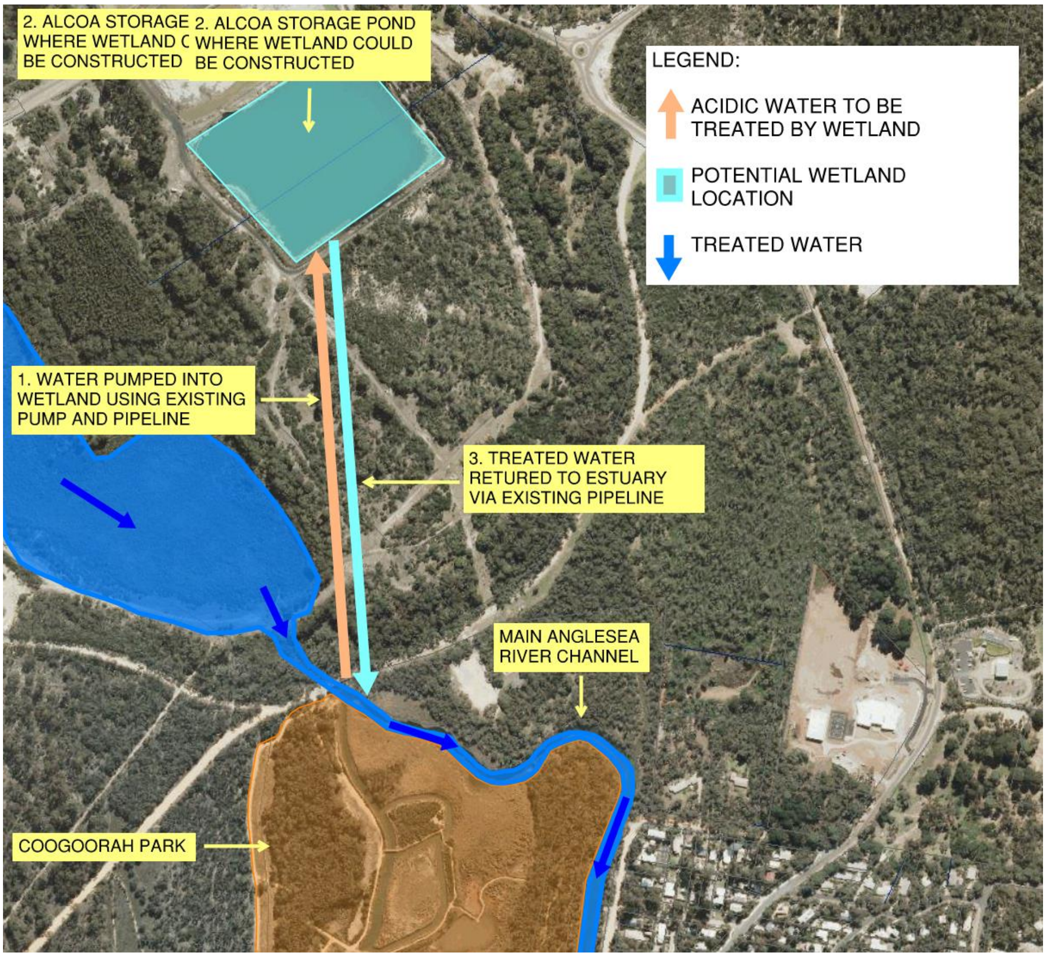

Figure 7-3 **Example location of wetland in former Alcoa Storage Pond.**

A constructed wetland requires a larger footprint than other options, and the design would need to factor in specific site features including hydraulic gradient and residence time. This option could make use of existing pump and pipeline infrastructure that is currently being used to store water to be released during drier periods to maintain estuary water levels. This option also has the benefit of using an already disturbed site that avoids significant impacts to the environment and recreational values.

7.2.1.4 High level cost estimate

Estimated costs (per 10 years operational time) are summarised in Table 7-3 below. Detailed feasibility cost estimates are included in Appendix E.

This cost excludes any upgrades to existing storage ponds that may be required such as for engineering stability. Costs also exclude land purchase that may be required depending on site location.

Table 7-3 RAPS wetland estimated cost- high level cost estimates provided for comparison purposes only[2]

Cost item	Estimate (AUD)	Notes
Capital	$ 990,000	Construction of a 3 hectare wetland. Cost inclusive of engineering, procurement and construction management, construction and 20% contingency.
Operation and Maintenance (Annual)	$ 105,000	Includes allowance for site survey and studies, design, tendering, permitting, construction. Quarterly cleaning and maintenance. Does not include waste disposal costs for sludge or land purchase costs.
Net Present Value	$ 1,840,000	Assuming a period of 10 years and 4% discount rate

7.2.1.5 Legislation and permit requirements

Approvals for this option that have been identified are:

- Water Act 1989
  - Approval from CCMA required for works and activities within the bed and banks of the Anglesea River estuary.
- Surf Coast Shire Community Amenity Local Law 2021
  - In a reserve, a person must not, without a permit or the written consent of an authorised officer, destroy, damage or interfere with any flora or kill, injure or interfere with any fauna.
  - Interference with Watercourse: (1) A person must not destroy, damage or interfere with any watercourse, wetland, ditch, creek, gutter, tunnel, bridge or levy which is vested in or under the management or control of Council; (2) A person must not, without a permit, divert the contents of any watercourse, wetland, ditch, creek, gutter, tunnel, bridge or levy which is vested in or under the management or control of Council.
- Aboriginal Heritage Regulations 2018
  - All or part of the site is an 'area of cultural heritage sensitivity'.
  - Requires a 'cultural heritage management plan' be prepared where a listed 'high impact activity' is proposed.
- Aboriginal Heritage Act 2006
  - Under the Aboriginal Heritage Act 2006, where a cultural heritage management plan is required, planning permits, licences and work authorities cannot be issued unless the cultural heritage management plan has been approved for the activity.
- Surf Coast Shire – Planning scheme
  - Special Use Zone – Section 2 – Permit required for Utility installation (other than Minor utility installation or if allowed under the Mines (Aluminium Agreement) Act 1961). Would apply if power supply or other utility required as part of the design.
  - Public Park and Recreation Zone – A permit is required to construct a building or construct or carry out works, unless this is carried out by or on behalf of a public land manager, Parks Victoria or the Great

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[2] Costs based on previous CDM experience on similar project(s) and engineer's estimates. Cost provided is high-level and indicative only and may vary based on further information and design refinement and does not include any stability works that may be required to repurpose the existing storage pond.

    Ocean Road Coast and Parks Authority, under the *Local Government Act 1989*, the *Reference Areas Act 1978*, the *National Parks Act 1975*, the *Fisheries Act 1995*, the *Wildlife Act 1975*, the *Forest Act 1958*, the *Water Industry Act 1994*, the *Water Act 1989*, the *Marine Safety Act 2010*, the *Port Management Act 1995* or the *Crown Land (Reserves) Act 1978*.

  - Environmental Significance Overlay – a permit is required to construct a building or construct or carry out works. This does not apply if a schedule to this overlay specifically states that a permit is not required.
  - Additional permits would be required if vegetation removal was required.
- Crown Land (Reserves) Act 1978:
  - Approval for release of water into the Anglesea River is required from Surf Coast Shire Council.

7.2.1.6 Environmental, cultural, social and economic considerations

Risks to values are likely to be minimal given the natural process the wetland employs. This relies however on an existing disturbed area being used for the wetland construction and pipeline.

This option has potential to disrupt natural flow regimes due to temporary extraction of water from the river. During dry periods this may negatively affect the ecological and physical functioning of the river and estuary and be contrary to previous recommendations made for management of the river (e.g. GHD, 2021); further design would need to consider whether this could be effectively managed.

7.2.1.7 Additional information or assessment required

The following additional information would be required to inform further consideration of this option:

- Rehabilitation planning for the Alcoa sites is ongoing. Consultation with Alcoa to understand the feasibility of using a portion of the site for this purpose would be required. The timing of implementing this option could be impacted based on the rehabilitation plans.
- A detailed assessment of the existing infrastructure and the pumping requirements to the selected location.
- Further characterisation of water quality and geochemistry would be required to progress the design. In particular, an understanding of concentrations of metals, dissolved oxygen and redox conditions would be required to develop a design, identify appropriate treatment matrices, refine effectiveness and costs.

7.2.2 Treatment of low pH catchment flows using an in-situ permeable reactive barrier (PRB) (option 24)

7.2.2.1 Conceptual overview of technology

A PRB uses the natural hydraulic gradient of a stream to treat contaminated water through physical, chemical, and biological processes (Banasiak & Indraratna, 2012). Treatment of acidic water from the upper catchment using a PRB would aim to raise the pH of the water prior to it entering the estuary, while having a minimal effect on flow conditions.

PRBs employ the use of reactive material (for example organic matter or limestone) placed within the flow path of the acidic water requiring treatment. As acidic water flows through the PRB, pH levels are increased. Depending on the reactive material, PRBs can also encourage the precipitation and removal of metals including aluminium and iron.

The passive PRB technique has been shown to successfully combat coastal ASS impacted groundwater in the Shoalhaven Floodplain, southeast NSW. In this case study several alkaline materials were tested including zeolite, oyster shells and recycled concrete. Recycled concrete crushed to a size of 1.18 to 10mm was selected to be installed in the constructed PRB (Indraratna et al, 2015).

A diagram of the potential construction of the passive PRB can be seen in Figure 7-4. PRBs allow water to continue flowing downstream, so environmental flows are maintained. They can also incorporate channels to allow fish movements.

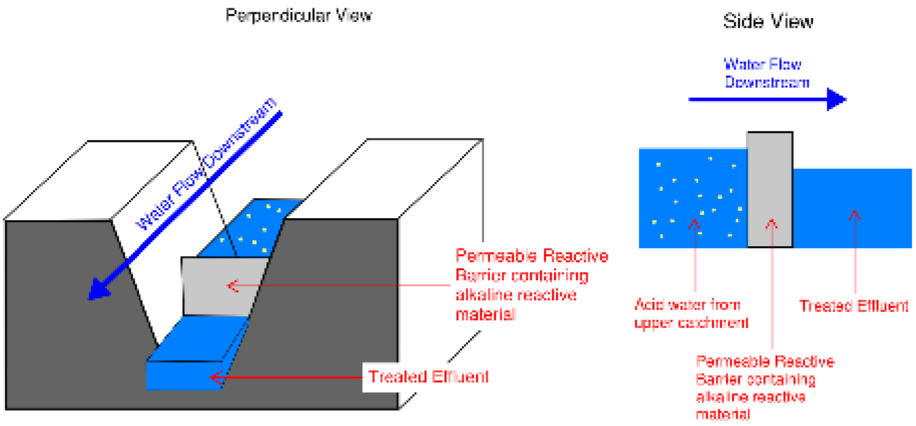

Figure 7-4 In-stream PRB diagram

A design specific to the conditions of the selected installation location would consider residence time for effective treatment, and the specific treatment material.

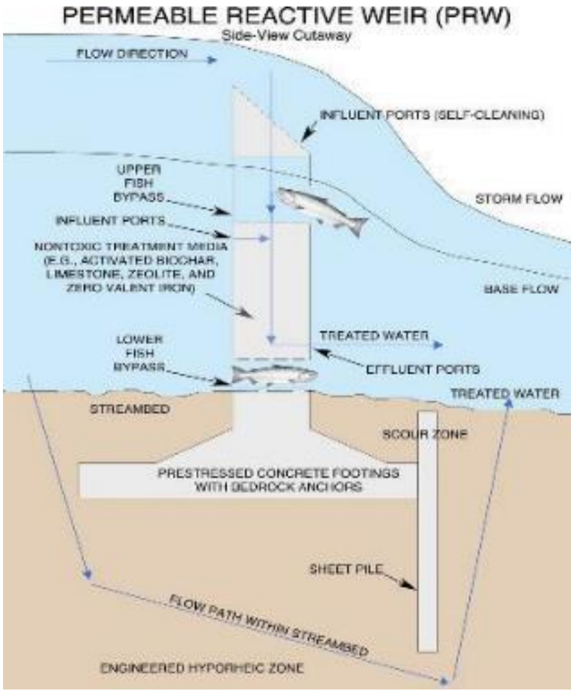

Figure 7-5 Example diagram of in-stream PRB showing fish bypass and different flow levels (base flow and storm flow)

7.2.2.2 Effectiveness

PRBs are an effective method of treating acidic surface water and are typically better suited to acidic waters with lower levels of acidity (pH > 3) and lower flow rates (<1 L/s) (Taylor et al., 2005). pH levels greater than 6.5 can be achieved.

Neutralising capacity for the Anglesea River would have varying levels of success depending on surface water flow rates, residence times and the alkaline material used.

- **High flow conditions**: A passive PRB would be less effective during high flow conditions and not effective in flood events as they rely on residence time and contact between the water and alkaline material. The barrier could be designed to have a lower porosity to have a weir like effect on the water, slowing flow and treating the water as it passes through the reactive media. Treatment would not be effective if water levels were above the barrier.
- **Low flow conditions**: A PRB would likely be very effective in treating the smaller volume of water in low flow conditions.
- **Estuary entrance conditions**: the effectiveness of PRB will be unaffected by different estuary entrance conditions. Low river flow velocities in the River will be potentially reduced, however this is unlikely to impact the ability for natural entrance openings to occur if PRBs were placed upstream of the estuary.
    - **Water quality:** Other water quality conditions such as turbidity and concentrations of metal ions will reduce the effectiveness of PRBs over time, through sedimentation and armouring of alkaline materials.
    - **Climate change:** A PRB has limited flexibility following construction to respond to changes in future conditions without replacement or changed design. Predicted reduced surface flows with greater extreme weather events with climate change however will mean that a PRB will be effective for the majority of the time during low flows, however unable to respond to extreme events.

This option will not manage ASS at Coogoorah Park.

Typical characteristics published by Earth Systems, 2005 for when a permeable reactive barrier would be effective compared to a subset of historical Anglesea Estuary data[3] (1/2/2022 to 31/1/2023) is presented in Table 7-4. This has been considered for three different installation locations that could be considered. This assessment does not consider other estuary conditions such as turbidity, dissolved oxygen and geochemistry that will influence the effectiveness, design or life of the option.

A PRB is considered to have lower levels of relative effectiveness than other passive or active treatment options due to the required flow rates that optimise effectiveness.

Chemical armouring (alkaline material selected becoming coated with inert chemicals) and sedimentation of the PRB needs to be managed to maintain long-term performance.

Table 7-4 Summary of estimated effectiveness of PBRs and percentage of days option could have met ideal conditions to effectively treat acidic load (February 2022 to January 2023).

Conditions where option is typically effective (Taylor, 2005)	Av. acidity range (kg $CaCO_3$/day)	Av. Flow rate (L/s)	Both acidity (kg $CaCO_3$/day) and flow rate (L/s)
	<14	<1	-
Anglesea river conditions (estimated at top of estuary, Feb 2022 – Jan 2023)	Av. 211 Max 3,713	Av. 132 Max 2,944	-
% days option would have met ideal conditions - treatment point downstream of Salt and Marshy Creeks confluence	36%	29%	17%
Salt Creek conditions (at WMIS site 235222, Feb 2022 – Jan 2023)	Av. 88 Max 1,456	Av. 7.3 Max 253	-
% days option would have met ideal conditions - treatment of Salt Creek	42%	47%	1%
Marshy Creek conditions (at WMIS site 235260, Feb 2022 – Jan 2023)	Av. 172 Max 2,587	Av. 47 Max 670	-
% days option would have met ideal conditions - treatment of Marshy Creel	33%	42%	23%

The effectiveness of the design is heavily dependent on the neutralising capacity of the material selected which will need to be specific to flow and water quality conditions in Anglesea. The material selected will also need to be cost effective, offer long-term performance and be able to remain in-situ for a long period of time. Small scale studies into the most appropriate material and number of PRBs required would need to be undertaken to design an appropriate treatment system. This would include further characterisation of surface water for metals and other ions to understand the optimum treatment material and operational life.

7.2.2.3 Potential siting options for PRBs

To maximise the treatment capacity of this option and reduce pH in surface water flows from both Salt and Marshy Creeks, the location of the permeable reactive barrier would most practicably be installed downstream of the confluence of Salt and Marshy Creeks. Construction in the upper estuary would also minimise effects on recreational activities on the Anglesea River and reduce visual impacts.

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[3] Flow and pH conditions recorded in Salt and Marshy Creeks at Alcoa (DEECA monitoring points 235222 and 235260 respectively).

As replacement of treatment material is required periodically to maintain effectiveness, selection of a logistically accessible location is required. Potential siting options have been identified where the channel is at more narrow points (rather than within marshy areas) and there is vehicle access.

Multiple installation locations could also be used, for example within both Salt Creek and Marshy Creek, as well as downstream of the confluence. Installation of multiple barriers could increase the effectiveness of treatment in low to average flow conditions. All systems would still be less effective in high flow conditions.

Siting Option 1 – Salt Creek tributary connection to the river. This area has a culvert to pass under the Alcoa Mine Road, where water has been redirected to a small channel. This channel could be used to install the PRB.

Siting Option 2 – Channel north of Coalmine Road or culvert beneath Coalmine Road. This location has a natural channel where flow is limited to a deeper channel. This natural channel could be used to install the PRB. Approximate locations of siting options shown on Figure 7-6.

Multiple PRBs could be installed to increase effectiveness; this would need to be considered during future design stages based on further analysis of flow conditions.

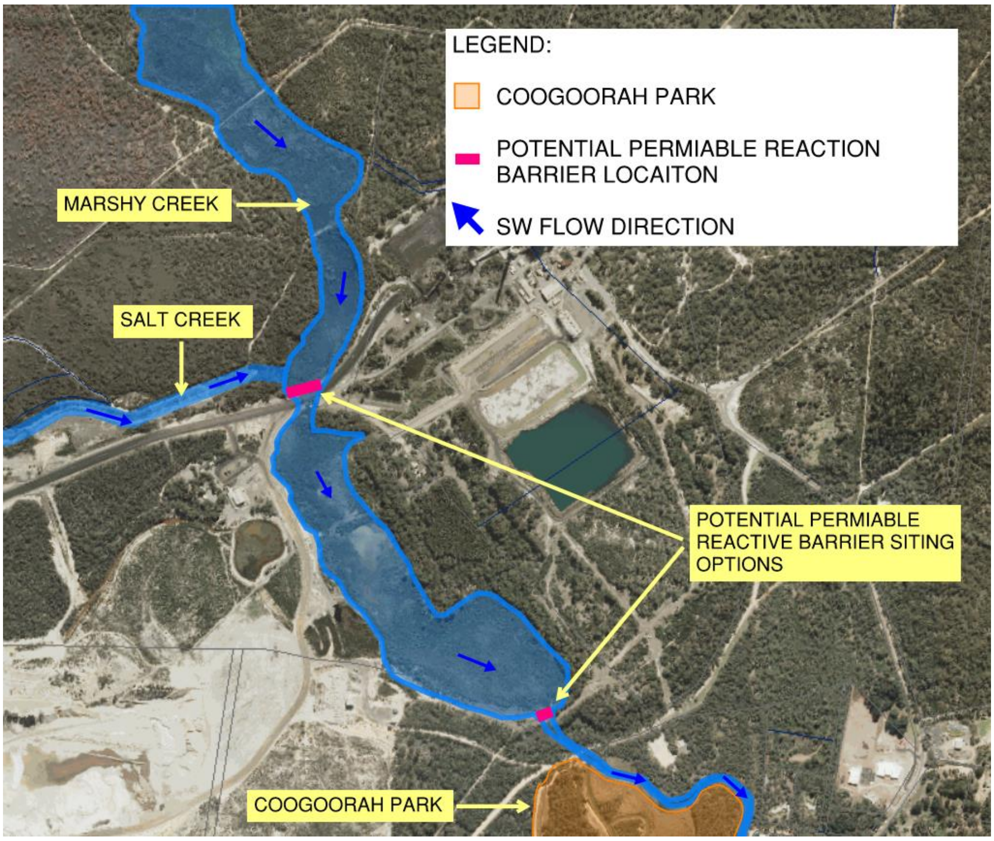

Figure 7-6 Potential siting options for PRB

7.2.2.4 High level cost estimate

Estimated costs (per 10 years operational time) are summarised in Table 7-5 below. Detailed feasibility cost estimates are included in Appendix E.

Table 7-5 Permeable reactive barrier cost estimate- high level cost estimates provided for comparison purposes only [4]

Cost item	Estimate (AUD)	Notes
Capital	$ 450,000	Construction of insitu PRB. Cost inclusive of engineering, procurement and construction management, construction and 20% contingency. Reactive barrier consists of 50 m^3 of crushed limestone.
Operation and Maintenance (Annual)	$ 105,000	Includes allowance for site survey, studies, design, tendering, permitting and construction. Quarterly replacement of limestone.
Net Present Value	$ 1,300,000	Assuming a period of 10 years and 4% discount rate

7.2.2.5 Legislation and permit requirements

Approvals for PRBs would be as for Option 23.

7.2.2.6 Environmental, cultural, social and economic considerations

The following factors would need to be considered with regards to environmental, cultural, social and economic values:

- Design would need to incorporate fish bypasses.
- Areas of cultural heritage sensitivity would need to be identified with the Traditional Owners, to avoid or minimise impacts where the PRBs are installed.
    - During excavation / installation of PRBs there is potential to release acidic sulfate soils, as well as heavy metals. This could be readily managed through good practice design and construction methods.
- Minimal impacts to other values would be expected given the low impact and small footprint of the option. There is potential for minor disruption to flows due to the slowing of water as it passes through the barrier; the design would need to further consider recommendations for maintenance of flows in the river for physical functioning of the system.

7.2.2.7 Additional information or assessment required

Further characterisation of water quality and geochemistry would be required to inform the design of this option. An understanding of concentrations of metals, dissolved oxygen and redox conditions would be required to identify appropriate treatment matrices, refine effectiveness and costs.

Further analysis of flow conditions would also assist in refining the design including ideal location, size and porosity.

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[4] Costs based on previous CDM experience on similar project(s) and engineer's estimates. Cost provided is high-level and indicative only and may vary significantly based on the Anglesea River Estuary specific input parameters.

7.2.3 Treatment of low pH catchment flow using passive alkaline berms/channels (open limestone drains) (option 20)

Figure 7-7 Example of in-situ open limestone channel (source: https://www.researchgate.net/figure/Open-limestone-channels-are-streams-or-ditches-lined-with-limestone-rock-Although-the_fig9_308702861)

7.2.3.1 Conceptual overview of technology

Alkaline berms use the natural hydraulic gradient to treat water, similar to PRBs, by allowing low pH surface water flows to pass over a reactive material within a channel. Commonly used in remediation as part of mine closure where acid mine drainage is an issue, the berms can be installed in existing waterways or in constructed drains. Typically, berms consist of crushed limestone rock, but can include other alkaline material such as crushed recycled concrete or shells.

7.2.3.2 Effectiveness

The extent of neutralising capacity and effectiveness for the Anglesea River would depend on:

- surface water flow rates,
- channel dimensions and slope,
- residence times, and
- alkaline material used.

The treatment area must be sufficiently long for low pH water to remain in contact with the reactive material for neutralisation to occur, typically several hours (Taylor, 2005). A longer treatment channel will be more effective than smaller sections of berms installed throughout the river. The channel ideally has less than 10 degrees slope to allow sufficient time for neutralisation. In ideal conditions, pH levels between 6 – 8 can be achieved. Over time, the effectiveness of this treatment option reduces, and replacement of the reactive material is required.

Under different conditions in the estuary catchment therefore an open limestone channel will have varying levels of effectiveness, including:

- **High flow conditions**: Not effective in high flow conditions or flood events as they rely on residence time and treatment is localised to water in contact with the alkaline material.
- **Low flow conditions**: Alkaline berms or an open limestone channel would likely be effective in treating the smaller volume of water in low flow conditions.
- **Estuary entrance conditions**: The effectiveness of alkaline berm will likely be unaffected under different estuary entrance conditions.

- **Water quality:** Other water quality conditions such as turbidity and concentrations of metal ions will reduce the effectiveness of the reactive material over time, through sedimentation and armouring of alkaline materials.
- **Climate change:** This option is inflexible to different climate conditions over time.

Typical characteristics published by Earth Systems, 2005 for when alkaline berms would be effective compared to a subset of historical Anglesea Estuary data[5] (1/2/2022 to 31/1/2023) is presented in Table 7-6. This assessment does not consider other estuary conditions such as turbidity, dissolved oxygen and geochemistry that will influence the effectiveness and design of the option.

Under right flow and slope conditions and with regular maintenance, limestone berms and channels can be a more effective way of treating low pH water than PRBs that require lower flow rates for effective treatment.

This option will not manage ASS at Coogoorah Park.

Table 7-6 Summary estimated effectiveness for passive berms and percentage of days option could have met ideal conditions to effectively treat acidic load (February 2022 and January 2023)

Conditions where option is typically effective (Taylor, 2005)	Av. acidity range (kg $CaCO_3$/day)	Av. Flow rate (L/s)	Both acidity range (kg $CaCO_3$/day) and flow rate (L/s)
	<150	<20	
Anglesea river conditions (estimated at top of estuary, Feb 2022 – Jan 2023)	Av. 211 Max 3,713	Av. 132 Max 2,944	-
% days option would have met ideal conditions - treatment point downstream of Salt and Marshy Creeks confluence	74%	61%	49%
Salt Creek conditions (at WMIS site 235222, Feb 2022 – Jan 2023)	Av. 88 Max 1,456	Av. 7.3 Max 253	-
% days option would have met ideal conditions - treatment of Salt Creek	89%	66%	20%
Marshy Creek conditions (at WMIS site 235260, Feb 2022 – Jan 2023)	Av. 172 Max 2,587	Av. 47 Max 670	-
% days option would have met ideal conditions - treatment of Marshy Creek	75%	74%	54%

7.2.3.3 Potential siting options for limestone drains

The most appropriate location for treatment of all surface water that flows through the catchment is as per Option 24, however the open limestone drain will require a greater length to be effective. The conceptual design and costs have allowed for a total length of 100m. A potential siting option is shown in Figure 7-8.

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[5] Flow and pH conditions recorded in Salt and Marshy Creeks at Alcoa (DEECA monitoring points 235222 and 235260 respectively).

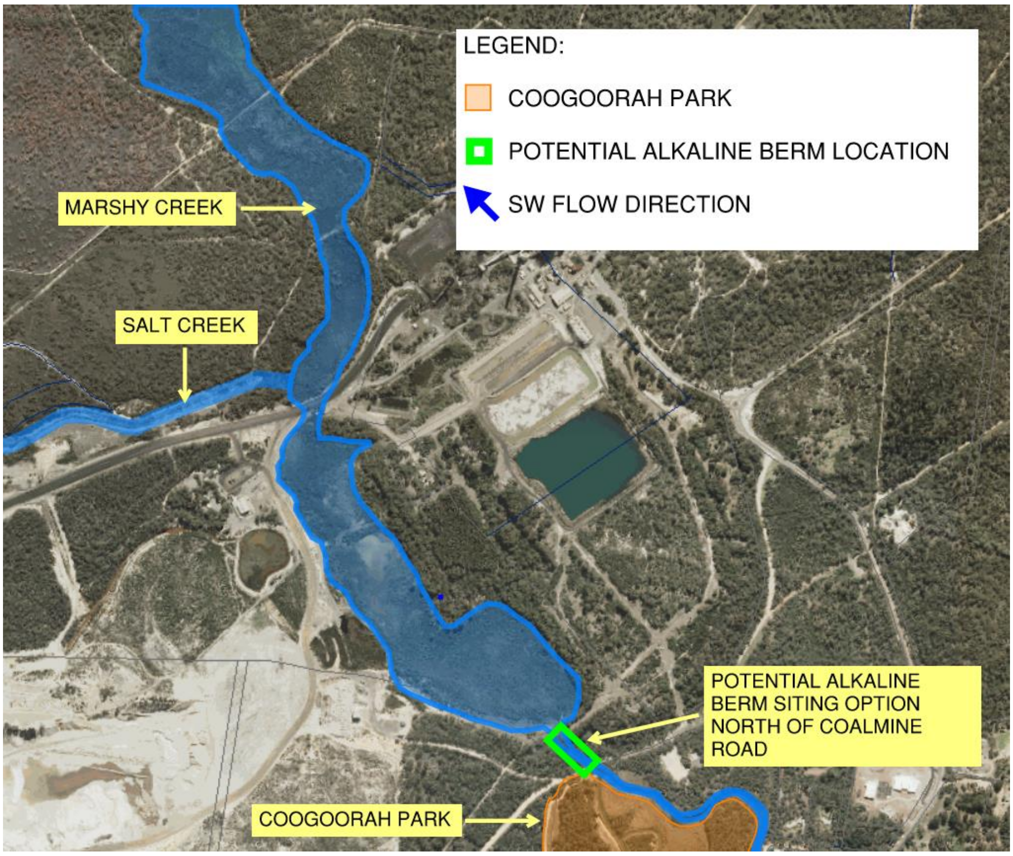

Figure 7-8 Potential siting option for limestone drain

Multiple installation locations could also be used, for example within the Salt Creek diversion channel and at a logistically suitable point along Marshy Creek. This would increase the effectiveness under low to average flow conditions, however, will not significantly increase the effectiveness in high flow conditions.

7.2.3.4 High level cost estimate

Estimated costs (per 10 years operational time) are summarised in Table 7-7 below. Detailed feasibility cost estimates are included in Appendix E.

Table 7-7 Limestone drain cost estimate, high level cost estimates provided for comparison purposes only[6]

Cost item	Estimate (AUD)	Notes
Capital	$ 415,000	Construction of limestone lined high/flow channel, 100 m in length. Cost inclusive of engineering, procurement and construction management, construction and 20% contingency.
Operation and Maintenance (Annual)	$ 108,000	Inclusive of inspections, utilities, operations, and maintenance, monitoring and report. Replacement of limestone 4 times per year.
Net Present Value	$ 1,300,000	Assuming a period of 10 years and 4% discount rate

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[6] Costs based on previous CDM experience on similar project(s) and engineer's estimates. Cost provided is high-level and indicative only and may vary significantly based on the Anglesea River Estuary specific input parameters.

7.2.3.5 Legislation and permit requirements

Approvals for open limestone drains and berms would be as for Option 5.

7.2.3.6 Environmental, cultural, social and economic considerations

Factors to consider for open limestone drains and berms would be as for Option 24. Amenity, cultural heritage and environmental disturbance within the river channel would be more affected by this option due to the length of channel required for treatment, compared to PRBs.

7.2.4 Treatment of low pH catchment flows by in-situ dosing with alkali materials (option 28)

Figure 7-9 Examples of dosing station infrastructure

7.2.4.1 Conceptual overview of technology

In-situ dosing involves the direct addition of alkaline material into the river from a treatment station adjacent to the river to raise pH conditions to an acceptable range. This treatment is flexible in a range of conditions and could be designed to operate only when required.

To be most effective, the longest possible residency time and area for the dosing substrate (alkaline material) is required to allow for the natural mixing as it flows through the estuary.

Dosing stations actively manage acidity through ongoing water quality monitoring stations both upstream and downstream that will feed into the station to trigger the commencement of dosing. The stations would use flow controllers to ensure that adequate amounts of alkaline material are added to the water, until the pH reached acceptable range.

A range of alkaline materials could be used, for example agricultural lime or crushed limestone comprises calcium carbonate ($CaCO_3$), are two of the cheapest neutralising agents and are generally not harmful to plants, livestock, humans and most aquatic species. However, the limitation of their application is their insolubility in water however is more soluble in strongly acid water.

Other potential reagents include caustic soda/sodium hydroxide ($NaOH$), quick lime or calcium oxide (CaO) and hydrated lime or slaked lime or calcium hydroxide ($Ca(OH)_2$), which can quickly increase the pH but are difficult to manage and can result in excessively high pH and so should be used with caution. Liquid reagent provides the best results with regards to mixing and quickly altering pH conditions. Consequently, specialist dosing equipment and expertise will be required.

Due to the highly ephemeral nature of the Anglesea catchment, the quantity of reagent required to treat flow from both Salt and Marshy Creeks will be determined by laboratory assessment and further evaluation of water quality and flow conditions. Factors affecting the quantity of reagent required include:

- The type, quality and purity of the neutralising agent being used;
- The particle size of the material and the degree to which the material becomes coated with iron and aluminium oxyhydroxides;
- Concentrations of other analytes including bioavailable metals and broader water quality objectives;
- The effectiveness of the application technique; and
- The existence of additional sources of acid leaching into the water body that may further acidify the water.

Treatment requirements will also depend on later design decisions regarding implementation, including:

- Treatment to a neutral pH of 7 may not be required. For example, treatment to reach a pH of 5.5 may be acceptable and protective of enough aquatic species to reduce impacts and protect recreational values. Treatment targets should consider specific aquatic species and established water quality guidelines relevant for the river.
- It may be preferred only to implement dosing when certain triggers are met. Assumptions in this report are based on treating all low pH flows from the upper catchment as a conservative approach. It is unlikely that this will be required, for example treatment would not be required if the estuary mouth is open, natural marine exchange is occurring and there are sufficient surface water flows to maintain an acceptable pH range in the estuary. This would be defined in management plan as part of later design.

The amount of required reagent will vary in differing conditions and (i.e., amount of acidic water, high or low flow conditions). For example, the conservative amount of reagent (as $CaCO_3$) required based on the estimated acidity reaching the estuary between February 2022 – January 2023 (using pH and flow rates combined from Salt and Marshy Creeks) are[7] presented in Table 7-8.

Table 7-8 High level Estimated reagent based on February 2022 – January 2023 pH and flow rates

	As $CaCO_3$	As hydrated lime
Median daily	38 kg	51 kg
Maximum daily during high flow event	3,713 kg	5,012 kg
Annual	68 t	91 t

As stated above, this is a conservative estimate based on treating all catchment flows to a neutral pH. 2022 represents the highest flow volumes on record since 2009, therefore these values are potentially greater than typical years, in particular in a drying climate. If data from 2017 – July 2023 was used, the average annual amount of reagent (as $CaCO_3$) required is 44 tonne/year.

Quantities of reagent required will depend on the selected material. For the purposes of this assessment and preparation of costs, hydrated lime has been assumed. A conversion factor of 1.35 mg of hydrated lime / equivalent mg $CaCO_3$ applies to determine the amount of reagent/

Some neutralising agents have a low solubility in water and are often mixed with water to form slurries before application. Consequently, thorough mixing is required to consistently raise pH levels, either as part of the dosing plant or within a mixing zone in-stream. Mixing of the alkaline solution can be achieved through ex-situ active techniques or in-situ passive or active means. To reduce the effects on recreational activities in the estuary and to protect the visual amenity of the estuary, passive mixing would be preferable due to the reduced energy consumption and required upkeep. This could involve either natural streamflow if there was sufficient turbulence and flow, however given the ephemeral nature of flow into the Anglesea River mixing would likely be more effective with passive infrastructure. This could include for example installation of baffles within a culvert, or ex-situ mixing of water from the river within the dosing plant before releasing back into the stream. Dosing at several points throughout the estuary would also assist in providing increased mixing of the alkalinity solution. Due to the mixing requirements liquid alkaline material is more effective than with dry materials. Alternative application could also be considered under different conditions, as outlined in Appendix C; the most robust and flexible option for a dosing station and liquid dosing has been carried forward for this assessment.

7.2.4.2 Effectiveness

This management method will be very effective at managing acidity in the estuary, as demonstrated through other examples where the technology has been implemented.

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[7] Data used for $CaCO_3$ calculations retrieved from DEWLP water data for the period of 1 February 2022 to 1 February 2023

In-situ active treatment methods typically can be designed to fit the conditions required, such as in coastal areas in the sugar plantations along the east coast of Australia as detailed in a case study in the McLeods Creek catchment in far northern NSW by Green (2005) and Green et al. (2006). The catchment contains ASS with sulfuric materials that discharged large quantities of acid and dissolved metals into waterways. The acidity from the hydrolysis of dissolved metal species, particularly aluminium and iron, contributes to greater than 70% of the total acidity in this catchment.

The dosing treatment system involved the addition of agriculture lime and hydrated lime as slurries to the drainage water, which was found to be more effective than the passive or semi-passive systems in treating highly acidic drainage waters dissolved metal species, particularly aluminium and iron. However, one of the main disadvantages is that direct dosing of alkaline reagents in streams or channels has potential to transport metal precipitates downstream of the treatment location.

The effectiveness of the instream dosing design will be primarily determined by the location of the dosing station(s) and the ability for the dosing station to adequately mixing the added alkaline solution through the water body.

This option has the flexibility to reduce or increase the level of treatment as needed to maintain pH conditions in the estuary within an acceptable range, under different flow conditions (Taylor, 2005).

Figure 7-10 In-stream dosing system immediately after $CaCO_3$ was added and dissolved metals (in particular iron) precipitated (Green, 2005)

It is one of the most flexible options effective in a range of flow and water quality conditions.

- **High flow conditions**: During high flow periods in-situ dosing of water entering the estuary will in theory be very effective at neutralising acidity even if there is a low pH event. The system would need to be designed with sufficient capacity to allow effective treatment within expected conditions. The required amount of mixing of the alkaline reagent may be met during high flow events, however an additional dosing point within the estuary could assist in adequate mixing and neutralisation of the low pH flow. The quantity of reagent required to be added to the river during very high flows however may render it undesirable, and during floods sufficient mixing and treatment may not be possible. For example, an estimated 8.5 tonnes of hydrated lime would have been required to return pH conditions to neutral on the highest pH and flow day in 2022.

- **Low flow conditions**: During low flow conditions the effectiveness of the in-situ dosing would also likely be effective however, will require the continuous mixing of the alkaline reagent into the estuary. For most of the year tributaries have little flow into the estuary, the mixing of the alkaline reagent would be mostly ineffective by way of insitu dosing. Additional techniques to ensure adequate mixing to manage the acid load in low flow conditions may be required. In period of no flow into the estuary the system would not be required.
- **Estuary mouth conditions**: When the estuary mouth is open and seawater is influencing the estuary, the effectiveness of in-situ dosing will not be affected. Dosing is a flexible option that would be inactive if estuary pH conditions are suitable.
- **Water quality**: The dosing requirement of alkaline reagent is dependent on the pH as well as the latent/mineral acidity, which is the potential concentration of hydrogen ions that could be generated by the precipitation of various metal and hydroxides in solution at a given pH such ferric hydroxide. Dosing can reduce concentrations of bioavailable metals, however can result in precipitation and generation of sludge which can have broader implications for environments and amenity.

As this option does not manage the flow in the estuary, it will not manage ASS at Coogoorah Park.

Typical characteristics published by Earth Systems, 2005 for when dosing systems can be effective compared to a subset of historical Anglesea Estuary data[8] (1/2/2022 to 31/1/2023) is presented in Table 7-9 below. This is an assessment of the capacity of the selected option to neutralise the acidic load on any given day as given the highly ephemeral nature of the upper catchment tributaries, climate, flow rates and acidity can vary considerably. This assessment does not consider other estuary conditions such as turbidity, dissolved oxygen and geochemistry that will influence the effectiveness and design of the option. This assessment also does not consider whether conditions were suitable for adequate mixing of alkaline material.

Table 7-9 Summary of estimated effectiveness of in-situ dosing and percentage of days option could have met ideal conditions to effectively treat acidic load (February 2022 to January 2023).

Conditions where option is typically effective (Taylor, 2005)	Av. acidity range (kg $CaCO_3$/day)	Av. Flow rate (L/s)	Both acidity (kg $CaCO_3$/day) and flow rate (L/s)
	<50,000	No limit	
Anglesea conditions (Feb 2022 – Jan 2023)	Av. 211 Max 3,713	Av. 132 Max 2,944	
% days option would have met ideal conditions	Theoretically all days within typical parameters, however in significant flows or flood conditions the mass of reagent required to treat pH likely to be undesirable and result in other adverse effects, and adequate mixing to effectively treat water may not be possible. For example: on the day with max conditions in 2022, 5 tonnes of hydrated lime would have been required to raise pH to 7.		

7.2.4.3 Potential locations

Dosing at a point upstream of the estuary where the river is narrower, but downstream of the confluence of Salt and Marshy Creeks, would allow for treatment of all low pH water from upstream before it enters the estuary. In-situ dosing of alkalinity can be undertaken at multiple sites throughout the estuary to maximise effectiveness.

At least one primary dosing station that can store and discharge large amounts of the selected alkaline substrate in highly acidic events will be required. Additional smaller dosing points can be dispersed down the estuary to ensure adequate alkalinity is added, these smaller dosing points will need to be designed to not affect visual amenity of, and recreational activities in, the estuary.

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[8] Flow and pH conditions recorded in Salt and Marshy Creeks at Alcoa (DEECA monitoring points 235222 and 235260 respectively).

It is preferable that dosing and mixing points are away from recreational activities in the estuary for amenity reasons, however there would not be a risk to recreational users or flora and fauna within the river in dosed locations.

Continuous pH test locations will be required upstream and downstream of the dosing stations to ensure adequate alkalinity is added. Figure 7-11 below shows the proposed locations of the dosing stations.

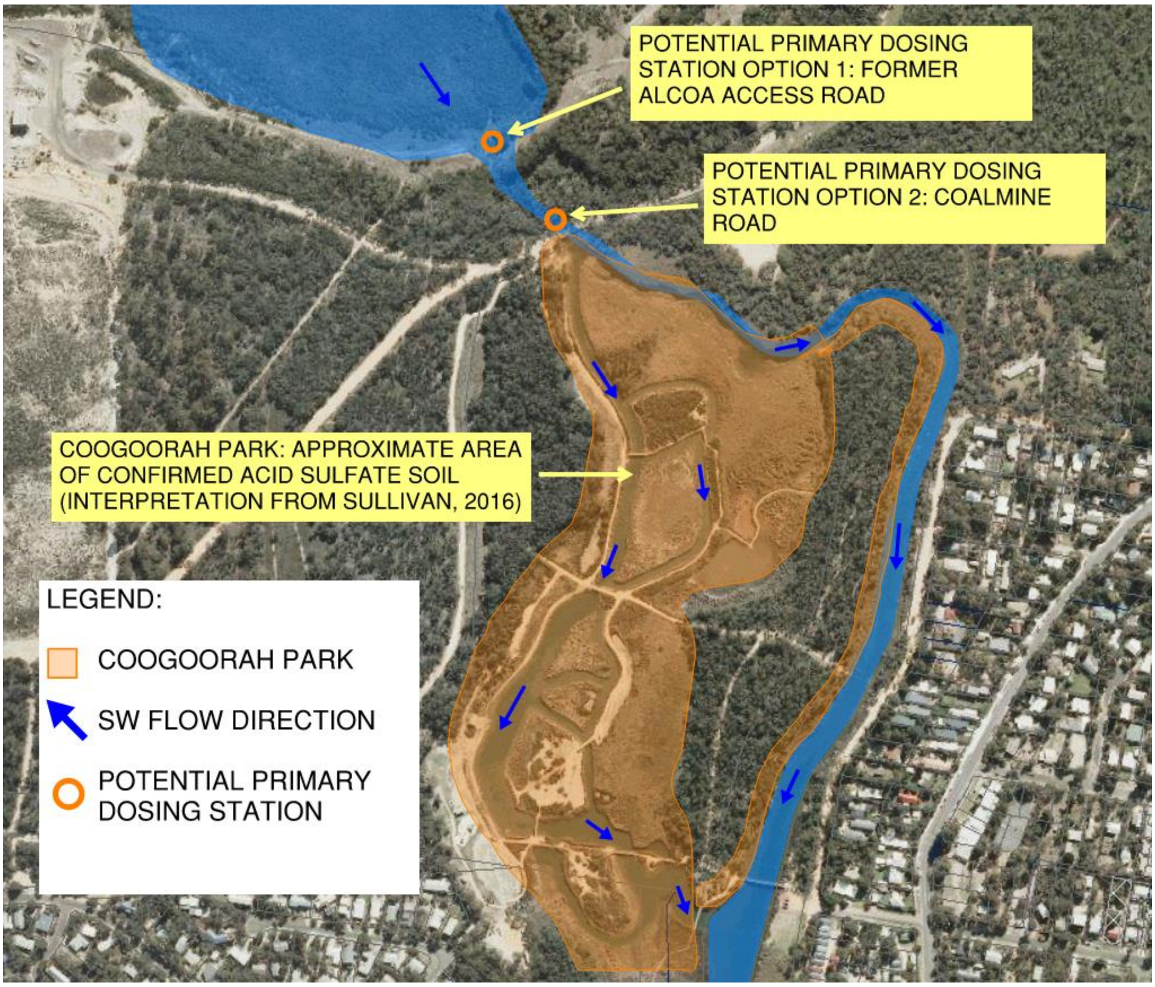

Figure 7-11 Potential siting options for dosing stations

7.2.4.4 High level cost estimate

Estimated costs (per 10 years operational time) are summarised in Table 7-10 below. Detailed feasibility cost estimates are included in Appendix E.

Costs exclude management of sludge if generated.

Table 7-10 In-situ Dosing station estimated cost- high level cost estimates for comparison purposes only[9]

Cost item	Estimate (AUD)	Notes
Capital	$ 590,000	Construction of lime solution insitu dosing station. Cost inclusive of engineering, procurement and construction management, construction and 20% contingency. Assume that services are readily available at selected location. Dosing quantity conservatively estimated based on calculated estimated acidity entering the estuary (flow rate and pH from Salt & Marshy Creeks), with daily treatment to pH of 7 using hydrated lime. Includes 50% safety factor.
Operation and Maintenance (Annual)	$ 169,000	Inclusive of inspections, utilities, operations, and maintenance, monitoring and report. Actual cost will depend on design, operating parameters and selected treatment reagent.
Net Present Value	$ 2,760,000	Assuming a period of 10 years and 4% discount rate

7.2.4.5 Legislation and permit requirements

Approvals for in-situ dosing would be as for Option 23.

7.2.4.6 Environmental, cultural, social and economic considerations

The following considerations and potential risks would need to be managed either through the design or in operation of the dosing treatment system:

- Design and operational controls would need to consider differences in fresh and saline water chemistry, and target pH. The pH and total titratable acidity of the water should be checked daily during at least the first two weeks following application or until the pH and acidity has been stabilised and then on a regular basis. The pH should be checked at least daily if there is any discharge from the site and preferably more frequently depending on the environmental sensitivity of the receiving environment.
- Addition of alkaline materials to the river could potentially change the level of dissolved solids and may result in precipitation of metal compounds within the estuary, as shown in Figure 7-10. Precipitation of iron and aluminium compound as pH increases can threaten gill breathing organisms and smother other aquatic life as was observed during the 2000 fish death event (Pope, 2010). Management of precipitated metals or metalloids will need to be investigated using similar methods outlined in Green (2005). This could be managed by active removal of precipitates, pairing with an option to reduce metal concentrations upstream (such as a PRB) or dosing in a treatment area out of the river.
- The dosing of acidic water entering or within the estuary does not manage the risk from oxidation of acid sulfate soils at Coogoorah Park. This option will need to be paired with a second option to ensure this risk is managed.
- Some visual amenity impacts during periods of dosing may occur including increased water turbidity and precipitation of solids. Design will need to factor in the mixing as this mixing could lead to the precipitation of metallic compounds following dosing leading to their deposition within the estuary with possible adverse effects as discussed previously. This risk could be minimised through the design and implementation through appropriate sizing, selection of an area for a mixing zone, and potentially introducing an additional step to capture precipitates.

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[9] Costs based on previous CDM experience on similar project(s). Cost provided is high-level and indicative only and may vary significantly based on tributary water input parameters. Cost is for one dosing station.

- Dosing stations may present visual amenity impacts; location of construction will need to be considered.

7.2.4.7 Additional information or assessment required

Mixing potential/stratification of natural flows will need to be assessed. Due to the low flow in the upper estuary for the majority of the year, additional active mixing may be required following detailed assessment of flow conditions and mixing potential at applicable site(s).

Further investigation into the most appropriate dosing technique should be sought to ensure the most effective implementation of the technology. The combination of passive dosing with active dosing when required could allow for a greater mixing capacity in the estuary.

7.2.5 Introduce seawater via dredging of artificial openings (berm grooming and shallow or deep opening) (options 12 & 13)

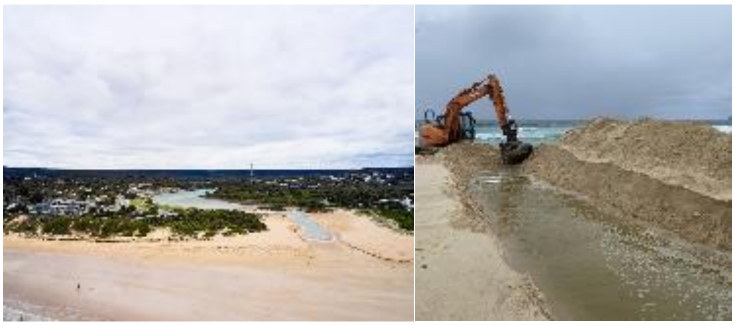

Figure 7-12 Estuary entrance opening examples

7.2.5.1 Conceptual overview of option

The theory of creating an artificial opening of the sand berm is to improve connectivity of the estuary with the sea by dredging the beach sand berm, either to a shallow depth (option 12) or more deeply (option 13). Seawater contains dissolved carbonate and bicarbonate and consequently has the ability to neutralise acidity in soils and waters.

Natural estuary openings have generally occurred historically when flow rates in the river are > 10ML/day over a week or more (GHD, 2021). Over time these are occurring less often due to reducing surface water flows through the catchment and changes to the entrance berm. An Environmental Flows Study (GHD, 2021) suggests that promoting a natural regime of estuary openings, marine exchange and bed scouring is required to increase salinity and promote fish movement, as well as maintain water quality and promote seagrass habitat, where there are sufficiently high inflows to the estuary. The report also notes however that natural openings are likely to be less frequent over time. Artificial estuary openings have been identified as a potential option that could be used in specific circumstances to facilitate an opening and tidal exchange with water in the estuary, where natural flows are not sufficient for this to occur.

7.2.5.2 Effectiveness

The introduction of sea water during flood tides while the berm is open has been observed to assist in regulating acidity in the estuary and maintain its water levels and water quality (GHD, 2021).

The pH neutralising effect of seawater would depend on the physical dimensions of the openings, sea level, the height of the tide, the amount of opposing river flow entering the estuary from upstream, and the degree to which the two water masses mix. Mixing may be limited due to a difference in salinity/density.

A key limiting factor of artificial berm openings is the natural marine processes driven by offshore dynamics that cause the regular build-up of sediment, closing the berm and re-forming the estuary lagoon. The entrance berm is increasing in height and length, transitioning to a more permanently closed system (GHD, 2021; Water Technology, 2011). Artificial openings will become more resource and cost intensive over time, and potentially less effective. Additionally, if a channel was maintained artificially for an extended period without natural flows through the system this could result in further extension of the berm upstream, with continued artificial openings reducing the hydrological functioning of the estuary (GHD, 2021).

The Environmental Flows Study (GHD, 2021) recommended:

- "Avoid artificial estuary openings where possible when sea conditions are unsuitable (i.e., spring tides, combined with high offshore waves, adverse south-westerly weather conditions), estuary oxygen levels are low, catchment flows are low (<5−7 ML/day) and will have limited impact on maintaining an open estuary".

Findings from the Environmental Flow Study (GHD, 2021) were consistent with earlier advice by experts that artificial openings are unlikely to provide a net environmental benefit to the Anglesea estuary and should be avoided (Alluvium, 2014).

Given these limitations, the suitability of the estuary opening option to neutralise acidic event in the estuary is dependent on the opening depth and extent. The necessary depth for the opening to be effective will depend on catchment flows, depth, width, and oceanographic factors such as long-shore drift, tide and wave heights as well as meteorological factors such as on-shore winds and atmospheric pressure. All can influence the delivery of sand to the entrance and act against the scouring effect of ebb tides. The duration of openings also influence the effectiveness but are hard to predict.

A successful opening occurred resulted in a successful opening which raised pH levels in November 2022. This related to water levels at the GOR bridge of 0.967 m depth (monthly average). This occurred after sustained very high catchment inflows (44.68 ML/day average, 208 ML/day max in October). Tidal conditions at this time were also favourable for seawater coming up into the estuary. The size of the opening is not known but based on available observations likely to be relatively shallow and wider than previous modelling by Water Technology (2011).

More assessment would be required to understand and identify conditions where artificial openings would be beneficial and not result in greater harm to the environment.

Shallow Artificial Opening or berm grooming

The shallow opening is the excavation of a channel to a height above mean sea level, but below the high tide level. Berm grooming to allow the overtopping of marine water during high tides, has been assumed to have a similar effectiveness. A shallow opening has been defined as a height of 0.75 m AHD. Water Technology modelled a shallow opening with a berm height of 0.75 m AHD and a channel with width of 7.5 m when modelled to determine its effectiveness (Water Technology, 2011).

The shallow berm opening modelled as part of the 2011 Water Technology Investigation of Anglesea River Estuary Mouth Dynamics Study concluded:

- A shallow (0.75 m AHD), narrow excavation at the entrance has only limited capacity to discharge estuary waters to the sea. Over the 7 day period of the simulation, the water depth in the estuary reduced from an initial 1.5 m AHD to around 0.9 m AHD;
- The peak predicted tidal elevation of the simulated period was 1.05 m AHD which was insufficient to allow saline water to enter the estuary.
- No mixing of estuary and sea water occurred in the estuary over the simulation period.
- Overall, the shallow excavation depth and limited capacity of the excavated channel are insufficient to allow saline waters to flush the estuary in the short term.

Deep Artificial Opening

The deep opening is proposed to be a height at or below mean sea level to allow saline intrusion and discharge of estuarine water. A deep opening has been defined as a channel height between -1.0 m AHD and 0.0 m AHD (Water Technology, 2011). The channel width required has not been specified, however it will be influenced by channel wall sloping factor due to the sediment geotechnical properties.

The deep berm opening modelled as part of the Water Technology (2011), which concluded:

- The salt wedge was observed extending further upstream during each subsequent incoming tide. After one high tide, there is only a small amount of fresh water on the surface upstream of the bridge. At the bed of the channel the salt wedge becomes stronger as more saline water is forced into the estuary under tidal conditions. After 3 days the channel is well stratified with salinity of up to 32 ppt at the deeper sections of the channel.

- There is little difference between the deep channel (0.0 m AHD) and the deeper channel options (-1.0 m AHD) in terms of saline intrusion and mixing in the estuary.
- Overall, the results show that an artificial opening of only 3 days (6 tidal cycles) is sufficient to flush the estuary with mixing of fresh and salt water throughout the system promoting marine exchanged, increasing salinity, supporting fish migration and habitat and seagrass recovery (GHD, 2021).

Regardless of the estuary opening depth, maximum recorded tide heights observed in 2022 were less than 2 m. Indicating high tides can reach approximately 1 m above AHD and low tides can fall to nearly 1 m below AHD (based on BoM 2023 tide table from nearest station: Lorne, Victoria).

Opening of the estuary mouth may reduce estuary water levels if there is insufficient surface water flow through the estuary which could expose ASS in Coogoorah Park to the risk of oxidation. This technology will require pairing with an additional option to maintain water levels in Coogoorah Park at 1.2-1.6m AHD (Pope, 2006). Artificial opening of the estuary may also cause net environmental detriment if particular adverse water quality parameters are present (particularly low dissolved oxygen [Arundel, 2006]) (Alluvium, 2014).

Managing acidity in the estuary through manipulation of the entrance is not a reliable strategy. A complex set of factors largely beyond human control influence both the degree to which seawater can enter through the channel and for how long:

- **High flow conditions**: Very high or flood flows into the estuary have the potential to naturally open the entrance. Under certain conditions the berm opening may have minimal impact on the neutralisation of acidity in the estuary. Due to the large volumes of acidic freshwater flowing downstream, movement of seawater up the estuary will be limited in major floods. As flow recedes there may be increased marine exchange through an open entrance for several days to weeks (GHD, 2021). This will re-introduce well oxygenated, neutral bottom water into the estuary providing a refuge for estuarine organisms and neutralising of acidic freshwaters. During high flow conditions insufficient to open a channel at the berm, dredging a channel may be a response option primarily to reduce flooding. The effectiveness of such an artificial opening in reducing acidity in the estuary will be dependent on the degree of seawater incursion. This, in turn will be dependent on factors such as the dimensions of the entrance channel, tide and sea states and magnitude of river flows.
- **Low flow conditions**: During low flow conditions a deep opening of the entrance will facilitate greater ingress of seawater into the estuary. A shallow opening or berm grooming will have less effect. The success of either opening type will depend heavily on the tide and sea state in the absence of upstream flows to aid entrance channel scour.
- **Water quality**: Opening of the entrance can promote marine exchange and increase water quality. However, the opening of the estuary needs to consider water quality prior to opening to ensure there is no impact to flora or fauna (Arundel 2006).

7.2.5.3 Indicative dredging extents

Opening the entrance berm involves excavation of a channel. The most cost effective excavation method would likely be with excavator(s), backhoe(s) or bulldozers with additional machinery to cart material as required. The required channel length could vary significantly depending on the height and width of the berm; however, for the purpose of this assessment, it is estimated to be in the order of 500m. Indicative dredging extents are shown on Figure 7-13 below.

Figure 7-13 Indicative berm dredging extents.

7.2.5.4 High level cost estimate

Indicative costs for artificial entrance openings are included in Table 7-11 below. Detailed feasibility cost estimates are included in Appendix E. Berm grooming specifically has not been quantified but is assumed to be a similar frequency and volume of material requiring excavation and transportation as the shallow estuary opening.

Currently the estuary is opened for the purpose of flood prevention. If this activity was to take place for the objectives of this project, a greater level of due diligence, investigation, management and monitoring would be required. Costs indicate the investigation, design, approval and other processes required to implement this as an ongoing pH management option.

Estimated distances are based on aerial images as a conservative value, however it is recognised that the length of excavation through the berm will vary based on the height of water in the estuary and size of the berm. Depths have been adopted based on previous modelling, however refinement of the most effective depth is suggested and will change future spoil management volumes and costs.

It is also noted that the berm is predicted to increase in height and length with climate change, as well as if the frequency of artificial openings increased. Over time therefore the cost for maintaining or implementing this option would increase as the frequency and scale would grow. This has not been factored into the costs presented.

Table 7-11 Artificial estuary opening estimated cost- high level cost estimate for comparison purposes only[10]

Cost item	Estimate (AUD)	Notes
Shallow Opening / Berm Grooming		
Capital	$ 425,000	Excavation of temporary shallow inlet (0.75m AHD). Cost inclusive of preliminary environmental studies and modelling, engineering, procurement and construction management, initial excavation to open and 20% contingency.
Operation and Maintenance (Annual)	$ 55,000	Inclusive of reinspection, re-excavation and monitoring and reporting. Twice yearly openings.
Net Present Value	$ 870,000	Assuming a period of 10 years and 4% discount rate
Deep Opening		
Capital	$ 575,000	Excavation of temporary deep inlet (-1 m AHD. Cost inclusive of preliminary environmental studies and modelling, engineering, procurement and construction management, and 20% contingency.
Operation and Maintenance (Annual)	$ 95,000	Inclusive of reinspection, re-excavation and monitoring and reporting. Twice yearly openings.
Net Present Value	$ 1,300,000	Assuming a period of 10 years and 4% discount rate

7.2.5.5 Legislation and permit requirements

Approvals for dredging of the estuary berm would be as for Option 23 along with the following:

Legislative Requirements:

- All dredging in Australia must be consistent with the requirements of an international agreement to which Australia is a signatory known as the Protocol to the London Convention (previously known as the *Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972*) (applicability depending on implementation and future management).

Commonwealth legislation

- *Environment Protection (Sea Dumping) Act 1981 (the Sea Dumping Act)* – On the open coast, dumping of dredged material, other than beach renourishment, must satisfy the *Sea dumping Act* (applicability depending on implementation and future management).

State legislation

- The *Marine and Coastal Management Act 2018* requires that in Victorian coastal regions, including estuaries to the extent of tidal influence, the Minister must provide written consent for any use or development on the coast, including dredging and spoil disposal.
- **Water Act 1989**

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[10] Costs based on previous CDM experience on similar project(s) and engineer's estimates. Cost provided is high-level and indicative only and may vary significantly based on the Anglesea River Estuary specific input parameters. Due to the northeast direction of longshore sediment transport, material removed from the entrance channel should ideally be placed to the east of the opening. Sand may require removal at additional cost.

  - Approval from CCMA required for works and activities within the bed and banks of the Anglesea River estuary. Additionally, the CCMA will have to give a permit for the estuary opening as per the Victorian Estuary Entrance Management Support System (EEMSS; Arundel 2006) as part of their management. The Shire may carry out the works once approval is given by the CCMA.

7.2.5.6 Environmental, cultural, social and economic considerations

- Continued artificial openings are likely to result in increased sedimentation and reduction in the hydrological function of the estuary. Broadly this option is contrary to previous recommendations for managing the river (GHD, 2021).
- Consideration to impacts on cultural heritage sites and values would need to be assessed and appropriate management and approvals in place.
- Precipitation of iron and aluminium compound as pH increases can threaten gill breathing organisms and smother other aquatic life (Pope, 2010) and cause environmental impact as per In-situ dosing, detailed in section 7.2.4.6.
- If the estuary berm was to open during periods of low dissolved oxygen in deeper waters of the estuary, surface flow of higher dissolved oxygen water out of the estuary leaves lower dissolved oxygen water behind, impacting aquatic life. Timing of estuary openings would need to be managed to ensure water quality within the estuary can support the opening.
- Estuaries are dynamic environments with naturally and highly variable water levels, flows, water quality and ecology. The plants and animals inhabiting the estuary are well adapted to changes occurring on a daily and seasonal basis, or under extreme events. Continued artificial openings reduce the hydrological function of the estuary, increase the potential for sedimentation (sand build-up) and restrict natural processes (Alluvium, 2014; GHD, 2021).
- Maintaining of a shallow artificial opening of the estuary over a period of days/tidal cycles will drawdown the water surface in the estuary and adjoining soils, introducing oxygen to the floodplain and the potential for the occurrence and presence of acid in the estuary (Alluvium, 2014).
- Risk that the artificial opening of the estuary does not provide the necessary cue or conditions for fish movement and thus the replenishing of fish stock in the estuary (Alluvium, 2014).

7.2.5.7 Additional information or assessment required

Further analysis of the interaction of tidal and meteorological conditions, surface water flows, water quality conditions, as well as long-shore and on-shore sand drift patterns to identify specific conditions in which this option could be implemented to be effective and minimise harm to the estuary environment. It is noted however that it is unlikely this analysis would result in an outcome that would identify conditions that would sufficiently manage pH conditions in the estuary if this option were to be implemented in isolation, and uphold the recommendations made for management of the river to maintain environmental values made through previous extensive studies (Alluvium, 2014; GHD, 2021). Further analysis may however identify specific conditions where artificial openings could be implemented in conjunction with other options, to increase effectiveness and flexibility.

7.2.6 Introduce seawater to the estuary via a pump and pipe (option 14)

Figure 7-14 Example images of sea water intake pipe (source: Adobe Stock images)

7.2.6.1 Conceptual overview of technology

The seawater pump and pipeline option involves pumping seawater from offshore over the beach and sand berm into the estuary. Relying on seawater pump and pipeline would allow for greater versatility in the volume of seawater added to the estuary and the location at which this water is discharged, compared to an artificial opening that relies passively on tides and catchment flows to be effective.

The discharge point for seawater could be near the ocean or further upstream; the location will change the effectiveness of the solution and needs to be carefully considered. Like the tidal option this filling would propagate upstream from the estuary mouth, so the reach of a pH neutralising effect of seawater would depend on similar factors – the volume pumped, the amount of opposing river flow entering the estuary, and the degree to which the two water masses mix (mixing may be limited due to a difference in salinity/density). The key difference with this option is that the estuary water level could be raised above sea level to the height of the berm, or the height of any channel bed that may naturally form through the berm from time to time.

7.2.6.2 Effectiveness

The addition of seawater is anticipated to be very effective at neutralising acidic flows in the estuary. The addition of sea water has been shown to provide a significant buffering effect on water from Salt and Marshy Creeks that is entering the estuary. In addition, the provision of well oxygenated marine bottom water provides a refuge for estuarine organisms while surface waters are acidic.

A previous study by Pope (2006) analysed the amount of seawater that would be required relative to the pH of Marshy and Salt Creeks and found that a mixture of 50% seawater is generally enough to increase pH to 6 or 7.

This option would be able to address the requirement of maintain water levels in Coogoorah Park to stop the oxidation of further ASS, provided the discharge point of seawater was sufficiently upstream in the estuary.

Mixing of the pumped seawater and acidic freshwater may be limited due to the differences in salinity/density. The discharge point of the pipeline should be as far upstream in the estuary as practicable to encourage propagation of a salt layer upstream and avoid erosion of the entrance berm. Prolonged saline conditions in surface waters may harm some wetland species in marshes and some bankside vegetation species

Assessment of option in differing estuary flow conditions:

- **High flow conditions**: This option could be limited in its effectiveness if high acidic flows were to be observed in the estuary. The capacity of a pump and pipeline will be necessarily limited due the pipe sizing and chosen pumping rate; if buffering requirement are in excess of this maximum flow rate, the pumping of seawater will be ineffective at neutralising the estuary. The pumping of large volumes of water to meet high flow periods would be limited in its effectiveness due to the large water volume resulting in the berm opening and allowing the flow of water out of the estuary. This however will promote marine exchange which would assist in the neutralisation of the acidic flows in the estuary. If the increased water volume does not result in a berm opening (shallow deep), there would be a risk of flooding if water levels were to rise above 1.6m AHD (Water Technology, 2011).

- **Low flow conditions**: In low flow conditions this option would be likely very effective in being able to employed when required and simple turned off if the water in the estuary is of a neutral pH.
- **Estuary Mouth open flow conditions**: When the estuary mouth berm is open and tidal water is entering the estuary, the pumping of seawater will not be required, and the system can be turned off. This option may help to induce estuary openings and so help support environmental values.
- **Water quality**: This option would be effective in increasing pH levels under a variety of flow scenarios. Addition of seawater to acidic river water could potentially change the level of dissolved solids and may result in precipitation of metals under some conditions. This could impact aquatic organisms and vegetation.

7.2.6.3 Potential location

A potential pipeline alignment and pump location are shown in Figure 7-15.

If the pipeline extended further upstream than immediately over the estuary berm, the option would be more effective at buffering pH as seawater would directly mix with inflowing creek water and act to neutralise pH throughout the estuary, in addition to supporting a suitable water level to avoid exposure of acid sulfate soil. If the pipeline is extended further inland consideration of potential impacts of prolonged saline conditions on wetland species in marshes and some bankside vegetation species will be required as well as the vastly increased cost required to pump and pipe the additional distance and height. For these reasons the potential discharge points proposed are all within the estuary.

Consideration of the offshore collection location needs to be made to ensure the existing social and environmental values of the estuary and surrounding areas are protected. Previous studies have recommended collection at a water depth of 10m at a site located in the lee of the reef and about 550m offshore.

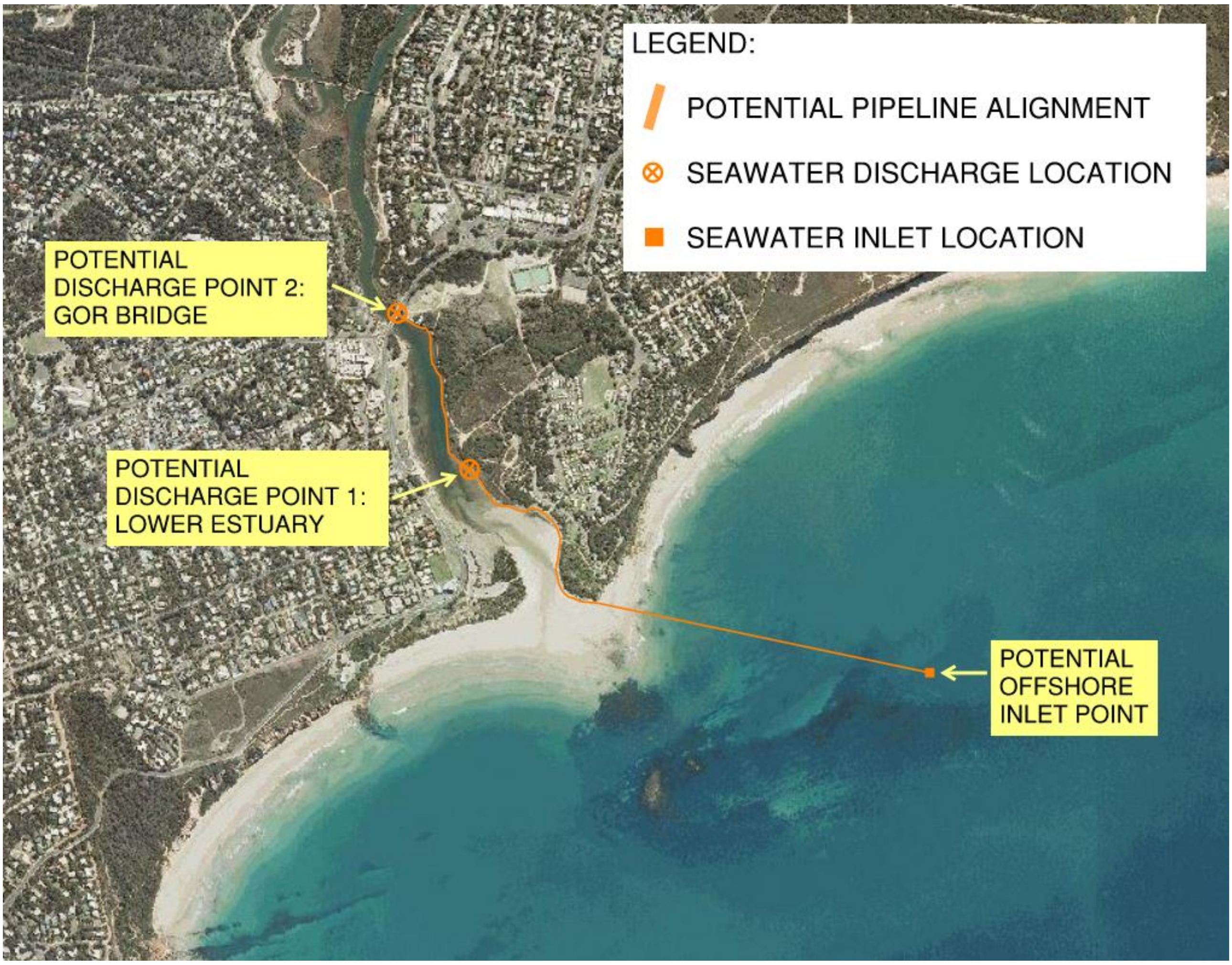

Figure 7-15 **Example siting option for seawater pipe and pumping station.**

7.2.6.4 High level cost estimate

Indicative costs for installation and operation of this option are provided in Table 7-12. Costs will depend on the final design and pumping rates, and exclude further studies, approvals, design, and will vary based on the estuary discharge point and any additional design requirements to manage risks. A previous study by GHD in 2016 investigated the implementation of a temporary pump and pipe structure that could be constructed and used, when necessary, in the summer months.

For the purpose of this report, the capital costs are for a temporary pump and pipeline that can be constructed and implemented when required and a permanent electric pumping station to be constructed and operated for a period of 10 years.

Table 7-12 Sea water pump and pipeline estimated cost, high level cost estimate for comparison purposes only[11]

Cost item	Estimate (AUD)	Notes
Temporary diesel pump and temporary pipeline (across beach or floated on estuary) (GHD, 2016)		
Capital	$100,000 to $150,000	Pipeline 500 m offshore and 500 m upstream, with pipeline above ground over the sand berm. Temporary implementation: rental of pump, fuel, contractor, operator in pumping season and offseason. Permanent: construction of pump station, inlet and outlet pipelines, annual inspections, utilities, maintenance, monitoring. Final cost will depend on sizing, location and other investigation, permitting and design elements.
Operation and Maintenance (Annual)	$66,550	Includes rental of pump, fuel, contractor, operator in pumping season and off season.
Permanent electric pump		
Capital	$ 1,200,000	Construction of permanent pump station and inlet and outlet pipelines (500 m total)
Operation and Maintenance (Annual)	$ 200,000	Inclusive of inspections, utilities, operations and maintenance, monitoring and report.
Total 10 years	$ 2,800,000	Assuming a period of 10 years and 4% discount rate

7.2.6.5 Legislation and permit requirements

Approvals for seawater pumping into the estuary would be as for Option 23.

Additional marine, Cultural Heritage Act and EPBC Act approvals are likely to be required, depending on the design and intake location.

7.2.6.6 Environmental, cultural, social and economic considerations

- In addition to the pH neutralising effect, the addition of seawater may result in the estuary becoming a more permanently saline system, particularly if introduced in the upper estuary. This would result in a transition of aquatic species. A pumped seawater option with a discharge further inland would need to consider the increase of salinity around the point(s) of discharge compared to the adaptability of adjacent vegetation communities and aquatic ecosystems.
- The buffering of the estuary with sea water would neutralise the acidic water in the estuary, however, could lead to the precipitation of metallic compounds following pH buffering leading to their deposition within the estuary with possible adverse effects as discussed previously. This has the potential to impact on aquatic ecosystems and would need to be managed to avoid contributing to fish deaths. The nature and speed of this reaction would depend on dissolved oxygen, redox, salinity conditions and metal concentrations. The risk to aquatic ecosystems from this will depend on the extent of the area impacted and specific species, including how they may be affected by precipitation. Further investigation into these aspects, understanding of the mixing zone hydraulics and species would be required to inform the design and minimise impacts.

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[11] Cost provided is high-level and indicative only and may vary significantly. Additional costs for design, permitting and monitoring would be required. An annual 120 run time of days at a rate of 0.7 -1 ML/day has been assumed. Construction of a permanent system, although being a large capital cost to construct, may be more cost effective over the 10-year period (cost not included in this options assessment).

- Offshore pipe inlet will need controls implemented that limit its accessibility. Anglesea beach is used by members of the public for surfing, swimming, and snorkelling. The inlet will also require controls to ensure marine ecosystems offshore are not impacted.
- Amenity to other receptors may also be impacted, including potential for noise and visual amenity effects on the adjacent caravan park and recreational users of the estuary.
- Cultural heritage values have the potential to be impacted from construction and implementation of this option. For this reason, an above ground pipeline is identified in this report, however further mitigation and management may be required based on advice from Wadawurrung Traditional Owners.
- Pipeline discharge location needs to consider local ecosystems and potential impact of river scouring or sediment disturbance and changes to the river hydrology.

7.2.6.7 Additional information or assessment required

- Assessment of the environmental effects of metal compounds precipitating within the estuary following the introduction of seawater (water quality, metal concentrations, flow conditions, species).
- Modelling of the mixing zone, potential impact from river scouring/sediment disturbance, and extent of influence for water levels to ensure pumped water reaches Coogoorah Park to maintain water levels.

7.2.7 Maintain water levels to manage ASS at Coogoorah Park with moveable weir/sluice gate weir system (option 5)

Figure 7-16 Examples of adjustable weir system (source: Adobe Stock images)

7.2.7.1 Conceptual overview of technology

Maintaining soil saturation is an effective method of managing ASS with hypersulfidic material to minimise or avoid oxidation and formation of sulfuric acid. Alternative methods of managing ASS at Coogoorah Park would impact more significantly on the recreational, environmental and amenity values of the area (for example infilling channels or in-situ treatment of ASS through capping or liming). Not managing ASS at Coogoorah Park has the potential to exacerbate the estuarine acidity and result in a more challenging issue to manage.

This option aims to maintain water levels using a weir in the Coogoorah Park channels which will maintain saturated sediments to avoid oxidation of ASS and formation of acid. Sullivan, 2016 recommended maintenance of water levels within the range (1.2 -1.6 m AHD) as one of the most appropriate methods of avoiding oxidation of ASS and exacerbating acidity issues in the estuary.

Soil results indicate this water level will ensure *“little potential for the release of acid sulphate soil related acidity and metal and metalloid from the surficial soils and sediments over and above the current rates of acidity and metals emanating from the jarositic soil materials already present at Coogoorah Park*” (Sullivan et al, 2016).

Maintenance of water levels within the Coogoorah Park sediments would involve installation of weirs at upstream and downstream inlets to isolate the channels from the main river. Weirs would aim to maintain water levels in the channels and sediments even if water levels in the main channel of the Anglesea River fall below weir height.

The height of the weirs would be designed to keep water levels at a level that maintains saturation of ASS with hypersulfidic material; between 1.2 – 1.6 m AHD. Further investigation to inform the specific depth and design would be required. Design considerations include:

- Allowance for fish movements.
- Measures to avoid stagnation of water within the channels if weirs remained closed for extended periods, such as moveable weirs or sluice gates that allow the movement of water in and out of Coogoorah Park during high flows but can retain water during drier periods.
- Maintaining recreational access to the waterways to the extent practicable. Installation of weirs could interrupt the utility of the area, particularly for water based recreation, with watercraft users be required to portage to enter Coogoorah Park.

7.2.7.2 Effectiveness

Maintaining saturation of ASS with hypersulfidic material is the simplest method of effectively avoiding oxidation and formation of acid.

This option is a preventative measure to manage one potential source of acid, however it will not address low pH conditions experienced in the estuary from ASS in the upper catchment. A separate option would also therefore need to be implemented to address the broader issue of acidity in the river.

A weir system would be a more permanent solution to managing ASS, therefore flexibility to operate effectively in different conditions is important.

- **High flow conditions**: During high or flood flow periods the weir system would not be required as the ASS in Coogoorah Park would be saturated and not require management. Effectiveness would be maintained. If under high flow conditions the estuary mouth opens, once the flow recedes the flow recedes this may lead to low estuary water levels (0.2mAHD (Pope 2006), therefore the weir may need to be closed during peak flood to maintain water levels.
- **Low flow conditions**: During low flow conditions the weirs would be designed to maintain the water level in Coogoorah Park channels. If isolation of channels without freshwater flow was for an extended period of time, the potential risk of deoxygenation and stagnation of the water within the channels would need to be managed to protect aquatic life and avoid odour, either by mechanical aeration or introduction of another water source. If the water level decreases below the chosen weir height for any significant amount of time and ASS begin to drain and oxidise, the water levels within Coogoorah Park would need to be topped up by pumping from the main channel or through supplementary water sources; this represents additional considerations as per other water sources assessed through Stage 1 of the project. Further investigation would be needed to understand how soils at Coogoorah Park drain and connectivity with the main river channel to have confidence that this option would be effective in persistent low flow conditions. Following estuary mouth openings, as the berm at the entrance rebuilds and closes the water level in the estuary can rise (1.3 – 1.7 m AHD, (GHD, 2016), and the weir system may not be required.
- **Estuary entrance conditions**: Conditions of the estuary entrance berm are not likely to alter the effectiveness of this option, with the exception of how this alters water levels in the river as above.
- **Water quality**: This option could be successful under a range of water quality conditions; however as above low dissolved oxygen conditions would need to be avoided to minimise risks to aquatic life.
- **Climate change**: Predicted future changes to water levels are likely to result in inundation of Coogoorah Park (Water Technology, 2011), assuming a sea level rise of 0.8 m as used in the Victorian Coastal Strategy

(VCC, 2008). Management of ASS at Coogoorah Park therefore is less likely to be required in the future once water levels increase. The effectiveness of this option would not vary through future water level fluctuations from climate change or other factors.

7.2.7.3 Example locations of weirs

Previous soil sampling undertaken by Sullivan et al (2016) has identified widespread ASS with hypersulfidic material throughout low lying areas of Coogoorah Park (approximate area shown onFigure 7-17). To manage water levels throughout the area, weirs at the upstream and downstream inlets of Coogoorah Park are the most effective locations.

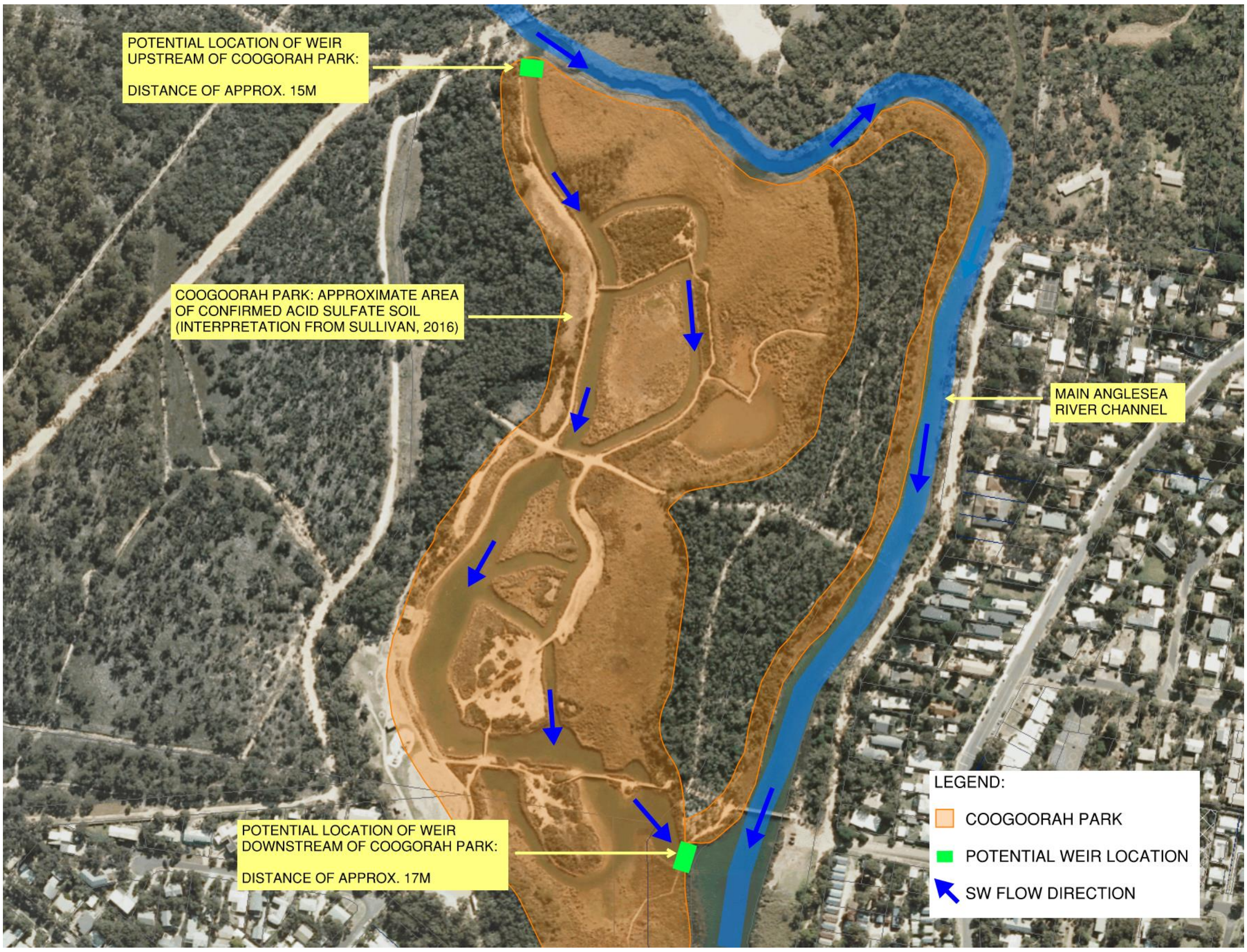

Figure 7-17 Possible locations of weirs and approximate area of ASS at Coogoorah Park

7.2.7.4 High level cost estimate

Estimated costs (per 10 years operational time) are summarised in Table 7-12. Detailed feasibility cost estimates are included in Appendix E.

Table 7-13 Weir system cost estimate-high level cost estimate for comparison purpose only[12]

Cost item	Estimate (AUD)	Notes
Capital	$ 2,200,000	Construction of inlet and outlet moveable weirs at Coogoorah Park. Cost inclusive of engineering, procurement and construction management, construction and 20% contingency.
Operation and Maintenance (Annual)	$ 140,000	Inclusive of inspections, utilities, operations and maintenance, monitoring and report.
Net Present Value	$ 3,350,000	Assuming a period of 10 years and 4% discount rate

7.2.7.5 Legislation and permit requirements

Approvals would be required as per Option 23.

7.2.7.6 Environmental, cultural, social and economic considerations

The following factors would need to be considered with regards to environmental, cultural, social and economic values:

- Coogoorah Park channels and the main river form a circuit that is commonly used for recreational activities by a wide variety of users. This includes local residents, participants in organised events, visitors, student camps and licenced activity providers Go Ride a Wave, Eco-Logic Education, Sea Earth and GORATS. Installation of weirs to manage ASS could interrupt the utility of the area, particularly for water based recreation. This would potentially also impact a range of businesses that use the area or hire watercraft (see below).
- Feedback from members of the stakeholder reference group is that "For teachers, community group leaders, disability group managers, respite group organisers, holiday program leaders it is the *perception* of being in a natural environment which is critical to their decision making of where to book a camp or day of activities"… Coogoorah Park "is a haven for playing children, hikers, bird watchers, bike riders, paddlers, fishers and dog walkers.". There is concern that installation of structures within the Coogoorah Park setting could negatively impact on the perceived natural environment of Anglesea, and hence the use of the area and economy (see below).
- Tourism is the primary economic driver for Anglesea, supported by recreation, amenity and education. Estimates from Surf Coast Shire, provided by Regina Gleeson (Eco-Logic Education), are that the camping and recreation sector contributed $10 million per year to the Anglesea economy (pre-COVID). Changes to the utility of the river and perceived natural environment could negatively affect tourism and ultimately the economy of Anglesea.
- During excavation / installation of weirs there is potential to release acidic sulfate soils, as well as heavy metals. This could be managed through design and construction methods.
- Stagnation of water within channels would need to be managed to avoid odour and ecological impacts, either through aeration, introduction of new water supply, or by the weir design allowing opening and closing to let water flow through and connection to the main river channel when flow conditions allow.

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[12] Costs based on previous CDM experience on similar project(s) and engineer's estimates. Cost provided is high-level and indicative only and may vary significantly based on the Anglesea River Estuary specific input parameters. This cost does not include mechanical aeration (if required), sludge removal, pump stations and other infrastructure for supplementary water supply, further investigation, and design.

- Design would need to consider fish and eel movement throughout the waterway to avoid disruption to life cycles, reduce gene pools, and create conditions where fish become more susceptible to disease and predation.
- This option may result in different levels of inundation of riparian zones which may alter vegetation communities and survival. Weirs can also affect channel geomorphology through trapping sediments from upstream, changes in flow velocity and turbulence. In turn this can alter stream depths, turbidity and water temperature which can affect aquatic organisms (NSW Department of Primary Industries, 2006). The design would need to consider these aspects to minimise impacts.

7.2.7.7 Additional information or assessment required

This option would be effective at managing ASS with hypersulfidic material at Coogoorah Park, however given the potentially significant changes to the environment, as well as impacts on social values and the economy, further assessment of the actual risk should be undertaken before considering this option further. Previous soil sampling indicates significant potential acidity (Sullivan et al., 2016), however further analysis of water levels, water quality and how ASS at Coogoorah Park drains and oxidises would be beneficial to inform actual risk of oxidation and acidity forming. This is further discussed in Section 8.

Further investigation would also be needed to determine whether placement of weir structures would adequately maintain saturation. For example, if water levels in the main river channel were lower, permeable sediments along riverbanks could still drain and oxidise even if water in the Coogoorah Park channels was maintained at a higher level.

Further hydrological, geotechnical and environmental assessment would also be required to inform the design of this option.

7.3 Summary of effectiveness of shortlisted options

A summary of the relative effectiveness of options further investigated as part of Stage 2 of the project is provided in Table 7-14. This information should be considered in conjunction with the other logistical, approval, cost, environmental, cultural, social and economic considerations presented in earlier sections of this report.

To be the most practical and effective at responding when pH conditions require, management approaches ideally would be adaptable and functional in a range of different conditions. No options assessed however are ideal and all options have trade-offs and potential impacts to stakeholders or the environment.

Table 7-14 Summary of the effectiveness of options to meet the objectives

Option	Confidence in the option effectively managing different acid sources		Confidence in the option being effective at managing pH during different flow conditions		Confidence this option will address the key issues and objective.
	Low pH water from sulfidic ASS in upper catchment	Avoiding oxidation of hypersulfuric ASS at Coogoorah Park	Low flows	High flows – flood conditions	
Option 23: Treatment of low pH catchment flows in a constructed wetland	High	Low (however could be designed with storage capacity sufficient to seasonally supplement water flow in estuary)	High	Low	Moderate Aside from management of acidity, option would help support a balance of aquatic and terrestrial life, as well as potentially having a positive impact on social and economic values by the addition of a wetland and potential recreational area.
Option 24: Treatment of low pH catchment flows using an in-situ PRB	Moderate	Low	High	Low	Moderate Option would help support a balance of aquatic and terrestrial life, and a negligible impact on recreational or economic activities in the estuary. Option would assist in limiting future potential low pH events under some conditions, however unlikely to be effective in conditions that have historically resulted in fish deaths.
Option 20: Treatment of low pH catchment flows using passive alkaline berms	Moderate	Low	High	Low	Moderate Option would help support a balance of aquatic and terrestrial life, and a negligible impact on recreational or economic activities in the estuary. Option would assist in limiting future potential low pH events under some conditions, however unlikely to be effective in conditions that have historically resulted in fish deaths.
Option 28: Treatment of low pH catchment flows by dosing with alkali materials	High	Low	High	Moderate - high	High Option would help support a balance of aquatic and terrestrial life and recreational use of the river. Some adverse environmental effects would need to be reduced and managed through the design and implementation. Unlikely to be fully effective under significant flood conditions and may not avoid fish death events, depending on capacity for mixing and effective treatment under specific flow conditions.

Option	**Confidence in the option effectively managing different acid sources**		**Confidence in the option being effective at managing pH during different flow conditions**		**Confidence this option will address the key issues and objective.**
	Low pH water from sulfidic ASS in upper catchment	**Avoiding oxidation of hypersulfuric ASS at Coogoorah Park**	**Low flows**	**High flows – flood conditions**	
Option 12: Treatment of low pH water in the estuary by shallow artificial openings or berm grooming to allow wave overtopping	Low	Low	Low (can be effective but only in specific conditions)	Low	Low – can facilitate marine exchange and assist with pH management but only under specific flow, water quality and tidal conditions, therefore unreliable. Option unlikely to have effect during most conditions or meet goals. Could be implemented, during specific times, when flow and tidal conditions are favourable for some improvement of pH conditions or to provide pathway to sea for fish during acid events. Potential impacts to the physical and ecological functioning of the estuary and contrary to previous recommendations (Alluvium, 2014; GHD, 2021).
Option 13: Treatment of low pH water in the estuary by deep artificial openings	Low – moderate	Low[13]	Low – moderate (can be effective but only in specific conditions)	Low	Low – can facilitate marine exchange and assist with pH management but only under specific flow, water quality and tidal conditions, therefore unreliable. Unlikely to achieve the broad goals for estuary functioning. May provide some support to minimise fish deaths through provision of a route to the sea during an acid event and some marine exchange. Option would require management to ensure openings are only implemented when flow and tidal conditions are favourable. Potential impacts to the physical and ecological functioning of the estuary and contrary to previous recommendations (Alluvium, 2014; GHD, 2021).

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[13] Potential for increased risk of Coogoorah Park ASS oxidation if catchment flows are low and deep estuary opening drains Coogoorah Park.

Option	**Confidence in the option effectively managing different acid sources**		**Confidence in the option being effective at managing pH during different flow conditions**		**Confidence this option will address the key issues and objective.**
	Low pH water from sulfidic ASS in upper catchment	**Avoiding oxidation of hypersulfuric ASS at Coogoorah Park**	**Low flows**	**High flows – flood conditions**	
Option 14: Treatment of low pH catchment flows by introducing seawater to the estuary through a pump and pipe	High	High	High	Moderate – high (limited by volumes)	High Option would help support a balance of aquatic and terrestrial life and recreational use of the river. Some adverse environmental effects would need to be reduced and managed through the design and implementation. Unlikely to be fully effective under significant flood conditions without significant infrastructure and may not avoid fish death events, depending on capacity for mixing and effective treatment under specific flow conditions. Option would assist in avoiding formation of acid from sustained periods of low water levels in Coogoorah Park.
Option 5: Maintain water levels with a weir system to manage ASS containing hypersulfidic materials at Coogoorah Park	Low[14]	High	High for Coogoorah Park Unknown for catchment flows	High for Coogoorah Park Unknown for catchment flows	Moderate Option would help support a balance of aquatic and terrestrial life, however may have negative impact on social and economic activities in the estuary. As option does not actively manage low pH flows from the upper catchment, limited capacity to reduce the potential for fish deaths.[14]

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[14] Further study required to confirm; some improvement may be possible due to reduced capacity of the estuary and increased flow through the main river channel

Section 8 Conclusion

8.1 Summary of findings and recommendations

The Anglesea River catchment is a complex dynamic system, where rainfall, surface water flows, estuary entrance state and tidal exchange interact to transport and influence acidity. Two key potential or actual sources of acidity have been identified: ASS containing sulfidic material in the mid and upper catchment currently drives pH conditions in the river, and ASS containing hypersulfuric material at Coogoorah Park represents a potential hazard if acidified. Acidity from both of these sources should be managed in order to meet the objectives of a functioning estuary and environment that supports a range of values.

Overall, this options investigation has found that:

- There are a range of options that could theoretically be implemented to manage pH conditions in the river, each with different levels of effectiveness in a complex and dynamic system.
- Due to the extensive areas of ASS and acidic soils in the catchment, treatment of surface water flow (rather than treatment of soils/sediments) is recommended as the most feasible approach for managing acidity from the mid and upper catchment, both to reduce impacts to the substantial environmental and cultural values and from a practicability perspective.
- After a multi-criteria analysis and more detailed assessment of shortlisted options, there is no single option that represents an ideal solution. Three options are recommended as the most feasible to manage acidity in the Anglesea River from the two source areas, based on the current understanding of the system and a range of assessment criteria:
  - <u>Dosing of low pH catchment flows</u> with alkaline material provides one of the most flexible treatment options under a range of conditions.
  - <u>Pumping of seawater</u> into the estuary would buffer low pH catchment flows and could be used to maintain water levels at Coogoorah Park to avoid oxidation of ASS, under a range of flow conditions.
  - <u>Use of weirs</u> would effectively maintain water levels at Coogoorah Park to avoid oxidation of ASS.
- Other options may be worthwhile considering in conjunction with the above options to complement their success or flexibility under specific conditions, however they were assessed to be less reliable. There is not a high degree of confidence that they could always be implemented and effective when needed.
- <u>It is unlikely however that any option will be completely effective at avoiding acid events or fish death events altogether.</u>
- All options, including those recommended as the most feasible, have a range of trade-offs with regards to other environmental effects, water quality considerations, and stakeholder and economic concerns.

The findings of the project are further summarised below with regard to each actual or potential acidity source.

8.2 Management of ASS and resulting acidic surface water from the upper catchment

Options investigated to manage acidity sourced from the mid and upper catchment included a range of soil and water treatments both within areas of ASS, in-stream and ex-situ. Options that treat acidic flows from the mid and upper catchment were identified as the most appropriate in the context of the Anglesea catchment, in preference of in-situ soil treatment methods, predominantly due to the extensive area of ASS and acidic soils and to minimise significant impacts to other values in the heathland.

Passive treatment options using a PRB or limestone channel berms **(Options 20 and 24)** would provide lower cost solutions to increase pH in catchment flows under low flow conditions. These options are not effective under high flow conditions as they rely on sufficiently long contact times between the treatment media and surface water. These options therefore are unlikely to be effective in conditions that have historically led to fish death events. Based on data from February 2022 – January 2023, flow and pH conditions in Marshy and Salt Creeks did not meet ideal treatment parameters for a greater portion of days.

Similarly, passive treatment using a reducing and alkalinity producing wetland **(Option 23)** is an effective method of neutralising acidity but is best suited to lower flow conditions. This option relies on residence time within the wetland to neutralise acidity, generally several days, and pumping rates and treatment would not be feasible in higher flow conditions. This option however would provide more flexibility in managing water levels in the estuary if storage capacity was inbuilt to the design. The suitability of this option relies on integration with an existing disturbed location (such as the Alcoa Storage Pond), increasing practicability through existing infrastructure and reducing other environmental impacts.

Artificial estuary openings or berm grooming of different depths **(Options 12 and 13)** would have varying levels of effectiveness at managing low pH conditions in the estuary through marine exchange and buffering of acidic water from carbonates in seawater. Shallow openings **(Option 12**) would have less benefit, as marine exchange would be lower and so less able to buffer low pH conditions. Deeper openings **(Option 13)** have greater potential to facilitate marine exchange, if other conditions are met (catchment flows, sufficient tidal conditions). Artificial openings would need careful management to avoid negative impacts to the estuarine ecology and physical functioning of the estuary. If dissolved oxygen levels in water at the base of the estuary are low for example, without sufficient tidal inflow or fresh catchment flows the estuary could become anoxic. Additionally, deep openings in particular bring environmental risks as detailed in section 7.2.5, including the potentially changing the sand deposition pattern at the entrance and lowering water levels at Coogoorah Park if the estuary is drained without sufficient catchment flow or buffering capacity (GHD, 2021). Previous extensive studies and expert inputs have recommended avoidance of artificial estuary openings and facilitation of flow conditions that encourage natural openings, however it is recognised that with a changing climate natural openings will become less frequent (Alluvium, 2014; GHD, 2021).

Dosing with alkali materials **(Option 28)** and introducing seawater via a pump and pipe **(Option 14)** are considered to be the options that will be most effective at managing pH in the greatest range of conditions. Both options could be switched on or off depending on pH levels and flow conditions. Both will be challenged however during flood conditions and may not be successful in conditions that have previously led to fish death events. Both options rely on adequate mixing to neutralise acidic water. For Option 28 this could be achieved either through mechanical in-situ means or by utilising a treatment area out of the main stream. For Option 14 mixing is a by-product of pumping but this option also creates a deep water refuge for estuarine organisms. These options are higher cost and have a more complex range of other considerations regarding environmental, social, and cultural aspects than simple passive in-stream techniques (PRB or limestone berms) but would be more effective and flexible to different conditions. These options could be combined with the passive options and utilised on an as needs basis (however likely at greater costs than implementing alone).

A range of other options identified in Stage 1 of the project could also effectively treat ASS or low pH catchment flows and are proven technologies, however are less likely to meet the objectives and expectations in the Anglesea River context. These options could be revisited in the future if conditions change.

8.3 Management of ASS at Coogoorah Park

Previous sampling has identified that there is a potential acidification hazard from ASS in the estuary at Coogoorah Park (Sullivan et al, 2016). The majority of soil within Coogoorah Park was found to contain hypersulfidic material, with significant acid forming potential. Lowering of water levels below recent historical levels (1.2 -1.6 m AHD, i.e., those maintained since excavation of Coogoorah Park) could result in oxidation of hypersulfidic material and generation of acidity.

The exposure of ASS with hypersulfidic material in the area and potential release of acidity to the estuary remains an ongoing risk that should be considered in any management strategy.

Options that are most suitable (based on a range of assessment criteria) for managing ASS at Coogoorah Park, involved maintaining water levels either using a weir **(Option 5)** or pumping of seawater (**Option 14**). Both are responsive to flow conditions and would be effective and be flexible to implement long term. Both options however represent a relatively high cost and have significant infrastructure requirements, as well as having several potential impacts for stakeholder, environmental and cultural values.

While data suggests the potential for sulfuric acid to be formed when soils are oxidised, the timeframe for this occurring is not known. Water level and quality measurements since cessation of Alcoa discharges in 2016 suggest that there have been periods when levels were below historic levels for a short period of time, with no significant observable changes to pH conditions (as measured in the estuary). Further analysis would be required to understand whether soils at Coogoorah Park did oxidise but acidity was buffered (for example due to catchment flows and marine exchange coinciding), or whether soils did not oxidise as sediments remained saturated (i.e., had not drained within the time period water levels were lower).

8.4 Future considerations

All recommended options require additional knowledge to inform the design and effective implementation. The below provides future recommendations that will provide additional knowledge to inform the design and effective implementation of each of the recommended options. It is also likely that these projects will identify the management linkages between the options, i.e. there may be one or more options that can be implemented in conjunction with each other depending on conditions.

- Sampling in Salt Creek, Marshy Creek and the estuary to understand water geochemistry (including metal concentrations), redox potential and other water quality parameters under a range of conditions. This monitoring will allow for a better understanding of the potential toxicity of neutralised acid waters and potential for precipitation of metallic compounds. It will also help to inform treatment rates and potential sizing of infrastructure.
- Targeted investigation of the nature and timeframes of ASS oxidation during periods of low water levels at Coogoorah Park. This could include field analysis of the relationship between water levels and water quality, during periods of oxidation and water level recovery (i.e. potential flushing events). This information, coupled with understanding of typical estuary conditions during potential flushing events, could be used to identify conditions when ASS at Coogoorah Park poses most risk to contribution of acidity of Anglesea Estuary, and hence when management is needed and or prevention is required.
- Monitoring and periodic interpretation of water quality should form part of an adaptive management strategy for the estuary and its catchment to allow early detection of future changes. EstuaryWatch and data available on the WMIS provides a good basis for this estuary surface water monitoring. There would be a need for ongoing review and interpretation by suitably qualified personnel of data collected during implementation of any management option to ensure early detection of trends so that management can be adapted and/or contingency measures implemented. For example, if trend analysis of monitoring data indicates deterioration in soil, surface water or groundwater quality, management approaches should be reviewed and adapted.
- Future activities in the catchment that could potentially influence pH conditions in the river (e.g., activities related to surface water runoff and flow, groundwater, soil in the upper catchment, or estuary entrance conditions) should consider this study and related previous studies to understand and minimise potential influence on the issue.

8.5 Assumptions and limitations

This project has been focused on identification and high level assessment of options to manage and minimise acidity in the Anglesea River. The understanding of the issue is based on a range of previous studies and public information and limited targeted sampling of soil in the upper catchment (Appendix D). There are a range of gaps in the current understanding of drivers of acidity and mass loads of acidity within the catchment that have not been addressed. Further assessment works would be required to support implementation and design of any of the identified options and verify assumptions made in this report on effectiveness and cost.

A range of other factors influence a healthy functioning catchment system and estuary, other than pH. Where options to manage pH could influence these other factors, these have been identified at a high level only. Any management action implemented in the catchment, including any actions to address pH, should be considered wholistically as part of the system.

This project has been completed at a point in time and a range of future changes could change the suitability of options to manage pH in the catchment.

Section 9 References

Alluvium Consulting 2014, Anglesea River estuary – Industry expert workshop and risk assessment. Report for Corangamite Catchment Management Authority and Surf Coast Shire.

Arundel H. (2006) EEMSS Background Report and User Manual: Estuary Entrance Management Decision Support System. Deakin University, Warrnambool, 120 p.

Australian Government. 2017, Australian National Water Quality Management Framework

Banasiak, L., & Indraratna, B. 2012, Permeable r ermeable reactive barrier (PRB) technology: An inno e barrier (PRB) technology: An innovative solution for the e solution for the. Wollongong: University of Wollongong.

Bureau of Meteorology 2022, Climate Data Online, viewed 24th October 2022, <http://www.bom.gov.au/climate/data/>.

Bowman, G.M, Hicks W.S., R.W. Fitzpatrick and P.J. Davies 2000. Remediation options for acid sulfate soil "hotspot" at East Trinity Inlet, Cairns, North Queensland. Proceedings of Workshop on Remediation and Assessment of Broadacre Acid Sulfate Soils. (Ed. P.G. Slavich). Southern Cross University, Lismore, 31 August to 2 September 1999. Acid Sulfate Soil Management Advisory Committee (ASSMAC), Australia. p.130-145.

Cheng Yau, C 2014, 'Identifying sources of acidity on the Anglesea River floodplain', Honours Thesis, Monash University.

Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE). 2018, National Remediation Framework - Guideline on performing remediation options assessment (Version 0.1: August 2018) (NRF)

Corangamite CMA (CCMA) 2012, Anglesea River Estuary Management Plan 2012-2020.

Department of Environment, Land, Water and Planning (DELWP), 2020, Long Term Water Resource Assessment for Southern Victoria, Basin by Basin Results, State Government of Victoria

Department of Environment, Land, Water and Planning (DELWP), 2022, Water Measurement Information System, Real time data for surface water sites 235260, 235222 and 235278, <https://data.water.vic.gov.au/>

Department of Environment, Land, Water and Planning, Bureau of Meteorology, Commonwealth Scientific and Industrial Research Organisation, The University of Melbourne, 2021, Victoria's Water in a Changing Climate

Department of Jobs, Precincts and Regions Earth Resources 2018, Geological Survey of Victoria, viewed 24th October 2022, < https://gsv.vic.gov.au/>.

East Trinity remediation case study (2022) https://www.qld.gov.au/environment/land/management/soil/acid-sulfate/east-trinity.Environmental Technology Solutions 2014, An Investigation of remediation options for Anglesea River. Report for Corangamite Catchment Management Authority.

EstuaryWatch. 2022, Anglesea River Estuary, viewed 24th October 2022, <http://www.estuarywatch.org.au/estuary_data_portal.php?action=export_estuary&estuary_id=45&cma=ccma>.

Firelight Consulting 2016, Anglesea River Estuary Management Options Feedback Analysis Report. Report for Department of Environment, Land, Water & Planning.

Fowler, K. 2022 Explaining changes in rainfall-runoff relationships during and after Australia's Millennium Drought: a community perspective

GHD 2016c, Anglesea River Estuary Flow Assessment Final Report. Report for Corangamite Catchment Management Authority.

GHD 2016a, Anglesea River Estuary Management Options Report. Report for Department of Environment, Land, Water & Planning.

GHD 2016b, Anglesea River Short Term Options Assessment. Report for Department of Environment, Land, Water & Planning.

GHD 2021, Anglesea River and Estuary Environmental Flows Study 2020 - Final Report. Report for Corangamite Catchment Management Authority.

Green, R 2005 Acidity barriers for improving the quality of acid sulfate soil discharge water: University of New South Wales, Sydney. http://dx.doi.org/https://doi.org/10.26190/unsworks/4452

Green R, Waite D, Melville M and Macdonald B 2006 Characteristics of the Acidity in Acid Sulfate Soil Drainage Waters, McLeods Creek, North-eastern NSW, Australia. Environ. Chem. 3, 225–232. doi:10.1071/EN05055

Haese, R, O'Hanlon, D & Shipton, K 2022, What has caused environmental decline in the Anglesea River catchment and estuary? – A Discussion Paper, Friends of the Anglesea River Group. (community paper)

Hicks W S, G M Bowman and Fitzpatrick R.W 1999. East Trinity Acid Sulfate Soils Part 1: Environmental Hazards. CSIRO Land & Water Technical Report. 14/99. 85pp. http://www.clw.csiro.au/publications/technical99/tr14-99.pdf

Maher, W 2011, Anglesea River Water Quality Review.

Mosaic Lab 2016, Anglesea Futures Community Conversations - Anglesea Senior Citizens. Report for Department of Environment, Land, Water & Planning and Surf Coast Shire Council.

National Working Party on Acid Sulfate Soils, 2000, National Strategy for the Management of Coastal Acid Sulfate Soils, published by NSW Agriculture Wollongbar Agricultural Institute January 2000

Pope A 2011, Investigation of Anglesea River estuary mouth dynamics. Review and recommendations for estuary management, Deakin University, Warrnambool, Victoria.

Pope, A 2010, Anglesea fish deaths : causes and recent investigations, Deakin University, Warrnambool, Vic. Report for EPA Victoria.

Pope, A 2006, Freshwater Influences on Hydrology and Seagrass Dynamics of Intermittent Estuaries, PhD thesis, Deakin University, August 2006

Queensland Government 2022, SILO - Australian climate data from 1889 to yesterday, viewed 24th October 2022, < https://www.longpaddock.qld.gov.au/silo/point-data/>.

Roussety, H, R 2014, 'Identifying Sources of Acidity in the Upper Catchment of the Anglesea River', Honours Thesis, Monash University.

Sharley D, Amos, C, & Pettigrove V 2012, Factors affecting the ecology of the Anglesea River, Centre for Aquatic Pollution Identification and Management. Report for Corangamite Catchment Management Authority.

Smith C.D., Manders J.A. and Brough D.M. (2016). East Trinity acid sulfate soil remediation project – Changes in soil properties after 13 years of remediation. (Department of Science, Information Technology and Innovation), Queensland Government, Brisbane

Smith, K. S., 1999. Metal sorption on mineral surfaces: An overview with examples relating to mineral deposits. In G. S. Plumlee, & M. J.Logsdon (Eds.), The environmental geochemistry of mineral deposits. Part A. Processes, techniques and health issues. (pp. 161-182). Chelsea, MI, USA: The Society of Economic Geologists Inc.

Sullivan L, A, Reeves, J, M & Trewarn, A 2016, Investigation into the acid generation potential of soils at Coogoorah Park, Anglesea, Federation University Australia, Mt Helen, Victoria. Report for Department of Environment, Land, Water & Planning.

Taylor, J., Pape, S., Murphy, N., 2005, A Summary of Passive and Active Treatment Technologies for Acid and Metalliferous Drainage (AMD), for the Australian Centre for Minerals Extension and Research

The Arthur Rylah Institute DSE 2011, Documenting fish assemblages in the Anglesea River estuary following acidification events.

Thomas, B., Fitzpatrick, R., Merry, R., & Hicks, W. (2003). Coastal Acid Sulfate Soil Management. CSIRO.

Tolhurst, G., Hope, P., Osburn, L., Rauniyar, S., 2022, Approaches to Understanding Decadal and Long-Term Shifts in Observed Precipitation Distributions in Victoria, Australia, Journal of Applied Meteorology and Climatology, 62, November 2022

Tonkin, Z, Pickworth, A, O'Mahony, J & Kitchingman, A 2014, Assessing the benefits of instream habitat works for fish populations in the Anglesea River, Arthur Rylah Institute for Environmental Research, Heidelberg Victoria. Report for Corangamite Catchment Management Authority.

Victorian Government Department of Sustainability and Environment, 2010, Victorian Best Practice Guidelines for Assessing and Managing Coastal Acid Sulfate Soils

Victorian Government Gazette, 2021, Environment Protection Act 2017 Environmental Reference Standard

Water Technology Pty Ltd 2010, Investigations of Anglesea River Estuary Mouth Dynamics. Report for Corangamite Catchment Management Authority.

Water Technology Pty Ltd 2012, Anglesea Estuary Rock Wall Removal – Risk Assessment. Report for Corangamite Catchment Management Authority.

Wong, V, N, L, Claff S,R, and Driscoll J 2020, Anglesea Acid Sulfate Soil Investigation, Monash University, Clayton Victoria. Report for Barwon Water

Blunden, B, G 2000, Management of acid sulfate soils by groundwater manipulation, University of Wollongong, Wollongong, NSW.

Indraratna, B, Pathirage, U 2015, Installation of a permeable reactive barrier in the containment of acid pollution. 6th International Geotechnical Symposium on Disaster Mitigation in Special Geoenvironmental Conditions (pp. 25-34).

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Appendix A Summary of previous reports

Ref. no	Document	Author	Commissioned by	Year	Description	Category	Issue conceptualisation
1	Anglesea River Water Quality Review	Maher, W	Corangamite CMA	2011	Independent review of acid events in Anglesea River including sources, impacts, and possible remediation options.	Management	Natural sources of acid in the catchment are from significant amounts of coal and tea tree marshes above the water table. Maher considered that marshes (swamps) are likely to be contributing a minor natural source of acid, with coal deposits and associated pyrites contributing to the catchment holding significant acid-generating potential. A review of geology and borehole data identified coal at depths that would likely allow for interaction with the river and be a source of acidity. An open cut brown coal mine was operational in the lower reaches of Salt Creek, west of Alcoa's current mine, in the late 1950s - early 1960s. The void was backfilled with ash high in aluminium and sulphates and capped with soil overburden. Water quality data from a sampling site near the former mine has reported higher aluminium and sulfate concentrations compared to other sites in the Salt Creek catchment. The proportional contribution compared to the remainder of the catchment is likely to be low. Marshes (water and ecology) in the upper catchment do not appear to be influenced or degraded as a result of groundwater drawdown. Numerical groundwater modelling identified potentially base flow dependent surface water features in the upper Anglesea River and Salt Creek which could be affected by groundwater drawdown. Acid flushes through the catchment are predominantly influenced by rainfall, which creates and transports acid. This is exacerbated when a dry period is followed by soaking (extended period and depth) rainfall. Fluctuating pH in the river has been measured since 1972 when monitoring began. Monitoring in 2010 and 2011 within Marshy and Salt Creek tributaries recorded pHs <4. During operation of the Alcoa power station, ash pond discharges at times contributed nearly the entire flow of the river. Fish deaths have been documented in 2000, 2007, spring 2010 and early 2011 during acid periods. In 2010, EPA-licenced discharge from Alcoa power station into the estuary were measured just above 7, with the estuary pH measured as 4 or lower in upstream tributaries. An EPA investigation into the 2010 fish kill found that there were likely a combination of factors that caused the event: pH, aluminium toxicity and suffocation due to precipitation of aluminium. Maher considered whether sulphur deposition from coal burning at the former Alcoa power station may influence acidification, however found based on soil and vegetation surveys that there was no indication of changes in soil pH or properties that would indicate soil acidification or higher sulphate concentrations within the deposition area. Trace metals also enter the estuary after rainfall including aluminium, iron, manganese, boron and trace elements. Flocculation can occur when acidic tributary waters meet neutral or alkaline water (for example in water discharged from the former Alcoa mine pit), and where saline and fresh water mix. Acid sulfate soils present in many coastal and inland settings around Australia. ASS contain metal sulfide minerals which can form sulfuric acid when exposed to oxygen and water. The acid can then release other contaminants such as metals. The toxicity of aluminium also increases with lower pH (higher acidity). The area of Coogoorah Park is a coastal peat swamp whith potential for acid generation. Coogoorah Park was created as "a series of channels created to let water from the river extinguish peat fires post the 1983 Ash Wednesday Bushfires.". The area remains saturated therefore is unlikely to be a significant source of acid in the system however has acid generating potential. Long term effects from fire vary depending on intensity and extent of tree death, but can include increased evapotranspiration, interception, reduced infiltration and changes in vegetation type. Significant fires such as the 1983 Ash Wednesday fires, would influence the hydrological conditions within the Anglesea catchment. Maher also considered the Anglesea landfill as a potential source of acid or trace metals however found it is not a significant source to the Anglesea River. A knowledge gap recognised was the extent of the leachate plume
2	Anglesea River Estuary Management Plan 2012-2020	Corangamite CMA		2012	Eight-year action plan aimed to improve the environmental condition of the Anglesea River estuary.	Management	The total catchment area is 885 ha comprising Marshy and Salt Creeks. The majority of the catchement is Crown Land managed as the Anglesea Heath FLora and Fauna Reserve. Ownership and management of land within the catchment and around the estuary falls to a variety of parties. This includes the former Alcoa open cut coal mine and power station. Salt Creek has been diverted at it's lowest section into a trapezoidal channel around the open cut mine. The river mouth dynamics are summarised from Water Technology (2010), Pope (2006) and Nelson (1981). The dominant process for shaping the river mouth is longshore drift, with river flows not being significant. Previous research (Pope, 2006) showed that the mouth has historically been closed for approximately 44% of the time. At the time of preparing the managemetn plan, there was no trigger for artificial opening of the estuary, rather based on threats to public and private assets. Water within the estuary is typically brackish, with asalt wedge beyond the Great Ocean Road bridge. Salinity is variable depending on stream flow volumes and mixing. Vegetation within the catchment is in a varied condition.
3	An investigation of remediation options for Anglesea River	ETS	Corangamite CMA	2014	Exploration of remediation options for Anglesea River at conceptual stage.	Management	Acidic events in the river observed as a result of acid sulfate soils.
4	Anglesea River Estuary Management Options Report	GHD	DELWP	2016	Identifies and and assesses short and long-term management options to reduce the risk of activation of acid sulphate soils and minimise impacts to environmental, social and economic values.	Management	Discharge from the Alcoa mine and power station has contributed an average of 4.5 ML/day to the Anglesea River, however this ceased on 31 March 2016. Reduction in water levels could occur by up to 1 m during summer and result in activation of acid sulfate soils.
5	Anglesea River Short Term Options Assessment	GHD	DELWP	2016	Further scopes short term management option to maintain water levels in the Anglesea River by storing water in the disused Alcoa ash pond to release during periods of low flow.	Management	Variability in climate and resulting catchment hydrology, as well as sand bar dynamics, have a material impact on water levels in the estuary and activation of acid sulfate soils.
6	Anglesea fish deaths: causes and recent investigations	Pope, A (Deakin University)	EPA	2010	Assessment of the likely causes of the September 2010 fish kill and review of investigations that relate to the likely causes.	Fish	September 2010 fish kill, estimated at thousands of individual fish occurred in Anglesea River estuary. Nine factors that may have likely contributed to the fish kills were assessed. The report found, pH stress and toxic effects (acid soil generated) were the likely causes for the 2010 event: -pH stress, waters in the estuary regularly acidic, evidence of gill and skin damaged on fish from the estuary consistent with exposure to acidic water. -Toxic effect, high levels of aluminium were detected in fish tissue (particularly gills). Aluminium becomes more mobile as decrease in pH, and common from flows from acid soils. Other factors, such as sediments/suffocation and salinity stress: -sediments/suffocation, clogging of the gills from formation of solid aluminium, some evidence of gill damaged and aluminium concentrations were detected in fish -salinity stress, salinity was less than 5 psu in the estuary, and deeper areas were around 15 psu, which may have impacted with freshwater species. Sources of acidic water and elevated concentrations of aluminium was Salt Creek sub catchment, with the creek substantially flowing for the first time since 2007, resulting in a 'slug' of acidic, metal rich water flowing downstream. At the time water reach the estuary, limited buffering capacity as the estuary was relatively fresh.
7	Documenting fish assemblages in the Anglesea River estuary following acidification events	ARI	Corangamite CMA	2011	Documents the fish species and relative numbers of fish present in the Anglesea River estuary, following a fish kill event in 2010.	Fish	Four opportunist sampling events (Oct-10, Apr-11, Mar-11, Nov-11) conducted post September 2010 and January 2011 fish kills in responds to community concern regarding the state of fish fauna in the estuary. No equivalent data was available prior to September 2010 fish kills, therefor unable to draw firm conclusions about the recovery of fish fauna in the estuary. Oct-10 sampling event strongly acidic (pH 4.4-4.9) water, and absence or very low numbers of several recreation species of fish. Nov-11 sampling event numbers of species and individual fish has increased, pH ranged from 5.7 to 7.5. Long term impacts of acidification are unclear as no baseline data to compare with, however works on another Victorian estuary (Surrey River) indicates estuarine fish communities can be quite resilient to fish kills of this magnitude.
8	Assessing the benefits of instream habitat works for fish populations in the Anglesea River	Tonkin et al. (ARI)	Corangamite CMA	2014	Presents the findings of the first fish surveys following instream habitat works (including lime stone rocks, root balls and "fish hotels") with the aim of detecting any short term benefits to in-situ fish populations as a result of the works.	Fish	Fish survey (Aug-2014) was conducted following the installation instream habitats with the aim to of detecting any short term benefits to in-situ fish populations as a result of the works. Habitats were largely installed to provide direct benefits to large bodied species. The project concluded that the data is limited, and the survey found system was devoid of large bodied and or migratory species. Recommended further work to understand the temporal variability in species occupancy to assess the effective management of the river mouth, both to aid the avoidance of fish kills (by allowing fish to exit the system when pH events are imminent) and to facilitate re-colonisation of the system. 50% reduction in species diversity and abundance when compared to the previous survey conducted in Nov-2011. Inferred larger fish with migratory capacity left the system during the recent estuary mouth opening.
9	Identifying sources of acidity on the Anglesea River floodplain	Cheng Yau, C (Monash University - Honours)	Corangamite CMA	2014	Looks at the distribution of acid sulfate soils on the Anglesea River floodplain and assesses the hazard level that the acid sulfate soils might pose to the aquatic ecosystem.	Acid-sulfate soils	Four core samples were collected, two from each of the upper and lower estuarine, to verify the presence (or absence) of acid sulphate oils on the Anglesea River floodplain and assess hazard level that acid sulphate soils might pose to the ecosystem. Upper estuarine samples were collected from the wetland and swamp scrub, in the lower estuary from the coastal tussock saltmarsh and woodland. Cheng Yau (2014) concluded: -no acid hazard in the wetland and coastal tussock saltmarsh, -high acid hazard in the swamp scrub and as consider to be acidifying soils and water and discharging metals. -Very high acid hazard in woodland, with a medium risk of acidification and mobilisation. The sites had potential for monosulfide formation in the surface and low risk of de-oxygenation of surface water Cheng Yau (2014) included acid neutralise capacity (ANC) to calculated net acidity. National Acid Sulfate Soils Guidance (2018) recommends ANC can only be included in calculations for net acidity if its effectiveness has been corroborated by other data (i.e., incubation) that demonstrate acidification is not experienced by the soil material during complete oxidation under field conditions. Therefore, the hazard assessment undertaken by Cheng Yau (2014) may underestimate the net acidity present. Calculating net acidity excluding ANC, and adopting pH instead of pHKCL indicated, actual acid sulphate soils were present at swamp scrub (9 out of 9 samples), woodland (6 out of 7 samples), wetland (2 out of 8 samples). Actual acid sulphate soils were not identified at coastal tussock saltmarsh.
10	Identifying Sources of Acidity in the Upper Catchment of the Anglesea River	Rousetty, H.R	Corangamite CMA	2014	Acidity in the upper catchment was quantified and assessed for hazards, risks and acid potential by acid base accounting. It was found that all sites sampled in the upper catchment have potential to contribute to acidic events.	Acid-sulfate soils	Four sites were sampled in the Marshy Creek tributary in the upper catchment of the Anglesea River (up gradient from Alcoa mine). Three sites classified as medium acidification, medium metal mobilisation, low deoxygenation and potential for monosulfidic sediment formation. The fourth site, furthest downstream was classified as high acidification, high metal mobilisation, high deoxygenation and potential for monosulfidic sediment formation. Sites evaluated showed low buffering capacity, and unlikely to contribute natural neutralisation during an acidic event.
11	Investigation into the acid generation potential of soils at Coogoorah Park, Anglesea	Sullivan et al. (Federation University)	DELWP	2016	Federation University (2016) identified acid sulphate soils were limited to Coogoorah Park and they had a high acid generation potential.	Acid-sulfate soils	60 samples were collected across two sites, Coogoorah Park at Anglesea and area south-eastern side of the bridge at Anglesea. Results found acidification hazard posed by acid sulfate soils was almost contained within Coogoorah Park and not the low-lying land on the south-eastern side of the bridge at Anglesea. Surficial soils layer of Coogoorah Park have appreciable potential for acidification should future conditions cause oxidation in those areas. If the water level is maintained at the current level (1.2-1.6m AHD), results indicate there will be little potential for release of acid sulphate soil acidity ad metal/metalloids from the surficial soils and sediment from the study location. If the water table is lowered during summer period (i.e., by ~1m), then surficial soil and sediment at Coogoorah Park would be subject to rapid acidification. The results indicated there would be a low potential for release of metal and metalloid into the surrounding waters.

Ref. no	Document	Author	Commissioned by	Year	Description	Category	Issue conceptualisation
12	Anglesea Acid Sulfate Soil Investigation	Wong et al. (Monash University)	Barwon Water	2020	Investigates the potential for acid generation as a result of drawdown from groundwater extraction from the Anglesea Borefield.	Acid-sulfate soils	Wong et al. (2020) undertook a study to investigate the distribution and characterisation of acid sulfate soils in the Salt Creek and Marshy Creek swamplands (also known as Anglesea Swamplands). 25 and 28 sites were samples in Salt Creek and Marshy Creek swamplands respectively. The study found Salt Creek and Marshy Creek had substantial volumes of acidity in form that can be mobilised rapidly. Three sources of acidity identified at each site i) potential sulfidic acidity, sourced from sulfidic sediments containing pyrite and monosulfides; ii) labile acidity, which is existing acidity and can be rapidly mobilised; and iii) retained acidity, which is existing latent acidity usually stored in minerals such as jarosite. Higher concentration of labile acidity was identified at Marsh Creek which can be transported readily, whereas Salt Creek contained higher concentration of retained acidity which can slowly be released over time. Marshy Creek and Salt Creek flow ephemerally following periods of high rainfall, therefore likely that acidity accumulates in the creeks during drier periods, when there is no or limited rainfall. Then high rainfall events cause the accumulated acidity to be flushed from the swamplands, downstream. Acidification events in Anglesea River estuary have usually occurred when extended dry periods have preceded high rainfall events. Anglesea swamplands are potentially supported by groundwater, however connectivity between the underlying aquifers, perched water table and swampland is not well understood.
13	Anglesea River estuary - Industry expert workshop and risk assessment	Alluvium	Corangamite CMA	2014	Review of risks and benefits of management actions by community working group and industry experts.	Community Engagement	Anglesea River estuary processes typical of many coastal systems across southern and eastern Australia. Combination of processes and elements of the Anglesea River catchment system has created a unique setting. Expert panel convened to hold a workshop and come to a level of agreement regarding the scientific findings of the Anglesea River catchment. General opinion from experts that acid events in the Anglesea River catchment largely natural assocaited with rainfall events following periods of dry conditions. Barwon Water's groundwater pumping program designed not to influence shallow aquifers and acid sulfate soils. Artificial openings of the estuary are currently underataken to avoid flooding; risks of inundation are considered greater than those associated with artificial openings. System is robust and generally recovers following acid events
14	Anglesea River Management Options - Community Feedback Analysis Report	Firelight consulting	DELWP	2016	Summary of community feedback on future management options for the Anglesea River.	Community Engagement	NA
15	Anglesea Futures Community Conversations - Anglesea Senior Citizens	MosaicLab	DELWP	2016	Summary of community views on short term management options for Anglesea River.	Community Engagement	Alcoa has discharged water into the Anglesea River since 1969 as part of the power generation process, and water levels are expected to drop following closure in particular during summer periods. This may result in exposure of acid sulfate soils at Coogoorah Park which poses a risk to environmental, social and economic values. A minimum flow of 0.75 - 1 ML/day is requried to maintain water levels (from the Flow Impact Assessment)
16	Factors affecting the ecology of the Anglesea River - Final Report	Sharley et al. (Centre For Aquatic Pollution Identification And Management)	Corangamite CMA	2014	Assessment of the ecological resilience of the Anglesea River and estuary following presumed ASS-related acidification of the estuary after heavy rains in 2010.	Ecology	Sharley et al. (2014) were engaged to assess the ecological resilience of the Anglesea River and estuary in relation to acid sulphate soil and acidic flush events. Effects of ASS on the waterways is mortality in resident fauna, and secondarily die back and growth inhibition of seagrass communities, death of smaller microinvertebrates and impaired health and condition of riparian vegetation due to poor water quality. Changes to water quality in estuaries such as the Anglesea River can lead to a reduction in sensitive species, resulting in an unbalance to the system.
17	Anglesea River Estuary Flow Assessment Final Report	GHD	Corangamite CMA	2016	Scopes options that may be available to reduce the predicted impacts of the mine and power station ceasing the discharge to the Anglesea River estuary and resultantant activation of acid sulfate soils. Identifies that one of the most feasible options to reduce impacts is to maintain water levels using an alternative water source.	Ecology	GHD (2016) study was aimed to (1) identify changes to the physical character and potential environmental, social and economic impacts as a result of the mine and power station ceasing the discharge to the Anglesea River estuary and (2) scope options that may be available to reduce the predicted impacts. The study identified that cessation of discharge from the mine and power station are likely to reduce water level by up to 1m in the summer period. During winter catchment inputs are sufficient to maintain water levels. An estimated minimum flow to the river of 0.75-1.0 ML/day is required to maintain water levels at approximately 1.5 m AHD during the summer period.
18	Anglesea River and Estuary Environmental Flows Study 2020 - Final Report	GHD	Corangamite CMA	2021	Identifies the environmental flow requirements of water-dependent environmental values in Anglesea River, Salt Creek and the Anglesea estuary.	Ecology	GHD (2020) undertook Environmental flows studies to provide information for environmental water planning and management and to inform the future management of the Anglesea River and Estuary. Major changes to the estuary were summarised as -Anglesea River and Salt Creek catchment flows to the estuary have decreased significantly since the Millennium Drought. -Water levels previously maintain by Alcoa's EPA licenced discharge (~4ML/day), masking the impact of climate variability that occurred over recent decades and recent low flow -Alcoa's EPA licenced discharge also maintain near continuous discharge of water from the estuary. Estuary berm previously relatively constant morphology and location with 50-100m to the see. Berm has migrated inland by 200 to 300m, and average height has increased to ~1.9m AHD, from earlier ~1.5m AHD. -Hence natural openings likely to occur less often, and due to urbanised nature of the catchment, openings likely to be triggered by impacts to infrastructure. -Estuary transitioning from an intermittently open and closed estuary (IOCE) to a near permanently closed estuary.
19	Anglesea Estuary Rock Wall Removal – Risk Assessment	Water Technology	Surf Coast Shire Council	2012	This report provides an assessment of the risks to the Anglesea River estuary entrance if the remnant rock wall was removed. Safety, recreational and economic risks were also assessed.	Estuary processes	Anglesea River estuary 2.6 km long, 110 m wide at the mouth with an estimated surface area at 1 m AHD of 13.4 ha. Transport of highly acidic water from the catchment into the estuary occurs when an extensively dry period is followed by high rainfall. The Anglesea estuary can be defined as an ICOLL (intermittently closed and open lake or lagoon). Estuary entrance is semi-permanent (Pope, 2006 found it was closed 44.4% of the time). Natural influences on the estuary mouth include erosion or accretion of the dune system and berm as well as flow conditions from the catchment. Anthropogenic influences have included alterations to vegetation or development resulting in changes to erosion or accretation of the dunes, as well as artificial openings to prevent flooding. Original rock wall constructed in 1975 as part of a weir structure across the estuary entrance. Majority of the rock wall was removed in the late 70s and early 80s. Survey in 2011 identified remaining wall section is 13 m x 0.5 m with minor rubble on the eastern side and central areasa of the estuary mouth. Depth is unknown but likely to be ~1.2m. Build-up of sand at the estuary entrance largely due to sand accumulating in the lee of the offshore reefs and deposition pattern is determined by longshore drift. Bass Straight wave dynamics are the primary cause of
20	Investigations of Anglesea River Estuary Mouth Dynamics	Water Technology	Corangamite CMA	2010	Report investigating mouth dynamics of the Anglesea River estuary and associated hydrodynamic and ecological processes.	Estuary processes	Detailed study of the hydrodynamic, salinity and sediment transport processes occurring in the Anglesea River estuary. This included a numerical modelling to to predict processes of the estuary. The estuary mouth faces south, with a submerged reef present 200m offshore. Offshore wave conditions are predominantly long-period swells from the southwest which results in a net alongshore transport of sand towards the northeast at Anglesea. This combined with low flows in the Anglesea River results in build-up of sand at the river mouth which can form a berm. Historical analysis of the shoreline showed a gradual retreatment of the shoreline. No changes in the river bank or entrance channel were observed associated with the rock weir since 1975. A water balance analysis was completed for the upper aquifer recharge using rainfall and groundwater extraction volumes. This indicated that the water balance was at or above the long term average for 2 out of 10 years (2001 - 2011), suggesting during that period there was likely significant accumulation of acid in the system. The flush of acid through the estuary in September 2010 was identified to be a result of transportation of the accumulated acid following a prolonged period of higher than average rainfall which allowed for the swamps to become saturated and transport of the accumulated acid downstream.

Ref. no	Document	Author	Commissioned by	Year	Description	Category	Issue conceptualisation
21	What has caused environmental decline in the Anglesea River catchment and estuary? - A Discussion Paper	Prof. Ralf Haese, Dick O'Hanlon and Keith Shipton (Friends of Anglesea River Group)	Friends of Anglesea River Group	2022	Discussion paper looking at conditions in the estuary and causes of acidity and flow decline.	Community/Estuary processes	Salt Creek flow measurements indicate a nearly 10-fold reduction in flow from the 1970s to current. Estuary Watch has monitored the estuary since 2007, with continuous pH monitoring since 2010. Correlation of pH and rainfall indicates short (weeks) periods of acidic water from 2010 - 2016 typically in late winter following significant rainfall. Longer 1 and >2 year acidic periods have occurred since 2016. pH has been between 4 - 5 since August 2019. Paper suggests cause of acidification due to Alcoa discharges ending (1640 ML/year, more than the total of recent Salt and Marshy Creek flows of 343 and 635 ML/year). pH of Salt and Marshy creeks typically 4 and 3. Source of acidity is acid sulfate soils - large amounts of acid are present in the catchment including in geological sediments. Paper questions relationship between reduction in Salt Creek flow (data available 1968 - 1981 and since 2010) and rainfall. 5 year and 10 year rolling averages of annual rainfall were lower in the early 1900s compared to the 132 year average and are shown to be declining gradually since the 1970s. Geology of the region includes coal seams and rocks that are potentially serving as impermeable units below perched aquifers that support swamps in the upper catchment. Mining activities by Alcoa involved extraction of groundwater from the Upper Eastern View Aquifer (1.6 GL / year) which resulted in lowering of groundwater levels in this aquifer. Graph of water levels in a well within the Upper Eastern View Aquifer and what is referred to as the perched water table is provided with data from 1993 (UEV) and 2010 (PW), which shows a gradual decline in the UEV water level and consistent fluctuation in the shallow groundwater.
22	Investigations of Anglesea River Estuary Mouth Dynamics - Review and recommendations	A. Pope, Deakin University	Corangamite CMA	2011	Review of Water Tech report investigating mouth dynamics of the Anglesea River estuary and associated hydrodynamic and ecological processes. Reviews the WT report against the project brief and provides recommendations for the Estuary Management Plan	Estuary processes	Review of Water Technology 2011 report. Water balance model of the Upper Eastern View formation aquifer has not been demonstrated as of primary importance in driving acid events.

Ref. no	Rehabilitation or management	Values for restoration	Stakeholder concerns
1	Possible remediation options for acidity in the estuary are summarised and include: - do nothing, allowing natural cycles of acidification with improved response plans and education - construction of refuges in the estuary to reduce the extremety of acid flushes - construction of refuge with increased buffering capacity (e.g. limestone rock) - Buffer estuary, for example with pumping sea water, opening estuary or installation of alkaline beaching/berms/ passive treatment systems - Flow treatment - Storage of water and release to regulate acidity and flow. Could be combined with treatment / dilution / buffer. - Install treatment into existing diversion drain on Salt Creek, such as buffering system or wetland. Additional details from this report will be further brought in to subsequent stages of this project.	NA	Maher notes that the estuary recovers from acid events over time, however the time for recovery may not be acceptable by the community.
2	An eight year action plan (2012 - 2020) was developed aimed at improving the environmental condition of the estuary. The plan was compiled in response to the Maher (2011) study, to improve knowledge about acid events, improve resiliency and maintain community and recreational values. 32 actions were identified and prioritised for the river. Details from this report will be further brought in to subsequent stages of this project.	Socio-economic values: tourism is the primary economic driver for the town; recreation, amenity and education; recreational fishing (bream, mullet, salmon, flounder and mulloway); infrastructure and landscape features.	Priority actions contributing to the following four borad directions: amenity and recreation, biodiversity, information and knowledge, and integrated managment
3	Conceptual evaluation of remediation options for the Anglesea River. Assessment involved a practical assessment of each option, then comparitive rating by scoring. Criteria used for scoring considered performance, protection of social, economic, ecological assets and amenity. Seventeen options were assessed. Recommended options included: do nothing, buffer estuary, addition of liquid neutralising materials, ion exchange system, installation of membrane treatment system to treat acidic water, or to treat sea water to buffer the river. Additional details from this report will be further brought in to subsequent stages of this project.	NA	NA
4	Potential management options for maintenance of water levels in the estuary to avoid activation of acid sufate soils include: discharge of groundwater and surface water, mine pit water, introduction of alternative freshwater (recycled water, stormwater, potable water, groundwater from Barwon Water borefield), introduction of seawater, mine pit buffering. Other options including infill of Coogoorah Park channels or hydraulic disconnection of channels were also identified as options. Additional details from this report will be further brought in to subsequent stages of this project.		
5	Project determined evaporation rates from the Alcoa storage pond and catchment to develop a water balance model and estimate the volume of water required to maintain water levels in the estuary. This indicated that the pumping volume from the river (106ML) is insufficient to fill the storage pond and manage estuarine water levels. Hot, dry and windy climate may further exacerbate this imbalance. Seawater pumping was considered as a short term option for improved certainty in maintaining water levels. The study indicated that this would be required at a daily rate of ~1,000 m3/day when water levels fall below 1.25 mAHD. A conceptual design and cost were developed for this option. Additional details from this report will be further brought in to subsequent stages of this project.	NA	NA
6	NA	NA	NA
7	NA	Recovery of fish populations following high level of mortality depends on a number of factors including suitable water quality, adequate connectivity of the estuary with freshwater and marine environments, and the presence of critical habitats and resources to sustain the survival, growth and reproduction of fish.	Study undertaken in response to community concern regarding the state of fish fauna in the estuary
8	In response to habitat assessment of Anglesea River documented limited amounts of instream habitats and resources, 15 habitat sites were installed (four 'rock/rootballs' and 11 'fish hotels).	NA	NA
9	NA	NA	NA
10	Recommended management strategy considers the whole catchment as sources of acidity present in the upper catchment of the Anglesea River. Management implications – ASS should remain in waterlogged state to prevent added acidity within the catchment and ensure the sulfide remain in a reduce state. Upper reaches of the Anglesea River does not have any major human disturbance, Rousetty (2014) suggested avoiding disturbance or minimise where possible to minimise the risk of acidification.	NA	NA
11	NA	NA	NA

Ref. no	Rehabilitation or management	Values for restoration	Stakeholder concerns
12	NA	NA	NA
13	Six management options reviewed and assessed by a community workshop with expert panel members. These were rated as to whether the risks outweighed the benefits. Four options were generally not supported: artificial deep estuary opening, rock wall removal, building fish refuge, building upstream dam/s. Standard artificial estuary opening had the most equal response; this was largely associated with fishing stock and less related to environmental and amenity. The expert panel considered this was not justified. Development of a response plan and use of the Alcoa mine pit for storage and treatment of acid runoff were the most supported options. Additional details from this report will be brought into subsequent stages of this project.	Restoration of fish stock for recreational fishing. Restoration of water quality following acid events.	
14	Feedback on short and long term options for maintenance of water levels in the estuary was sought: use of potable water, bore water, sea water and mine pit water. Feedback on criteria for assessing management options was provided, with the most respondents rating as the most important: water quality, aquatic fauna, vegetation, volume of water and water security. All other criteria including costs, ownership, construction impacts, flexibility, amenity and recreation, and sustinability were also ranked as extremely important by the majority of participants. Other suggestions on criteria included tourism benefits, environmental impact and water levels. Additional details from this report will be brought into subsequent stages of this project.	Survey data identified walking, nature observation and bird watching as the most common activities undertaken by participants related to the Anglesea River. Others including education, boating, swimming, fishing, kayaking and photography were also identified. Respondents rated values of waterway health and water quality, biodiversity and habitat, amenity and enjoyment as the most important. Others including history, education, tourism and economic opportunities also rated highly.	Summarises the comments and data received from open houses and an online survey conducted regarding the future management of the Anglesea River at the point of closure of the Alcoa power station and mine. Participants were predominantly from Anglesea with some from other postcodes in the Surf Coast, Geelong or Melbourne areas. Community members generally agreed with values identified as important for the river and ranked all values and criteria for assessment as important. Community members raised the most concerns regarding the use of potable water for maintaining water levels in the estuary (short and long term). Diverse views regarding short
15	Options discussed relate to maintenance of water levels in the estuary. These include: pumping of bore water, sea water, water from the mine pit or potable water into the river. Preferred short term option involves pumping water from an existing storage pond into the river. DELWP in partnership with Barwon Water and Alcoa to deliver the option. Long term options raised in GHD options report discussed and feedback from community mixed.	Historical value, boating and water sports.	Summarises the conversation from a community meeting regarding the health of the river. Community would like to be informed and have a voice in deciding the future use of the area. Outcomes need to ensure the natural environment is protected.
16	NA	NA	NA
17	Thirteen options were identified to reduce or halt oxidation of ASS to the receiving environment, options that were recommended for further assessment include: Options that are recommended for further assessment are: 1.Discharge at a reduced rate to that currently from mine and power station site– modified management of discharge continues to the Anglesea River estuary to maintain condition and values 2.Discharge treated mine pit water - This may be implemented in the short and long term and would use water from mine pit during the decommissioning process and continue to access groundwater as it recovers 3.Introduce alternative freshwater inflows to Anglesea River estuary –stormwater harvesting and recycled water discharge 4.Pump seawater into lower Anglesea River estuary – seawater has the potential to be pumped into the lower estuary to maintain water levels. This assumes there would need to be construction of temporary or permanent pumping infrastructure and 5.Mine pit buffering – utilise a mix of water sources, including seawater to buffer acidity and reduce metal concentrations. As a longer term option mine pit water can be used to maintain flows. Options that are not recommended to be assessed further are: 1.Infill Coogoorah Park channels – This option has limited effectiveness in mitigating the oxidation of acid sulphate soils as the soils will continue to oxidise due to the lowered water level and exposure to air. The option will also have significant negative impacts on Coogoorah Park as a recreational area for on and off water activities and the overall amenity of the site. 2.Hydrologically disconnect Coogoorah Park from the Anglesea River estuary - This option has limited effectiveness as the lowered water level will continue to allow oxidation of acid sulphate soils and they are expected to be able to enter the river through groundwater leachate. 3.Lime dosing is unlikely to be effective and would only be implemented if acid sulphate soils are activated. As an option it is effectively a last resort as preventative actions will not have been implemented. 4.Deep estuary opening – Estuary entrance is deepened to allow acid water to be flushed. This option is likely to lead to a significant drop in water levels and will not reduce activation of acid sulphate soils. Deep openings lead to prolonged exposure of seagrass beds in lower estuary. Expert panel assessment identified the impacts outweighed the benefits of the option. 5.Allow natural groundwater recovery. The expected recovery time of groundwater to contribute baseflows to Marshy Creek is decades. Natural recovery will not limit oxidation of acid sulphate soils as they will be activated once water levels are reduced. Option feasible in the long term but not short term. 6.Salt Creek / Marshy Creek diversion for water storage and treatment requires a large off stream storage of sufficient capacity to maintain water levels during the low flow summer months and reduce activation of acid sulphate soils. Treatment may also be required as the option may capture low pH catchment water. Probable security of supply issues due to drought and climate change may limit ability to maintain water levels. 7.Capture and storage of Anglesea River flows - during high flow events requires a significant storage on the floodplain in the urbanised area of Anglesea. The security of supply under drought and climate change conditions may reduce the capacity to maintain water levels and reduce activation of acid sulphate soils. 8.Do nothing – Is not listed as an option as it will not prevent the activation and oxidation of acid sulphate soils in the floodplain. Additional details from this report will be brought into subsequent stages of this project.	The study identified that cessation of discharge from the mine and power station are likely to reduce water level by up to 1m in the summer period, in turn: -Result in exposure and drying of mudflats at Coogoorah Park. -Reduced extent and composition of some water dependent and salt sensitive vegetation communities and increased extent to those communities that are less water or salt sensitive -Impact frog breeding event and habitat availability; changes to habitat and foraging areas for water birds -Likely results in reduction of seagrass area, increased risk of algal blooms -Potential benefit to marine and estuarine fish species from increased salinity	The study identified that cessation of discharge from the mine and power station are likely to reduce water level by up to 1m in the summer period, in turn: -impact on water activities (motor and non-motor boating) , swimming, recreational fishing, amenity, bird watching, beside water activities, boat hire business, markets, estuary education activities and infrastructure and -Activation of acid sulphate soils and lowering of pH in the estuary has the potential to impact infrastructure increasing deterioration of the asset and a reduction in the design life.
18	Key recommendations include: -Reach 3 (Salt Creek diversion and Anglesea River through Alcoa) flow recommendations should be considered in light of rehabilitation planning and development of the Alcoa mine site. It is recommended rehabilitation planning consider minimising water retention through the rehabilitated mine site so flows to the estuary are maximised. -Further extraction of surface water through the private and crown land areas of the Alcoa site is not recommended due to impacts to flows and downstream impacts to the estuary. -Artificial openings are unlikely to provide a net environmental benefit and serve only to lessen the risk to infrastructure surrounding the estuary. -Further extraction of surface waters from Salt Creek and Anglesea River is not supported. Significant reductions in surface water inflows have impacted the estuary and will continue to limit its ecological and physical functioning. -Continue to investigate securing alternative water sources as opportunities arise for maintenance of water levels in the estuary. -Prioritise flows to avoid prolonged periods of estuary levels below 1.3 m AHD, to reduce risk of activation of acid sulfate soils in Coogoorah Park. -Where possible consider using Anglesea River estuary water levels for winter extraction to the offstream storage noting extraction is limited to 2 ML/day. Extraction during periods of high water levels may reduce the need for an artificial estuary opening of short duration.		Impacts to ecology -Transition of seagrass dominated communities to freshwater macrophytes -Reduction in extent and condition of seagrass and indirect effects on aquatic food web -Altered estuarine fish communities -Possible impact of frog breeding and habitat availability; changes to habitat and foraging areas for waterbirds
19	Removal of the remnant rock wall has been considered for the purpose of increasing estuary flushing. WT found that the rock wall presence or absence is unlikely to affect sand deposition in the estuary mouth and alter the frequency of the natural estuary mouth openings. Risks and considerations associated with removal of the rock wall include: - Removal of the remnant rock wall would involve a CH permit, consent from DELWP and permit from CCMA. - Coastal acid sulfate soils may be disturbed - Safety, recreational and economic costs exist A risk ranking was completed which identified that there were less overall risks associated with the remant rock wall remaining in place compared to removal. Additional details from this report will be brought into subsequent stages of this project.	Estuary opening and coast has shifted over time.	
20	The model developed by WT to look at artificial openings of the estuary, pumping sea water into the estuary and how this would affect salinity, channel and bank stability as well as other impacts. The model was used to predict changes in salinity and mixing in the estuary during artificial openings. Four scenarious were modelled including four deep excavations and one shallow excavation. Overall the results showed that maintaining a deep artificial opening for 3 days (6 tidal cycles) resulted in significant flushing of the fresh water in the estuary with salt water. Shallow openings were modelled to have limited capacity to allow saline waters to flush the estuary however due to reduction in the surface water level acidic water would be removed. The model was also used to model pumping of sea water into the estuary (to the GOR Bridge) to understand how this would alter salinity in the estuary. Additional details from this report will be brought into subsequent stages of this project.		

Ref. no	Rehabilitation or management	Values for restoration	Stakeholder concerns
21	NA	Fish habitat, ecosystems including frogs, birdlife, water quality, recreational amenity.	Would like impact of mining in the catchment considered with relation to impacts on the estuary. Consider that extraction from the upper Eastern View Group aquifer is a major contributor to the acidification and drying of the catchment. Changes in the catchment have resulted in detrimental effects on the estuary including loss of fish breeding, recreation, reduction in estuary mouth openings, changes to frog carolling. Rehabilitation should consider the Anglesea River catchment and estuary, not just the Alcoa mine pit.
22	NA	NA	NA

Appendix B Stage 1 assessment tables

Table A1: Feasibility screening of identified options

Strategy	ID	Option	Description of how it would work	Feasibility screening discussion	Option carried through for MCA?
Minimise or prevent further oxidation	1	In fill Coogoorah Park channels	Option identified previously to avoid exposure of ASS at Coogoorah Park and formation of acid within the estuary if water levels were reduced (GHD, 2016). Would reduce potential for generation of acid from acid sulphate soils at Coogoorah Park and therefore negate need for maintaining water levels in the estuary.	Does not address continual source from acidic material in upper catchment via Salt and Marshy Creeks. Reduced capacity of estuary system would mean that flows from upstream would directly flow into estuary rather than needing to fill Coogoorah Park channels. Potential that this would change functioning of the estuary system, including how the swamps swamps drain to the lower part of Anglesea River, as well as potentially natural estuary mouth opening dynamics from changes to flow conditions. Further assessment based on estuary capacity and flow conditions would be required to understand whether these changes are potentially realistic and influence on regulating acidity. Unclear therefore whether this would improve acidity issue broadly. Would avoid need to further manage ASS at Coogoorah Park and address risks presented by acid forming potential. Previous studies discounted this as a viable option for managing ASS at Coogoorah Park with the assumption that water levels would still lower and expose ASS (GHD, 2016), however this should be considered further in the context of reduced estuary capacity. Significant resource use sourcing fill material, environmental and logistical requirements during implementation. Unlikely to be acceptable to some stakeholders due to high social and economic value of the area for recreation and business operation (boat hire, recreational camps).	Y
	2	Restrict access to upper reach of the catchment to minimise soil erosion from recreational activities	Option raised by members of the community, with the objective of reducing soil erosion and sedimentation from recreational access to upper catchment.	Soil erosion from recreational four wheel driving is unlikely to be contributing to low pH conditions in Marshy or Salt Creeks or the Anglesea River, based on previous studies to understand where ASS is present in the catchment. This is being further investigated. Erosion and sedimentation can increase risk of hypoxic black water which if combined with low pH conditions in particular results in fish deaths. Unlikely this option would provide significant improvement in pH conditions in river therefore not considered feasible to address the objectives. May reduce impact of acid events. Erosion management may be addressed to improve protection of environmental values outside of this project.	N
	3	Managed aquifer recharge to restore water levels in UEVF aquifer	Involves pumping into UEVF aquifer to reverse historic groundwater drawdown more rapidly than allowing levels to recover naturally, which is currently occurring. This option has been identified in response to community concerns that groundwater extraction from the UEVF has historically contributed to the issue. If there is connectivity between shallow groundwater supporting swamplands where ASS is present and the UEVF, intent of the option would be to reduce potential for further oxidation of acid sulphate soils within the area of groundwater drawdown. Ultimately inundation would reverse geochemical processes and reduce in-situ acidity. Would require construction of infrastructure and identification of a water source.	Extent to which shallow groundwater supporting marshlands with ASS is connected to the UEVF is not fully understood, however previous studies (GHD, 2008; Maher, 2011) suggest that extraction from the UEVF or LEVF has not resulted in changes to the marshes in the upper catchment. Unknown therefore whether recovery of groundwater levels in the UEVF aquifer would result in changes to water levels where ASS is present, so unknown effectiveness at addressing the issue. Range of other contributors to formation and transport of acid in catchment, therefore would most likely not fully address issue and reduce severity of low pH events. MAR is complex to design, significant additional studies would be required. Water source would also need to be identified. Significant timeframe for studies and approvals prior to implementation. Not feasible for the objectives of this project and uncertain outcome related to the issue.	N
	4	Maintain water levels with weir system (upper catchment)	Option involves installation of weirs to maintain water levels in areas where ASS are present, with the aim of reducing oxidation and release of acidic water. By maintaining saturation of acidified areas in the upper catchment, this would have the ability to regulate flows and contain acidity in the upper catchment. Ultimately would reverse geochemical processes and reduce in-situ acidity. Simplest way to ensure that ASS materials remain under sufficient depth of water. Weirs can have different levels of permeability, and be constructed from sandbags or more permanent structures, incorporating habitat protection measures such as fish ladders.	Technically feasible method to effectively reduce potential for oxidation of acidic sulphate soils in upper catchment and migration of acidic water downstream. Has been successfully implemented in other Australian coastal and inland systems to address acidity (e.g. Indraratna et al, 2001), however limited long term improvement as does not manage stored acid that has already formed. Would likely reduce frequency and duration of events for the river, as creates resilience against fluctuating wet-dry conditions. For previously oxidised ASS, saturated conditions provide limiting factor. Saturation also minimises risks of further oxidation and acid formation. This strategy is most effective when there is a plentiful and reliable supply of water. In the context of Anglesea River catchment with significant cease-to-flow periods in Salt and Marshy Creeks, and that swamplands already act attenuate much of the surface flow (GHD, 2021) would require top up from a water source during dry periods so as not to exacerbate the issue. At times of low volume or flow in the river, a weir system may be effective at regulating low pH events in the estuary in that acidic water could be controlled. For example, could be implemented with windmill system to pump groundwater, or paired with introducing recycled water. In isolation, option would likely result in reduction of water levels at Coogoorah Park. Ongoing maintenance and addition of water supply for dry periods would mean this is able to be implemented long term.	Y
	5	Maintain water levels with weir system (estuary - Coogoorah Park channels)	Involves installing a hydraulic barrier / weir between Coogoorah Park channels and Anglesea River estuary, with the aim of maintaining an area of suitable water quality. Barrier could be permanent or temporary. Isolating channels would also aim to provide a refuge where water quality is maintained and environmental values are protected. Water level would need to be maintained in Coogoorah Park channels via redirecting stormwater and catchment flows, or via pumping into the channels.	Will reduce potential for exposure of acid generating material at Coogoorah Park contributing to acid events and could provide refuge for fish and other aquatic life during periods of low pH in the estuary. Acidic water from the upper catchment will not be addressed with this option, however reduced capacity of estuary system would mean that flows from upstream would directly flow into estuary rather than needing to fill Coogoorah Park. Unknown the extent to which this would alter pH conditions in the estuary. May not be suitable as a long term option if extended periods of low pH experienced. Water levels would need to be maintained to prevent oxidation of ASS and isolation/stagnation of water which could represent a health and environmental risk. This would need to be managed through introduction of fresh water. Refer to constraints and benefits associated with different water sources (Options 10-12, 16, 17). Social recreational values may be impacted if permanent structure in place disconnecting channels.	Y
Inundation	6	Introduce water to upper catchment to saturate areas of acidity	Option involves introducing water to areas of acidic soils that have already oxidised in the upper catchment, and continual maintenance of maintain water levels and saturation of acidic soils. This would aim to minimise oxidation and release of acidic water, and ultimately reverse geochemical processes and reduce in-situ acidity.	Technically feasible method to effectively reduce potential for oxidation of acidic sulphate soils and migration of acidic water downstream. Given extent of acidic soils in upper catchment, large area would require inundation to be effective, likely altering environment and recreational values. Refer to constraints and benefits associated with different water sources (Options 10-12, 16, 17). Identification of suitable water source to provide volume required and extent of area that would require inundation render option likely unfeasible for Anglesea.	Y
Isolation of impacted areas	7	Physical capping of acid sources	Involves placement of a cap over areas where acid forming materials present. This would avoid exposure of pyrites and sulfidic materials to oxygen and prevent formation of acid. A clay cap would also reduce rainfall infiltration and runoff of labile acidity (already formed acid).	Technically feasible as a prevention and treatment option for containment of acid sulfate soils, however given extent of acidic soils within the catchment not considered feasible option. Would likely need to be widespread in Anglesea catchment to be effective and result in significant environmental impacts within established heathlands. Unlikely to be feasible or acceptable for management of ASS at Coogoorah Park due to disturbance this would cause to vegetation. Extent to which run off surface water could still cause acid events in the river would need further investigation, even if the base is capped. More detailed mapping of acid soils would also need to be undertaken in order to understand the location and extend of capping that could be effective. The option of capping would have little or no impact on river flows, unless the river volume profile is modified. Not acceptable to stakeholders.	Y
	8	Diversion of low pH water from Salt and/or Marshy Creek	Option raised by members of the community, with the objective of diverting and containing acidic water to avoid downstream low pH conditions.	Technically feasible as an option for minimising volume of low pH water reaching the estuary however as a standalone option likely to exacerbate the issue, as water levels at Coogoorah Park would lower resulting in activation of ASS. Likely that there would be insufficient downstream flow required for maintaining functioning estuary. Would need to be paired with a water supply to maintain flow and support environmental and social values within the river, and to maintain water levels at Coogoorah Park and avoid exposure of ASS. Refer to constraints and benefits of water supply options (Options 10-12, 16, 17). Legislation in place to maintain sustainable natural flow volumes; significant regulatory barriers in place currently to avoid environmental impacts as a result of this. Likely in contradiction with Water Quality Management Frameworks that aim to improve water quality over time.	N
Dilution Min. or prevent oxidation	9	Introduce potable water to estuary	Introduce potable water to the estuary system to maintain water levels and prevent exposure of acid sulfate soils within this portion of the catchment. Would involve construction of infrastructure including a pipeline and dechlorination plant.	The option would reduce the potential for formation of acid within estuary system (e.g. from Coogoorah Park) and may dilute acidic water from upper catchment, however the volume required for dilution would be significant and unlikely to be feasible. Approximately 100 - 1000 times the volume of the system is required for dilution of acidic waters, depending on the waters buffering capacity and alkalinity. Potable water would have limited capacity for buffering low pH conditions. Less effective than maintaining water levels with sea water or recycled/storm water as provides no treatment. Unsustainable use of potable water. Not acceptable to stakeholders.	N
Passive treat in-situ	10	Introduce recycled water to estuary from Anglesea RWTP	Introduce recycled water to the estuary system to maintain water levels and prevent exposure of acid sulfate soils within this portion of the catchment. Would likely provide some support for bioremediation (introduction of organic matter) to treat acidic water, further regulating the pH, depending on it's composition. Would involve construction of a pipeline from Anglesea water recycling plant (Class B water) and a treatment facility. Could be combined with other options (e.g. lime slurry or bioremediation) to enhance treatment capacity.	Organic matter in recycled water would provide some treatment of acidity. Further investigation into characteristics would be required to understand treatment capacity. Existing Anglesea WRP provides class B water for reuse, this will need to be treated to achieve Class A water suitable for human contact. Existing WRP may require modifications if nutrient levels or water quality parameters need reduction. Volume of water available from Anglesea WRP has previously been assessed as insufficient to maintain water levels required at Coogoorah Park (GHD, 2014). Supply not secure, therefore not a high confidence long term option.	Y
	11	Introduce recycled water to estuary from Black Rock RWTP	As for Option 10, with construction of a pipeline from Black Rock (Class A water). Treatment would not be required to meet quality for human health. Less likely to support bioremediation objectives as treatment is to a higher quality.	As for Option 10. Further investigation would be required to understand treatment capacity. Supply volume greater than Anglesea. Quality of water meets requirements for protection of human health.	Y

Table A1: Feasibility screening of identified options

Strategy	ID	Option	Description of how it would work	Feasibility screening discussion	Option carried through for MCA?
	12	Introduction of seawater to estuary via dredging of shallow artificial openings	Physically dredge the estuary berm to increase tidal flows and volumes through the estuary, with seawater providing buffering capacity to neutralise acidic water from the upper catchment.	Seawater introduction to the estuary technically feasible option for increasing pH conditions due to buffering capacity of seawater and dilution. Previous studies suggested net environmental benefit unlikely from artificial openings, and prioritisation of flows through the catchment would be preferable (GHD, 2021). Shallow excavation maintenance over 7 day period shows limited capacity to discharge estuary waters to the sea however "acid waters would be removed as surface water level is reduced" (Water Technology, 2011). Does not alter sources of acidity and may have only local influence for majority of tidal heights. Unless catchment flows are high (>7 ML/day), artificial opening will have limited impact on maintaining an open estuary (GHD, 2021). Not controlling pH as far up-stream of the river as possible and limited to tidal extent within estuary, therefore less effective than seawater pipeline/pumping option. Maintenance of an open estuary would result in a shift in the sand deposition further upstream. More frequent introduction of sea water to the estuary would likely change the aquatic and terrestrial environments due to changes in the salinity of the system (Water Technology, 2011; GHD, 2014). Could be implemented as a reactive measure to pH conditions however logistically this would be challenging and present amenity challenges. Supported by some stakeholders. Not supported by Traditional Owners.	Y
	13	Introduction of seawater to estuary via dredging of deep artificial openings	Physically dredge the estuary berm to increase tidal flows and volumes through the estuary, with seawater providing buffering capacity to neutralise acidic water from the upper catchment.	As for option 11, however effects on salinity of estuary and berm location would be more significant. Continual deep estuary opening would result in lowering of water levels in estuary and exposure of acid sulfate soils in Coogoorah Park, further contributing to the issue. Deep openings for 3 days / 6 tidal cycles is sufficient to provide significant flushing of the estuary with salt water replacing freshwater throghout much of the system (Water Technology, 2011)	Y
	14	Introduce sea water to estuary via pump and pipe, or via passive tidal pipe	Introduce sea water to the estuary system by pumping via a pipe upstream. The objective of this option would be to maintain water levels and avoid oxidation of ASS at Coogoorah Park, and to dilute and buffer low pH water that flows into the estuary from the upper catchment. Design could include for example construction of a pipeline and pumping system from the ocean to a point in the river, or a system for passively harvesting seawater during high spring tides.	Seawater introduction to the estuary technically feasible option for increasing pH conditions due to buffering capacity of seawater and dilution. Pump and pipe to upper estuary feasible option for maintaining water levels to reduce potential for exposing acid sulfate soils at Coogoorah Park, and provides buffering capacity and dilution to regulate acidity from Salt and Marshy Creeks. Further studies would be required to factor in seasonal flow and understand requirements for buffering capacity as well as volumes. Use of a pump and pipeline upstream rather than tidal harvesting or dredging would provide more flexible approach to respond to pH conditions and flow volumes. Would require ongoing maintenance of pipeline to maintain effectiveness. Pumping frequency could be responsive to pH conditions and water levels. Some environmental disturbance would occur during construction and operation and design would need to factor in potential impacts. The extraction location of saline water would need to be offshore to limit potential for sand incursion and pipeline buried in some areas (Water Technology, 2011). Noise and amenity constraints also exist depending on the location and design. More frequent introduction of sea water to the estuary would likely change the aquatic and terrestrial environments due to changes in the salinity of the system, or frequency of the estuary being saline (Water Technology, 2011). GHD (2014) found the impacts on vegetation community structure would be considerable. Passive tidal pipe at the sand berm is unlikely to be feasible due to sand build up offshore and in estuary, therefore this option not carried through.	Y
	15	Introduce seawater to estuary through removal of rock wall remnants at estuary mouth	Remove 13 m remaining portion of rock wall at estuary mouth. This has been raised by the community as an option for reducing sand build up at the estuary mouth and subsequently increasing the instances of seawater entering the estuary to dilute and buffer low pH conditions.	Previous studies (Water Technology, 2012) have found that the remaining section of rock wall is unlikely to affect: - volume of water entering or leaving the estuary from tidal flushing - sand deposition at the estuary mouth or upstream - the frequency of naturally occurring openings Removal of the remaining portion of rock wall therefore is unlikely therefore to positively influence pH conditions. Risks and considerations in additional to little technical viability to address issue include potential for disturbance of cultural heritage values, coastal ASS, safety, recreational and economic costs. Disturbance of coastal ASS from removal of the rock wall has the potential to result in acidification.	N
	16	Introduce water to estuary from stormwater harvesting	This option involves harvesting of stormwater and addition to the estuary system to maintain water levels at Coogoorah Park and prevent exposure of acid sulfate soils within this portion of the catchment. Depending on volumes and composition, may provide some support for dilution and bioremediation (introduction of organic matter) to treat acidic water, further regulating the pH. Infrastructure required including storage basins, diversion of stormwater, pump station and a pressure or gravity pipeline.	Stormwater from Anglesea township currently discharges into the river. Anecdotally there are sedimentation issues as a result of this. As for option 17, volume required would likely be significant to effectively dilute acidic water, depending on characteristics and treatment capacity. Highly reliant on rainfall - has not been successful with the current stormwater discharge and would require capture and storage of stormwater then addition to the system at particular times to be effective. Additional stormwater catchment area may need to be identified to increase available volume. Previous assessment of options to maintain estuary water levels (GHD, 2016) considered less feasible than alternatives (e.g. recycled water, seasonal capture and release) due to storage volume and land availability constraints.	Y
	17	Introduce groundwater to estuary	This option involves pumping of groundwater from a regional aquifer to the estuary system to dilute low pH water. This would also support maintenance of water levels and prevent exposure of acid sulfate soils at Coogoorah Park. Would involve identification of suitable groundwater source, construction of infrastructure including a pipeline and potentially new production bores, depending on capacity of existing bores.	The option would reduce the potential for formation of acid within estuary system (e.g. from Coogoorah Park) and may dilute acidic water from upper catchment, however the volume required for dilution would be significant and unlikely to be feasible. Further investigation to understand whether groundwater would provide buffering capacity would be required. Does not address source and unlikely to provide buffering capacity to treat acidic inflows transported from upper catchment. Further groundwater extraction is not supported by stakeholders.	N
Soil neutralisation	18	In-situ addition of a neutralising agent (e.g. lime) to ASS in marshes	Involves addition of soil neutralising agents (eg lime) where acid forming materials present such as in the upper catchment and at Coogoorah Park. Could be targeted to "hotspots".	Technically feasible as a prevention and treatment option for acid sulfate soils. Would likely need to be widespread in Anglesea catchment to be effective. Preliminary estimates (Wong et al, 2020) of net acidity in the swamplands suggest up to 100 tonnes of lime per hectare would be required to neutralise acid (i.e. up to approx 9,300 tonnes total). This could be targeted at key areas. Potential secondary environmental impacts due to disturbance of vegetation within areas of ASS. Not supported by stakeholders due to potential for this environmental disturbance.	Y
	19	In-situ bioremediation of sulfidic material in marshes	This option would involve addition of organic material (through mulching or planting of additional vegetation) to areas of sulfidic material.	Technically feasible option to encourage anaerobic conditions to form via increasing organic loads, to enforce sulfidic formation in freshwater environments. This is essentially a reversal of the oxidation reaction that generates acidity from exposed acid sulfate soils. Organic matter (e.g. mulch) can quickly control acidic hot spots. Long term revegetation of areas would be required to supply continued organic matter. Some areas are already heavily vegetated therefore this option may not provide significant change to managing the issue.	Y
Passive treat in-situ	20	Install passive alkaline berms for treatment of acidity in-situ within river / open limestone drains	The option involves installation of passive alkaline treatment materials to increase the pH of water within the river. This would involve placement of alkaline beaching or berms throughout catchment / river, or limestone drain beds. For example, this could involve placement of limestone gravel treatment beds within stream beds in the upper catchment, and/or placement of limestone rock within the estuary.	Limestone drain beds or berms common approach to managing low pH runoff, in particular for acid mine drainage. Presence of alkaline materials through the entire catchment / estuary is likely to somewhat regulate pH variations, however likely significant points of installation would be required to be broadly effective. However, the slow release or alkaline rocks are still regarded as a relatively ineffective method of managing alkalinity vs acid demand and river flows when compared to other alkaline treatment options (e.g. active dosing), as the surface of gravel / rocks becomes coated with calcium sulphate soon after reaction with acid occurring, therefore reducing in effectiveness within short timeframe. May not be effective at controlling pH during acidic events, and use of rock or solid forms of alkali is not a reliable means of maintaining a narrow pH control range. Local pH close to alkaline rocks may be high however may not effectively treat entire estuary volume. Installation within specific points (e.g. Salt Creek diversion drain) will be less effective at regulating pH in other areas or from other sources. Readily implemented. Supported by stakeholders in combination with other options.	Y
	21	In-stream limestone sand	Option involves placement of limestone sand stockpiles within stream beds, increasing the pH and alkalinity of the water progressively.	Feasible as a treatment option for low pH water, however unlikely to be effective in the Anglesea catchment as requires high gradient streams to wash limestone particles downstream as well as to minimise armouring to maintain treatment effectiveness.	N
	22	Limestone diversion wells	Option involves construction of a shallow, wide well containing crushed limestone aggregate, and diversion of water to be treated into the well via a pipeline. Limestone increases the pH and alkalinity of the diverted water.	Feasible as a treatment option for low pH water, however unlikely to be effective in the Anglesea catchment as requires high velocity stream flow to maintain effectiveness.	N
	23	Constructed wetland	Construction of a managed wetland that captures flow through catchment, regulating water levels and providing capacity to manage and treat acidic water water from the upper catchment. Wetlands can be aerobic, anaerobic, or reducing and alkalinity producing. If combined with another passive treatment option, aeration and settling wetlands can be used. A range of designs can be applied within each wetland type. Processes within a constructed wetland to improve water quality include (depending on wetland design): oxidation, reduction, precipitation, sedimentation, filtration, adsorption, complexation, chelation, active metal uptake by plants and microbial conversion/immobilisation mechanisms. **Assumes existing basins/channels could be repurposed for construction of the wetland (e.g. part of Alcoa site during rehabilitation or Coogoorah Park channels)**	Technically feasible option for effectively treating low pH water and regulating acidic flows downstream, however type of wetland and design will vary in applicability for Anglesea. Aerobic wetlands typically suited for pH greater than 4.5, therefore unlikely to be feasible for Anglesea. Anaerobic wetlands are typically able to treat pH levels around 4.0, however may require pairing with aeration or aerobic stages due to low dissolved and soluble metals in effluent. pH measurements in the catchment are frequently <4 therefore unlikely to be feasible option. Reducing and alkalinity producing systems use limestone (alkaline materials) and organic matter to raise the pH of water. Active pumping would be required to be effective as natural elevation changes within the Anglesea River are insufficient (requires ~2.5 m relief). Reducing and alkalinity producing system taken forward for MCA. Aerobic and anaerobic wetlands not feasible based on typical pH levels. Would most likely need to be paired with rehabilitation of the former Alcoa site and beneficial reuse of a pond/pit, to avoid disturbance for construction of a wetland.	Y

Table A1: Feasibility screening of identified options

Strategy	ID	Option	Description of how it would work	Feasibility screening discussion	Option carried through for MCA?
	24	In-situ passive permeable reactive barrier	Option involves construction of a permeable barrier within the river or creek bed, similar to berms however with greater treatment capacity due to capturing and treating all flow. PRB contains treatment materials (alkaline material such as limestone, and/or organic matter). As water passes through the barrier it is treated to increase the pH.	Technically feasible, similar to options 20, 21 and 22 with regard to the mechanism for treatment. Can be more effective due to increased amount of water in contact with treatment material, however more complex to implement. Residence time and surface water flow would require further understanding, to ensure treatment would be effective while maintaining flow downstream. Design would need to incorporate habitat protection measures such as fish ladders to minimise environmental impacts.	Y
Active ex-situ treatment	25	Ex-situ filtration and membrane water treatment system	Option involves construction of a treatment system at a selected point, pumping of water from the river through the treatment system then back into the river. Specific technology uses filters and membranes to filter out sulphates. The passing of acidic water through a filtration / membrane plant will produce two outlet streams. One stream will be purified (sulphate free water) that could be returned back to the river. The second stream would be a concentrated sulphate rich stream that would need to be diverted away from the river.	Technically feasible option for treating acidic water. Could be triggered based on real-time pH measurements and treatment system start within a few hours. By passing the acidic water through a membrane the acid can be “filtered out”. Filters / membranes would require ongoing replacement to maintain effectiveness. To be most effective would be most suitable to be installed near confluence of Salt and Marshy Creek or in upper catchment. Stations could potentially be located at multiple points along the river, at saline and non-saline sections. Disposal of sulphate rich waste stream would be required.	Y
	26	Ex-situ treatment by alkali material dosing	Option involves construction of a storage dam or series of dams or holding tanks designed to store or hold back acidic water, which could then be treated by dosing with alkali material (calcium hydroxide or calcium oxide) and released.	Represents an effective option from a technical perspective for treating low pH and managing acidic events. At times of low volume or flow in the river, a storage system may be manageable in that acidic water could be detected and diverted to storage. Capacity to establish a large enough ex-situ storage and treatment area may reduce feasibility of implementing this option in the estuary, however could be implemented in the upper catchment to treat smaller volumes and reduce low pH water flows downstream. Release of treated water would also present complex issues regarding the timing and the amount of water released. Further studies would be required to understand whether an ex-situ treatment would impact environmental flow requirements. A storage system would need to be designed with a specified hydraulic and acidic load - further studies would be required to understand this.	Y
	27	Ex-situ active resin ion-exchange treatment system	Option involves construction of a fixed point treatment system which pumps diverted streamflow via cation exchange resin to remove acidity from water. Treated water with higher pH is then returned to the river. The passing of acidic water through a resin bed, or series of resin beds allows target ions such as sulphates to be fixed onto the resin, and depending on the types of resins, the sulphates would either be replaced with a more benign ion, or taken a step further, the water could be “demineralised.”	Technically feasible option for increasing pH of water. Could be triggered based on real-time pH measurements and treatment system start within a few hours. After a certain mass of sulphate has been fixed or adsorbed onto the resin, the resin becomes “exhausted” and at this point the resin can either be replaced or re-generated. To be most effective would be most suitable to be installed near confluence of Salt and Marshy Creek or in upper catchment.	Y
Active in-stream treatment of acidic water	28	In-situ dosing with alkali materials	Involves direct addition of materials such as calcium hydroxide (“lime”), sodium hydroxide, potassium hydroxide, magnesium hydroxide and carbonate salts to the river when there is a detection of low pH. Dosing stations could be located at multiple points along the river in the upper catchment and/or estuary.	Effective method for controlling pH levels. Small, portable plants with low capital cost that have been implemented successfully in other locations. Options for the alkaline reagent include dry/solid forms, or liquid materials. Dry powders or solid briquette forms of neutralizing materials would present difficulty in terms of mixing and diluting evenly into the river. The risk of localized effects such as high pH would be significantly increased if dry materials are applied into the river. Liquid materials can be dosed at a controlled rate (known mass) as a response to an acidic river condition. The success of pH control with neutralizing materials is highly dependent on the integrity of the pH measurement and control instrumentation, and the ability to mix and dilute treatment materials into water.	Y
	29	In-situ bioremediation of water	This option would involve addition of organic bioremediation amendments (e.g. oxygen, hydrogen peroxide, ozone, magnesium peroxide, calcium peroxide) directly into the river or creeks in upper catchment or the estuary. Organic material containing carbon promotes sulphate reduction, increased alkalinity and pH.	Effective treatment method however unlikely to have significant impact if completed in localised areas. Widespread application potentially has detrimental environmental and social impacts due to changes in dissolved oxygen levels - would need to be paired with oxygenagion method to counter this and improve mixing and treatment. Less effective option than ex-situ bioremediation system.	Y
	30	Construction of aquatic habitat refuges	Option involves installing refuges to improve resilience during periods of low pH. This could include construction of a network of pools/branches or diversion channels in the river system that remain at a pH suitable for supporting aquatic organisms.	Will not improve pH conditions broadly and address the issue, however provides a potential measure for better protection of environmental values when pH conditions change. Use of rock or solid forms of alkali materials is not a reliable means of maintaining a narrow pH control range (as these become ineffective over time) and consequently fish preservation during acidic events, therefore active treatment likely to be required. High river flows and extreme acidic conditions may also render refuge point ineffective. May not be effective at supporting environmental values for prolonged periods of low pH, depending on the scale of the refuge. Could involve construction of new channels or use of existing areas (e.g. Coogoorah Park). Excavation of channels if required would need to avoid potential release of acidic sulphate soils as well as heavy metals. Most appropriate to be applied in combination with other options.	N

Table A2: Multicriteria analysis of feasible options

Strategy	ID	Option	Applicable area		Technical					Practicability					
					Relative effectiveness in achieving and sustaining outcomes	Timeframe for achieving effectiveness	Flexibility to be implemented as long term solution	**Total category score**	**Weighted category score**	Timeframe for implementation	Logistical constraints (access, availability of resource/facility)	Legislative, regulatory and permit requirements	Ongoing maintenance requirements	**Total category score**	**Weighted category score**
		Weighting			16.7%					16.7%					
		Maximum category score						6	1.67					8	1.67
Strategy	**ID**	**Option**	**Upper catchment / estuary**	**Coogoorah Park**											
Minimise	1	In fill Coogoorah Park channels		■	1	0	0	1	0.3	0	-1	-1	2	0	0.0
	4	Maintain water levels with weir system (upper catchment)	■		1	1	-1	1	0.3	2	-1	1	1	3	0.6
	5	Maintain water levels with weir system (estuary - Coogoorah Park channels)		■	1	1	-1	1	0.3	1	1	1	1	4	0.8
In	6	Introduce water to upper catchment to saturate areas of acidity	■		1	-1	1	1	0.3	-1	-2	-1	-1	-5	-1.0
Iso	7	Physical capping of acid sources	■	■	1	1	1	3	0.8	-1	-1	-2	-1	-5	-1.0
Passive treat in-sit Dilution	10	Introduce recycled water to estuary - Anglesea WTP	■	■	2	1	2	5	1.4	-1	-2	-2	-1	-6	-1.3
	11	Introduce recycled water to estuary - Black Rock WTP	■	■	2	1	2	5	1.4	-1	-1	-2	-1	-5	-1.0
	12	Introduction of seawater to estuary via dredging of shallow artificial openings	■		0	1	-1	0	0.0	1	1	-1	-2	-1	-0.2
	13	Introduction of seawater to estuary via dredging of deep artificial openings	■		1	1	-1	1	0.3	1	1	-1	-2	-1	-0.2
	14	Introduce sea water to estuary via offshore pump and pipe	■	■	2	2	2	6	1.7	-1	1	-2	-1	-3	-0.6
	16	Introduce water to estuary from stormwater harvesting	■	■	1	-1	1	1	0.3	0	-2	-1	-2	-5	-1.0
Soil n	18	In-situ addition of a neutralising agent (e.g. lime) to ASS in marshes	■	■	2	2	2	6	1.7	0	-1	-1	-1	-3	-0.6
	19	In-situ bioremediation of sulfidic material in marshes	■	■	1	1	2	4	1.1	0	-1	-1	-1	-3	-0.6
Passive t	20	Install passive alkaline berms for treatment of acidity in-situ within river / open limestone drains	■		1	1	2	4	1.1	2	2	1	-1	4	0.8
	23	Constructed wetland (reducing and alkalinity producing type)	■		1	1	2	4	1.1	0	2	0	1	3	0.6
	24	Insitu passive permeable reactive barrier	■		1	1	2	4	1.1	2	2	1	-1	4	0.8
Active e	25	Ex-situ filtration and membrane water treatment system	■		1	2	2	5	1.4	-1	1	-1	-2	-3	-0.6
	26	Ex-situ treatment by alkali material dosing	■		1	2	2	5	1.4	-1	1	-1	-2	-3	-0.6
	27	Ex-situ active resin ion-exchange treatment system	■		1	2	2	5	1.4	-1	1	-1	-2	-3	-0.6
Active	28	In-situ dosing with alkali materials	■		1	2	2	5	1.4	0	2	-1	-1	0	0.0
	29	In-situ bioremediation of water	■		1	-1	1	1	0.3	1	2	-2	0	1	0.2

Table A2: Multicriteria analysis of feasible options

ID	Option	Environmental							Cultural			
		Energy and resource consumption	Waste disposal requirements	Climate resiliency (ability to be scaled up etc.)	Potential effects on the broader environment	Potential risks to aquatic and terrestrial ecosystems within remediation area	**Total category score**	**Weighted category score**	Effects on areas of cultural significance	Acceptance by Traditional Owners	**Total category score**	**Weighted category score**
		16.7%							16.7%			
	Maximum						10	1.67			4	1.67
1	In fill Coogoorah Park channels	-2	2	2	-1	-1	0	0.0	-1	-1	-2	-0.8
4	Maintain water levels with weir system (upper catchment)	0	2	0	-1	-2	-1	-0.2	-1	-1	-2	-0.8
5	Maintain water levels with weir system (estuary - Coogoorah Park channels)	0	2	0	1	-1	2	0.3	0	0	0	0.0
6	Introduce water to upper catchment to saturate areas of acidity	-2	2	1	-2	-1	-2	-0.3	-1	-1	-2	-0.8
7	Physical capping of acid sources	-1	2	-1	-2	-2	-4	-0.7	-2	-2	-4	-1.7
10	Introduce recycled water to estuary - Anglesea WTP	-1	2	1	-1	-1	0	0.0	-1	0	-1	-0.4
11	Introduce recycled water to estuary - Black Rock WTP	-1	2	1	-1	-1	0	0.0	-1	0	-1	-0.4
12	Introduction of seawater to estuary via dredging of shallow artificial openings	-1	2	1	-1	-2	-1	-0.2	-2	-2	-4	-1.7
13	Introduction of seawater to estuary via dredging of deep artificial openings	-1	2	2	-2	-2	-1	-0.2	-2	-2	-4	-1.7
14	Introduce sea water to estuary via offshore pump and pipe	-1	2	2	-1	0	2	0.3	-1	0	-1	-0.4
16	Introduce water to estuary from stormwater harvesting	-1	1	-1	-1	-2	-4	-0.7	0	0	0	0.0
18	In-situ addition of a neutralising agent (e.g. lime) to ASS in marshes	-1	2	1	-2	-2	-2	-0.3	-2	-2	-4	-1.7
19	In-situ bioremediation of sulfidic material in marshes	-1	2	1	-2	-2	-2	-0.3	-2	-2	-4	-1.7
20	Install passive alkaline berms for treatment of acidity in-situ within river / open limestone drains	1	1	2	1	1	6	1.0	0	0	0	0.0
23	Constructed wetland (reducing and alkalinity producing type)	0	2	1	1	0	4	0.7	1	0	1	0.4
24	Insitu passive permeable reactive barrier	1	-1	0	1	0	1	0.2	0	0	0	0.0
25	Ex-situ filtration and membrane water treatment system	-2	-2	1	-1	1	-3	-0.5	0	0	0	0.0
26	Ex-situ treatment by alkali material dosing	-2	2	1	-1	1	1	0.2	-1	0	-1	-0.4
27	Ex-situ active resin ion-exchange treatment system	-2	-2	1	-1	1	-3	-0.5	0	0	0	0.0
28	In-situ dosing with alkali materials	-1	1	1	0	1	2	0.3	0	0	0	0.0
29	In-situ bioremediation of water	-1	1	1	-1	-2	-2	-0.3	0	0	0	0.0

Table A2: Multicriteria analysis of feasible options

ID	Option	Economic					Social/stakeholder					Total score
		Relative capital cost	Relative operational cost	Relative potential effects on local economy	**Total category score**	**Weighted category score**	Acceptance by community, regulators, DEECA, CCMA, Surf Coast	Effects on recreational values (swimming, fishing, water activities)	Amenity impacts (dust, noise, footprint, visual, odour)	**Total category score**	**Weighted category score**	
		16.7%					16.7%					**100%**
	Maximum				6	1.67				6	1.67	10
1	In fill Coogoorah Park channels	1	2	-1	2	0.6	-2	-2	-2	-6	-1.7	🔴 -1.7
4	Maintain water levels with weir system (upper catchment)	1	1	1	3	0.8	-2	-1	-1	-4	-1.1	🟡 -0.4
5	Maintain water levels with weir system (estuary - Coogoorah Park channels)	1	1	-1	1	0.3	-2	-1	-1	-4	-1.1	🟢 0.6
6	Introduce water to upper catchment to saturate areas of acidity	-1	-1	0	-2	-0.6	-2	1	-1	-2	-0.6	🔴 -3.0
7	Physical capping of acid sources	-1	-1	-1	-3	-0.8	-2	-1	-2	-5	-1.4	🔴 -4.8
10	Introduce recycled water to estuary - Anglesea WTP	-1	-1	1	-1	-0.3	1	1	0	2	0.6	🟡 0.0
11	Introduce recycled water to estuary - Black Rock WTP	-2	-1	1	-2	-0.6	1	1	0	2	0.6	🟡 -0.1
12	Introduction of seawater to estuary via dredging of shallow artificial openings	1	-1	-1	-1	-0.3	0	-1	-2	-3	-0.8	🔴 -3.2
13	Introduction of seawater to estuary via dredging of deep artificial openings	0	-1	-1	-2	-0.6	-1	-1	-2	-4	-1.1	🔴 -3.4
14	Introduce sea water to estuary via offshore pump and pipe	-1	-1	1	-1	-0.3	1	1	0	2	0.6	🟢 1.2
16	Introduce water to estuary from stormwater harvesting	-1	-1	0	-2	-0.6	-1	-1	-1	-3	-0.8	🔴 -2.8
18	In-situ addition of a neutralising agent (e.g. lime) to ASS in marshes	-1	-1	-1	-3	-0.8	-2	1	-2	-3	-0.8	🔴 -2.6
19	In-situ bioremediation of sulfidic material in marshes	-1	-1	-1	-3	-0.8	-2	1	-2	-3	-0.8	🔴 -3.2
20	Install passive alkaline berms for treatment of acidity in-situ within river / open limestone drains	2	1	0	3	0.8	2	0	0	2	0.6	🟢 4.3
23	Constructed wetland (reducing and alkalinity producing type)	0	1	1	2	0.6	2	1	1	4	1.1	🟢 4.5
24	Insitu passive permeable reactive barrier	1	1	1	3	0.8	0	0	1	1	0.3	🟢 3.2
25	Ex-situ filtration and membrane water treatment system	-2	-2	0	-4	-1.1	1	2	-1	2	0.6	🟡 -0.3
26	Ex-situ treatment by alkali material dosing	-1	-1	0	-2	-0.6	-1	1	-1	-1	-0.3	🟡 -0.3
27	Ex-situ active resin ion-exchange treatment system	-2	-2	0	-4	-1.1	0	2	-1	1	0.3	🟡 -0.6
28	In-situ dosing with alkali materials	-1	-1	0	-2	-0.6	2	1	-1	2	0.6	🟢 1.7
29	In-situ bioremediation of water	0	-1	0	-1	-0.3	-1	-1	-1	-3	-0.8	🟡 -1.0

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Table A3: Discussion of Multicriteria Analaysis Options

Option No.	Option	Technical	Environmental	Economic	Cultural	Social/stakeholder	Practicability
1	In fill Coogoorah Park channels	Would reduce potential for generation of acid from acid sulphate soils at Coogoorah Park (and therefore reduce need for maintaining water levels through this area). Reduced capacity of system would mean that flows from upstream would directly flow into estuary (rather than needing to fill Coogoorah Park). Unclear whether this would significantly improve current drivers of acidity in the catchment, further studies would be required, however unlikely to significantly alter due to continual source from Salt and Marshy Creeks.	Source of material to infill channels would be required. Soil in area likely acid sulphate soils therefore may need to be imported from elsewhere, increasing transport and construction emissions. Change in vegetation may be observed and reduces aquatic habitat areas, however returning park to pre-1980s condition. No longer term energy requirements, no chemical usage and no waste streams.	High capital cost. Minimal ongoing cost. Potentially detrimental to economic values of stakeholders and impact on local tourism economy that utilises this area.	Risk of impact to cultural heritage during construction. Unlikely to be culturally acceptable. Would improve cultural values if health of estuary improved.	Current amenity of Coogoorah park will be altered, likely the community will expect and investment to replace the change of amenity if not maintained in its current form. The estuary is likely to experience low water levels and loss of amenity, decreasing visual amenity and recreational activity.	Will require various approvals including planning permits, cultural heritage and works on waterways. Suitable material would need to be sourced and transported. Volume likely to be significant for effective infilling.
4	Maintain water levels in Salt and Marshy Creeks with weir system	Technically feasible method to effectively reduce potential for oxidation of acidic sulphate soils in upper catchment and migration of acidic water downstream. Has been successfully implemented in other Australian river systems. Would likely reduce frequency and duration of events for the river, as creates resilience against fluctuating wet-dry conditions. For previously oxidised ASS, saturated conditions provide limiting factor. Saturation also minimises risks of further oxidation and acid formation. At times of low volume or flow in the river, a weir system may be effective at regulating low pH events in the estuary in that acidic water could be controlled. May require combination with other option for supply of water during dry periods to maintain saturation in upper catchment and water levels at Coogoorah Park. Depending on supply may require a treatment process (e.g. use of recycled water or stormwater to provide water supply and support bioremediation). Ongoing maintenance and addition of water supply for dry periods would mean this is able to be implemented long term.	Weirs and other infrastructure would need to be designed to avoid creating barriers and impacts to fish, eels or other aquatic organisms. Would need further consideration of flow through catchment and volumes required for maintaining functioning estuary system (i.e.. retention of water in the upper catchment to maintain saturation may reduce flow downstream). Minimal environmental impacts during construction or operation, low footprint and low energy consumption. During excavation / installation of weirs there is potential to release acidic sulphate soils, as well as heavy metals. This could be managed through design and construction methods.	Low capital and operational/maintenance cost, depending on number and design. Moderate to high cost for addition of water supply for dry periods.	Would require further assessment to understand potential impacts on cultural values in heathland.	Minimal impact on social and recreational values, public amenity and tourism during implementation and operation. Stakeholder reference group not supportive due to potential for introducing environmental disturbance.	Sandbags less intrusive than earthen berms/construction, readily able to be removed and flexible. Maintenance minimal to keep effectiveness. Approvals required negotiation with land managers, planning permits, cultural heritage and works on waterways. Combined with water supply option would increase logistical and regulatory requirements. May need to be combined with a treatment option for restoration during high flow and acidic events which increases logistical and regulatory requirements.
5	Maintain water levels with weir system (estuary - Coogoorah Park channels)	As per Option #4, technically feasible as it will also maintain water levels in the upper estuary. Additionally weirs in Coogoorah Park will needs to be removal to allow waterflow to pass through or active aeration to ensure the water in Coogoorah Park doesn't become stagnated.	s per Option #4, the weirs will need to allow aquatic species to pass through	As per Option #4 Low capital and operational/maintenance cost.	As per Option #1 there is a risk of impact to cultural heritage during construction. Unlikely to be culturally acceptable. Would improve cultural values if health of estuary improved.	As per Option #1 the current amenity of Coogoorah park will be altered, likely the community will expect and investment to replace the change of amenity if not maintained in its current form. The estuary is likely to experience low water levels and loss of amenity, decreasing visual amenity and recreational activity.	If stagnation is observed, the addition of aeration or removal weir system could be installed as needed instead of upfront. As per option #4 may need to be combined with a treatment option for restoration during high flow and acidic events which increases logistical and regulatory requirements.
6	Introduce water to upper catchment to saturate areas of acidity	Technically feasible method to effectively reduce potential for oxidation of acidic sulphate soils and migration of acidic water downstream. Given extent of acidic soils in upper catchment, large area would require inundation to be effective, likely altering environment and recreational values. Refer to constraints and benefits associated with different water sources (Options XXX). Identification of suitable water source to provide volume required and extent of area that would require inundation render option likely unfeasible for Anglesea.	Not likely to pose major threat to water quality in the estuary, however low salinity and nutrient levels could create a deficit in nutrients impacting ecology (hydrodynamic and chemical modelling required). Estuary environment has adapted to cope with salinity therefore changes to this cycle may affect type of vegetation and aquatic ecosystem (further studies would be required). Minor impacts from construction may exist. Low energy requirements for operation and no ongoing waste streams. Higher water levels in the upper catchment could have effects on fringing vegetation communities. Potential for native vegetation to be impacted during construction of pumping station(s) and pipeline	Ongoing pumping costs associated with the transfer of water to the upper catchment. High to very high capital cost to construct pumping station(s) and pipeline to supply water to upper catchment. Moderate ongoing operational cost.	Risk of impact to cultural heritage during construction. Unlikely to be culturally acceptable. Would improve cultural values if health of estuary improved.	Maintenance of social values once operational (recreational use of estuary).	Requires ongoing maintenance and monitoring of effectiveness. Widespread area, not logistically feasible to apply to majority of catchment. Approvals for the construction of the pipeline and pumping station(s) will likely be required for planning permits, cultural heritage and construction on crown land.
7	Physical capping of acid sources	Technically feasible as a prevention and treatment option for containment of acid sulfate soils, however would need to be widespread in Anglesea catchment to be effective. Preliminary estimates (Wong et al, 2020) of net acidity in the swamplands suggest up to 100 tonnes of lime per hectare would be required to neutralise acid (i.e. up to approx 9,300 tonnes total). Could be targeted at key areas. Extent to which run off surface water could still cause acid events in the river would need further investigation, even if the base is capped. More detailed mapping of acid soils would need to be undertaken in order to understand the location and extend of capping that could be effective. The option of capping would have little or no impact on river flows, unless the river volume profile is modified.	Significant environmental impacts for effective capping to be installed and maintained (flora and fauna). Release of metals during works may present risk to aquatic life.	High capital cost, low ongoing operational / maintenance costs.	Likely unacceptable for protection of traditional owner heritage and to significantly impact upon cultural values.	Access of machinery may be prohibitive and works are likely to be disruptive to social amenity. Potential to protect recreational fishing and recreational use. Release of metals during works may present risk to recreational use.	Requires ongoing maintenance and monitoring of effectiveness. Widespread area, not logistically feasible to apply to majority of catchment.
10	Introduce recycled water to estuary - Anglesea WTP	Organic matter in recycled water would provide some treatment of acidity. Further investigation into characteristics would be required to understand treatment capacity. Existing Anglesea WRP provides class B water for reuse, this will need to be treated to achieve Class A water suitable for human contact. Existing WRP may require modifications if nutrient levels or water quality parameters need reduction. Supply not secure, therefore not a high confidence long term option. Option to combine with bioremediation or lime dosing system prior to adding to river.	Higher nutrient levels expected, treatment may be required to reduce risk of algal blooms. Water quality and vegetation may be impacted by increase in algal blooms, influenced by daily flow rates mixing and stratification within the estuary. If water availability decreases, estuarine water levels may be reduced and result in changes to fringing vegetation communities. Potential for native vegetation to be impacted during construction. Pipeline will likely be located in road reserves in the centre of township.	No pumping costs associated with the transfer of recycled effluent if gravity fed from Anglesea. Additional costs required for treatment of Class B water to Class A water. Moderate ongoing operational cost.	Risk of impact to cultural heritage during construction. Unlikely to be culturally acceptable. Would improve cultural values if health of estuary improved.	Reduction in water level of the estuary is possible due to low security of supply. Recycled effluent into the estuary is likely to be an issue for public due to perception and to maintain recreational use. Recycled effluent will need to be Class A to be suitable for human contact. Pipeline infrastructure would traverse township in close proximity to shopping centre and recreational areas. Public education would be required.	Approvals are likely to be required for planning permits, cultural heritage, construction on crown land, works on waterways, coastal management Act, discharge licence, and approval for installing plant and equipment. Volume of water available from WRP is a primary limitation - volume discharged varies significantly, influenced by tourist populations in summer and holiday periods. Increased daily volumes may be required in dry years.

11	Introduce recycled water to estuary - Black Rock WTP	As per Option #10 further investigation into the characteristic would be required. Class A available from Black Rock which would require construction of a pipeline. AS per option #10, supply not secure, therefore not a high confidence long term option but option could be combined with bioremediation or lime dosing system prior to adding to river.	Elevated nutrients levels are not expected as with water sourced from the Anglesea WTP as the water will be of Class A quality. Environmental impacts becoming more significant if recycled water sourced from Black Rock rather than Anglesea WTP.	High to very high capital cost if sourced from other Black Rock, with moderate ongoing operational cost.	Risk of impact to cultural heritage during construction. Unlikely to be culturally acceptable. Would improve cultural values if health of estuary improved.	As per option #10 reduction in water level of the estuary is possible due to low security of supply. Likely less of an issue with the community as the water from Black Rock WTP will be Class A.	As per Option #10 approvals are likely required. The pumping of the recycled water will require ongoing operation costs and upkeep.
12	Introduction of seawater to estuary via dredging of shallow artificial openings	May provide some relief from low pH conditions in the estuary due to buffering capacity of seawater and dilution, however does not alter sources of acidity and may have only local influence for majority of tidal heights. Not controlling pH as far up-stream of the river as possible, therefore less effective than seawater pipeline/pumping option. Not a feasible long term solution as maintenance of an open estuary would result in a shift in the sand deposition further upstream.	Estuary would become more permanently saline environment, potentially affecting aquatic and terrestrial ecosystems. This would be a fundamental change to natural flows and water level related pressures, the impact of which is unknown, and impact on environment including local wildlife during dredging operations is also unknown. The impact or change to tidal movements in the estuary is unknown. Similarly, sediment movement impacts and effects is unknown however likely sand deposition would most likely shift further upstream. Longer term potential for increased negative effects due to changes in sand berm location and ecosystem of the estuary. The protection of aquatic life, against acidic events, in the fresh water sections of the river is not possible with this option. The fresh water sections of the river would not be protected. Improves access for marine fish to come into estuary.	High capital and ongoing cost. Potentially detrimental to economic values of stakeholders and impact on tourism.	May not be supported by Traditional Owners due to artificial change to flow and natural state. Unlikely to have positive impact on cultural values. General consensus with Traditional Owners to let natural conditions take place.	Noise and visual impact during dredging operations would be significant. Impact on public during dredging operations. Longer term potential for negative effects on social values due to changes in sand berm location and ecosystem of the estuary. Ongoing impact to social values due to continual upkeep required.	Requires continual upkeep. The longevity of dredging the beach would be difficult to predict, but it is likely that the dredged portion would collapse over time, unless a structure is built to maintain the dredged volume.
13	Introduction of seawater to estuary via dredging of deep artificial openings	As per option #13 limited effectiveness expected. Continual deep estuary opening may result in lowering of water levels in estuary and exposure of acid sulphate soils in Coogoorah Park, further contributing to the issue.	Similar to Option #13, however deeper dredging would have a more significant impact on environmental receptors than shallow dredging.	High capital and ongoing cost. Potentially detrimental to economic values of stakeholders and impact on tourism.	As per Option #13, may not be supported by Traditional Owners	As per option #13, although deeper dredging would have a more significant impact due to the additional dredging works required	As per option #13, will require continual upkeep.
14	Introduce sea water to estuary via offshore pump and pipe	Feasible option for maintaining water levels to reduce potential for exposing acid sulfate soils within estuary and provides buffering capacity and dilution to regulate acidity from Salt and Marshy Creeks. Further studies would be required to factor in seasonal flow and understand requirements for buffering capacity as well as volumes. Use of a pump and pipeline upstream rather than tidal harvesting would provide more flexible approach to respond to pH conditions. Control of sea water pumping rates can be controlled by signals taken from pH probe instrumentation. A testing program could be set up to predict the amount of sea water required to neutralise acidic loading. Would require ongoing pumping and maintenance of pipeline to maintain effectiveness.	Estuary is adapted to cope with salinity however introduction of seawater on a more continuous basis may change this to a permanently saline system, rather than the stratified or fluctuating conditions that occur now. Protection of aquatic life against acidic events in freshwater is not possible with this option. Not controlling pH as far up-stream as possible increases the risk of metal release from sediment. An increase in salinity may impact vegetation and any freshwater fish species and organisms, benefit estuarine and marine fish species, and freshwater dependent invertebrates may be replaced with estuarine dependent invertebrates. Overall, this option as a feasible solution to reducing extended periods of low pH however would improve the environmental health of the estuary compared to these periods. Construction impacts to the foreshore / marine area, however construction could be located away from the township to reduce noise and visual impacts. Impacts could be reduced by trenchless construction techniques. Pumping may impact local marine environment or points of inflow to estuary. Plant and equipment would require measures to prevent animal entry. Barriers for the impact on localised flow on local ecology and the risk of not reducing solubilisation of metals in the river will need to be implemented.	High capital cost (depending on design and whether desalination required). Moderate ongoing operational costs.	Potential for some impacts on cultural values due to possibility of changes in ecosystems from alteration of salinity cycles of estuary. Positive maintenance of cultural values related to fishing and general health of the system. Potential impacts to traditional owner values during construction that would require management	Impacts of increased salinity may be a cause of concern for the community. Construction impacts on the foreshore and inshore areas are likely to be high profile (noise/visual amenity). Health and safety risks from marine (boating activity and marine biota/divers) and mechanical plant aspects. Increased salinity may benefit recreational fishing of typical angling fish in the estuary.	Infrastructure requirements include offshore intake pipeline, onshore pumping station and discharge pipeline to estuary. There is no existing infrastructure. Quantity of sea water available is feasible for reduced flows. Likely to require approvals for planning permits, cultural heritage, construction on crown land, works on waterways and Coastal Management Act. Requires land purchase or easements for seawater pump station and pipeline. Pumping techniques are likely to collect seaweed and may require intermittent cleaning.
16	Introduce water to estuary from stormwater harvesting	Feasible option to maintain water levels in estuary and avoid exposure of acid sulfate soils from this portion of the catchment, provide some regulation / treatment of low pH. Organic matter in stormwater would provide some treatment of acidity. Further investigation into characteristics of stormwater would be required to understand treatment capacity.	Water quality risk is low as stormwater already discharges into the river. Flushing of sediment in the system may be reduced. Risks of litter and pollutants from urban catchments (manageable using traps). Risks of algal blooms in the storage basin due to retention time. Stormwater flows are unlikely to alter vegetation and fauna communities. Significant impacts expected during construction, including noise, dust and vibration, loss of vegetation and/or amenity. If storage is constructed below the water table, potential to activate acid sulfate soils exists. Harvested stormwater runoff may reduce discharge to the river. Overall water balance and outflow to the Bass Strait will need consideration. Sizing the system on average rainfall is inadequate. Water quality may need to be monitored due to risks of algal blooms.	Very high capital cost (depending on design and whether treatment required). Moderate ongoing operational costs.	Potential for some impacts on cultural values due to possibility of changes in ecosystems from alteration of salinity cycles of estuary. Positive maintenance of cultural values related to fishing and general health of the system. Risk of impacts to traditional owner values during construction that would require management	Infrastructure requirements and footprint are likely to make this option undesirable.	Approvals are likely to be required for planning permits, cultural heritage and construction on crown land. Infrastructure required fits with the stormwater system that is responsibility of the council. Surf Coast Shire would own and operate assets.

18	In-situ addition of a neutralising agent (e.g. lime) to ASS in marshes	Technically feasible as a prevention and treatment option for containment of acid sulfate soils, however would need to be widespread in Anglesea catchment to be effective. Preliminary estimates (Wong et al, 2020) of net acidity in the swamplands suggest up to 100 tonnes of lime per hectare would be required to neutralise acid (i.e. up to approx 9,300 tonnes total). Could be targeted at key areas. Extent to which run off surface water could still cause acid events in the river would need further investigation, even if the base is capped. More detailed mapping of acid soils would need to be undertaken in order to understand the location and extend of capping that could be effective. The option of capping would have little or no impact on river flows, unless the river volume profile is modified.	Significant environmental impacts for effective capping to be installed and maintained (flora and fauna). Release of metals during works may present risk to aquatic life.	High capital cost, low ongoing operational / maintenance costs.	Likely unacceptable for protection of traditional owner heritage and to significantly impact upon cultural values.	Access of machinery may be prohibitive and works are likely to be disruptive to social amenity. Potential to protect recreational fishing and recreational use. Release of metals during works may present risk to recreational use.	Requires ongoing maintenance and monitoring of effectiveness. Widespread area, not logistically feasible to apply to majority of catchment.
19	In-situ bioremediation of sulfidic material in marshes	Encourage anaerobic conditions to form via increasing organic loads, to enforce sulfidic formation in freshwater environments. Essentially a reversal of the oxidation reaction that generate acidity from exposed acid sulfate soils. Use of local native species to establish plants and habitat resources around the river estuary and upper catchment. Organic matter (e.g. mulch) can be able quick to control acidic hot spots. Long term revegetation of areas to supply continued organic matter. Effective treatment method however unlikely to have significant impact if completed in localised areas. Would be more effective to consider bioremediation in an ex-situ treatment area (see other option). Some areas are already heavily vegetated therefore this option may not provide significant change to managing the issue.	May improve water quality and improve environmental health if successful, however implementation would need to consider specific local ecosystems including plant species and maintenance of aquatic habitats. During times of non-acidic water being present, there is no change or disruption in the environment or surrounds. Widespread application of organic matter to upper catchment may have detrimental effect, design would need to consider. May provide a refuge point for ecology, and improve degraded habitats. Revegetation will have little to no impact on river flows.	High capital cost and low ongoing operational costs, depending on changes to conditions and requirement for ongoing addition of organic material.	Alteration of current environment therefore unlikely to be acceptable to Traditional Owners or protective of cultural values. Would improve cultural values if health of estuary improved.	Potential to improve recreational use by establishing new habitats. Anaerobic conditions can emit hydrogen sulfide which may produce offensive odours for recreational users. May be some minor disruption to recreational areas, depending on selected locations for application.	Encourage anaerobic conditions to form via increasing organic loads, to enforce sulfidic formation in freshwater environments. Essentially a reversal of the oxidation reaction that generate acidity from exposed acid sulfate soils. Use of local native species to establish plants and habitat resources around the river estuary and upper catchment. Organic matter (e.g. mulch+K18:O18) can be able quick to control acidic hot spots. Long term revegetation of areas to supply continued organic matter. Effective treatment method however unlikely to have significant impact if completed in localised areas. Would be more effective to consider bioremediation in an ex-situ treatment area (see other option). Some areas are already heavily vegetated therefore this option may not provide significant change to managing the issue.
20	Install passive alkaline berms for treatment of acidity in-situ within river / open limestone drains	Presence of alkaline materials through the entire catchment / estuary is likely to somewhat regulate pH variations, however likely significant points of installation would be required to be broadly effective. However, the slow release or alkaline rocks are still regarded as a relatively ineffective method of managing alkalinity vs acid demand and river flows. May not be effective at controlling pH during acidic events. Surface of gravel / rocks becomes coated with calcium sulphate soon after reaction with acid occurring, therefore reduces in effectiveness within short timeframe. Use of rock or solid forms of alkali is not a reliable means of maintaining a narrow pH control range. Local pH close to alkaline rocks may be high however may not effectively treat entire estuary volume. Installation within specific points (e.g. Salt Creek diversion drain) will be less effective at regulating pH in other areas or from other sources. Less effective than a pumping system with treatment ex-situ. Could be combined with other options to increase effectiveness.	Variations in environmental flows and acid loading will cause a varying level of refuge, high river flows and extreme acidic conditions may render refuge point ineffective. The required quantity of material dissolution into water to neutralise pH cannot be controlled. Use of solid alkali materials may not result in an effective means of controlling pH and consequent fish preservation during acidic events. Excessive pH buffering could be harmful to fish when there is little to no acid present. Solid forms of alkaline materials will require regular replacement and disposal due to surface becoming ineffective over time. No impact on river flows.	Low to moderate capital cost. Ongoing low to moderate operational cost, depending on acid load. Potentially detrimental to economic values of stakeholders and impact on local tourism economy if acid events not fully mitigated.	Minor impact during installation and replacement of berms. Unlikely to be significant issue or improvement for cultural values.	Minor impact during installation and replacement of berms. Unlikely to be significant issue and minor improvement in social values for stakeholders.	Likely to require approvals for planning permits, cultural heritage, construction on crown land and works on waterways. Requires continual maintenance. Unlikely to be effective during acid events therefore would need to be combined with another option.
23	Constructed wetland (reducing and alkalinity producing type)	Likely to be effective at managing / regulating acidic flows downstream. Depending on position and proportional contribution of other drivers of acidity effectiveness and longevity may not fully address issue, however feasible option for reducing significance and duration of acid events in estuary. Could be combined with other options (e.g. weir system as avoidance) to improve effectiveness.	Environmental impact during construction would depend on selected location. Little to no impact if installed in existing available area (e.g. Alcoa mine pit), some impact on vegetation and potential for disturbance of sulfidic materials and metals if new area was constructed. Design would need to protect fish and eel migration and other aquatic organisms and habitats. Overall would be positive environmental benefit on river system from reduced impact and duration of low pH events.	Moderate capital cost, low operational cost (periodic maintenance and monitoring)	Minor impact during installation possible which would require management. Unlikely to be significant issue or improvement for cultural values.	May be some impact on recreational access, amenity and noise during construction, depending on location and design. Once implemented likely to improve social values. Would require negotiation with regulators and land managers to determine if acceptable.	Likely to require approvals for planning permits, cultural heritage, construction on crown land and works on waterways. Would require minimal long term maintenance.
24	Insitu passive permeable reactive barrier	Presence of alkaline materials through the entire catchment / estuary is likely to somewhat regulate pH variations, however likely significant points of installation would be required to be broadly effective. The slow release or alkaline rocks are still regarded as a relatively ineffective method of managing alkalinity vs acid demand and river flows. May not be effective at controlling pH during acidic events. Surface of gravel / rocks becomes coated with calcium sulphate soon after reaction with acid occurring, therefore reduces in effectiveness within short timeframe. Use of rock or solid forms of alkali is not a reliable means of maintaining a narrow pH control range. Local pH close to alkaline rocks may be high however may not effectively treat entire estuary volume. Installation within specific points (e.g. Salt Creek diversion drain) will be less effective at regulating pH in other areas or from other sources. Less effective than a pumping system with treatment ex-situ. Could be combined with other options to increase effectiveness.	Variations in environmental flows and acid loading will cause a varying level of refuge, high river flows and extreme acidic conditions may render refuge point ineffective. The required quantity of material dissolution into water to neutralise pH cannot be controlled. Use of solid alkali materials may not result in an effective means of controlling pH and consequent fish preservation during acidic events. Excessive pH buffering could be harmful to fish when there is little to no acid present. Solid forms of alkaline materials will require regular replacement and disposal due to surface becoming ineffective over time. No impact on river flows.	Low to moderate capital cost. Ongoing low to moderate operational cost, depending on acid load. Potentially detrimental to economic values of stakeholders and impact on local tourism economy if acid events not fully mitigated.	Minor impact during installation and replacement of berms. Unlikely to be significant issue or improvement for cultural values.	Minor impact during installation and replacement of berms. Unlikely to be significant issue and minor improvement in social values for stakeholders.	Likely to require approvals for planning permits, cultural heritage, construction on crown land and works on waterways. Requires continual maintenance. Unlikely to be effective during acid events therefore would need to be combined with another option.
25	Ex-situ filtration and membrane water treatment system	Technically feasible option for treating acidity. Could be triggered based on real-time pH measurements and treatment system start within a few hours. By passing the acidic water through a membrane the acid can be "filtered out". Filters / membranes would require ongoing replacement to maintain effectiveness. To be most effective would be most suitable to be installed near confluence of Salt and Marshy Creek or in upper catchment.	Concentrated sulphate rich wastewater generated would require disposal or discharge (e.g. to the ocean or a wastewater treatment facility). Potential for impacts to other environments, depending on concentrations and receiving point. The option of treatment of acidic water via a membrane plant will not impact river flows. Neutral pH, or the control of acid events in the river is aimed at protecting aquatic life.	High capital cost, with increased costs for additional systems throughout catchment. Operational costs low for maintenance and waste disposal.	Positive improvement/maintenance of cultural values related to fishing and general health of the system. Potential impacts to traditional owner values during construction that would require management. Potentially unacceptable and impacts to values related to waste stream discharge point (e.g. if ocean).	Access of machinery to install system in upper catchment may be prohibitive and works may be disruptive to social amenity. Potential to protect recreational fishing and recreational use from implementation. Noise would result from pumps but this can be insulated. Unlikely to be acceptable to stakeholders due to environmental / sustainability concerns.	Maintenance not practical due to requirement to swap filtration/membrane system once spent and dispose of. Regulatory requirements would include planning permits, cultural heritage, construction on crown land and works on waterways. Additional regulatory requirements would be related to direction of wastewater stream.

26	Ex-situ treatment by alkali material dosing	Technically feasible option for treating acidity. As per option #25, could be triggered based on real-time pH measurements and treatment system start within a few hours. By pumping acidic water out of the estuary and treating, acidic water can be treated and returned to the estuary. Technology will require ongoing cost of alkali dosing material. To be most effective would be most suitable to be installed near confluence of Salt and Marshy Creek or in upper catchment.	Generates waste spent resin which would require disposal long term. Ongoing energy consumption for running pumps and treatment systems. Some impact to vegetation during construction may occur, depending on location/s selected. The impact of water inlet and outlet systems would need careful consideration to avoid adverse impact on aquatic life. Neutral pH, or the control of acid events in the river is aimed at protecting aquatic life and the recreational amenity surrounding the river. Resins can also be designed to remove heavy metals from river and estuary water. Would have a positive impact on pH and water quality of the estuary. The option of treatment of acidic water via ion-exchange resins will not impact river flows. Neutral pH, or the control of acid events in the river is aimed at protecting aquatic life.	High capital cost, with increased costs for additional systems throughout catchment. Operational costs low for maintenance and waste disposal.	Positive improvement/maintenance of cultural values related to fishing and general health of the system. Potential impacts to traditional owner values during construction that would require management. Potentially unacceptable and impacts to values related to waste stream discharge point (e.g. if ocean).	Access of machinery to install system in upper catchment may be prohibitive and works may be disruptive to social amenity. Potential to protect recreational fishing and recreational use from implementation. Noise would result from pumps but this can be insulated. Unlikely to be acceptable to stakeholders due to environmental / sustainability concerns.	Maintenance not practical due to requirement to swap filtration/membrane system once spent and dispose of. Will need to be combined with additional treatment to effectively manage low pH events.
27	Ex-situ active resin ion-exchange treatment system	Would need to be cation exchange resin to be effective. Technically feasible option for treating acidity. Could be triggered based on real-time pH measurements and treatment system start within a few hours. The passing of acidic water through a resin bed, or series of resin beds allows target ions such as sulphates to be fixed onto the resin, and depending on the types of resins, the sulphates would either be replaced with a more benign ion, or taken a step further, the water could be "demineralised." At some point in time, after a certain mass of sulphate has been fixed or adsorbed onto the resin, the resin becomes "exhausted" and at this point the resin can either be replaced or re-generated. To be most effective would be most suitable to be installed near confluence of Salt and Marshy Creek or in upper catchment.	Generates waste spent resin which would require disposal long term. Ongoing energy consumption for running pumps and treatment systems. Some impact to vegetation during construction may occur, depending on location/s selected. The impact of water inlet and outlet systems would need careful consideration to avoid adverse impact on aquatic life. Neutral pH, or the control of acid events in the river is aimed at protecting aquatic life and the recreational amenity surrounding the river. Resins can also be designed to remove heavy metals from river and estuary water. Would have a positive impact on pH and water quality of the estuary. The option of treatment of acidic water via ion-exchange resins will not impact river flows.	High capital cost, with increased costs for additional systems throughout catchment. Operational costs low for maintenance and waste disposal.	Positive improvement/maintenance of cultural values related to fishing and general health of the system. Potential impacts to traditional owner values during construction that would require management.	Access of machinery to install system in upper catchment may be prohibitive and works may be disruptive to social amenity. Potential to protect recreational fishing and recreational use and reduce concentrations of other potential contaminants (e.g. metals) from implementation. Noise would result from pumps but this can be insulated. Unlikely to be acceptable to stakeholders due to environmental / sustainability concerns.	Maintenance not practical due to requirement to swap resin once spent and dispose. Typical footprint for an ion-exchange resin system is 6 square metres (2m x 3m).
28	In-situ dosing with alkali materials	Dry powders or solid briquette forms of neutralizing materials would present difficulty in terms of mixing and diluting evenly into the river. The risk of localized effects such as high pH would be significantly increased if dry materials are applied into the river. Liquid materials can be dosed at a controlled rate (known mass) as a response to an acidic river condition. The success of pH control with neutralizing materials is highly dependent on the integrity of the pH measurement and control instrumentation, and the ability to mix and dilute treatment materials into water.	Option would overall improve protection of environmental values. Design would need to consider differences in fresh and saline water, target pH and likely change to dissolved solids. Precipitation may also occur which may impact aquatic organisms and vegetation. Greater potential for impacts if direct treatment applied in upper catchment. Low energy use for dosing system compared to other options. No waste generation.	Cost depends on number of dosing stations - low to moderate cost per station. Ongoing low to moderate operational cost, depending on acid load.	Unlikely to have negative effect on cultural values. Positive improvement related to general health of system and cultural values.	Neutral pH, or the control of acid events in the river is aimed at protecting recreational amenity surrounding the river. Potential hazards due to chemical storage and dosing near recreational areas however this could be managed and would be low risk and disruption.	Typical footprint for a liquid dosing system is 25 square meters (5m x 5m). Multiple dosing systems may be required. Control measures include security fencing or barriers to uncontrolled entry, a catchment bund for any chemical spills. Of the chemicals that would be considered, magnesium hydroxide offers the lowest hazardous rating and can be manufactured as a non-dangerous good. Likely to require approvals for planning permits, cultural heritage, construction on crown land and works on waterways.
29	In-situ bioremediation of water	Less effective option than ex-situ bioremediation system. Effective treatment method however unlikely to have significant impact if completed in localised areas.	Application of a treatment option in-situ would likely maintain connectivity through the river system for fish and other aquatic organisms. Potential for impacts to aquatic organisms and habitats during construction and implementation. Potential for increased algal blooms due to higher nutrient load. Depending on location of implementation may be some impact to environment to create access, in particular in upper catchment.	Moderate capital cost, low ongoing operational costs depending on changes to conditions and requirement for treatment.	Alteration of current environment therefore unlikely to be acceptable to Traditional Owners or protective of cultural values. Would improve cultural values if health of estuary improved.	Anaerobic conditions can emit hydrogen sulfide which may produce offensive odours for recreational users. May be some minor disruption to recreational areas, depending on selected locations for application.	Logistically feasible location would need to be identified - Coogoorah Park channels may be appropriate. Logistically difficult in upper catchment due to access constraints without significant environmental impact. Will require various approvals including planning permits, cultural heritage and works on waterways.

Table A4: MCA Screening for different sensitivities

2. Excluding technical (already identified as feasible)

ID	Option	Applicable area		Technical					Practicability						Environmental							Cultural				Economic					Social/stakeholder					Total score
		Upper catchment / estuary	Coogoorah Park	Relative effectiveness in achieving and	Timeframe for achieving effectiveness	Flexibility to be implemented as long term solution	Total category score	Weighted category score	Timeframe for implementation & effectiveness	Logistical constraints (access,	Legislative, regulatory and permit	Ongoing maintenance requirements	Total category score	Weighted category score	Energy and resource consumption	Waste disposal requirements	Climate resiliency (ability to be scaled up etc.)	Potential effects on the broader environment	Potential risks to aquatic and terrestrial	Total category score	Weighted category score	Effects on areas of cultural significance	Acceptance by Traditional Owners	Total category score	Weighted category score	Relative capital cost	Relative operational cost	Relative potential effects on local economy	Total category score	Weighted category score	Acceptance by community, regulators,	Effects on recreational values (swimming,	Amenity impacts (dust, noise, footprint, visual,	Total category score	Weighted category score	
	Weighting								20.0%						20.0%							20.0%				20.0%					20.0%					100%
	Maximum category score												8	2.00						10	2.00			4	2.00				6	2.00				6	2.00	10
1	In fill Coogoorah Park channels		■						0	-1	-1	2	0	0.0	-2	2	2	-1	-1	0	0.0	-1	-1	-2	-1.0	1	2	-1	2	0.7	-2	-2	-2	-6	-2.0	🔴 -2.3
4	Maintain water levels with weir system (upper catchment)	■							2	-1	1	1	3	0.8	0	2	0	-1	-2	-1	-0.2	-1	-1	-2	-1.0	1	1	1	3	1.0	-2	-1	-1	-4	-1.3	🟡 -0.8
5	Maintain water levels with weir system (estuary - Coogoorah Park channels)		■						1	1	1	1	4	1.0	0	2	0	1	-1	2	0.4	0	0	0	0.0	1	1	-1	1	0.3	-2	-1	-1	-4	-1.3	🟢 0.4
6	Introduce water to upper catchment to saturate areas of acidity	■							-1	-2	-1	-1	-5	-1.3	-2	2	1	-2	-1	-2	-0.4	-1	-1	-2	-1.0	-1	-1	0	-2	-0.7	-2	1	-1	-2	-0.7	🔴 -4.0
7	Physical capping of acid sources	■	■						-1	-1	-2	-1	-5	-1.3	-1	2	-1	-2	-2	-4	-0.8	-2	-2	-4	-2.0	-1	-1	-1	-3	-1.0	-2	-1	-2	-5	-1.7	🔴 -6.7
10	Introduce recycled water to estuary - Anglesea WTP	■	■						-1	-2	-2	-1	-6	-1.5	-1	2	1	-1	-1	0	0.0	-1	0	-1	-0.5	-1	-1	1	-1	-0.3	1	1	0	2	0.7	🔴 -1.7
11	Introduce recycled water to estuary - Black Rock WTP	■	■						-1	-1	-2	-1	-5	-1.3	-1	2	1	-1	-1	0	0.0	-1	0	-1	-0.5	-2	-1	1	-2	-0.7	1	1	0	2	0.7	🔴 -1.8
12	Introduction of seawater to estuary via dredging of shallow artificial openings	■							1	1	-1	-2	-1	-0.3	-1	2	1	-1	-2	-1	-0.2	-2	-2	-4	-2.0	1	-1	-1	-1	-0.3	0	-1	-2	-3	-1.0	🔴 -3.8
13	Introduction of seawater to estuary via dredging of deep artificial openings	■							1	1	-1	-2	-1	-0.3	-1	2	2	-2	-2	-1	-0.2	-2	-2	-4	-2.0	0	-1	-1	-2	-0.7	-1	-1	-2	-4	-1.3	🔴 -4.5
14	Introduce sea water to estuary via offshore pump and pipe	■	■						-1	1	-2	-1	-3	-0.8	-1	2	2	-1	0	2	0.4	-1	0	-1	-0.5	-1	-1	1	-1	-0.3	1	1	0	2	0.7	🟡 -0.5
16	Introduce water to estuary from stormwater harvesting	■	■						0	-2	-1	-2	-5	-1.3	-1	1	-1	-1	-2	-4	-0.8	0	0	0	0.0	-1	-1	0	-2	-0.7	-1	-1	-1	-3	-1.0	🔴 -3.7
18	In-situ addition of a neutralising agent (e.g. lime) to ASS in marshes	■	■						0	-1	-1	-1	-3	-0.8	-1	2	1	-2	-2	-2	-0.4	-2	-2	-4	-2.0	-1	-1	-1	-3	-1.0	-2	1	-2	-3	-1.0	🔴 -5.2
19	In-situ bioremediation of sulfidic material in marshes	■	■						0	-1	-1	-1	-3	-0.8	-1	2	1	-2	-2	-2	-0.4	-2	-2	-4	-2.0	-1	-1	-1	-3	-1.0	-2	1	-2	-3	-1.0	🔴 -5.2
20	Install passive alkaline berms for treatment of acidity in-situ within river / open limestone drains	■							2	2	1	-1	4	1.0	1	1	2	1	1	6	1.2	0	0	0	0.0	2	1	0	3	1.0	2	0	0	2	0.7	🟢 3.9
23	Constructed wetland (reducing and alkalinity producing type)	■							0	2	0	1	3	0.8	0	2	1	1	0	4	0.8	1	0	1	0.5	0	1	1	2	0.7	2	1	1	4	1.3	🟢 4.1
24	Insitu passive permeable reactive barrier	■							2	2	1	-1	4	1.0	1	-1	0	1	0	1	0.2	0	0	0	0.0	1	1	1	3	1.0	0	0	1	1	0.3	🟢 2.5
25	Ex-situ filtration and membrane water treatment system	■							-1	1	-1	-2	-3	-0.8	-2	-2	1	-1	1	-3	-0.6	0	0	0	0.0	-2	-2	0	-4	-1.3	1	2	-1	2	0.7	🔴 -2.0
26	Ex-situ treatment by alkali material dosing	■							-1	1	-1	-2	-3	-0.8	-2	2	1	-1	1	1	0.2	-1	0	-1	-0.5	-1	-1	0	-2	-0.7	-1	1	-1	-1	-0.3	🔴 -2.1
27	Ex-situ active resin ion-exchange treatment system	■							-1	1	-1	-2	-3	-0.8	-2	-2	1	-1	1	-3	-0.6	0	0	0	0.0	-2	-2	0	-4	-1.3	0	2	-1	1	0.3	🔴 -2.4
28	In-situ dosing with alkali materials	■							0	2	-1	-1	0	0.0	-1	1	1	0	1	2	0.4	0	0	0	0.0	-1	-1	0	-2	-0.7	2	1	-1	2	0.7	🟢 0.4
29	In-situ bioremediation of water	■							1	2	-2	0	1	0.3	-1	1	1	-1	-2	-2	-0.4	0	0	0	0.0	0	-1	0	-1	-0.3	-1	-1	-1	-3	-1.0	🔴 -1.5

3. Excluding cultural, economic and social/stakeholder

ID	Option	Applicable area		Technical					Practicability						Environmental							Cultural				Economic					Social/stakeholder					Total score
		Upper catchment / estuary	Coogoorah Park	Relative effectiveness in achieving and	Timeframe for achieving effectiveness	Flexibility to be implemented as long term solution	Total category score	Weighted category score	Timeframe for implementation	Logistical constraints (access,	Legislative, regulatory and permit	Ongoing maintenance requirements	Total category score	Weighted category score	Energy and resource consumption	Waste disposal requirements	Climate resiliency (ability to be scaled up etc.)	Potential effects on the broader environment	Potential risks to aquatic and terrestrial	Total category score	Weighted category score	Effects on areas of cultural significance	Acceptance by Traditional Owners	Total category score	Weighted category score	Relative capital cost	Relative operational cost	Relative potential effects on local economy	Total category score	Weighted category score	Acceptance by community, regulators,	Effects on recreational values (swimming,	Amenity impacts (dust, noise, footprint, visual,	Total category score	Weighted category score	
	Weighting			33.3%					33.3%						33.3%																					100%
	Maximum category score						6	3.33					8	3.33						10	3.33				0.00					0.00					0.00	10
1	In fill Coogoorah Park channels		■	1	0	0	1	0.6	0	-1	-1	2	0	0.0	-2	2	2	-1	-1	0	0.0															🟢 0.6
4	Maintain water levels with weir system (upper catchment)	■		1	1	-1	1	0.6	2	-1	1	1	3	1.3	0	2	0	-1	-2	-1	-0.3															🟢 1.5
5	Maintain water levels with weir system (estuary - Coogoorah Park channels)		■	1	1	-1	1	0.6	1	1	1	1	4	1.7	0	2	0	1	-1	2	0.7															🟢 2.9
6	Introduce water to upper catchment to saturate areas of acidity	■		1	-1	1	1	0.6	-1	-2	-1	-1	-5	-2.1	-2	2	1	-2	-1	-2	-0.7															🔴 -2.2
7	Physical capping of acid sources	■	■	1	1	1	3	1.7	-1	-1	-2	-1	-5	-2.1	-1	2	-1	-2	-2	-4	-1.3															🔴 -1.8
10	Introduce recycled water to estuary - Anglesea WTP	■	■	2	1	2	5	2.8	-1	-2	-2	-1	-6	-2.5	-1	2	1	-1	-1	0	0.0															🟢 0.3
11	Introduce recycled water to estuary - Black Rock WTP	■	■	2	1	2	5	2.8	-1	-1	-2	-1	-5	-2.1	-1	2	1	-1	-1	0	0.0															🟢 0.7
12	Introduction of seawater to estuary via dredging of shallow artificial openings	■		0	1	-1	0	0.0	1	1	-1	-2	-1	-0.4	-1	2	1	-1	-2	-1	-0.3															🟡 -0.8
13	Introduction of seawater to estuary via dredging of deep artificial openings	■		1	1	-1	1	0.6	1	1	-1	-2	-1	-0.4	-1	2	2	-2	-2	-1	-0.3															🟡 -0.2
14	Introduce sea water to estuary via offshore pump and pipe	■	■	2	2	2	6	3.3	-1	1	-2	-1	-3	-1.3	-1	2	2	-1	0	2	0.7															🟢 2.8
16	Introduce water to estuary from stormwater harvesting	■	■	1	-1	1	1	0.6	0	-2	-1	-2	-5	-2.1	-1	1	-1	-1	-2	-4	-1.3															🔴 -2.9
18	In-situ addition of a neutralising agent (e.g. lime) to ASS in marshes	■	■	2	2	2	6	3.3	0	-1	-1	-1	-3	-1.3	-1	2	1	-2	-2	-2	-0.7															🟢 1.4
19	In-situ bioremediation of sulfidic material in marshes	■	■	1	1	2	4	2.2	0	-1	-1	-1	-3	-1.3	-1	2	1	-2	-2	-2	-0.7															🟢 0.3
20	Install passive alkaline berms for treatment of acidity in-situ within river / open limestone drains	■		1	1	2	4	2.2	2	2	1	-1	4	1.7	1	1	2	1	1	6	2.0															🟢 5.9
23	Constructed wetland (reducing and alkalinity producing type)	■		1	1	2	4	2.2	0	2	0	1	3	1.3	0	2	1	1	0	4	1.3															🟢 4.8
24	Insitu passive permeable reactive barrier	■		1	1	2	4	2.2	2	2	1	-1	4	1.7	1	-1	0	1	0	1	0.3															🟢 4.2
25	Ex-situ filtration and membrane water treatment system	■		1	2	2	5	2.8	-1	1	-1	-2	-3	-1.3	-2	-2	1	-1	1	-3	-1.0															🟢 0.5
26	Ex-situ treatment by alkali material dosing	■		1	2	2	5	2.8	-1	1	-1	-2	-3	-1.3	-2	2	1	-1	1	1	0.3															🟢 1.9
27	Ex-situ active resin ion-exchange treatment system	■		1	2	2	5	2.8	-1	1	-1	-2	-3	-1.3	-2	-2	1	-1	1	-3	-1.0															🟢 0.5
28	In-situ dosing with alkali materials	■		1	2	2	5	2.8	0	2	-1	-1	0	0.0	-1	1	1	0	1	2	0.7															🟢 3.4
29	In-situ bioremediation of water	■		1	-1	1	1	0.6	1	2	-2	0	1	0.4	-1	1	1	-1	-2	-2	-0.7															🟢 0.3

Table A4: MCA Screening for different sensitivities

4. Weighted categories

				Technical					Practicability						Environmental							Cultural				Economic					Social/stakeholder					
				Relative effectiveness in achieving and	Timeframe for achieving effectiveness	Flexibility to be implemented as long term solution	**Total category score**	**Weighted category score**	Timeframe for implementation	Logistical constraints (access,	Legislative, regulatory and permit	Ongoing maintenance requirements	**Total category score**	**Weighted category score**	Energy and resource consumption	Waste disposal requirements	Climate resiliency (ability to be scaled up etc.)	Potential effects on the broader environment	Potential risks to aquatic and terrestrial	**Total category score**	**Weighted category score**	Effects on areas of cultural significance	Acceptance by Traditional Owners	**Total category score**	**Weighted category score**	Relative capital cost	Relative operational cost	Relative potential effects on local economy	**Total category score**	**Weighted category score**	Acceptance by community, regulators,	Effects on recreational values (swimming,	Amenity impacts (dust, noise, footprint, visual,	**Total category score**	**Weighted category score**	**Total score**
		Weighting		20.0%					20.0%						20.0%							15.0%				10.0%					15.0%					**100%**
		Maximum category score					6	2.00					8	2.00						10	2.00			4	1.50				6	1.00				6	1.50	10
		Applicable area																																		
ID	**Option**	**Upper catchment / estuary**	**Coogoorah Park**																																	
1	In fill Coogoorah Park channels		■	1	0	0	1	0.3	0	-1	-1	2	0	0.0	-2	2	2	-1	-1	0	0.0	-1	-1	-2	-0.8	1	2	-1	2	0.3	-2	-2	-2	-6	-1.5	● -1.6
4	Maintain water levels with weir system (upper catchment)	■		1	1	-1	1	0.3	2	-1	1	1	3	0.8	0	2	0	-1	-2	-1	-0.2	-1	-1	-2	-0.8	1	1	1	3	0.5	-2	-1	-1	-4	-1.0	● -0.4
5	Maintain water levels with weir system (estuary - Coogoorah Park channels)		■	1	1	-1	1	0.3	1	1	1	1	4	1.0	0	2	0	1	-1	2	0.4	0	0	0	0.0	1	1	-1	1	0.2	-2	-1	-1	-4	-1.0	● 0.9
6	Introduce water to upper catchment to saturate areas of acidity	■		1	-1	1	1	0.3	-1	-2	-1	-1	-5	-1.3	-2	2	1	-2	-1	-2	-0.4	-1	-1	-2	-0.8	-1	-1	0	-2	-0.3	-2	1	-1	-2	-0.5	● -2.9
7	Physical capping of acid sources	■	■	1	1	1	3	1.0	-1	-1	-2	-1	-5	-1.3	-1	2	-1	-2	-2	-4	-0.8	-2	-2	-4	-1.5	-1	-1	-1	-3	-0.5	-2	-1	-2	-5	-1.3	● -4.3
10	Introduce recycled water to estuary - Anglesea WTP	■	■	2	1	2	5	1.7	-1	-2	-2	-1	-6	-1.5	-1	2	1	-1	-1	0	0.0	-1	0	-1	-0.4	-1	-1	1	-1	-0.2	1	1	0	2	0.5	● 0.1
11	Introduce recycled water to estuary - Black Rock WTP	■	■	2	1	2	5	1.7	-1	-1	-2	-1	-5	-1.3	-1	2	1	-1	-1	0	0.0	-1	0	-1	-0.4	-2	-1	1	-2	-0.3	1	1	0	2	0.5	● 0.2
12	Introduction of seawater to estuary via dredging of shallow artificial openings	■		0	1	-1	0	0.0	1	1	-1	-2	-1	-0.3	-1	2	1	-1	-2	-1	-0.2	-2	-2	-4	-1.5	1	-1	-1	-1	-0.2	0	-1	-2	-3	-0.8	● -2.9
13	Introduction of seawater to estuary via dredging of deep artificial openings	■		1	1	-1	1	0.3	1	1	-1	-2	-1	-0.3	-1	2	2	-2	-2	-1	-0.2	-2	-2	-4	-1.5	0	-1	-1	-2	-0.3	-1	-1	-2	-4	-1.0	● -3.0
14	Introduce sea water to estuary via offshore pump and pipe	■	■	2	2	2	6	2.0	-1	1	-2	-1	-3	-0.8	-1	2	2	-1	0	2	0.4	-1	0	-1	-0.4	-1	-1	1	-1	-0.2	1	1	0	2	0.5	● 1.6
16	Introduce water to estuary from stormwater harvesting	■	■	1	-1	1	1	0.3	0	-2	-1	-2	-5	-1.3	-1	1	-1	-1	-2	-4	-0.8	0	0	0	0.0	-1	-1	0	-2	-0.3	-1	-1	-1	-3	-0.8	● -2.8
18	In-situ addition of a neutralising agent (e.g. lime) to ASS in marshes	■	■	2	2	2	6	2.0	0	-1	-1	-1	-3	-0.8	-1	2	1	-2	-2	-2	-0.4	-2	-2	-4	-1.5	-1	-1	-1	-3	-0.5	-2	1	-2	-3	-0.8	● -1.9
19	In-situ bioremediation of sulfidic material in marshes	■	■	1	1	2	4	1.3	0	-1	-1	-1	-3	-0.8	-1	2	1	-2	-2	-2	-0.4	-2	-2	-4	-1.5	-1	-1	-1	-3	-0.5	-2	1	-2	-3	-0.8	● -2.6
20	Install passive alkaline berms for treatment of acidity in-situ within river / open limestone drains	■		1	1	2	4	1.3	2	2	1	-1	4	1.0	1	1	2	1	1	6	1.2	0	0	0	0.0	2	1	0	3	0.5	2	0	0	2	0.5	● 4.5
23	Constructed wetland (reducing and alkalinity producing type)	■		1	1	2	4	1.3	0	2	0	1	3	0.8	0	2	1	1	0	4	0.8	1	0	1	0.4	0	1	1	2	0.3	2	1	1	4	1.0	● 4.6
24	Insitu passive permeable reactive barrier	■		1	1	2	4	1.3	2	2	1	-1	4	1.0	1	-1	0	1	0	1	0.2	0	0	0	0.0	1	1	1	3	0.5	0	0	1	1	0.3	● 3.3
25	Ex-situ filtration and membrane water treatment system	■		1	2	2	5	1.7	-1	1	-1	-2	-3	-0.8	-2	-2	1	-1	1	-3	-0.6	0	0	0	0.0	-2	-2	0	-4	-0.7	1	2	-1	2	0.5	● 0.2
26	Ex-situ treatment by alkali material dosing	■		1	2	2	5	1.7	-1	1	-1	-2	-3	-0.8	-2	2	1	-1	1	1	0.2	-1	0	-1	-0.4	-1	-1	0	-2	-0.3	-1	1	-1	-1	-0.3	● 0.2
27	Ex-situ active resin ion-exchange treatment system	■		1	2	2	5	1.7	-1	1	-1	-2	-3	-0.8	-2	-2	1	-1	1	-3	-0.6	0	0	0	0.0	-2	-2	0	-4	-0.7	0	2	-1	1	0.3	● -0.1
28	In-situ dosing with alkali materials	■		1	2	2	5	1.7	0	2	-1	-1	0	0.0	-1	1	1	0	1	2	0.4	0	0	0	0.0	-1	-1	0	-2	-0.3	2	1	-1	2	0.5	● 2.2
29	In-situ bioremediation of water	■		1	-1	1	1	0.3	1	2	-2	0	1	0.3	-1	1	1	-1	-2	-2	-0.4	0	0	0	0.0	0	-1	0	-1	-0.2	-1	-1	-1	-3	-0.8	● -0.7

5. Weighted categories excluding technical

				Technical					Practicability						Environmental							Cultural				Economic					Social/stakeholder					
				Relative effectiveness in achieving and	Timeframe for achieving effectiveness	Flexibility to be implemented as long term solution	**Total category score**	**Weighted category score**	Timeframe for implementation	Logistical constraints (access,	Legislative, regulatory and permit	Ongoing maintenance requirements	**Total category score**	**Weighted category score**	Energy and resource consumption	Waste disposal requirements	Climate resiliency (ability to be scaled up etc.)	Potential effects on the broader environment	Potential risks to aquatic and terrestrial	**Total category score**	**Weighted category score**	Effects on areas of cultural significance	Acceptance by Traditional Owners	**Total category score**	**Weighted category score**	Relative capital cost	Relative operational cost	Relative potential effects on local economy	**Total category score**	**Weighted category score**	Acceptance by community, regulators,	Effects on recreational values (swimming,	Amenity impacts (dust, noise, footprint, visual,	**Total category score**	**Weighted category score**	**Total score**
		Weighting							25.0%						25.0%							20.0%				10.0%					20.0%					**100%**
		Maximum category score						0.00					8	2.50						10	2.50			4	2.00				6	1.00				6	2.00	10
		Applicable area																																		
ID	**Option**	**Upper catchment / estuary**	**Coogoorah Park**																																	
1	In fill Coogoorah Park channels		■						0	-1	-1	2	0	0.0	-2	2	2	-1	-1	0	0.0	-1	-1	-2	-1.0	1	2	-1	2	0.3	-2	-2	-2	-6	-2.0	● -2.7
4	Maintain water levels with weir system (upper catchment)	■							2	-1	1	1	3	0.9	0	2	0	-1	-2	-1	-0.3	-1	-1	-2	-1.0	1	1	1	3	0.5	-2	-1	-1	-4	-1.3	● -1.1
5	Maintain water levels with weir system (estuary - Coogoorah Park channels)		■						1	1	1	1	4	1.3	0	2	0	1	-1	2	0.5	0	0	0	0.0	1	1	-1	1	0.2	-2	-1	-1	-4	-1.3	● 0.6
6	Introduce water to upper catchment to saturate areas of acidity	■							-1	-2	-1	-1	-5	-1.6	-2	2	1	-2	-1	-2	-0.5	-1	-1	-2	-1.0	-1	-1	0	-2	-0.3	-2	1	-1	-2	-0.7	● -4.1
7	Physical capping of acid sources	■	■						-1	-1	-2	-1	-5	-1.6	-1	2	-1	-2	-2	-4	-1.0	-2	-2	-4	-2.0	-1	-1	-1	-3	-0.5	-2	-1	-2	-5	-1.7	● -6.7
10	Introduce recycled water to estuary - Anglesea WTP	■	■						-1	-2	-2	-1	-6	-1.9	-1	2	1	-1	-1	0	0.0	-1	0	-1	-0.5	-1	-1	1	-1	-0.2	1	1	0	2	0.7	● -1.9
11	Introduce recycled water to estuary - Black Rock WTP	■	■						-1	-1	-2	-1	-5	-1.6	-1	2	1	-1	-1	0	0.0	-1	0	-1	-0.5	-2	-1	1	-2	-0.3	1	1	0	2	0.7	● -1.7
12	Introduction of seawater to estuary via dredging of shallow artificial openings	■							1	1	-1	-2	-1	-0.3	-1	2	1	-1	-2	-1	-0.3	-2	-2	-4	-2.0	1	-1	-1	-1	-0.2	0	-1	-2	-3	-1.0	● -3.7
13	Introduction of seawater to estuary via dredging of deep artificial openings	■							1	1	-1	-2	-1	-0.3	-1	2	2	-2	-2	-1	-0.3	-2	-2	-4	-2.0	0	-1	-1	-2	-0.3	-1	-1	-2	-4	-1.3	● -4.2
14	Introduce sea water to estuary via offshore pump and pipe	■	■						-1	1	-2	-1	-3	-0.9	-1	2	2	-1	0	2	0.5	-1	0	-1	-0.5	-1	-1	1	-1	-0.2	1	1	0	2	0.7	● -0.4
16	Introduce water to estuary from stormwater harvesting	■	■						0	-2	-1	-2	-5	-1.6	-1	1	-1	-1	-2	-4	-1.0	0	0	0	0.0	-1	-1	0	-2	-0.3	-1	-1	-1	-3	-1.0	● -3.9
18	In-situ addition of a neutralising agent (e.g. lime) to ASS in marshes	■	■						0	-1	-1	-1	-3	-0.9	-1	2	1	-2	-2	-2	-0.5	-2	-2	-4	-2.0	-1	-1	-1	-3	-0.5	-2	1	-2	-3	-1.0	● -4.9
19	In-situ bioremediation of sulfidic material in marshes	■	■						0	-1	-1	-1	-3	-0.9	-1	2	1	-2	-2	-2	-0.5	-2	-2	-4	-2.0	-1	-1	-1	-3	-0.5	-2	1	-2	-3	-1.0	● -4.9
20	Install passive alkaline berms for treatment of acidity in-situ within river / open limestone drains	■							2	2	1	-1	4	1.3	1	1	2	1	1	6	1.5	0	0	0	0.0	2	1	0	3	0.5	2	0	0	2	0.7	● 3.9
23	Constructed wetland (reducing and alkalinity producing type)	■							0	2	0	1	3	0.9	0	2	1	1	0	4	1.0	1	0	1	0.5	0	1	1	2	0.3	2	1	1	4	1.3	● 4.1
24	Insitu passive permeable reactive barrier	■							2	2	1	-1	4	1.3	1	-1	0	1	0	1	0.3	0	0	0	0.0	1	1	1	3	0.5	0	0	1	1	0.3	● 2.3
25	Ex-situ filtration and membrane water treatment system	■							-1	1	-1	-2	-3	-0.9	-2	-2	1	-1	1	-3	-0.8	0	0	0	0.0	-2	-2	0	-4	-0.7	1	2	-1	2	0.7	● -1.7
26	Ex-situ treatment by alkali material dosing	■							-1	1	-1	-2	-3	-0.9	-2	2	1	-1	1	1	0.3	-1	0	-1	-0.5	-1	-1	0	-2	-0.3	-1	1	-1	-1	-0.3	● -1.9
27	Ex-situ active resin ion-exchange treatment system	■							-1	1	-1	-2	-3	-0.9	-2	-2	1	-1	1	-3	-0.8	0	0	0	0.0	-2	-2	0	-4	-0.7	0	2	-1	1	0.3	● -2.0
28	In-situ dosing with alkali materials	■							0	2	-1	-1	0	0.0	-1	1	1	0	1	2	0.5	0	0	0	0.0	-1	-1	0	-2	-0.3	2	1	-1	2	0.7	● 0.8
29	In-situ bioremediation of water	■							1	2	-2	0	1	0.3	-1	1	1	-1	-2	-2	-0.5	0	0	0	0.0	0	-1	0	-1	-0.2	-1	-1	-1	-3	-1.0	● -1.4

Table A4: MCA Screening for different sensitivities

6. Combined cultural with social/stakeholder

ID	Option	Applicable area		Technical					Practicability						Environmental							Cultural				Economic					Social/stakeholder					Total score
		Upper catchment / estuary	Coogoorah Park	Relative effectiveness in achieving and	Timeframe for achieving effectiveness	Flexibility to be implemented as long term solution	**Total category score**	**Weighted category score**	Timeframe for implementation	Logistical constraints (access,	Legislative, regulatory and permit	Ongoing maintenance requirements	**Total category score**	**Weighted category score**	Energy and resource consumption	Waste disposal requirements	Climate resiliency (ability to be scaled up etc.)	Potential effects on the broader environment	Potential risks to aquatic and terrestrial	**Total category score**	**Weighted category score**	Effects on areas of cultural significance	Acceptance by Traditional Owners	**Total category score**	**Weighted category score**	Relative capital cost	Relative operational cost	Relative potential effects on local economy	**Total category score**	**Weighted category score**	Acceptance by Traditional Owners,	Effects on cultural (TO significance) and recreational	Amenity impacts (dust, noise, footprint, visual,	**Total category score**	**Weighted category score**	
	Weighting			20.0%					20.0%						20.0%											20.0%					20.0%					**100%**
	Maximum category score						6	2.00					8	2.00						10	2.00				0.00				6	2.00				6	2.00	10
1	In fill Coogoorah Park channels		■	1	0	0	1	0.3	0	-1	-1	2	0	0.0	-2	2	2	-1	-1	0	0.0					1	2	-1	2	0.7	-2	-2	-2	-6	-2.0	🟡 -1.0
4	Maintain water levels with weir system (upper catchment)	■		1	1	-1	1	0.3	2	-1	1	1	3	0.8	0	2	0	-1	-2	-1	-0.2					1	1	1	3	1.0	-2	-1	-1	-4	-1.3	🟢 0.6
5	Maintain water levels with weir system (estuary - Coogoorah Park channels)		■	1	1	-1	1	0.3	1	1	1	1	4	1.0	0	2	0	1	-1	2	0.4					1	1	-1	1	0.3	-2	-1	-1	-4	-1.3	🟢 0.7
6	Introduce water to upper catchment to saturate areas of acidity	■		1	-1	1	1	0.3	-1	-2	-1	-1	-5	-1.3	-2	2	1	-2	-1	-2	-0.4					-1	-1	0	-2	-0.7	-2	1	-1	-2	-0.7	🔴 -2.7
7	Physical capping of acid sources	■	■	1	1	1	3	1.0	-1	-1	-2	-1	-5	-1.3	-1	2	-1	-2	-2	-4	-0.8					-1	-1	-1	-3	-1.0	-2	-1	-2	-5	-1.7	🔴 -3.7
10	Introduce recycled water to estuary - Anglesea WTP	■	■	2	1	2	5	1.7	-1	-2	-2	-1	-6	-1.5	-1	2	1	-1	-1	0	0.0					-1	-1	1	-1	-0.3	1	1	0	2	0.7	🟢 0.5
11	Introduce recycled water to estuary - Black Rock WTP	■	■	2	1	2	5	1.7	-1	-1	-2	-1	-5	-1.3	-1	2	1	-1	-1	0	0.0					-2	-1	1	-2	-0.7	1	1	0	2	0.7	🟢 0.4
12	Introduction of seawater to estuary via dredging of shallow artificial openings	■		0	1	-1	0	0.0	1	1	-1	-2	-1	-0.3	-1	2	1	-1	-2	-1	-0.2					1	-1	-1	-1	-0.3	0	-1	-2	-3	-1.0	🔴 -1.8
13	Introduction of seawater to estuary via dredging of deep artificial openings	■		1	1	-1	1	0.3	1	1	-1	-2	-1	-0.3	-1	2	2	-2	-2	-1	-0.2					0	-1	-1	-2	-0.7	-1	-1	-2	-4	-1.3	🔴 -2.1
14	Introduce sea water to estuary via offshore pump and pipe	■	■	2	2	2	6	2.0	-1	1	-2	-1	-3	-0.8	-1	2	2	-1	0	2	0.4					-1	-1	1	-1	-0.3	1	1	0	2	0.7	🟢 2.0
16	Introduce water to estuary from stormwater harvesting	■	■	1	-1	1	1	0.3	0	-2	-1	-2	-5	-1.3	-1	1	-1	-1	-2	-4	-0.8					-1	-1	0	-2	-0.7	-1	-1	-1	-3	-1.0	🔴 -3.4
18	In-situ addition of a neutralising agent (e.g. lime) to ASS in marshes	■	■	2	2	2	6	2.0	0	-1	-1	-1	-3	-0.8	-1	2	1	-2	-2	-2	-0.4					-1	-1	-1	-3	-1.0	-2	1	-2	-3	-1.0	🔴 -1.2
19	In-situ bioremediation of sulfidic material in marshes	■	■	1	1	2	4	1.3	0	-1	-1	-1	-3	-0.8	-1	2	1	-2	-2	-2	-0.4					-1	-1	-1	-3	-1.0	-2	1	-2	-3	-1.0	🔴 -1.8
20	Install passive alkaline berms for treatment of acidity in-situ within river / open limestone drains	■		1	1	2	4	1.3	2	2	1	-1	4	1.0	1	1	2	1	1	6	1.2					2	1	0	3	1.0	2	0	0	2	0.7	🟢 5.2
23	Constructed wetland (reducing and alkalinity producing type)	■	■	1	1	2	4	1.3	0	2	0	1	3	0.8	0	2	1	1	0	4	0.8					0	1	1	2	0.7	2	1	1	4	1.3	🟢 4.9
24	Insitu passive permeable reactive barrier	■		1	1	2	4	1.3	2	2	1	-1	4	1.0	1	-1	0	1	0	1	0.2					1	1	1	3	1.0	0	0	1	1	0.3	🟢 3.9
25	Ex-situ filtration and membrane water treatment system	■		1	2	2	5	1.7	-1	1	-1	-2	-3	-0.8	-2	-2	1	-1	1	-3	-0.6					-2	-2	0	-4	-1.3	1	2	-1	2	0.7	🟡 -0.4
26	Ex-situ treatment by alkali material dosing	■		1	2	2	5	1.7	-1	1	-1	-2	-3	-0.8	-2	2	1	-1	1	1	0.2					-1	-1	0	-2	-0.7	-1	1	-1	-1	-0.3	🟢 0.1
27	Ex-situ active resin ion-exchange treatment system	■		1	2	2	5	1.7	-1	1	-1	-2	-3	-0.8	-2	-2	1	-1	1	-3	-0.6					-2	-2	0	-4	-1.3	0	2	-1	1	0.3	🟡 -0.7
28	In-situ dosing with alkali materials	■		1	2	2	5	1.7	0	2	-1	-1	0	0.0	-1	1	1	0	1	2	0.4					-1	-1	0	-2	-0.7	2	1	-1	2	0.7	🟢 2.1
29	In-situ bioremediation of water	■		1	-1	1	1	0.3	1	2	-2	0	1	0.3	-1	1	1	-1	-2	-2	-0.4					0	-1	0	-1	-0.3	-1	-1	-1	-3	-1.0	🔴 -1.2

Appendix C Remediation and management strategies

C.1 Minimise or Prevent Further Oxidation

The simplest way to minimise or prevent further oxidation is to avoid release of acidic material. This can be for example through management of water levels where ASS are present to ensure that ASS materials remain under sufficient depth of water. This strategy provides two benefits:

- The low solubility of oxygen in water provides a limiting factor to development of primary oxidation processes in previously oxidised ASS sediments.
- Elevating the water table minimises the risks of deeper un-oxidised ASS sediments being exposed to oxygen and initiating acid forming reactions.

This strategy is most effective when there is a plentiful and reliable supply of water. However, in cases where water is limited, artificial structures can be installed so that water levels are maintained across critical areas with highest potential for generation of acidity.

C.2 Inundation of Acidified Areas

Permanent inundation (or reflooding) of drained, acidified areas is a management strategy that has several benefits, including:

- prevent further ASS oxidation;
- contain acidity in the landscape/decreasing acid export;
- assist with ecological restoration; and,
- neutralise in situ acidity within the wetland by reversing key geochemical processes.

The last point relates to the potential for inundated areas to encourage natural microbial sulfate and iron reduction processes to neutralise acidity, generate alkalinity and precipitate metals. If organic matter ($2CH_2O$) is available in the inundated areas, sulfate reducing bacteria can use ferric iron (Fe^{3+}) and sulfate (SO_4^{2-}) as terminal electron acceptors, consuming protons and generating bicarbonate alkalinity (HCO_3^-):

- $CH_2O + 4Fe(OH)_3 + 8H^+ \text{->} 4Fe^{2+} + CO_2 + 11H_2O$
- $2CH_2O + SO_4^{2-} \text{–>} H_2S + 2HCO_3^-$

The reduction of sulfate is an important mechanism for removing reduced metals (which may otherwise re-oxidise and release acidity), because formation of highly insoluble sulfides is enacted. For example:

- $Fe^{2+} + H_2S \text{->} FeS + 2H^+$

It is noted that this strategy in most effective when the following conditions occur:

- Reduced metals can be effectively precipitated and retained in the system, minimising the potential for acidity to be exported outside of the system.
- The alkalinity generated by iron and sulfate reduction can be retained in the system to neutralise acidity in the system.
- The system is maintained in an anoxic saturated state preventing re-oxidation of metals and associated generation of acidity.

C.3 Isolation of Impacted Areas

If it is not feasible to restore an ASS impacted ecosystem, the focus will then be on protecting connected ecosystems from potential adverse effects caused by transport of acidification by-products though surface water, groundwater or overland flow.

Physical isolation of ASS sediments is a potentially effective method for protecting connected ecosystems; however, should only be considered when the benefits are greater than the negative effects of isolation.

Isolation can have negative effects on aquatic ecosystems, increased ASS oxidation rates and potential risks of mobilisation of acidification by products (i.e., wind erosion of dry ASS sediments or high flow events breaching the integrity of the isolation barrier).

Isolation techniques include diverting flow of creek across impacted areas, construction of impermeable barriers or flow regulators.

C.4 Dilution of Acidic Discharge

Dilution is a management approach that relies on mixing poor quality water with high quality water to reduce impacts on the receiving environments.

However, because of the relatively large volume of water required for effective dilution of acidic waters (up to 100 to 1000 times the volume of the system, depending on the inherent buffering capacity, or alkalinity, of the dilution water), coupled with the cost and sustainability consideration of using high quality water for management of impacts, dilution as a mitigation option may be useful in only a few cases.

C.5 Soil Neutralisation

These technologies can be broadly described as addition of acid neutralising compounds to raise pH and increase alkalinity of the soil which presents the source of the issue. Under these conditions, the aqueous solubility of most metals is reduced, and they tend to precipitate out of solution.

Technical consideration for implementation of soil neutralisation technologies include the selection of the neutralising agent to be employed, method of application and application rates.

C.5.1 Neutralising Compounds

There are many types of neutralising compounds available for the treatment of ASS, which differ on their theoretical neutralising capacity, pH, solubility, moisture content, purity, particle size distribution, suitable application methods and health and safety considerations.

Commercially available products include calcium carbonate ($CaCO_3$) in the form of finely crushed limestone (‘aglime’), dolomite (a rock comprising varying proportions of calcium carbonate and magnesium carbonate ($MgCO_3$), magnesite ($MgCO_3$), quick lime (CaO), hydrated lime ($Ca(OH)_2$), burnt magnesia (MgO), burnt dolomite (CaO/MgO), soda ash (Na_2CO_3) and sodium bicarbonate ($NaHCO_3$).

Industry by-products with neutralising capacity can also be used in some applications and tend to be considered for their generally lower costs and sustainability considerations. Some examples include by-products of the cement manufacturing industry such as fly ash, and bauxite residues.

C.5.2 Application Methods

Surface

Surface applications involve spreading the neutralising compound over all or a part of the ASS affected catchment.

The aim of surface applications is to neutralise the acidity of the water draining from the catchment and improve surface soil conditions as the neutralising compounds slowly penetrate through the profile (depending on soil properties, precipitation and surface application rates).

Depending on the area requiring treatment and access constraints, surface application can be undertaken using truck mounted devices, specialised spreading equipment (i.e., pressurised slurries) or by air (i.e., fixed wing aeroplane or helicopter).

Mechanical

Mechanical applications involve incorporation of the neutralising compound into the soil requiring treatment using conventional earth moving equipment or large diameter mixing devices.

In the first case, the soil is typically excavated, and incorporation of the neutralising compound is carried out on a specifically built treatment pad. In the second case (usually referred to as 'deep soil mixing'), the neutralising compound is added directly to the in-situ soil with no need for excavation.

Injection

Injection applications involve injection of specifically formulated mixtures of neutralising agents and other compounds (slurries) that are injected under pressure in the subsurface with the aim of achieving a uniform distribution in the volume of soil requiring treatment.

Application Rates

For surface applications using lime (either granular or in a pelletised form), rates in the range of 2.5-5.0 t/ha are generally reported. For mechanical and injection applications, the mass of neutralising agent required is usually evaluated based on the acid-forming properties of the materials to be neutralised, which is determined from laboratory results.

Depending on the complexity of the project, required application rates can be also assessed using pilot trials, use of geochemical modelling tools or development of trial/error procedures.

C.6 Passive Systems for Treatment of ASS Impacted Water

C.6.1 In-stream Limestone Sand

This technology is based on placing piles of limestone sand directly in the streambed of high gradient streams. The piles are washed downstream during high flow events, with the limestone increasing pH and alkalinity of the streams as it progressively dissolves in the water.

Figure B-1 Limestone sand placed along a polluted stream

Coating of limestone particles with iron hydroxides (armouring) can occur, but the energy of the water in the stream causes agitation and scouring of limestone to keep fresh limestone surfaces available for reaction.

Selection of the locations of piles is based on access constraints and water quality objectives along various reaches of the stream. Application rates are calculated using empirical formulas, which consider the annual acid load into the stream.

C.6.2 Limestone Diversion Wells

Limestone diversion wells (LDWs) consist of in-ground wells (1.5-1.8 m in diameter and 2.0-2.5 m in depth) containing crushed limestone aggregates into which part of a fast-flowing stream flow is diverted, usually via a pipeline.

The turbulence caused by the water flowing into the well enhances dissolution of limestone, as wells as minimising the potential for armouring of the limestone surfaces.

Figure B-2 Limestone diversion well

The water leaving the diversion well, with increased pH/alkalinity and carrying limestone particles abraded from the well, is then reintroduced into the stream where further pH neutralisation and metal precipitation occurs.

LDWs are generally employed at sites with suitable topographic fall between the stream diversion point and the intake of the well (minimum of 10 m vertical change), so that enough hydraulic force is applied to the limestone, promoting abrasion and grinding of the aggregate.

LDWs are maintenance intensive systems (i.e., require frequent re-filling of limestone, cleaning of leaves and debris, etc.) and are not generally suitable for sites that are remote or difficult to access. In addition, aluminium and other metals may precipitate in the receiving stream as a result of increased pH and alkalinity.

C.6.3 Limestone Drains

Limestone drains can be constructed as open (OLDs) or anoxic (ALDs). OLDs are open channels containing coarse limestone aggregate (15-30 cm diameter) used to increase pH and alkalinity of the waters requiring treatment. A typical OLD may have 0.3 m to 1 m of limestone at the bottom and 1 m to 3 m of water with a residence time of at least 14 hours.

Figure B-3 Example OLD

To minimise reduction of treatment efficiency caused by formation of Fe and Al precipitates on the surface of the aggregate (armouring), OLD are constructed with high gradients (>20%) if site conditions allow. One of the drawbacks of steep OLDs is that they require additional aggregate volume to achieve the required residence time.

Depending on the characteristic of incoming water, a properly designed OLD can raise pH to 6-8 and generate alkalinity in the range of 40-60 mg/L $CaCO_3$. A settling pond is usually required after the OLD to retain the metal precipitates, prior to final discharge of the treated water in the environment.

ALDs are buried trenches lined with an impermeable material, backfilled with coarse limestone aggregate (15-30 cm diameter) and buried under clay (Figure B-4). The ALD is then filled with the water requiring treatment and maintained in a saturated condition so that ingress of oxygen is prevented and armouring of the limestone is minimised.

Figure B-4 ALD under construction

Dissolution of limestone within the ALD increases pH and alkalinity of the water requiring treatment, creating favourable conditions for metal precipitation. Typically, an ALD is followed by an aerobic treatment unit (such as an aerobic wetland or settling pond) where dissolved metals are oxidised, precipitated and retained prior to final discharge of the treated water in the environment.

ALDs are typically constructed to achieve residence times of approximately 14 hours, increase of water pH to 6-8 and alkalinity generation in the range of 250-300 mg/L $CaCO_3$.

For best performances, ALDs should receive incoming water with low concentrations of dissolved oxygen (<1 mg/L), aluminium (<1 mg/L), ferric iron (Fe^{3+}) and sulfate (<1,500 mg/L). If these conditions are not met, precipitation of iron oxide/hydroxides, aluminium hydroxide hydrate and gypsum is likely to occur, causing armouring of the limestone and plugging of the void spaces within the drain.

C.6.4 Constructed Wetlands

Constructed wetlands are a form of passive system for treatment of acidic discharges that relies on a combination of physical, chemical, microbial and plant-mediated processes for amelioration of water quality. These include (depending on wetland design): oxidation, reduction, precipitation, sedimentation, filtration, adsorption, complexation, chelation, active metal uptake by plants and microbial conversion/immobilisation mechanisms.

The key considerations when determining the type and size of a constructed wetland include:

- The influent water acidity load, pH and redox state.
- Water flow rates (including assessment of seasonal variability) and retention times.
- The area available for a wetland.
- Access requirements for ongoing monitoring and maintenance.

The main types of constructed wetlands are discussed in the following sections.

Aerobic Wetlands

The main process undertaken within constructed aerobic wetlands is aeration of the water requiring treatment, which encourages dissolved iron to oxidise, precipitate and settle (Figure B-5).

Figure B-5 Aerobic Wetland

Aerobic wetlands can be described as shallow excavations (lined or unlined) filled with 300-900 mm of soil where shallow water (depths in the range of 100-300 mm) flows horizontally through planted vegetation. Plants are an important component of the wetland because they increase water retention time by preventing channelised flow, increase dissolved oxygen concentrations and have the potential to uptake some of the metals in the incoming waters.

Used primarily when iron is the main contaminant (ferric Iron is the primary contaminant of concern in ASS affected waters). Traditional aerobic compost wetlands are effective but require large land areas and high retention times to achieve the desired naturalisation effect. Because of large area requirements and limitations associated with available space, aerobic wetlands are often undersized, leading to inadequate retention times and poor effluent water quality. Additional mechanisms can be employed to increase the effectiveness of neutralizing acidity and removing other contaminants from the water. A Successive Alkaline Producing System (SAPS) similar that shown in Figure B-6 below, would increase the efficiency of the wetland at neutralizing acidity by adding a bed of limestone gravel below the organic compost:

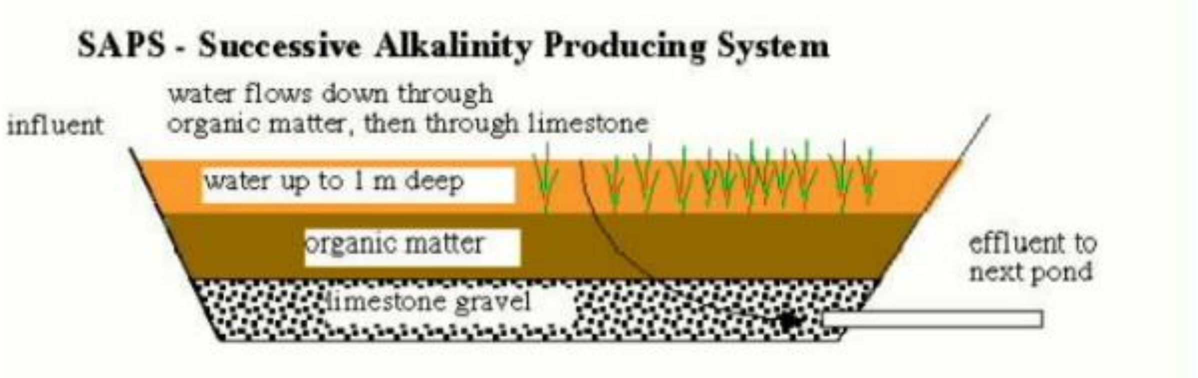


Figure B-6 Example design of anaerobic wetland

Aerobic wetlands are usually designed with variable water depths to encourage plant community diversity and with a series of ponds (containing no plants) to allow settling of metal precipitates.

Because of the acidity generated by the hydrolysis of iron ($Fe^{3+} + 3\ H_2O \dashrightarrow Fe\ (OH)_3 + 3\ H^+$) and the increased toxicity associated with metal precipitates retained in the wetland, these systems are usually suited for treatment of mildly acidic or net alkaline waters with pH greater than 4.5 and low to moderate concentration of iron and other metals. Aerobic wetlands are often included as a final step in treatment processes containing other technologies, such as OLD or ALD, where they act as oxidation stages and/or settling ponds.

The size of the wetland is an important factor in the success of water treatment. Design must consider total acidity loads and water flow rates. General design criteria indicate iron removal rates of 10-20 g of Fe/m^2/d and 0.5-1.0 g of Mn/m^2/d.

Because of large area requirements and limitations associated with available space, aerobic wetlands are often undersized, leading to inadequate retention times and poor effluent water quality.

Anaerobic Wetlands

Anaerobic compost wetlands are based on microbial sulfate reduction for the generation of alkalinity, neutralization of the acidity of influent waters and precipitation of metals mainly as sulfide (Turunen, 2019). The dominant mechanism of chemical and microbial reduction, precipitating metals and naturalising acid. Anerobic wetlands also employ the use of a limestone bed to add alkalinity and treat the upper catchment water's acidity. One potential benefit of anaerobic wetlands over an aerobic SAPS wetland is the reduced likelihood of chemical armouring of the underlying limestone layer. See Figure B-7 for an example of an anaerobic wetland:

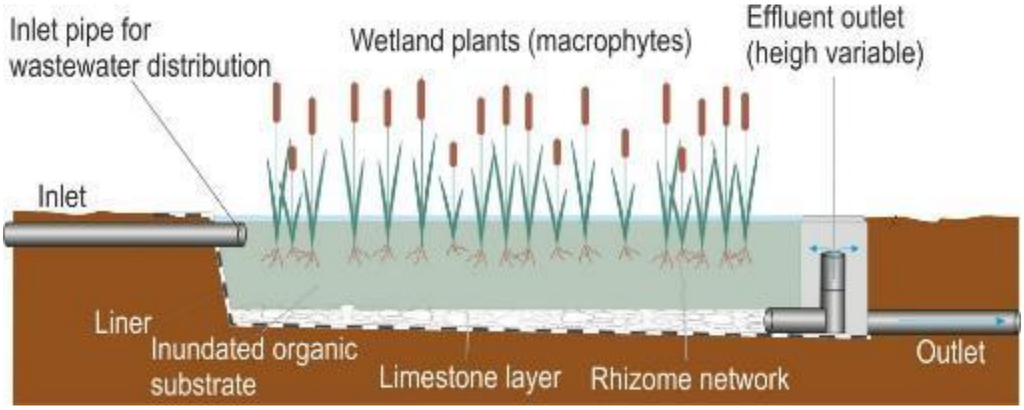


Figure B-7 Example design of anaerobic wetland

Anaerobic wetlands (also referred to as compost wetlands) have shallow water depths (in the range of 100 mm) and a thick permeable anoxic substrate (≥ 300 mm) comprising various forms of organic matter (Figure B-8).

Figure B-8 Anaerobic Wetland

As the water moves horizontally through the substrates, several microbial processes are enacted to neutralise acidity, generate alkalinity and remove metals from solution. These processes can be summarised in the following equations:

- $2CH_2O + SO_4^{2-} + 2H^+ \rightarrow 2\ CO_2 + H_2S + 2H_2O$

  (Reduction of sulfate to hydrogen sulfide, consuming protons i.e., acidity.)

- $2CH_2O + SO_4^{2-} \rightarrow H_2S + 2HCO^{3-.}$

  (Reduction of sulfate to form hydron sulfide (H_2S), with generation of bicarbonate alkalinity.)

- $M^{2+} + H_2S + 2HCO^{3-} \rightarrow MS + 2H_2O + 2CO_2$

  (Reaction of a generic metal, M^{2+}, with H_2S to form insoluble metal monosulfide.)

Wetland plants are usually incorporated in the wetland design, since they stimulate microbial processes and act as an organic carbon source; however, they may not survive in highly acidic environments. Limestone can also be mixed with the organic material to increase generation of alkalinity. The presence of anaerobic conditions prevents or mitigates metal precipitation and armouring of the limestone.

Aluminium dissolved in the water entering the anaerobic wetland is poorly soluble at pH above 4.5 and generally precipitates on the top of the organic layer due to the increase of pH via sulfate reduction and limestone dissolution.

Because the effluent from an anaerobic wetland has low dissolved oxygen and potentially soluble metals in the reduced form, it is normal practice to add further treatment steps such as an aeration/settling pond or an aerobic wetland to oxygenate the water and remove residual iron concentrations. The acidity released by metal hydrolysis is compensated by the alkalinity added in the anaerobic wetland.

Since anaerobic wetlands produce alkalinity, they can be used to treat waters with net acidity (300-500 mg/L), low pH (around 4.0), high dissolved oxygen (> 2 mg/L) and moderate to high metal concentrations. Typical sizing guidelines for anaerobic wetlands are 3.5-7 $g/m^2\ d^{-1}$ (acidity) and 10 $g/m^2\ d^{-1}$ (iron).

Reducing and Alkalinity Producing Systems

Reducing and alkalinity producing systems (RAPS) combine the benefits of ALDs and anaerobic wetlands. While many design variations are possible (i.e., vertical flow wetland, vertical flow ponds and vertical flow reactors), the basic concepts of RAPS are common and can be summarised as follows:

- Use mixtures of limestone and organic matter, combining organic and inorganic approaches to water treatment.
- Rely on alkalinity generation by dissolution of limestone and sulfate reducing bacteria activity.
- Promote reducing conditions in the water so that metal sulfide precipitation can occur and armouring of limestone is minimised.
- Provide sites for metal absorption in the organic matter layer.
- Raise the pH of water to near neutral conditions.

The type of RAPS selected for water treatment is generally dependent on site-specific conditions such as topography, available surface area for the treatment system, soils and geology, groundwater flows, etc., as well as the availability of resources for setting up and maintaining the treatment system. As a result, RAPS have been implemented in various forms, ranging from fully engineered constructions to relatively unmodified natural systems (Figure B-9).

Figure B-9 Vertical flow wetland

The main difference between a RAPS and an anaerobic wetland is that in a RAPS, water flows in a predominantly vertical manner, so that the interaction of water with organic matter and limestone is greatly increased. Underlying drainage pipes at the bottom of the RAPS convey the water into a settling pond or an aerobic wetland, where precipitation and sedimentation processes can take place before discharging the water to the receiving environment.

Because of the increased efficiency realised by vertical flow conditions, RAPS require less surface area compared to anaerobic wetlands (as little as 20% for the same degree of treatment). For influents containing significant quantities of ferric iron (Fe^{3+}) and/or sediment, vertical-flow systems should be preceded by either a settling pond or an aerobic wetland so as to limit accumulation of solids on the organic layer surface. For treating highly acidic discharges, several vertical flow cells can be placed in sequence, separated by settling ponds.

The drawback of RAPS is that the site must have sufficient natural relief to overcome the head losses associated with water flow across the organic layer and limestone (in the range of 1.5 m). Additionally, at least 1 m of freeboard is advisable on top of the organic layer (to guarantee sufficient driving head), so a minimum relief in order of 2.5 m is required to allow water flow without the need for active pumping.

General design guidelines for RAPS recommend limestone drainage layer thickness in the range of 60-100 cm, organic layer thickness in the range of 15-60 cm and loading rate of 25-30 $g/m^2\ d^{-1}$ (acidity) with a 15 hour retention time in the limestone layer.

Aeration and Settling

Aeration (i.e., increase of dissolved oxygen concentration in water) and settling are used to collect treated or partially treated waters discharging from a range of passive treatment systems (such as OLDs, ALDs or RAPS) to promote oxidation, precipitation and settling of metals. In cases of net alkaline discharges containing high concentrations of iron where no further alkaline addition is needed, aeration and settling may be the only process required to achieve suitable treatment.

Aeration can be achieved by mechanical or chemical means. When topography and land availability allow, passive mechanical means (such as aeration cascades) are typically employed. Assuming aeration can achieve a dissolved iron concentration of 8 mg/L, a single aeration step is generally suitable for treatment of water with 30-50 mg/L of iron (based on stochiometric and efficiency considerations). If higher iron concentrations are present, successive aeration steps with settling units between them are required.

Settling for removal of metal precipitates can be achieved in settling ponds or clarifiers. Coagulants and flocculants may be required to assist the settling process in case of large flow rates and limitation of available land.

Available design recommendations for settling ponds include the following:

- Water residence time of 8-72 hours.
- The length-to-width ratio should be within the range 2:1 to 5:1, to help minimise possible streaming and short-circuiting.
- The depth of the pond should be in the range of 3 m to prevent resuspension of settled particles due to the horizontal velocity of water and / or wind.
- The most effective shape of ponds, from a hydraulic point of view, is rectilinear. However, amenity considerations may lead to less effective shapes requiring larger land area requirements than initial calculations would suggest.
- Sludge captured in the settling pond requires periodic removal (typically every few years) and is often a significant cost element in the long-term operation of this type of passive treatment system.

C.6.5 Permeable Reactive Barriers

Permeable reactive barriers (PRBs) are subsurface structures filled with reactive material (i.e., organic matter/limestone or zero valent iron) that are designed to intercept and treat impacted water (Figure B-8). Typically, PRBs are installed for treatment of groundwater. Organic material can promote bacterially mediated sulfate reduction, which results in generation of alkalinity and precipitation of dissolved metals in the form of sulfide precipitates within the barrier.

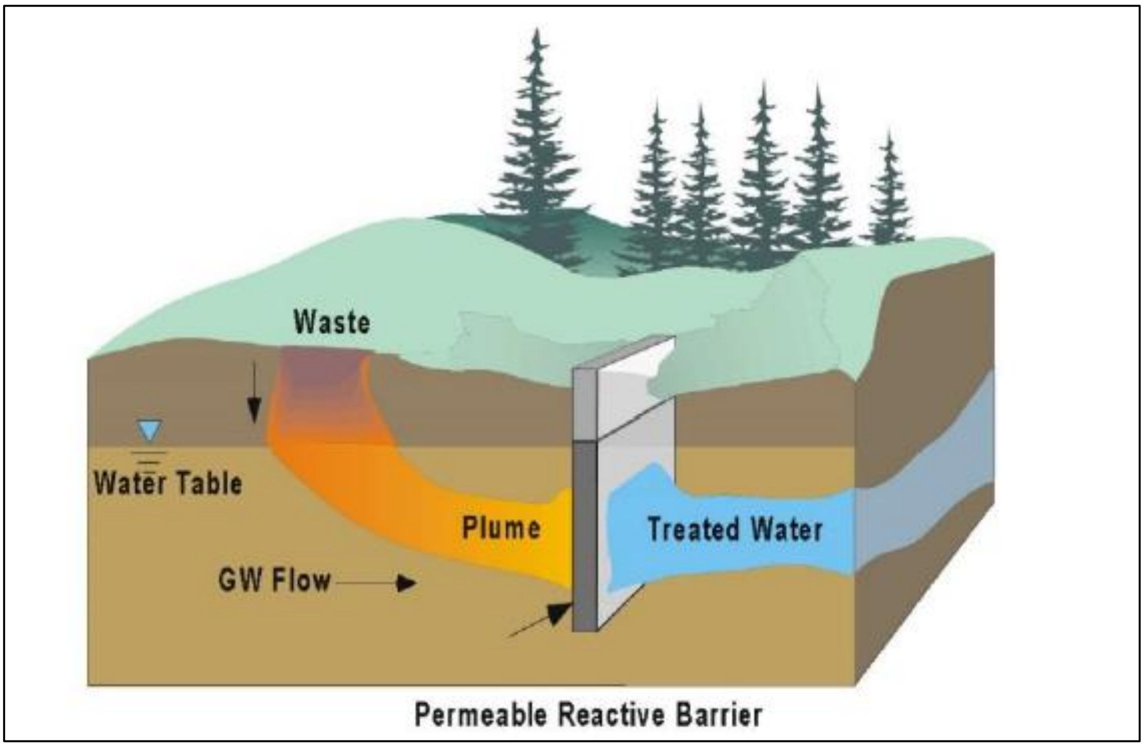


Figure B-8 PRB diagram for subsurface treatment (US EPA, 1998)

The key factors that may limit the lifetime of PRBs are the mass of available reactive material and the available volume of pore spaces (and permeability) of the barrier. Metal precipitation and substrate compaction can result in a decrease in porosity and permeability of the barrier. Typical width of PRBs are between 1.4 – 4.0 m and residence times within 3 – 90 days.

C.7 Active Systems for Treatment of ASS Impacted Water

Active systems for treatment of acidic water discharges include physical, chemical and biological approaches that manage a broad range of influent characteristics, flow regimes and discharge criteria. The main processes employed by active systems include:

- pH control or precipitation.
- Electrochemical concentration.
- Biological mediation / redox control (sulfate reduction).
- Ion exchange / absorption or adsorption / flocculation and filtration.

Active systems can be classified as fixed plant (where the water requiring treatment is directed to a conventional water treatment plant) or in-stream (where portable active or passive systems perform the treatment within or adjacent to the affected water body).

C.7.1 Ex-situ treatment (fixed plant)

Ex-situ treatment plants can comprise a range of technologies to increase the pH of water. Increasing pH with inorganic alkaline amendments (calcium hydroxide or calcium oxide) followed by oxidation and sedimentation (by flocculation and clarification) is one of the most widely applied for treatment of acid mine drainage worldwide because of its effectiveness and relatively low cost.

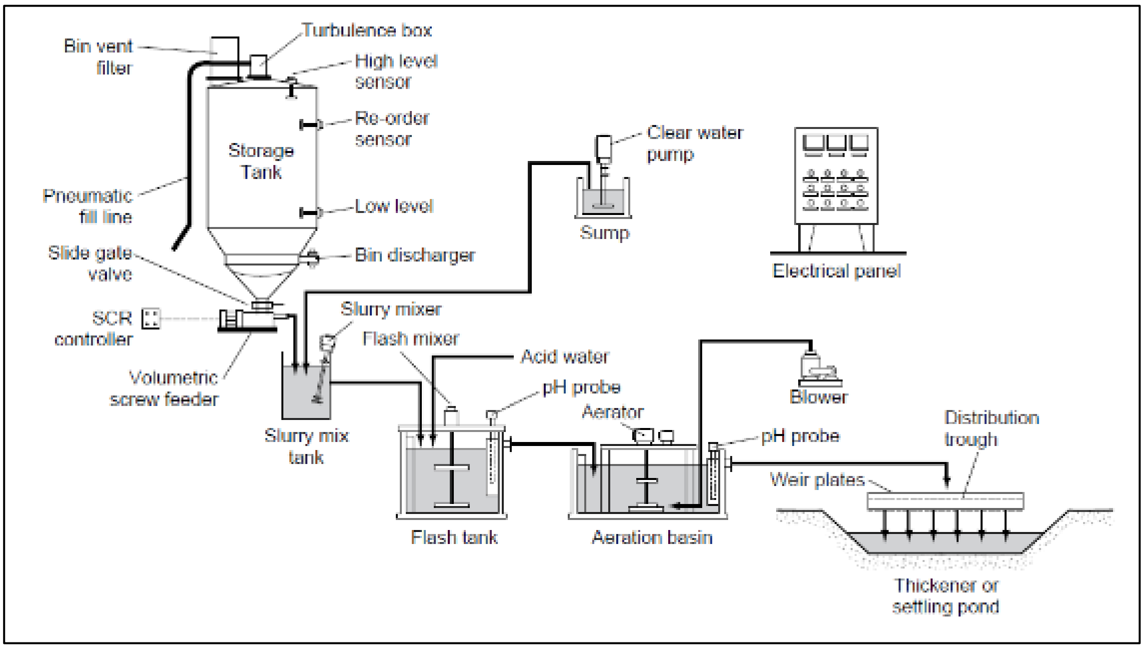


Figure B-9 Conventional water treatment utilizing lime. (Source: AMD Treat, US DoI)

Despite the general concept behind the treatment process being relatively simple, numerous variations are possible depending on project-specific parameters and factors, including total suspended solids content, flow rate, iron/manganese concentrations, chemical costs, health and safety considerations and available land area.

C.7.2 In-stream Treatment

In-stream treatment systems generally use pH control/precipitation methods for the treatment of water by using small portable plants (manual, semi-automated or fully automated) with low capital costs. The common feature of these systems is the capability for storage and dispensing of alkaline reagents (such as calcium hydroxide or calcium oxide) in the water body requiring treatment (Figure C-).

Figure C-10 In-stream dosing system

The dosing of large quantities of water such as the Anglesea River Estuary to alter the chemical composition of the water body is a specialised and highly technical task that requires considerable expertise and experience and as such, professional guidance will be required to be obtained before being implemented a design of this scale is common within the mining industry for the treatment of acidic mine water or acid mine drainage (AMD). Other known methods that are used for application of alkaline material for the management of soil and water in acid sulfate soil landscapes include:

- spraying the slurry over the water with a dispersion pump;
- pumping the slurry into the water body with air sparging (compressed air delivered through pipes) to improve mixing once added to water;
- pouring the slurry out behind a small motorboat and letting the motor mix it in;
- incorporating the slurry into the dredge line (when pumping dredge material); or
- using mobile water treatment equipment such as the ‘Neutra-mill’, ‘Aqua Fix’ and ‘CRAB’ (Calibrated Reagent Application Blender) to dispense neutralising agents to large water bodies.

The main advantages of these systems are the limited requirements for power, reduced operation and maintenance intensity and flexible implementation. One of the main disadvantages is that direct dosing of alkaline reagents in streams or channels has the potential to transport metal precipitates downstream of the treatment location.

For the above reasons, in-stream treatment is generally only suitable for the following circumstances:

- Emergency response or other short-term treatment applications, where a large quantity of reagent needs to be dosed into a water body or stream over a short period of time.
- Long-term treatment applications, where a relatively low dose rate is required over an extended period.

C.7.3 Artificial Seawater Introduction Treatment

Ocean pH is naturally alkaline, maintained between 8.1 and 8.3 by a series of reversible equilibrium reactions relating to the carbonate and hydrogen-carbonate system, where:

$\mathrm{CO2\ (gas) + H2O\ (liquid) \rightleftharpoons H2CO3\ (aqueous) \rightleftharpoons HCO3\text{-}\ (aqueous) + H+\ (aqueous) \rightleftharpoons CO3\ (aqueous) + 2H+\ (aqueous)}$

This chemical equilibrium between various forms of carbon and hydrogen ions (protons) creates a buffering system that is the most important factor controlling the pH of seawater.

Pope, 2006 preformed titrations on effluent from Marshy and Salt Creek with seawater and determined that a mixture of approx. 45% and 70% seawater to effluent ration was required to achieve a pH of 7 respectively. See figure XXXX:

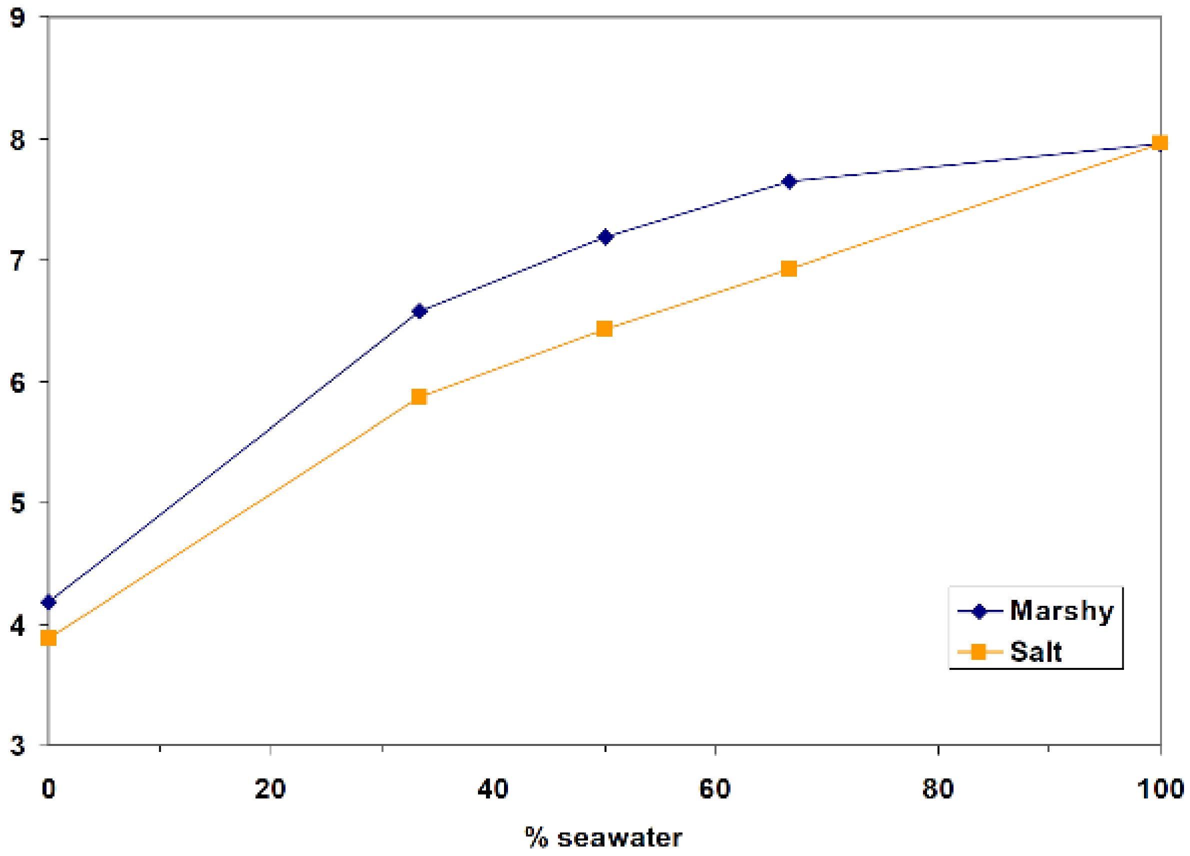


Figure C-11 Percentage of seawater to pH change in samples from Marshy Creek and Salt Creek (from Pope, 2006)

It is important to note that, the two water sources must be well mixed for any significant neutralising effect to occur, so ideally water types should enter the estuary at the same location rather than at opposite ends as occurs naturally.

For reference, Mean Sea Level (MSL) is the midpoint between recorded low and high tides, which is approximately equivalent to the Australian Height Datum (AHD), as set out in the Australian Tides Manual (ICSM 2021). Tide height ranges at the nearest observation station (Lorne) for the year 2023 (predicted) indicated tides ranged from 2.72 m to 0.25 m (Bureau of Meteorology, 2022), indicating a tide range of 2.47 m and an approximate maximum king tide level of 1.235 m AHD.

C.8 Limiting Further Intervention

Limiting further intervention or adopting a range of targeted contingency measures may be an acceptable management strategy in particular cases.

The decision of limiting intervention and/or deferring broad scale management strategies is usually supported by a suitable set of monitoring data and a properly developed risk assessment process.

When a strategy of limited further intervention is being considered, the following steps should be undertaken to support the decision:

- Engage the stakeholders and community to explain the rationale behind the limited further intervention strategy.
- If necessary, refine the assessments of the risk to both adjacent ecosystems and landholders as a consequence of the decision not to take further action.
- Implement a monitoring and reporting regime to enable periodic review of the quality of affected aquatic ecosystem and connected waters.

C.9 General Considerations for Options Assessment

C.9.1 Active vs. Passive Systems

Advantages and disadvantages of active and passive treatment systems are summarised in Table B-1.

Table B-1 Comparison of Active and Passive Systems

System Type	Advantages	Disadvantages
Active	• Ability to meet high and variable flow rates • Effective treatment of acidic water • Precise process control, such that they can be engineered and operated to produce a specific water chemistry • Suitability in locations where only a small land area is available (however sludge capture may still require large land areas)	• High capital cost • High ongoing O&M costs • Power and other infrastructure requirements • Loss of amenity values
Passive	• Overall treatment costs are less compared to an equivalent active system • Less requirement for specialised operators • Can enhance amenity values	• Relatively new technologies and lack of understanding of some relevant processes (i.e., sulfate reduction) and experience of long-term application • Precise adjustment to change of influent quality and flow rates is not possible • Performance of passive systems is subject to seasonal and other variations

C.9.2 Inflow Water Characteristics

Figure B-11 depicts acid load guidelines for selecting effective active and passive treatment systems. Contours shown are for acid loads in tonne $CaCO_3$/d.

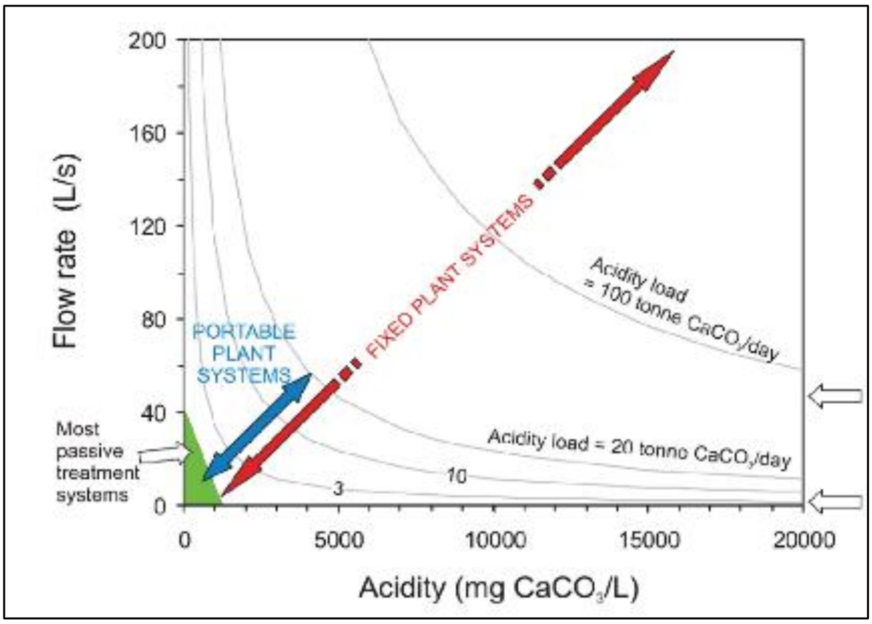


Figure B-11 Applicability Range of Active and Passive Systems (Taylor et al., 2005)

The guideline indicates that passive systems are best suited to the treatment of waters with low acidity (<800 mg $CaCO_3$/L) and low acidity loads (100–150 kg $CaCO_3$ per day)

Appendix D Targeted soil sampling of recreational tracks in the upper catchment - factual results

Appendix D Targeted soil sampling of recreational tracks in the upper catchment - factual results

Introduction

Department of Energy, Environment and Climate Action (DEECA) engaged CDM Smith Australia Pty Ltd (CDM Smith) to undertake targeted soil sampling within the Anglesea River catchment. The purpose of the sampling was to understand whether four-wheel drive (4WD) activities and associated erosion on unsealed roads could be contributing to low pH conditions in the Anglesea River and estuary. This assessment was undertaken to inform whether actions to address erosion should be considered as part of the Anglesea River Estuary Options Investigation project.

Through consultation with a stakeholder reference group, some community members have raised concerns that observed erosion of recreational 4WD tracks in the upper catchment could be a potential source of acidity.

Soil sampling completed in the catchment to-date has focused on low lying swamplands and marshes along Marshy Creek and Salt Creek. It is understood that the presence of Acid Sulfate Soil (ASS) in the foothills of the Anglesea Otway Forest Park has not previously been assessed, however it is documented in a range of previous studies that soils in the region contain acidic minerals.

Scope

The following tasks were undertaken:

1. **A targeted desktop** including review of publicly available geological maps, acid sulfate soil risk maps, historical assessment reports (which have been reviewed as part of the options investigation)
2. **A site visit** undertaken with community members to better understand the area and nature of disturbance, the environmental setting and presence of geomorphological indicators of ASS in the targeted areas
3. **Collection and analysis of 10 soil samples** in targeted eroded areas for assessment of the presence of ASS

Soil samples were collected from five areas of observed erosion from on or adjacent to Gum Flats Tanner Link Track 2, Anglesea. See figure 1 below.

The area was selected as representative of eroded tracks in the upper catchment, as observed by community members.

Sampling was undertaken to provide an indication of the likelihood that the eroded soils are contributing to the acidity issue and were not collected at frequencies outlined in the National Acid Sulphate Soil Guidance (2018) for characterisation of an area. Works were not undertaken to support waste classification of soils or management measures of insitu soils.

Soil samples were collected from the exposed face of the eroded soil profile on or immediately adjacent to 4WD tracks. Sample depth was measured from the top of the exposed soil profile.

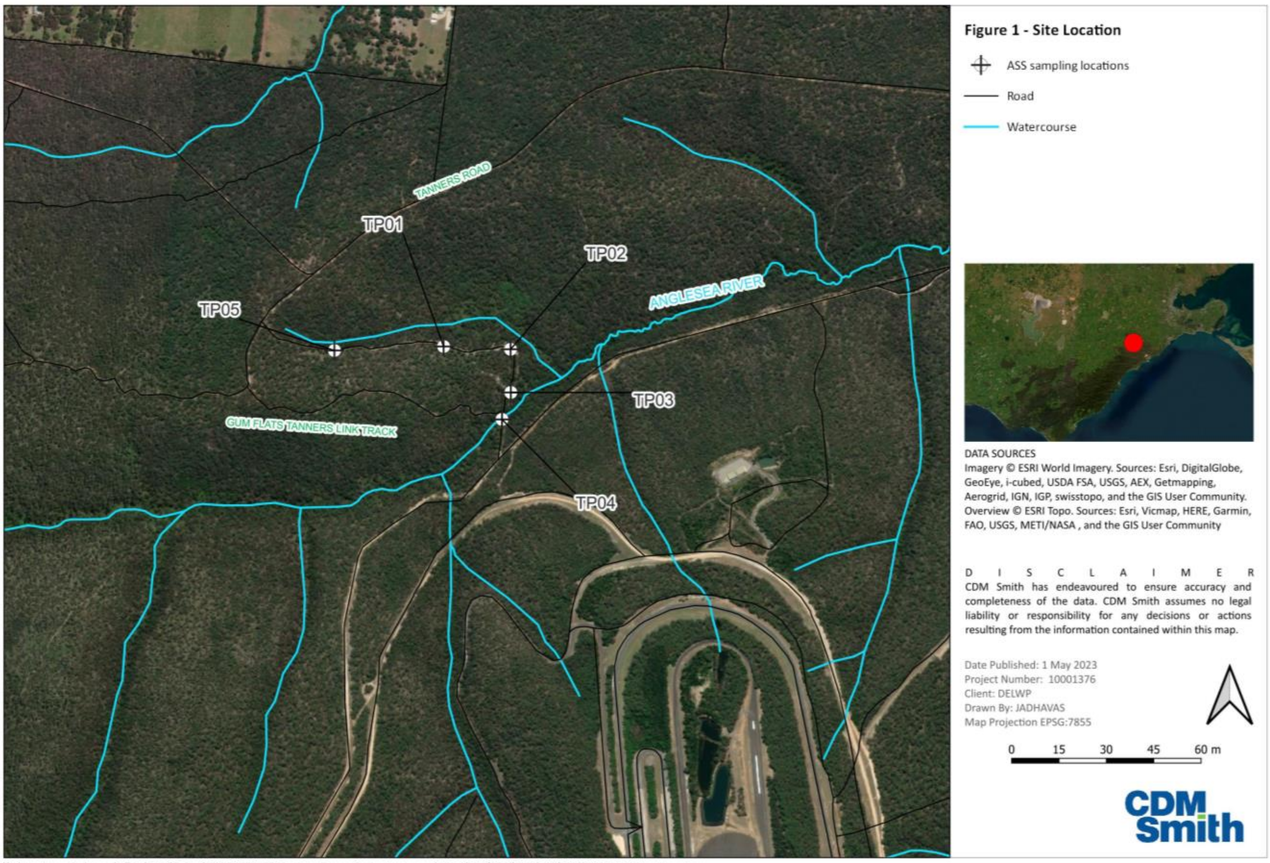
One bore was augered at location TP04, to a depth of 0.55 m below ground level in sediments, adjacent to Anglesea River (Marshy Creek).

One sample at location TP03 was collected from the surface and represented eroded soil that had washed off the track.

Samples were collected in accordance with national sampling guidance for analysis of ASS.

All samples were analysed for field pH (pH_F) and field pH Ox (pH_{FOX}). 8 selected samples were analysed for net acidity using the chromium reducible sulfur method (S_{CR}).

Appendix D Targeted soil sampling of recreational tracks in the upper catchment - factual results



DATA SOURCES
Imagery © ESRI World Imagery. Sources: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community. Overview © ESRI Topo. Sources: Esri, Vicmap, HERE, Garmin, FAO, USGS, METI/NASA , and the GIS User Community

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Figure D-1 Targeted sampling locations

Findings

The results of the limited soil sampling works provide further indication that regional soils in the Anglesea catchment are acidic and include ASS, with a pH (KCl) ranging from 4.8 to 5.8 pH units.

The assessment observed areas of soil erosion, associated with four-wheel drive activities. The activities occur in areas upgradient of the Anglesea River, with potential for eroded soils to migrate into the Anglesea River. In situ soils in areas of 4WDing activities were identified acid sulfate soils with hypersulfidic material based on the definitions of ASS in national guidance, which contained both actual acidity and Potential Sulfidic Acidity based on Reduced Inorganic Sulfur (RIS), which indicated potential to generate further acidity following further oxidation.

The net acidity measured in in situ soils on 4WD tracks was lower than in sediments (one sample) collected in the Anglesea River (Marshy Creek) and an order of magnitude lower than the average historical net acidity results for samples collected in the marshes along Marshy Creek and Salt Creek.

Low potential acidity (measured as chromium reducible sulfur) from 0.008 %S to 0.013%S was detected in the assessed soil and sediment samples. This suggests that disturbance of these soils (i.e., by erosion and erosion causing activities) has a low potential to generate further acidity.

The areas of erosion observed were also relatively small in comparison to the extensive marshes where ASS with significant estimated acid generating potential have been identified within the Anglesea River, Marshy and Salt Creeks.

Given the catchment context (consisting of large source of acidity), the localised areas of erosion of acidic soils, and potential increased oxidation of soils as a result of recreational 4WDing, is unlikely to be significantly contributing to lower pH water conditions in Anglesea River. That is to say, it is unlikely that restricting recreational 4WDing activities in the catchment would provide a measurable improvement to the pH conditions in the Anglesea River, under current conditions.

It is noted that the presence of increased erosion may have other impacts to the ecological health of the Anglesea River (for example associated with increased turbidity, increased metal toxicity and organic matter) which is outside the scope of the current project.

Appendix E Feasibility Cost Estimates for Shortlisted Options

SUMMARY TABLE

Feasibility Cost Estimate Summary of Options

Treatment Options			Capital				O&M	Net Present Value
ID	Option	Description	EPCM	Construction	Contingency (20%)	Total Capital	Annual	10 years 4% discount rate
5	Weir System at Coogoorah Park	Install inlet and outlet moveable weirs at Coogoorah Park	$ 385,000	$ 1,450,000	$ 367,000	$ 2,202,000	$ 142,000	$ 3,353,747
12	Estuary Opening (Shallow)	Excavate shallow, temporary trench across beach	$ 225,000	$ 129,875	$ 70,975	$ 425,850	$ 55,000	$ 871,949
13	Estuary Opening (Deep)	Excavate deeper, temporary trench across beach	$ 225,000	$ 254,563	$ 95,913	$ 575,475	$ 95,000	$ 1,346,010
14	Seawater Pumping	Install pump station with 500 m inlet and outlet pipelines	$ 445,000	$ 553,000	$ 199,600	$ 1,197,600	$ 194,800	$ 2,777,602
20	Open Limestone Channel	Limestone-lined high/low flow channel, 100 m long	$ 180,000	$ 165,500	$ 69,100	$ 414,600	$ 107,500	$ 1,286,521
23	Constructed Wetland	Construct 3 hectare wetland upstream of Coolgoorah Park	$ 205,000	$ 620,000	$ 165,000	$ 990,000	$ 105,000	$ 1,841,644
24	In Situ Permeable Reactive Barrier	Construct in-stream crushed limestone PRB	$ 205,000	$ 174,700	$ 75,940	$ 455,640	$ 105,000	$ 1,307,284
28	In Situ Lime Dosing	Construct dosing station (lime solution)	$ 265,000	$ 223,000	$ 97,600	$ 585,600	$ 268,100	$ 2,760,131

EPCM	Engineering, Procurement, Construction Management
O&M	Operation and Maintenance (Annual)
Note	Costs are "feasibility" level (-30% to +50%)

TABLE 1
Feasibility Cost Estimate: (5) Weir System

Description: Install 10 metre wide moveable weirs/sluice gates, one each at the 20 metre wide inlet and outlet of the Coogoorah Wetlands to maintain water levels within the wetlands above acid sulfate sediments, to prevent exposure to the atmosphere and subsequent oxidation of sulfidic materials; excluding land acquisition

Item	Description	Quantity	Unit	Unit Price	Line Item Total	Task Subtotal	Comments
1	**Project Management**						
	Contract Administration	1	Lump Sum	$ 10,000	$ 10,000		Contract / Program Manager
	Regulatory Liaison	1	Lump Sum	$ 10,000	$ 10,000		Agency interaction
	Scheduling and Coordination	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Construction Management	1	Lump Sum	$ 50,000	$ 50,000		Engineer's estimate
	QA/QC Documentation	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Subtotal					**$ 90,000**	
2	**Preliminary Design - Weir System**	**onstruct in-stream crushed limestone PRB**					
	Investigations	1	Lump Sum	$ 100,000	$ 100,000		Flora, fauna, soil, hydrology
	Concept Design and Report	1	Lump Sum	$ 10,000	$ 10,000		Objectives, design basis
	Functional Design and Report	1	Lump Sum	$ 20,000	$ 20,000		Design parameters
	Subtotal					**$ 130,000**	
3	**Detailed Design - Weir System**						
	Civil and Landscape Drawings	1	Lump Sum	$ 40,000	$ 40,000		Engineer's estimate
	Mechanical, Electrical, Controls	1	Lump Sum	$ 40,000	$ 40,000		
	Construction Specifications	1	Lump Sum	$ 20,000	$ 20,000		Engineer's estimate
	Maintenance Plan	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Preliminary Construction Schedule	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Subtotal					**$ 115,000**	
4	**Pre-Construction / Permitting**						
	Tender Process	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Environmental Management Plan	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Health and Safety Plan	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Permits	1	Lump Sum	$ 25,000	$ 25,000		Engineer's estimate
	Subtotal					**$ 50,000**	
5	**Mobilisation / Demobilisation**						
	Construction Equipment	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Office Trailer / Storage Facilities	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Security, Fencing and Signs	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Temporary Utilities	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Subtotal					**$ 20,000**	
6	**Weir Construction**						
	Civil						
	Access Roads	2	Lump Sum	$ 20,000	$ 40,000		Rawlinsons
	Clearing	2	Lump Sum	$ 25,000	$ 50,000		Rawlinsons
	Earthwork and Grading	2	Lump Sum	$ 40,000	$ 80,000		Rawlinsons
	Construct Basins, Dikes, Concrete	2	Lump Sum	$ 80,000	$ 160,000		Rawlinsons
	Mechanical / Electrical						
	Weir / Sluice Gate	2	Lump Sum	$ 300,000	$ 600,000		Stainless steel, 10 m wide by 2 metre high
	Control Building	2	Lump Sum	$ 200,000	$ 400,000		Motors, pumps, high voltage equip, hydraulics
	Instrumentation and Controls	2	Lump Sum	$ 50,000	$ 100,000		Supervisory control and data acquisition (SCADA)
	Subtotal					**$ 1,430,000**	
	Project Subtotal Total					**$ 1,835,000**	
	Contingency (20%)					**$ 367,000**	
	Project Capital					**$ 2,202,000**	

	Annual Operation and Maintenance						
	Inspection	12	Month	$ 1,000	$ 12,000		Monthly Inspection (Engineer's Estimate)
	Utilities	12	Month	$ 5,000	$ 60,000		
	Operations and Maintenance	12	Month	$ 5,000	$ 60,000		
	Monitoring and Reporting	4	Each	$ 2,500	$ 10,000		Quarterly (Engineer's Estimate)
	Subtotal					**$ 142,000**	

TABLE 2
Feasibility Cost Estimate: (12) Shallow Estuary Opening

Description: Construct a *temporary* , *shallow* inlet (0.75 mAHD base) with approximate dimensions of 1.5 m deep x 7.5 m wide x 500 m long) to the estuary to allow interchange of seawater with acidic estuarine waters from upstream, partially buffering the low pH water from the upper catchment.

Item	Description	Quantity	Unit	Unit Price	Line Item Total	Task Subtotal	Comments
1	**Project Management**						
	Contract Administration	1	Lump Sum	$ 5,000	$ 5,000		Contract / Program Manager
	Regulatory Liaison	1	Lump Sum	$ 10,000	$ 10,000		Agency interaction
	Scheduling and Coordination	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	QA/QC Documentation	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Construction Management	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Subtotal					**$ 35,000**	
2	**Preliminary Studies**	**onstruct in-stream crushed limestone PRB**					
	Site Survey and cultural heritage study	1	Lump Sum	$ 25,000	$ 25,000		Engineer's estimate
	River / Marine / Tidal Study	1	Lump Sum	$ 25,000	$ 25,000		Engineer's estimate, to inform timing/design
	Modelling	1	Lump Sum	$ 25,000	$ 25,000		Engineer's estimate, to inform timing/design
	Report	1	Lump Sum	$ 20,000	$ 20,000		Engineer's estimate
	Subtotal					**$ 95,000**	
3	**Design and Specifications**						
	Plans and Specifications	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Construction Cost Estimate	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Construction Schedule	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Subtotal					**$ 25,000**	
4	**Procurement / Tender**						
	Tender Specifications	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Tender Issue, Review, and Selection	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Contract Negotiations	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Contract Award	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Subtotal					**$ 25,000**	
5	**Pre-Field and Planning**						
	Health and Safety Plan	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Air / Dust Monitoring Plan	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Sampling and Analysis Plan	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Storm Water Pollution Prevention Plan	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Permits	1	Lump Sum	$ 20,000	$ 20,000		Engineer's estimate
	Subtotal					**$ 45,000**	
6	**Mobilisation / Demobilisation**						
	Construction Equipment	1	Lump Sum	$ 3,000	$ 3,000		Engineer's estimate
	Office Trailer / Storage Facilities	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Security, Fencing and Signs	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Temporary Utilities	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Subtotal					**$ 23,000**	
7	**Excavation**						
	Excavation (500 m long x 7.5 m wide x 1.5 m	5625	m3	$ 15	$ 84,375		Rawlinsons
	Load, cart, spread, level within 500 m	5625	m3	$ 4	$ 22,500		Rawlinsons, beach sand redistributed onsite
	Subtotal					**$ 106,875**	
	Project Subtotal Total					**$ 354,875**	
	Contingency (20%)					**$ 70,975**	
	Project Capital					**$ 425,850**	

	Annual Operation and Maintenance						
	Inspection	12	Month	$ 1,000	$ 12,000		Monthly Inspection (Engineer's Estimate)
	Re-excavation	2	Each	$ 20,000	$ 40,000		Quarterly (Engineer's Estimate)
	Monitoring and Reporting	2	Each	$ 1,500	$ 3,000		Quarterly (Engineer's Estimate)
	Subtotal					**$ 55,000**	

TABLE 3
Feasibility Cost Estimate: (13) Deep Estuary Opening

Description: Construct a *temporary* , *shallow* inlet (-1.0 mAHD base) with approximate dimensions of 3.25 m deep x 7.5 m wide x 500 m long) to the estuary to allow interchange of seawater with acidic estuarine waters from upstream, partially buffering the low pH water from the upper catchment.

Item	Description	Quantity	Unit	Unit Price	Line Item Total	Task Subtotal	Comments
1	**Project Management**						
	Contract Administration	1	Lump Sum	$ 5,000	$ 5,000		Contract / Program Manager
	Regulatory Liaison	1	Lump Sum	$ 10,000	$ 10,000		Agency interaction
	Scheduling and Coordination	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	QA/QC Documentation	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Construction Management	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Subtotal					**$ 35,000**	
2	**Preliminary Studies**	**onstruct in-stream crushed limestone PRB**					
	Site Survey and cultural heritage study	1	Lump Sum	$ 25,000	$ 25,000		Engineer's estimate
	River / Marine / Tidal Study	1	Lump Sum	$ 25,000	$ 25,000		Engineer's estimate, to inform timing/design
	Modelling	1	Lump Sum	$ 25,000	$ 25,000		Engineer's estimate, to inform timing/design
	Report	1	Lump Sum	$ 20,000	$ 20,000		Engineer's estimate
	Subtotal					**$ 95,000**	
3	**Design and Specifications**						
	Plans and Specifications	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Construction Cost Estimate	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Construction Schedule	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Subtotal					**$ 25,000**	
4	**Procurement / Tender**						
	Tender Specifications	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Tender Issue, Review, and Selection	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Contract Negotiations	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Contract Award	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Subtotal					**$ 25,000**	
5	**Pre-Field and Planning**						
	Health and Safety Plan	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Air / Dust Monitoring Plan	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Sampling and Analysis Plan	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Storm Water Pollution Prevention Plan	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Permits	1	Lump Sum	$ 20,000	$ 20,000		Engineer's estimate
	Subtotal					**$ 45,000**	
6	**Mobilisation / Demobilisation**						
	Construction Equipment	1	Lump Sum	$ 3,000	$ 3,000		Engineer's estimate
	Office Trailer / Storage Facilities	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Security, Fencing and Signs	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Temporary Utilities	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Subtotal					**$ 23,000**	
7	**Excavation**						
	Excavation (500 m long x 7.5 m wide x 3.25	12187.5	m3	$ 15	$ 182,813		Rawlinsons
	Load, cart, spread, level, within 500 m	12187.5	m3	$ 4	$ 48,750		Rawlinsons
	Subtotal					**$ 231,563**	
	Project Subtotal Total					**$ 479,563**	
	Contingency (20%)					**$ 95,913**	
	Project Capital					**$ 575,475**	

	Annual Operation and Maintenance						
	Inspection	12	Month	$ 1,000	$ 12,000		Monthly Inspection (Engineer's Estimate)
	Re-excavation	2	Each	$ 40,000	$ 80,000		Quarterly (Engineer's Estimate)
	Monitoring and Reporting	2	Each	$ 1,500	$ 3,000		Quarterly (Engineer's Estimate)
	Subtotal					**$ 95,000**	

TABLE 4

Feasibility Cost Estimate: (14) Seawater Pumping

Description (GHD Option 2) - Construct and operate a dedicated, permanent 5 ML/day pump station and pipeline to intermittently (as needed) pump seawater from the ocean and discharge to an upstream location within the estuary, to buffer the low pH water flowing into the estuary from the upper catchment.

Item	Description	Quantity	Unit	Unit Price	Line Item Total	Task Subtotal	Comments
1	**Project Management**						
	Contract Administration	1	Lump Sum	$ 10,000	$ 10,000		Contract / Program Manager
	Regulatory Liaison	1	Lump Sum	$ 10,000	$ 10,000		Agency interaction
	Scheduling and Coordination	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	QA/QC Documentation	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Construction Management	1	Lump Sum	$ 20,000	$ 20,000		One month
	Subtotal					**$ 60,000**	
2	**Preliminary Design - Seawater Pumping**	**onstruct in-stream crushed limestone PRB**					
	Investigations	1	Lump Sum	$ 200,000	$ 200,000		Marine, cultural heritage, flora, fauna, soil, hydrology
	Concept Design and Report	1	Lump Sum	$ 10,000	$ 10,000		Objectives, design basis
	Functional Design and Report	1	Lump Sum	$ 20,000	$ 20,000		Design parameters
	Subtotal					**$ 230,000**	
3	**Detailed Design - Seawater Pumping**						
	Civil / Excavation Drawings	1	Lump Sum	$ 20,000	$ 20,000		Engineer's estimate
	Mechanical Drawings	1	Lump Sum	$ 25,000	$ 25,000		Engineer's estimate
	Electrical Drawings	1	Lump Sum	$ 25,000	$ 25,000		Engineer's estimate
	Construction Specifications	1	Lump Sum	$ 20,000	$ 20,000		Engineer's estimate
	Maintenance Plan	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Preliminary Construction Schedule	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Subtotal					**$ 105,000**	
4	**Pre-Construction / Permitting**						
	Tender Process	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Environmental Management Plan	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Health and Safety Plan	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Permits	1	Lump Sum	$ 25,000	$ 25,000		Engineer's estimate
	Subtotal					**$ 50,000**	
5	**Mobilisation / Demobilisation**						
	Construction Equipment	1	Lump Sum	$ 3,000	$ 3,000		Engineer's estimate
	Office Trailer / Storage Facilities	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Security, Fencing and Signs	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Temporary Utilities	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Subtotal					**$ 23,000**	
6	**Pipeline Excavation and Installation**						
	Excavation, Installation, Anchor	1	Lump Sum	$ 250,000	$ 250,000		Engineer's estimate
	Pipe-Inlet Suction (150 mm HDPE)	500	Metre	$ 130	$ 65,000		Rawlinsons
	Pipe-Outlet Discharge (150 mm HDPE)	500	Metre	$ 130	$ 65,000		Rawlinsons
	Subtotal					**$ 380,000**	
7	**Pump Station Construct and Commission**						
	Civil (earthwork, concrete)	1	Lump Sum	$ 30,000	$ 30,000		Rawlinsons
	Structural (Pump Station Building)	1	Lump Sum	$ 25,000	$ 25,000		Rawlinsons
	Electrical and Controls	1	Lump Sum	$ 20,000	$ 20,000		Rawlinsons
	Mechanical	1	Lump Sum	$ 25,000	$ 25,000		Rawlinsons
	Pumps	2	Each	$ 25,000	$ 50,000		Rawlinsons
	Subtotal					**$ 150,000**	
	Project Subtotal Total					**$ 998,000**	
	Contingency (20%)					**$ 199,600**	
	Project Capital					**$ 1,197,600**	

TABLE 5
Feasibility Cost Estimate: (20) Open Limestone Channel

Description: Construct 1-metre deep, 100 metre long limestone channel downstream of confluence of Salt Creek and Marshy Creek, combined high-flow (5 m wide) / low-flow (1 m wide)

Item	Description	Quantity	Unit	Unit Price	Line Item Total	Task Subtotal	Comments
1	**Project Management**						
	Contract Administration	1	Lump Sum	$ 5,000	$ 5,000		Contract / Program Manager
	Regulatory Liaison	1	Lump Sum	$ 10,000	$ 10,000		Agency interaction
	Scheduling and Coordination	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Construction Management	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	QA/QC Documentation	1	Lump Sum	$ 10,000	$ 10,000		Dockets, reports
	Subtotal					**$ 40,000**	
2	**Preliminary Design - Limestone Channel**	**onstruct in-stream crushed limestone PRB**					
	Site Survey	1	Lump Sum	$ 25,000	$ 25,000		Topography, flora, fauna, geology, hydrology
	Concept Design and Report	1	Lump Sum	$ 10,000	$ 10,000		Objectives, design basis
	Functional Design and Report	1	Lump Sum	$ 20,000	$ 20,000		Design parameters
	Subtotal					**$ 55,000**	
3	**Detailed Design - Limestone Channel**						
	Civil and Landscape Drawings	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Construction Specifications	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Maintenance Plan	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Preliminary Construction Schedule	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Subtotal					**$ 35,000**	
4	**Pre-Construction / Permitting**						
	Tender Process	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Environmental Management Plan	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Health and Safety Plan	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Permits	1	Lump Sum	$ 25,000	$ 25,000		Engineer's estimate
	Subtotal					**$ 50,000**	
5	**Mobilisation / Demobilisation**						
	Construction Equipment	1	Lump Sum	$ 3,000	$ 3,000		Engineer's estimate
	Office Trailer / Storage Facilities	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Security, Fencing and Signs	1	Lump Sum	$ 2,500	$ 2,500		Engineer's estimate
	Temporary Utilities	1	Lump Sum	$ 1,000	$ 1,000		Engineer's estimate
	Subtotal					**$ 11,500**	
6	**Earthworks / Limestone Channel Construction**						
	Access Roads	1	Lump Sum	$ 20,000	$ 20,000		Engineer's estimate
	Clearing	1	Lump Sum	$ 20,000	$ 20,000		Engineer's estimate
	Earthwork and Grading	1	Lump Sum	$ 40,000	$ 40,000		Engineer's estimate
	Materials (crushed limestone)	400	Tonnes	$ 110	$ 44,000		150 m3 @ 2.4T/m3
	Construct Limestone Channel	1	Lump Sum	$ 30,000	$ 30,000		Engineer's estimate
	Subtotal					**$ 154,000**	
	Project Subtotal Total					**$ 345,500**	
	Contingency (20%)					**$ 69,100**	
	Project Capital					**$ 414,600**	

	Annual Operation and Maintenance						
	Inspection	60	Hour	$ 125	$ 7,500		Monthly Inspection (Engineer's Estimate)
	Cleaning and Maintenance	4	Each	$ 20,000	$ 80,000		Quarterly (Engineer's Estimate)
	Monitoring and Reporting	4	Each	$ 5,000	$ 20,000		Quarterly (Engineer's Estimate)
	Subtotal					**$ 107,500**	

TABLE 6

Feasibility Cost Estimate: (23) Constructed Wetlands

Description: Construct a 3 hectare wetland (flow approx. 0.45 m3/m2-day) through which the water from the upstream catchment would flow prior to discharge to the estuary.

Item	Description	Quantity	Unit	Unit Price	Line Item Total	Task Subtotal	Comments
1	**Project Management**						
	Contract Administration	1	Lump Sum	$ 10,000	$ 10,000		Contract / Program Manager
	Regulatory Liaison	1	Lump Sum	$ 10,000	$ 10,000		Agency interaction
	Scheduling and Coordination	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	QA/QC Documentation	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Construction Management	1	Lump Sum	$ 20,000	$ 20,000		Engineer's estimate
	Subtotal					**$ 60,000**	
2	**Preliminary Design - Constructed Wetlands**	**onstruct in-stream crushed limestone PRB**					
	Site Survey	1	Lump Sum	$ 10,000	$ 10,000		Topography, flora, fauna, geology, hydrology
	Concept Design and Report	1	Lump Sum	$ 10,000	$ 10,000		Objectives, design basis
	Functional Design and Report	1	Lump Sum	$ 20,000	$ 20,000		Design parameters
	Subtotal					**$ 40,000**	
3	**Detailed Design - Constructed Wetlands**						
	Civil and Landscape Drawings	1	Lump Sum	$ 20,000	$ 20,000		Engineer's estimate
	Construction Specifications	1	Lump Sum	$ 20,000	$ 20,000		Engineer's estimate
	Maintenance Plan	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Preliminary Construction Schedule	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Subtotal					**$ 55,000**	
4	**Pre-Construction / Permitting**						
	Tender Process	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Environmental Management Plan	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Health and Safety Plan	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Permits	1	Lump Sum	$ 25,000	$ 25,000		Engineer's estimate
	Subtotal					**$ 50,000**	
5	**Mobilisation / Demobilisation**						
	Construction Equipment	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Office Trailer / Storage Facilities	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Security, Fencing and Signs	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Temporary Utilities	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Subtotal					**$ 20,000**	
6	**Earthworks / Construction**						
	Access Roads	1	Lump Sum	$ 20,000	$ 20,000		Rawlinsons
	Clearing	3	Hectare	$ 20,000	$ 60,000		Rawlinsons
	Earthwork and Grading	3	Hectare	$ 20,000	$ 60,000		Rawlinsons
	Construct Basins, Dikes, Weir	1	Lump Sum	$ 200,000	$ 200,000		Rawlinsons
	Piping and Valving at outlet weir	1	Lump Sum	$ 50,000	$ 50,000		Rawlinsons
	Planting	3	Hectare	$ 25,000	$ 75,000		Rawlinsons
	Seeding	3	Hectare	$ 25,000	$ 75,000		Rawlinsons
	Liming / Fertilising / Mulching	3	Hectare	$ 20,000	$ 60,000		Rawlinsons
	Subtotal					**$ 600,000**	
	Estimated Capital Cost					**$ 825,000**	
	Contingency (20%)					**$ 165,000**	
	Project Capital					**$ 990,000**	

	Annual Operation and Maintenance						
	Inspection	120	Hour	$ 125	$ 15,000		Monthly Inspection (Engineer's Estimate)
	Cleaning and Maintenance	4	Each	$ 20,000	$ 80,000		Quarterly (Engineer's Estimate)
	Monitoring and Reporting	4	Each	$ 2,500	$ 10,000		Quarterly (Engineer's Estimate)
	Subtotal					**$ 105,000**	

TABLE 7
Feasibility Cost Estimate: (24) In Situ PRB

Description: Construct a reactive barrier through which the water from the upstream catchment would flow prior to discharge to the estuary (10 metre wide, 5 metre long, 2 meter tall).

Item	Description	Quantity	Unit	Unit Price	Line Item Total	Task Subtotal	Comments
1	**Project Management**						
	Contract Administration	1	Lump Sum	$ 10,000	$ 10,000		Contract / Program Manager
	Regulatory Liaison	1	Lump Sum	$ 10,000	$ 10,000		Agency interaction
	Scheduling and Coordination	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	QA/QC Documentation	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Construction Management	1	Lump Sum	$ 20,000	$ 20,000		Engineer's estimate
	Subtotal					**$ 60,000**	
2	**Preliminary Design - In Situ PRB**	**onstruct in-stream crushed limestone PRB**					
	Site Survey	1	Lump Sum	$ 10,000	$ 10,000		Topography, flora, fauna, geology, hydrology
	Concept Design and Report	1	Lump Sum	$ 10,000	$ 10,000		Objectives, design basis
	Functional Design and Report	1	Lump Sum	$ 20,000	$ 20,000		Design parameters
	Subtotal					**$ 40,000**	
3	**Detailed Design - In Situ PRB**						
	Civil and Landscape Drawings	1	Lump Sum	$ 20,000	$ 20,000		Engineer's estimate
	Construction Specifications	1	Lump Sum	$ 20,000	$ 20,000		Engineer's estimate
	Maintenance Plan	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Preliminary Construction Schedule	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Subtotal					**$ 55,000**	
4	**Pre-Construction / Permitting**						
	Tender Process	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Environmental Management Plan	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Health and Safety Plan	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Permits	1	Lump Sum	$ 25,000	$ 25,000		Engineer's estimate
	Subtotal					**$ 50,000**	
5	**Mobilisation / Demobilisation**						
	Construction Equipment	1	Lump Sum	$ 3,000	$ 3,000		Engineer's estimate
	Office Trailer / Storage Facilities	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Security, Fencing and Signs	1	Lump Sum	$ 2,500	$ 2,500		Engineer's estimate
	Temporary Utilities	1	Lump Sum	$ 1,000	$ 1,000		Engineer's estimate
	Subtotal					**$ 11,500**	
6	**Earthworks / PRB Construction**						
	Access Roads	1	Lump Sum	$ 20,000	$ 20,000		Rawlinsons
	Clearing	1	Lump Sum	$ 20,000	$ 20,000		Rawlinsons
	Earthwork and Grading	1	Lump Sum	$ 20,000	$ 20,000		Rawlinsons
	Materials (crushed limestone)	120	Tonnes	$ 110	$ 13,200		Rawlinsons (50 m3 @ 2.4 T/m3)
	Construct PRB	1	Lump Sum	$ 90,000	$ 90,000		Rawlinsons
	Subtotal					**$ 163,200**	
	Project Subtotal Total					**$ 379,700**	
	Contingency (20%)					**$ 75,940**	
	Project Capital					**$ 455,640**	

	Annual Operation and Maintenance						
	Labour	120	Hour	$ 125	$ 15,000		Monthly Inspection (Engineer's Estimate)
	Cleaning and Maintenance	4	Each	$ 20,000	$ 80,000		Quarterly (Engineer's Estimate)
	Monitoring and Reporting	4	Each	$ 2,500	$ 10,000		Quarterly (Engineer's Estimate)
	Subtotal					**$ 105,000**	

TABLE 8
Feasibility Cost Estimate: (28) In Situ Lime Dosing

Description: Construct a lime blending, dosing and discharge station along the creek. Storage volume based on pH and flow conditions 2017-2023 approx treatment rate/year + safety factor.

Item	Description	Quantity	Unit	Unit Price	Line Item Total	Task Subtotal	Comments
1	**Project Management**						
	Contract Administration	1	Lump Sum	$ 10,000	$ 10,000		Contract / Program Manager
	Regulatory Liaison	1	Lump Sum	$ 10,000	$ 10,000		Agency interaction
	Scheduling and Coordination	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	QA/QC Documentation	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Construction Management	1	Lump Sum	$ 20,000	$ 20,000		One month
	Subtotal					**$ 60,000**	
2	**Preliminary Design - Lime Dosing Station**	**onstruct in-stream crushed limestone PRB**					
	Investigations and survey	1	Lump Sum	$ 20,000	$ 20,000		Topography, flora, fauna, geology, hydrology
	Concept Design and Report	1	Lump Sum	$ 10,000	$ 10,000		Objectives, design basis
	Functional Design and Report	1	Lump Sum	$ 20,000	$ 20,000		Design parameters
	Subtotal					**$ 50,000**	
3	**Detailed Design - Lime Dosing Station**						
	Civil / Excavation Drawings	1	Lump Sum	$ 20,000	$ 20,000		Engineer's estimate
	Mechhnical Drawings	1	Lump Sum	$ 25,000	$ 25,000		Engineer's estimate
	Electrical Drawings	1	Lump Sum	$ 25,000	$ 25,000		Engineer's estimate
	Construction Specifications	1	Lump Sum	$ 20,000	$ 20,000		Engineer's estimate
	Maintenance Plan	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Preliminary Construction Schedule	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Subtotal					**$ 105,000**	
4	**Pre-Construction / Permitting**						
	Tender Process	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Environmental Management Plan	1	Lump Sum	$ 10,000	$ 10,000		Engineer's estimate
	Health and Safety Plan	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Permits	1	Lump Sum	$ 25,000	$ 25,000		Engineer's estimate
	Subtotal					**$ 50,000**	
5	**Mobilisation / Demobilisation**						
	Construction Equipment	1	Lump Sum	$ 3,000	$ 3,000		Engineer's estimate
	Office Trailer / Storage Facilities	1	Lump Sum	$ 5,000	$ 5,000		Engineer's estimate
	Security, Fencing and Signs	1	Lump Sum	$ 2,500	$ 2,500		Engineer's estimate
	Temporary Utilities	1	Lump Sum	$ 1,000	$ 1,000		Engineer's estimate
	Subtotal					**$ 11,500**	
6	**Pipeline Excavation and Installation**						
	Excavation, Installation, Anchor	1	Lump Sum	$ 30,000	$ 30,000		Engineer's estimate
	Pipe-Outlet Discharge (150 mm HDPE)	50	Metre	$ 130	$ 6,500		Engineer's estimate
	In-Line Static Mixers	1	Each	$ 5,000	$ 5,000		Engineer's estimate
	Subtotal					**$ 41,500**	
7	**Lime Dosing Station Construct and Commission**						
	Civil (earthwork, concrete)	1	Lump Sum	$ 30,000	$ 30,000		Rawlinsons
	Structural (Pump Station Building)	1	Lump Sum	$ 25,000	$ 25,000		Rawlinsons
	Electrical and Controls	1	Lump Sum	$ 20,000	$ 20,000		Rawlinsons
	Mechanical Assembly	1	Each	$ 25,000	$ 25,000		Rawlinsons
	Lime Storage Silo (40 m3)	1	Each	$ 30,000	$ 30,000		Engineer's estimate (approx. 90 tonne storage)
	Screw Conveyor	1	Each	$ 15,000	$ 15,000		Rawlinsons
	Mixing Tank	1	Each	$ 10,000	$ 10,000		Rawlinsons
	Transfer / Dosing Pump	1	Each	$ 15,000	$ 15,000		Rawlinsons
	Subtotal					**$ 170,000**	
	Project Subtotal Total					**$ 488,000**	
	Contingency (20%)					**$ 97,600**	
	Project Capital					**$ 585,600**	

	Annual Operation and Maintenance						
	Labour	500	Hour	$ 125	$ 62,500		Weekly O&M
	Utilities	22000	kW-hr	$ 0.15	$ 3,300		5kW pump, 50% up time; controls and telemetry
	Lime	138	tonne	$ 850	$ 117,300		Maximum annual usage based on 2022 data + 50% safety fac
	Parts and Supplies	1	Lump Sum	$ 10,000	$ 10,000		Engineer's Estimate
	Monitoring and Reporting	50	Each	$ 1,500	$ 75,000		Weekly
	Subtotal					**$ 268,100**	