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Summary Report

Anglesea River Management Options Investigation – Summary Report

PREPARED FOR:

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

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Section 1 Introduction

1.1 Background

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. The river is known by the Wadawurrung Traditional Owners as kuarka dorla, place of fishing mullet.

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, including 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) have been observed during extended periods of low pH. 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 document presents a summary of the project's methodology and findings.

1.2 Objective and scope

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

The scope for the project included:

- 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 in the river, through review of literature, experience from an expert panel, case studies and previous studies completed in Anglesea
- Screening and shortlisting of options against a developed assessment framework
- Further detailed evaluation of shortlisted options.

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.

Throughout the project, a project community and stakeholder reference group was consulted at key stages to provide input and feedback. In particular, the group provided information relating to the issue understanding, helped to inform the success factors, raised options for consideration and informed aspects of the options evaluation particularly related to local social and stakeholder values.

A panel of independent experts in fields of acid sulfate soil, estuary dynamics, waterway health, and ecological risk contributed to the project as part of the CDM Smith team. This panel provided expert advice, information, and review to support the issue understanding and options evaluation.

1.3 Project state of knowledge

This project was completed using current knowledge including conceptual understanding of the catchment and the potential drivers of the acidity issue that was formed from previous studies, current catchment physical and environmental setting, and available technologies.

A number of potential future changes to the catchment were identified that were not able to be quantified and considered in the project, but may influence water quality and pH conditions in the Anglesea River. These include:

- Changes to the catchment hydrology or hydrogeology following rehabilitation of the Alcoa open cut coal mine and power station.
- Climate change, including projected changes to surface water availability and flow from changes in temperature and rainfall patterns; changes to the estuary berm; changes to sea level and water levels in the estuary; and increased extreme weather events.
- Episodic events such as bushfire.
- Changes in pH trends or other water quality conditions.

Future activities in the catchment that could potentially influence pH conditions in the river should consider this study and related previous studies to understand potential impacts and minimise the activity's effects. This includes activities related to surface water runoff and flow, groundwater, soil in the upper catchment or where ASS are present, or estuary entrance conditions.

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.

1.4 Issue overview

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.

Since pH monitoring started in 1969, water quality data collected by Alcoa, DEECA and EstuaryWatch has indicated that the Anglesea River estuary has frequently experienced periods of acidic or low pH conditions resulting from upstream river flow. Measurements of pH in the catchment tributaries of Salt Creek and Marshy Creek indicate acidic conditions most of the time. Longer periods of low pH conditions have been recorded in the estuary in recent years, most significantly from August 2019 until the end of October 2022.

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.

Fish death events have been recorded in 2000, 2007, spring 2010 and early 2011 during acidic periods.

Figure 1 illustrates the range of drivers, stressors and endpoints identified for the Anglesea River system in 2016 & 2019 that potentially influence pH conditions.

Figure 2 provides an overview of the catchment features and activities related to this project.

Acidity sources

- The key source of acidity in the river is ASS in the upper and mid-catchment that has oxidised to form sulfuric acid. A range of studies have estimated that there is a very high acid generating potential within the catchment (Maher, 2011; Wong, Claff & Driscoll, 2020; Sullivan et al, 2016; Roussety, 2014; Cheng, 2014)
- ASS sulfidic minerals (of which the most prevalent is pyrite, FeS_2) are stable under waterlogged, anaerobic (no oxygen) conditions. Disturbances of hypersulfidic ASS 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.

- Previous studies sampling soil along the ephemeral tributaries in the mid and upper catchment (Salt Creek and Marshy Creek) have identified significant acid potential in the extensive marshlands. Net acidity values up to 7,168 mol H+/t within 224 ha of marshlands along Marshy Creek and 609 mol H+/t within 93 ha of marshlands along Salt Creek were measured (Wong, Claff & Driscoll, 2020) have been recorded (note that an Acid Sulfate Soil Management Plan is triggered when net acidity > 18 mol H+/t). ASS in the catchment is both labile (readily transported) and retained (slowly released) acidity. Review of previous studies indicates Salt Creek has more evidence of historical oxidation than Marshy Creek. The pH level in Marshy Creek is typically lower than in Salt Creek (WMIS; EstuaryWatch).
- Geological units containing acidic minerals are also widespread in the catchment (coal deposits, pyritic shale and siltstone) (Maher, 2011; Holdgate, 2001; Tutt, 2008; Douglas and Ferguson, 1988). There have not been any estimates made of the total acidity potential in the catchment, however runoff from the broader catchment may also contribute to acidity in the river. Targeted sampling of eroded recreational tracks in the upper catchment outside the marshlands has identified soils that are acidic however have significantly lower potential to generate acid than soils within marshland sediments (CDM Smith, 2023).
- ASS with a net acidity up to 3,795 mol H+/t has also been identified at depths greater than 1 metre below surface across a 26ha area at Coogoorah Park in the upper estuary (Sullivan et al, 2016). ASS at Coogoorah Park is predominantly hypersulfidic material that has not yet been oxidised to form acid.
- A range of previous studies have identified that climate (rainfall patterns, temperature, evapotranspiration) is the main influence on formation of acid. Climate variation lowers catchment water tables and water levels in swamps in the upper catchment allowing oxidation, acid production, and acid transport (Maher, 2011; Wong, Claff & Driscoll, 2020; GHD, 2021; Water Technology, 2010).
- Other potential causes of ASS being oxidised have been considered, including the potential for interaction between shallow groundwater that supports the marshes (where ASS present) and the lowering of the regional Upper Eastern View Formation (UEVF) groundwater aquifer that was extracted from between the 1970s and 2016.
  - Studies in the 2000s note that ecosystems within these areas do not appear to be degraded however longitudinal studies (studies involving continuous or repeated measures over prolonged periods of time) have not been completed (Maher, 2011).
  - Previous investigations have indicated that in the lower Anglesea River where groundwater levels in the UEVF have historically been lowered from pumping, shallow groundwater and the UEVF are "*generally hydraulically disconnected*" (GHD, 2021, summarising GHD, 2013). In the upper catchment, previous investigations suggest there is "*an upwards vertical gradient from the LEVF to the UEVF and the UEVF to shallow groundwater*" (GHD, 2021, summarising GHD, 2013).
  - The influence of the historic pumping of groundwater from the UEVF on acid events is currently not fully understood, therefore it has been assumed for the purposes of this assessment that historic changes to regional groundwater levels could have influenced acidity in the catchment.
- Fire and land clearing, which results in changes to vegetation cover, may have historically influenced acidity. Changes in vegetation cover affects evapotranspiration rates, surface water runoff and infiltration, and as a result alters the wetting and drying of ASS materials. The influence of changes in vegetation cover 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).
- Erosion of soil from recreational four-wheel driving (4WDing) in the upper catchment was raised as a potential contributing factor. Targeted sampling of a representative area of soil erosion indicated the presence of acidic soil with a net acidity up to 8.1 mol H+/t, which is significantly lower than the net acidity of ASS in the marshlands (up to 7,168 mol H+/t within Marshy Creek and 609 mol H+/t within Salt Creek). In the context of the wider catchment area, which is a larger source of acidity particularly within Salt and Marshy Creek, the localised erosion of slightly acidic soils and potential increased oxidation of soils from recreational 4WDing is unlikely to be significantly contributing to lower pH water conditions in Anglesea River. Restricting 4WDing in the upper catchment is unlikely to influence acidity in the river.

Transportation and regulation of acidity

- Acid is transported and regulated in the catchment by surface water flows downstream to the estuary. When the acid mixes with marine water (when the estuary mouth is open), the carbonates in sea water buffer, or neutralise, the acid.
- 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 which rapidly mobilise acid into the river (Pope 2006, Tutt 2008, Maher, 2011; Wong, Claff & Driscoll, 2020).
- Marine exchange either from overtopping of the berm by waves or through a channel when the entrance is open can raise pH in the estuary. The estuary is classified as wave-dominated intermittently open/closed, with the balance between wave and fluvial (catchment surface flows) determining whether the entrance berm is open or closed (Ranasinghe & Pattiaratchi, 1999; McSweeney et al, 2018; GHD, 2021; Water Technology, 2011). The most common natural mechanism for opening the estuary is overtopping from high river flows; overtopping from the marine side is more common during spring tides and above average wave heights (GHD, 2021; Pope, 2006). Recently, artificial openings to avoid flooding of infrastructure are the most common mechanism of opening (Pope, 2006). Predictions with climate change are that the entrance will transition to a more permanently closed system, with the berm increasing in height and length (GHD, 2021; Water Technology, 2011). Previous expert workshops (Alluvium, 2014) and the Anglesea River Environmental Flow Study (GHD, 2021) suggest that that artificial openings should occur only in specific circumstances to maintain healthy functioning of the estuary and ecosystem, and that natural openings should be encouraged where there are sufficient catchment flows to support this.
- There have been a range of anthropogenic (artificial) 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:
  - Development of an open cut coalmine from the 1970s with its associated change in vegetation extent, surface runoff and lowering of local groundwater levels in the Upper Eastern View Formation aquifer.
  - 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. This increased the volume of the estuary and may have changed hydraulics of the estuary such as flow velocity and mouth openings.
  - 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 catchment.

1.5 Project area and objective

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. Actions in other parts of the catchment can also influence conditions in the estuary, therefore the entire catchment was considered as part of the project.

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

Specifically, goals identified through feedback from the stakeholder reference group 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 fish deaths are avoided to the extent possible.

In order to meet the overall objective, two acid sources require management. The first is ASS in the upper and midcatchment 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).

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 and detailed evaluation of the most appropriate and effective options to meet the greatest number of priorities.

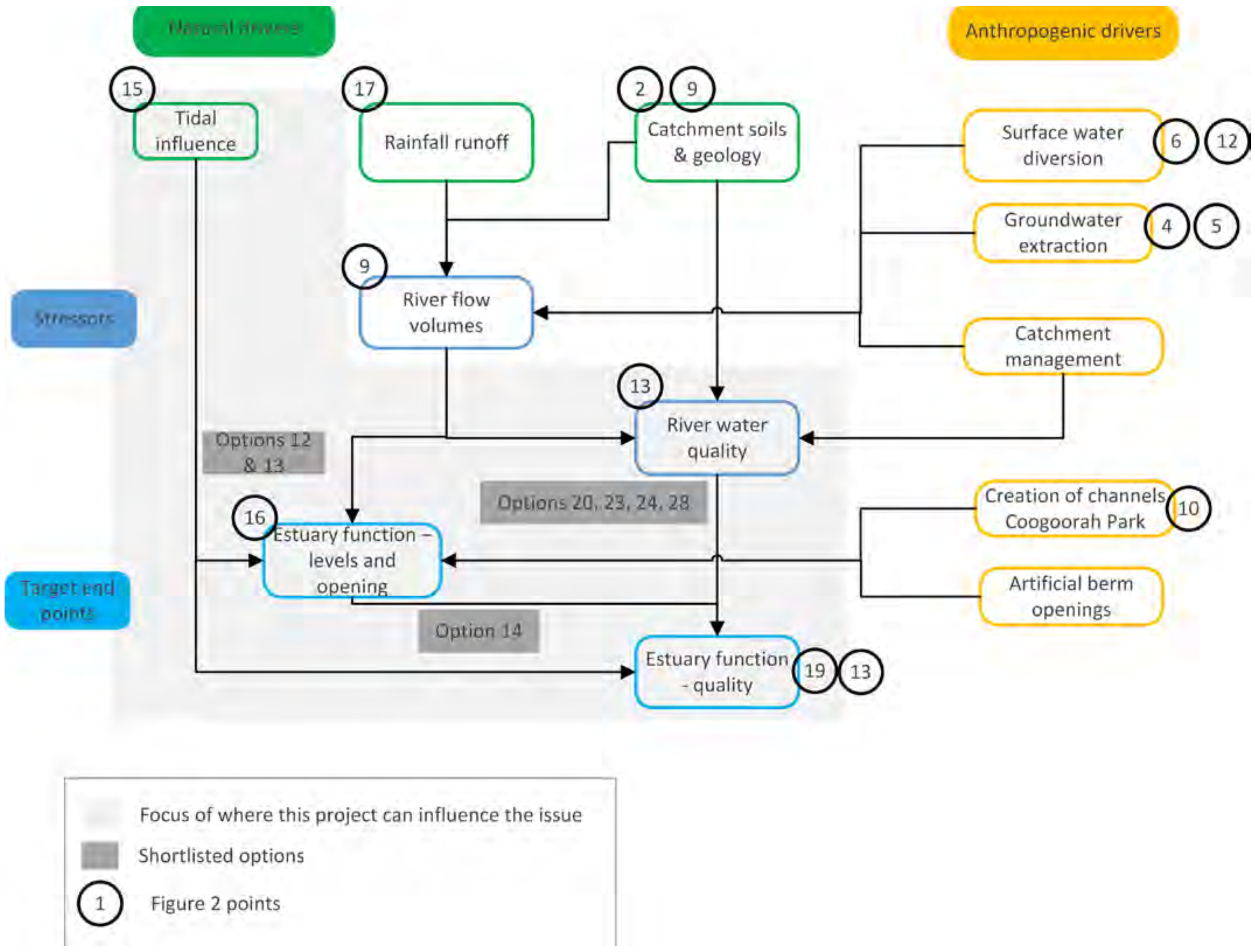

Figure 1 Driver stressor diagram

Figure 2: Anglesea River Catchment Conceptual Model Overview

Figure 2: Anglesea River Catchment Conceptual Model Overview

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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, and therefore potential to influence acidity historically, is not fully understood.

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

Section 2 Stage 1 Options assessment and shortlisted options

2.1 Overview and assessment framework

Thirty potential options for management of acidity in the river were identified. The options were based on previous studies completed in Anglesea, published literature, public information, expert panel experience, and inputs from the stakeholder reference group. Broadly the options aligned with strategies proven to treat, avoid or manage ASS or acidic runoff. Options considered low pH flows from the upper and mid catchment and continued management of ASS at Coogoorah Park.

Nine identified options were not considered further as they would not address the issue in the context of the Anglesea catchment based on the current understanding.

Twenty one options were further examined using a multicriteria analysis (MCA) with relative scoring to compare options against adopted criteria. An MCA was used because it enables the assessment of a range of factors and the identification of options that represent a balanced outcome.

Each category in the MCA was considered equally. A sensitivity analysis was undertaken to understand the influence of weighting assessment criteria differently (for example placing greater importance on some categories or excluding some categories altogether) on the scored outcomes of the MCA.

Once the MCA was completed, eight options were shortlisted for further detailed assessment as part of the next stage of the project. The eight options comprised the top six scoring options from the MCA plus an additional two options agreed as part of a meeting with CDM Smith and the project stakeholder reference group including representatives from relevant regulatory bodies and the Anglesea community members.

Table 1 Adopted MCA framework

Category	Sub-criteria
Technical	Relative effectiveness in achieving and sustaining outcomes (related to acidity and management of ASS at Coogoorah Park) Timeframe for achieving effectiveness Flexibility to be implemented as long term solution
Practicability	Timeframe for implementation Logistical constraints (access, availability of resource/facility) Legislative, regulatory, and permit requirements Ongoing maintenance requirements
Environmental	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
Cultural	Effects on areas of cultural significance Acceptance by Traditional Owners
Economic	Relative capital cost Relative operational cost Relative potential effects on local economy
Social/ Stakeholder	Acceptance by community, regulators, DEECA, CCMA , Surf Coast Shire, Great Ocean Road Coast and Parks Authority (GORCAPA), Barwon Water, community and other stakeholders Effects on recreational values (swimming, fishing, water activities) Amenity impacts (dust, noise, footprint, visual, odour)

2.2 Identified options not carried forward

Table 2 Options identified, not carried forward for MCA

#	Option	Summary of reasons why not considered further for project
2	**Restrict access to upper reach of the catchment to minimise soil erosion from recreational activities to reduce acidic runoff**	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. 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.
3	**Managed aquifer recharge (MAR) to restore groundwater levels in the Upper Eastern View Formation groundwater aquifer.**	Influence of historic groundwater extraction and lowering of the UEVF on acidity in the river is unknown. 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 the catchment. 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 – suitable water source for reinjection to groundwater that is sustainable, meets stakeholder expectations and with sufficient supply and quality has not been identified. Significant timeframe for studies and approvals prior to implementation. Potentially significant timeframe for effect of MAR to be realised. 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 to a holding facility**	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.
9	**Introduce potable water to estuary to maintain saturation of ASS at Coogoorah Park and dilute low pH catchment flows**	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; recycled/stormwater or seawater may provide some capacity for increasing pH levels through carbonate buffering or organic matter. 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**	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 to maintain saturation of ASS at Coogoorah Park and dilute low pH catchment flows**	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	**Placement of stockpile of limestone sand in-stream to treat acidic surface water flow**	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.

22	**Diversion of acidic surface water flow via limestone diversion wells to raise pH**	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**	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.

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2.3 Multicriteria analysis

Table 3 Multicriteria analysis of identified options

			Assessment Criteria						
		Technical	Practicability	Environment	Cultural	Economic	Social/ Stakeholder	Total Score	
Options carried through to MCA analysis—Technically feasible however more significant trade-offs	1 In fill Coogoorah Park channels to reduce the risk of ASS oxidation and formation of acid when water levels in the river are low								This option would avoid the need for ongoing management of ASS in the Coogoorah Park area. It is unknown whether this will improve pH conditions in estuary broadly as it does not directly address low pH flows from the mid and upper catchment. Importation of soil would be required and potentially the removal of recently established aquatic habitat. This option would reduce amenity of the Coogoorah Park recreational values and have economic impacts on businesses that use the area.
	4 Maintain water levels with weir system in the upper and mid-catchment. Re-saturation of ASS would aim to reduce low pH flows downstream.								Depending on design there may be some disturbance of localised areas. This option would affect surface water flow downstream if saturated conditions were effectively maintained, potentially impacting on environmental values in the river and estuary. Stakeholder reference group are not supportive of this option due to the potential for introducing environmental disturbance.
	6 Introduce water to the upper and mid-catchment to saturate areas of sulfuric ASS, reducing potential for formation of further acidity and eventually reforming hypersulfidic ASS.								This option would require identification of a water source (or multiple water sources); there are challenges associated with potable water, groundwater, recycled water and other sources which render this option unsustainable and impractical. A significant area would need to be maintained in saturated conditions, with an estimated 913 ha of ASS marshlands in upper and mid-catchment. Low levels of salinity and nutrient levels could create a deficit in nutrients, impacting ecology.

	Option	Technical	Practicability	Environment	Cultural	Economic	Social/ Stakeholder	Total Score	Comment
		Assessment Criteria							
7	Physical capping of acid sources to avoid oxidation and infiltration of water which transports acid downstream								Widespread, extensive acid source area; it is not sustainable and is logistically difficult to apply physical capping to the majority of the catchment. This option would have a significant impact on cultural and environmental values, and works are likely to be disruptive to social amenity.
10	Dilute low pH catchment flows and maintain saturation of ASS at Coogoorah Park to avoid formation of acid by introducing recycled water to the estuary from Anglesea Water Treatment Plant								Recycled effluent will need to be Class A to be suitable for human contact, therefore additional practicability elements and costs required for treatment of Class B water to Class A water. The volume of water available from the Anglesea Water Treatment Plant is limited and may vary significantly; therefore security of sufficient supply is less certain.
11	Dilute low pH catchment flows and maintain saturation of ASS at Coogoorah Park to avoid formation of acid by introducing recycled water to estuary from Black Rock Water Treatment Plant								Very high capital cost, practicability, and environmental challenges given the length of the pipeline needed to transport water from the Black Rock Water Treatment Plant to Coogoorah Park (20 km+). The available volume of water for use is greater and more reliable than Anglesea Water Treatment Plant. The water is already treated to Class A water; but further assessment would be required to understand the capacity for treating low pH water, risks to the environment from discharge and volume.
16	Dilute low pH catchment flows and maintain saturation of ASS at Coogoorah Park to avoid formation of acid by introducing water to estuary from stormwater harvesting								The capacity for stormwater harvesting is limited and unlikely to be sufficient. This options introduces risk of litter and pollutants from urban catchments and algal blooms from increased nutrient load. The effectiveness of this option is limited in periods of low rainfall.
18	In-situ addition of a neutralising agent (e.g. lime) to ASS in the mid and upper catchment and/or Coogoorah Park								This option would require ongoing maintenance and monitoring of effectiveness. A widespread area is affected by ASS; it is not logistically feasible to apply a neutralising agent to the majority of the catchment and it could have significant

Option	Technical	Practicability	Environment	Cultural	Economic	Social/ Stakeholder	Total Score	Comments
								detrimental effect on the heathland environment.
19 In-situ bioremediation of ASS with sulfidic material to neutralise acidity								As for option 18. Works are likely to be disruptive to social amenity and ongoing requirement for addition of organic matter.
25 Treatment of low pH catchment flows with an ex-situ filtration and membrane water treatment system								This option is less sustainable than other options due to its ongoing energy consumption and the waste generated from maintenance of filters/membranes. The waste stream discharge point would require regulatory approval.
26 Treatment of low pH catchment flows with an ex-situ dosing system								This option has a greater physical footprint than in-situ options so it creates a greater disturbance area. It is lower cost and has lower ongoing energy/waste considerations than other ex-situ treatment options.
27 Treatment of low pH catchment flows with an ex-situ active resin ion-exchange system								This option is less sustainable than other options due to its ongoing energy consumption and the creation of waste from the maintenance of resin. It poses more significant cost and energy use than other ex-situ treatment options.
29 Treatment of low pH catchment flows with an in-situ bioremediation of water								There is potential for increased risk of algal blooms due to higher nutrient load from addition of bioremediation treatment media. The anaerobic conditions generated from bioremediation can emit hydrogen sulphide (odour) and affect commercial and recreational amenity.
12 Introduce seawater to estuary via dredging of shallow artificial openings or grooming of berm height (to allow overtopping) to increase pH with buffering via tidal								Dredging or berm grooming may impact on environmental receptors and cultural heritage. Potential amenity impacts. Less effective than Option 13 as there is limited tidal exchange. Modelling by Water Technology (2011) indicates shallow openings will have little influence on pH in the estuary. Grooming to maintain

		Assessment Criteria							
		Technical	Practicability	Environment	Cultural	Economic	Social/ Stakeholder	Total Score	
Shortlisted Options	exchange								berm height would rely on specific tidal heights to allow overtopping and require frequent maintenance. Current management recommendations for the river are to avoid artificial openings unless during specific conditions to minimise environmental effects(GHD, 2021; Alluvium, 2016).
	13 Introduction of seawater to estuary via dredging of deep artificial openings to increase pH with buffering via tidal exchange								As for Option 12, however potential environmental and cultural heritage impacts are more significant for deeper openings. This option would result in sand deposition upstream if frequent artificial openings are created and subsequently impacts vegetation and aquatic organisms. There would be a requirement for more frequent maintenance.
	14 Introduce sea water to estuary via offshore pump and pipe to maintain water levels and saturation of ASS at Coogoorah Park, and to treat low pH water using buffering capacity of sea water								This option may change the estuary into a permanently saline system which could affect existing ecosystems. There is potential for impacts to cultural heritage as well as businesses and amenity on the foreshore and inshore areas from the pipeline and pump house, which could be partly mitigated by using an above ground pipeline. Risks to boating, marine biota, and divers offshore due to the pump location would require management.
	20 Install passive alkaline berms for treatment of low pH catchment flows in-situ within river / open limestone drains								Less effective than a liquid dosing system (Option 28), however this option is relatively quick and cost effective to implement and maintain. It may not be effective in a high flow or severe acid event as it relies on contact between water and the treatment media. This option will not manage ASS at Coogoorah Park.
	23 Treatment of low pH catchment flows in a constructed wetland (reducing and alkalinity producing type)								This option is effective for treating low pH water with minimal negative effects if an existing area can be repurposed (e.g. within Coogoorah Park). If a new area is required, it would introduce social, cultural and environmental impacts. This option could provide some management of ASS at Coogoorah Park if channels are

Option	Technical	Practicability	Environment	Cultural	Economic	Social/ Stakeholder	Total Score	Comments
								isolated and the wetland system is installed within channels.
24 Treatment of low pH catchment flows with in-situ passive permeable reactive barrier								This option is effective for treating low pH water with a limited footprint and fewer negative effects. It is less effective than a dosing system (Option 28), however its relatively simple and cost effective to implement and maintain. It will not manage ASS at Coogoorah Park. It may not be effective in a high flow or severe acid event as it relies on water contact with treatment media.
28 Treatment of low pH catchment flows with in-situ dosing with alkali materials								This option has limited potential impacts to values if it is effectively designed and a suitable location for the treatment plant is selected. The design could be reactive dosing specific to pH conditions, with adequate mixing zone to be most effective. There is moderate cost due to plant construction and ongoing maintenance. It will not manage ASS at Coogoorah Park.
5 Maintain water levels at Coogoorah Park to keep ASS saturated using a weir system								This is an option for managing ASS at Coogoorah Park, however it is unknown the extent to which it could assist with mitigating low pH events in the estuary from reduced capacity and allowing greater proportion of surface flows to reach the estuary entrance. Current amenity of Coogoorah Park will be altered which could negatively affect businesses and local recreation. It may require management of oxygen levels to avoid stagnation of channels, however this could be readily combated by aeration or adjustable gates allowing flow and boat passing during periods of higher flow.

Section 3 Stage 2 Detailed options assessment

3.1 Overview and methodology

Further assessment of options shortlisted in Stage 1 was undertaken to understand how each option could be implemented in the Anglesea River context, and to investigate in more detail how effective each option could be.

The Anglesea catchment and estuary is a highly dynamic system (GHD, 2021; Pope, 2006). Rainfall and thus run-off is highly variable with periods of no flow as well as 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 reacting when pH conditions require a response, management approaches should ideally be adaptable and functional in a range of different conditions.

The following aspects were further assessed for each shortlisted option during Stage 2 of the project:

- Further refinement of the conceptual design.
- Qualitative evaluation under some key factors in the dynamic system, including whether the option functions to manage acidity in a range of flow conditions (high flow/flood conditions, above base flow, and low/cease to flow conditions), and under different estuary entrance conditions.
- More detailed evaluation of the technical effectiveness of each option based on the specific pH, flow and other characteristics of the Anglesea River. The assessment was based on implementing each option in isolation, however it is recognised that options could potentially be combined to provide greater flexibility or success under the right conditions (further discussed in Section 4). The evaluation of effectiveness involved:
  - 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 was combined to obtain an estimate of the quantity entering the estuary each day.
  - 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 installation locations, both from a practicability perspective and to effectively intercept / manage acidic flows from the mid and upper catchment or ASS.
- Feasibility level costs were developed (-30%/+50%) based on early conceptual design, previous CDM Smith experience on similar project(s) and engineer's estimates (such as construction costs from Rawlinsons).
- Further information regarding legislative and permit requirements was gathered.
- Data gaps to better understand the effectiveness or inform further design of the option were also identified.

A summary of the detailed assessment information for each option is presented below.

3.2 Summary of findings for shortlisted options

<table>
<tr><th colspan="4">Option 23: Treatment of low pH catchment flows in a constructed wetland</th></tr>
<tr><th>Treatment Option Effectiveness</th><th>Feasibility level cost</th><th>Expected Legislative and permit requirements</th><th>Environmental, cultural, and social considerations</th></tr>
<tr>
<td>
Management of low pH catchment flows
<table>
<tr><th>Dynamic condition</th><th>Confidence in effectiveness</th></tr>
<tr><td>High flows/floods</td><td>Low confidence (limited by pumping rates and residence time to neutralise pH within wetland)</td></tr>
<tr><td>Low flows</td><td>High confidence</td></tr>
<tr><td>Indicative proportion of time that the ideal pH and flow rate range were met (Feb 2022-Jan 2023[1])</td><td>~40 – 50% of the time</td></tr>
</table>
Management of ASS at Coogoorah Park
Low confidence – will not actively address risk from ASS at Coogoorah Park. Potential to be designed with sufficient storage capacity to seasonally supplement water levels in estuary.
</td>
<td>
Capital: $0.99 million[2]

Operation and maintenance (annual cost): $105,000

Cost Assumptions

3ha treatment area.

Existing infrastructure and storage pond suitable, stability work or upgrading infrastructure excluded.

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.
</td>
<td>
The construction of the permeable reactive barrier(s) would require the following legislative and permit requirements[3]:

Approval from CCMA required for works and activities within the bed and banks of the Anglesea River estuary.
Compliance with Surf Coast Community Amenity Local Law 2021
Compliance with Surf Coast Shire – Planning scheme:

Special Use Zone – Section 2;
Public Park and Recreation Zone; and
Environmental Significance Overlay

</td>
<td>
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.

May disrupt natural flow regimes.

Could be used to complement a seasonal storage system to release during dry periods.
</td>
</tr>
</table>

[1] Indication for Anglesea River based on flow rate and pH measured in Salt Creek and Marshy Creek and comparison against successful characteristics from Earth Systems, 2005.

[2] Excludes upgrades to existing storage ponds for geotechnical stability. Assumes construction of new pipelines for transfer of water from river to wetland and return to river.

[3] Legislative and permit requirements are based on the potential location of the wetland to be constructed within an existing former storage pond.

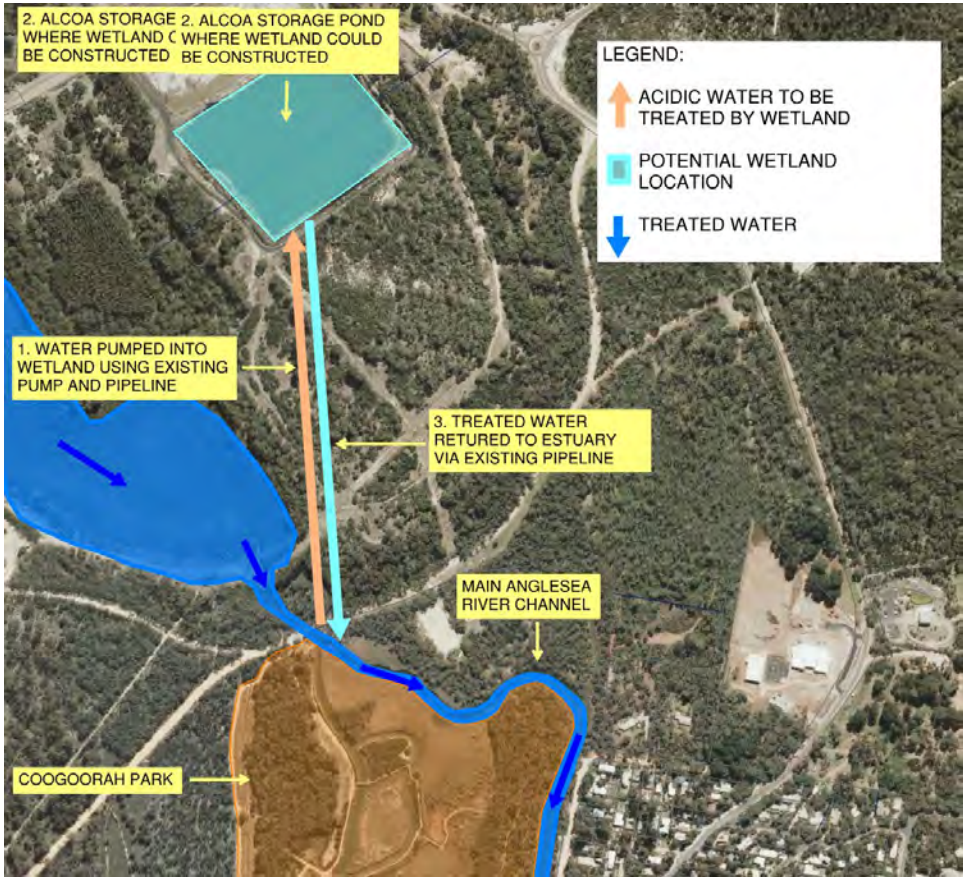
Option 23: Treatment of low pH catchment flows in a constructed wetland

Comment: This option would treat water from the mid and upper catchment prior to discharge into the estuary. The constructed wetland's effectiveness would be limited in times of high flow and would be ineffective during times of flood as effective treatment requires residence time within treatment media in the wetland. Further investigation would be required prior to the construction of the wetland including:

- Consultation with Alcoa and the planned rehabilitation of the former coal mine. The timing of implementing this option could be drastically impacted based on Alcoa's rehabilitation plan;
- A detailed assessment of the existing infrastructure and the pumping requirements to the selected location; and
- Further characterisation of water quality and geochemistry. 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

Option 23: Treatment of low pH catchment flows in a constructed wetland

Potential location



Examples

Source: https://www.wesa.fm/environment-energy/2016-07-21/constructed-wetlands-may-be-key-to-tackling-acid-mine-drainage

Source: https://www.researchgate.net/figure/Anaerobic-wetlands-can-treat-net-acidic-water-because-microbial-sulfate-reduction-and_fig12_308702861

Option 24: Treatment of low pH catchment flows using an In – Situ Permeable Reactive Barriers

<table>
<tr><th>Treatment Option Effectiveness</th><th>Feasibility level cost</th><th>Expected Legislative and permit requirements</th><th>Environmental, cultural, and social considerations</th></tr>
<tr>
<td>
Management of low pH catchment flows
<table>
<tr><th>Dynamic condition</th><th>Confidence in effectiveness</th></tr>
<tr><td>High flows/floods</td><td>Low confidence</td></tr>
<tr><td>Low flows</td><td>High confidence</td></tr>
<tr><td>Indicative proportion of time that the ideal pH and flow rate range were met (Feb 2022-Jan 2023[4])</td><td>~10 - 30% of the time</td></tr>
</table>
Management of ASS at Coogoorah Park
Low confidence – will not actively address risk from ASS at Coogoorah Park.
</td>
<td>
Capital: $450,000
Operation and maintenance (annual cost): $105,000
Cost Assumptions
Reactive barrier consists of 50 m^3 of crushed limestone.
Includes allowance for site survey, studies, design, tendering, permitting and construction.
Quarterly replacement of limestone.
</td>
<td>
The construction of the permeable reactive barrier(s) would require the following legislative and permit requirements:

Approval from CCMA required for works and activities within the bed and banks of the Anglesea River estuary.
Compliance with Surf Coast Community Amenity Local Law 2021
Compliance with the Aboriginal Heritage Act 2006 as part of the proposed site is in an area of cultural heritage sensitivity.
Compliance with Surf Coast Shire – Planning scheme:

Special Use Zone – Section 2;
Public Park and Recreation Zone; and
Environmental Significance Overlay

Additional permits would be required if vegetation removal is required.

</td>
<td>
During excavation / construction of the limestone drains, there is potential to release acidic sulfate soils, as well as heavy metals, however this could be managed through design and construction methods.
This option could have impacts on Traditional Owner cultural values due to the excavation which would require assessment and management.
No significant environmental risks identified during operation.
Location selection would need to consider amenity and recreational use of the river.
</td>
</tr>
</table>

Comment: Permeable reactive barriers use the natural hydraulic gradient of a stream to treat contaminated water through physical, chemical, and biological processes (Banasiak & Indraratna, 2012). The passive permeable reactive barrier technique has been used successfully to combat coastal ASS impacted groundwater in the Shoalhaven

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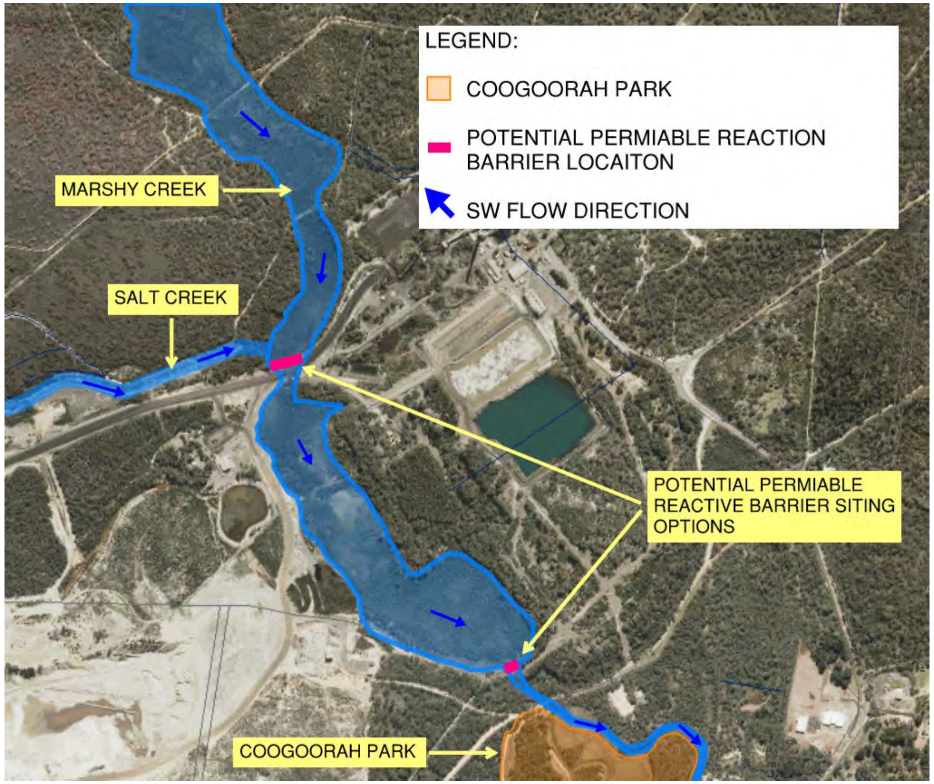
[4] Indication for Anglesea River based on flow rate and pH measured in Salt Creek and Marshy Creek and comparison against successful characteristics from Earth Systems, 2005.

Floodplain, southeast NSW. In this case study, recycled concrete crushed to a size of 1.18 to 10mm was selected to be installed in the constructed PRB. This option would treat water from upper catchment tributaries prior to it flowing into the estuary. The permeable reactive barrier's effectiveness would be limited in times of high flow and ineffective in times of flood, as treatment relies on contact between water and the treatment media. Effectiveness and long-term performance is highly dependent on the neutralising capacity of the material selected.

Option 24: Treatment of low pH catchment flows using an In – Situ Permeable Reactive Barrier

Potential locations



Example

Source: https://gabion1.com/gabion-pic-info-33/

Option 20: Treatment of low pH catchment flows using passive alkaline berms/channels (limestone drains)

<table>
<tr><th>Treatment Option Effectiveness</th><th>Feasibility level cost</th><th>Expected Legislative and permit requirements</th><th>Environmental, cultural, and social considerations</th></tr>
<tr>
<td>

Management of low pH catchment flows

Dynamic condition	Confidence in effectiveness
High flows/floods	Low confidence
Low flows	High confidence
Indicative proportion of time that the ideal pH and flow rate range were met (Feb 2022-Jan 2023[5])	~40 - 50% of the time

Management of ASS at Coogoorah Park

Low confidence – will not actively address risk from ASS at Coogoorah Park:

</td>
<td>

Capital: $415,000

Operation and maintenance (annual cost): $108,000

Cost Assumptions

100 m channel length (400 tonnes limestone).

Replacement of limestone 4 times per year.

Includes allowance for site survey and studies, design, tendering, permitting, construction.

</td>
<td>

The construction of the limestone drains would require the following legislative and permit requirements:

- Approval from CCMA required for works and activities within the bed and banks of the Anglesea River estuary.
- Compliance with *Surf Coast Community Amenity Local Law 2021*
- Compliance with the *Aboriginal Heritage Act 2006* as part of the proposed site is in an area of cultural heritage sensitivity.
- Compliance with Surf Coast Shire – Planning scheme:
  - Special Use Zone – Section 2;
  - Public Park and Recreation Zone; and
  - Environmental Significance Overlay
- Additional permits would be required if vegetation removal is required.

</td>
<td>

During excavation / construction of the limestone drains, there is potential to release acidic sulfate soils, as well as heavy metals, however this could be managed through design and construction methods.

This option could have impacts on Traditional Owner cultural values due to the excavation which would require assessment and management.

Amenity may be affected by this option due to the length of channel required for treatment, compared to PRBs.

No significant environmental risks identified during operation.

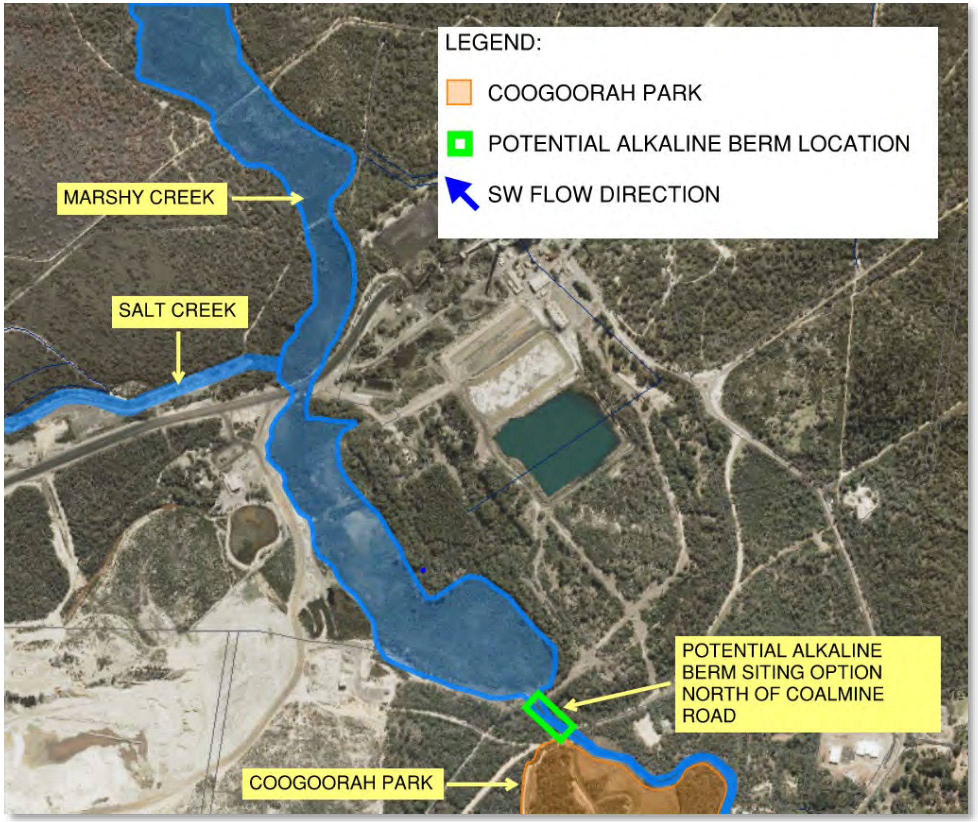
</td>
</tr>
</table>

Comment: This option would treat water from upper catchment tributaries prior to it flowing into the estuary, by placing limestone or another suitable alkaline material within ~100 m of the river channel bed. The option's effectiveness would be limited in times of high flow and ineffective in times of flood and is highly dependent on the channel length and residency time of the water in the channel.

[5] Indication for Anglesea River based on flow rate and pH measured in Salt Creek and Marshy Creek and comparison against successful characteristics from Earth Systems, 2005.

Option 20: Treatment of low pH catchment flows using passive alkaline berms/channels (limestone drains)

Potential location



Example

Source: https://mineclosure.gtk.fi/open-limestone-channel/

Option 28: In-situ Dosing with Alkali Materials

<table>
<tr><th>Treatment Option Effectiveness</th><th>Feasibility level cost</th><th>Expected Legislative and permit requirements</th><th>Environmental, cultural, and social considerations</th></tr>
<tr>
<td>
Management of low pH catchment flows
<table>
<tr><th>Dynamic condition</th><th>Confidence in effectiveness</th></tr>
<tr><td>High flows/floods</td><td>High confidence</td></tr>
<tr><td>Low flows</td><td>High confidence</td></tr>
<tr><td>Indicative proportion of time that the ideal pH and flow rate range were met (Feb 2022-Jan 2023[6])</td><td>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.</td></tr>
</table>
Management of ASS at Coogoorah Park
Low confidence – will not actively address risk from ASS at Coogoorah Park
</td>
<td>
Capital: $590,000 per dosing station

Operation and maintenance (annual cost): $268,000

Cost Assumptions

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.

Includes estimate for further studies, design and construction.

Actual cost will depend on design, operating parameters and selected treatment reagent.
</td>
<td>
The construction of in-situ dosing station(s) would require the following legislative and permit requirements:

Approval from CCMA required for works and activities within the bed and banks of the Anglesea River estuary.
Compliance with Surf Coast Community Amenity Local Law 2021
Compliance with the Aboriginal Heritage Act 2006 as part of the proposed site is in an area of cultural heritage sensitivity.
Compliance with Surf Coast Shire – Planning scheme:

Special Use Zone – Section 2;
Public Park and Recreation Zone; and
Environmental Significance Overlay

Additional permits would be required if vegetation removal is required.

</td>
<td>
Depending on the pH level, dosing rate, concentrations of metals, speed of reaction and other factors, 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. This would be managed within a mixing zone and an assessment of environmental and public health would inform placement and dosing rates.

Design and operations would need to consider water chemistry and target pH.

Some visual amenity impacts may be experienced.
</td>
</tr>
</table>

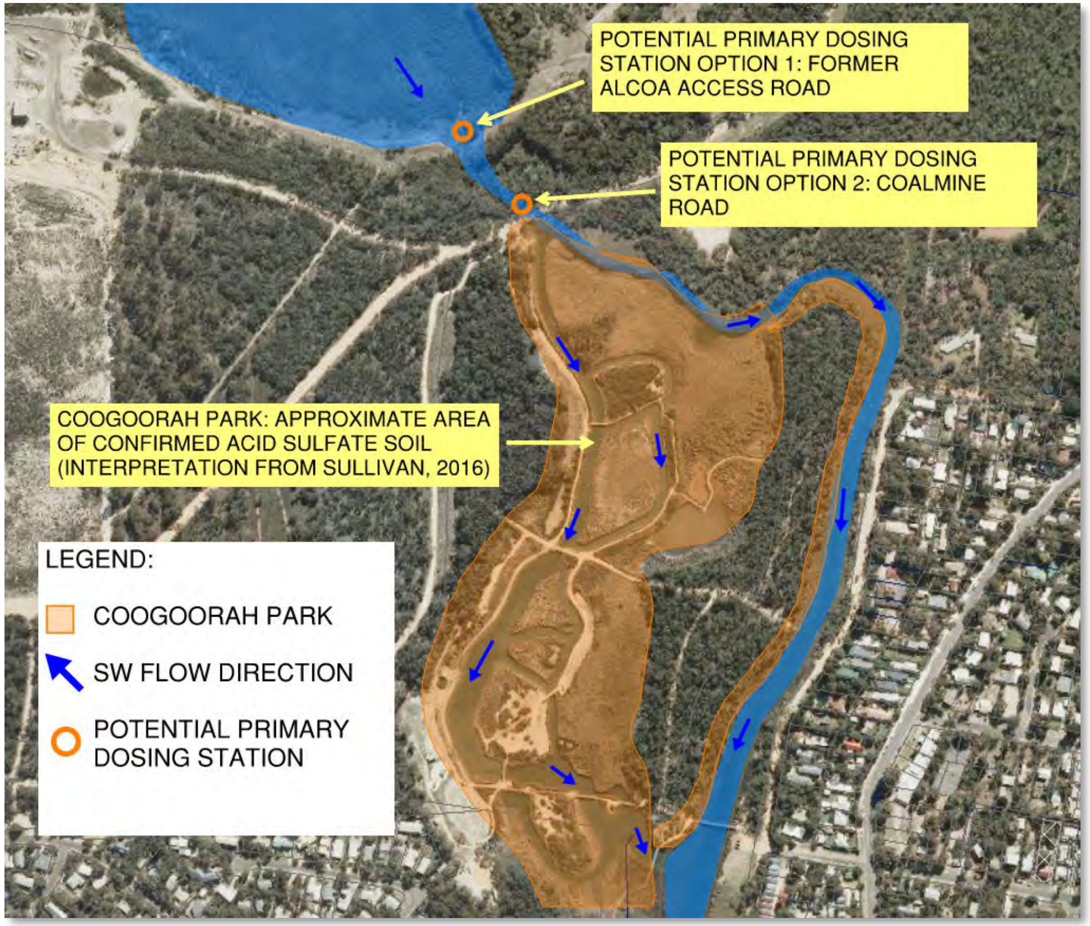
[6] Indication for Anglesea River based on flow rate and pH measured in Salt Creek and Marshy Creek and comparison against successful characteristics from Earth Systems, 2005.

Option 28: In-situ Dosing with Alkali Materials

Comment: In-situ active treatment can be adapted to suit the estuary pH and flow conditions and has been employed in other areas affected by acidic flows, for example 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) that contain ASS with sulfuric materials that discharged large quantities of acid and dissolved metals into waterways. This option would treat water from the upper catchment prior and/or following it's flow into the estuary. To be more effective in high flow or flood conditions, this option could include a secondary dosing site or employ one or more active dosing methods such as spraying of alkaline slurry, air sparging of dosing area or a mobile water treatment equipment. This assessment has assumed a single dosing station with 90 tonnes of storage, conservatively based on the estimated mass required for daily treatment of catchment flows from February 2022 – January 2023, to neutralise water to a pH of 7 and using hydrated lime as the treatment reagent.

Option 28: In-situ Dosing with Alkali Materials

Potential location



Example

Source: https://earthsystems.com.au/services/water-treatment/portable-treatment-systems/vertical-mixing-systems/

Option 12 & 13: Introduce seawater via dredging of artificial openings (berm grooming or shallow opening, or deep opening)

Treatment Option Effectiveness	Feasibility level cost	Expected Legislative and permit requirements	Environmental, cultural, and social considerations
Management of low pH catchment flows **Dynamic condition** – **Confidence in effectiveness** **Shallow opening / berm grooming** High flows/floods: Low confidence (noting in high flows the entrance can open naturally, but effectiveness depends on factors such as tidal conditions) Low flows: Low confidence (ability to maintain opening for long enough to be effective) **Deep Opening** High flows/floods: Low to moderate confidence (noting in high flows the entrance can open naturally, but effectiveness depends on factors such as tidal conditions) Low flows: Low to moderate confidence, due to limited conditions where artificial opening could be implemented to avoid significant environmental risks and be effective Modelling and water quality observations suggest artificial openings can be effective at raising pH; depth, width and period of opening depends on tidal and estuary conditions. Success and depth of openings depends on a range of catchment and oceanographic factors. Confidence relates to whether could be implemented on a regular basis or guaranteed on an as-needed basis, due to the conditions required for good outcomes and avoidance of negative environmental impacts.	**Shallow Opening:** Capital: $425,000 Operation and maintenance (annual): $55,000 **Deep Opening:** Capital: $575,000 O&M (annual): $95,000 Costs represent the additional due diligence investigations, design, management controls and permitting that would be required to implement artificial openings as a water quality management solution. **Cost Assumptions** Excavation depths, lengths and widths conservatively estimated. Sand removed to create channel is spread on the	Artificial openings would require the same legislative approvals and permits as Option 28. Depending on the extent, the following may also apply: ▪ 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. ▪ *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. ▪ *Marine and Coastal act 2018*. ▪ *Water Act 1989* ▪ Approval from CCMA required for works and activities within the bed and banks of the Anglesea River estuary	Continued artificial openings are likely to result in increased sedimentation, altering of the entrance berm (longer and higher) and reduction in the hydrological and ecological function of the estuary (Alluvium, 2014; GHD, 2021). These previous studies have recommended that artificial openings are minimised or only considered under specific sea, estuary and surface water flow conditions to maintain ecosystem functioning and avoid negative impacts. This option may impact on Traditional Owner values due to the excavation required within culturally significant areas. The potential for precipitation of metals and metalloids from a change in pH exists, per dosing discussed above. Amenity impacts may be experienced during excavation. Long term would require increased

Option 12 & 13: Introduce seawater via dredging of artificial openings (berm grooming or shallow opening, or deep opening)			
Management of ASS at Coogoorah Park Low confidence – neither deep nor shallow openings will actively address risk from ASS at Coogoorah Park. Note that deeper openings may present a risk of lowering water levels in the estuary and exposure of ASS to oxygen.	entrance berm or beach. Twice yearly openings.		maintenance. Risk of water levels in estuary lowering, exposing ASS at Coogoorah Park, would need to be managed.

Comment: This option was assessed for it's potential to encourage marine water to enter the estuary to buffer acidity. The introduction of sea water during flood tides while the berm is open, when there is sufficient surface water flow and quality, has been observed to assist in regulating acidity in the estuary and maintain its water levels and water quality (GHD, 2021).

Modelling (Water Technology, 2011) and more recent water quality observations also suggest that openings can be effective at raising pH if there is sufficient tidal exchange. The necessary depth, width and period of opening for success depends on tidal, estuary and catchment flow conditions. Previous modelling of tidal interaction with a shallow opening of 0.75 mAHD with a 7.5 m width suggested that there would be limited opportunity for pH buffering (Water Technology, 2011). Recent data in late 2022 indicates a successful opening where pH levels were raised, relating to water levels at the Great Ocean Road Bridge of 0.967 m (monthly average, Nov 2022), after a sustained period of high catchment inflows (44.68 ML/day average, Oct 2022), together with favourable tidal conditions. The entrance opening depth during this event is unknown.

As there are limitations around when openings could occur to be successful or to minimise environmental risks, artificial openings are less reliable and flexible than other options.

Costs assume excavation of 100 m length conservatively, to a depth of 0.75 mAHD (shallow) or -1 mAHD (deep). Actual costs would depend on the height of water in the estuary and berm height, whether disposal of spoil or redistribution across the berm was possible, and final selected depth to maximise marine exchange.

Could be implemented when surface water flow, quality and tidal conditions are favourable for some improvement of pH conditions or to provide pathway to sea for fish during acid events. Could also complement other options to encourage marine exchange if implemented under specific conditions. Further investigations are required for this option including:

- 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, and to identify specific depth that would be most suitable.

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

Potential location	Example
 Location and distance conservatively assumed, would depend on water levels and berm conditions at the time	 Source: https://www.pumpsandsystems.com/reclaim-water-pumping

Option 14: Seawater Pump and Pipeline Detailed Option Assessment Summary

<table>
<tr><th>Treatment Option Effectiveness</th><th>Feasibility level cost</th><th>Expected Legislative and permit requirements</th><th>Environmental, cultural, and social considerations</th></tr>
<tr>
<td>
Management of low pH catchment flows
<table>
<tr><th>Dynamic condition</th><th>Confidence in effectiveness</th></tr>
<tr><td>High flows/floods</td><td>Moderate to high confidence</td></tr>
<tr><td>Low flows</td><td>High confidence</td></tr>
</table>

Management of ASS at Coogoorah Park
High confidence – will actively address risk from ASS at Coogoorah Park by maintaining saturation of soils.
</td>
<td>
Temporary implementation[7]:

Capital: $100,00 to $150,000

Operation and maintenance (annual): $66,550

Permanent Implementation[8]

Capital: $1.2 million

O&M (annual): $200,000

Cost Assumptions

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,
</td>
<td>
The construction of the pump and pipeline would require the following legislative and permit requirements:

Approval from CCMA required for works and activities within the bed and banks of the Anglesea River estuary.
Compliance with Surf Coast Community Amenity Local Law 2021
Compliance with the Aboriginal Heritage Act 2006 as part of the proposed site is in an area of cultural heritage sensitivity.
Compliance with Surf Coast Shire – Planning scheme:

Special Use Zone – Section 2;
Public Park and Recreation Zone; and
Environmental Significance Overlay

Additional permits would be required if vegetation removal is required.

</td>
<td>
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 may result in a change to the species present and ecosystem function.

Neutralising of the acidic flows could lead to the precipitation of metallic compounds following pH buffering leading to deposition within the estuary with possible adverse effects to flora and fauna.

Offshore pipe inlet will need controls implemented that limit its accessibility and minimise potential impacts to marine life.

Anglesea beach is used by members of the public for surfing, swimming, and snorkelling, so amenity impacts may be experienced.

Potential cultural heritage impacts that would require assessment and management (for this reason an above ground pipeline is assumed).
</td>
</tr>
</table>

[7] Temporary diesel pump and temporary pipeline (across beach or floated on estuary) (GHD, 2016)

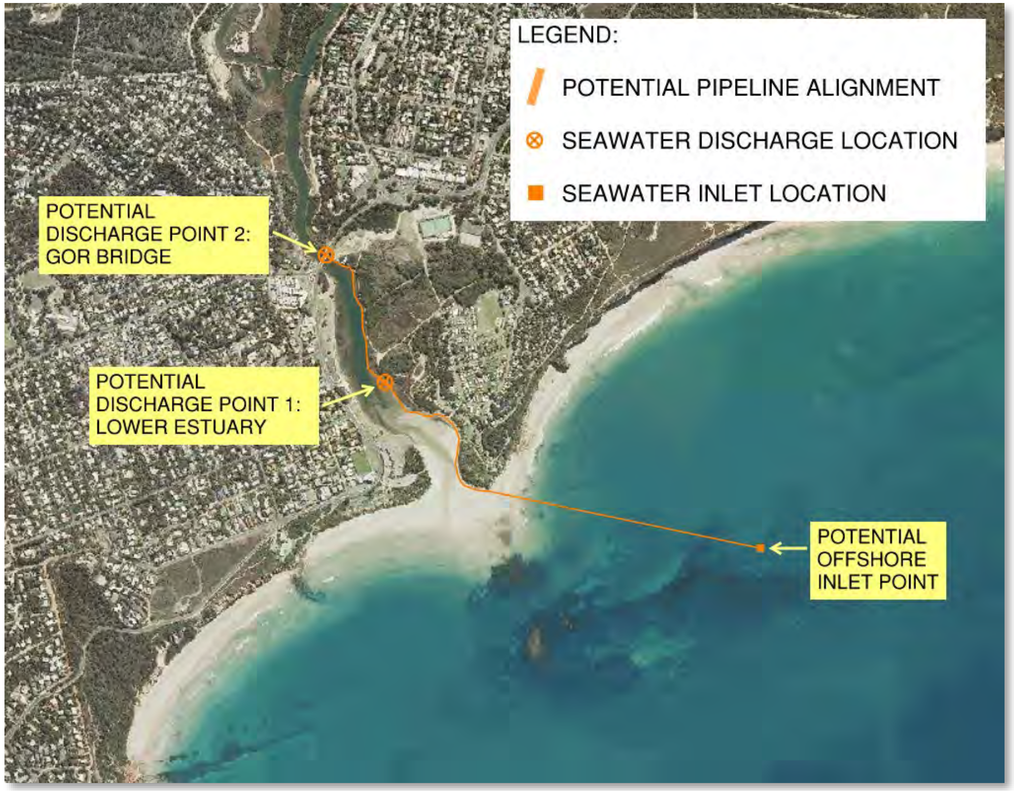
[8] Permanent electric pump and above ground pipeline

Option 14: Seawater Pump and Pipeline Detailed Option Assessment Summary			
	maintenance, monitoring. Final cost will depend on sizing, location and other investigation, permitting and design elements.		

Comment: This option would add alkaline seawater with additional buffering capacity of the acidic flows to neutralise acidic flows within the estuary. The ratio of mixing to achieve the range of 6 or 7 pH units is approximately 50% seawater to surface water volume (Pope, 2006). This option would be effective in most flow conditions excluding high flow or flood conditions that exceed the capacity of the pump/pipeline, but could be designed flexibly to suit preferred treatment conditions. 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. A pipeline distance of 500 m off-shore and 500 m into the estuary (approximately to the Great Ocean Road) is assumed for this assessment and costing; the discharge point within the estuary will affect the mixing and effectiveness of the solution – the further upstream the greater benefit, however this increases cost and other considerations regarding amenity and habitat.

Option 14: Seawater Pump and Pipeline Detailed Option Assessment Summary

Potential location



Example

Source: Adobe Stock Images

<table>
<tr><th colspan="4">Option 5: Maintain water levels to manage ASS at Coogoorah Park with moveable weir/sluice gate weir system</th></tr>
<tr><th>Treatment Option Effectiveness</th><th>Feasibility level cost</th><th>Expected Legislative and permit requirements</th><th>Environmental, cultural, and social considerations</th></tr>
<tr>
<td>
Management of low pH catchment flows
<table>
<tr><th>Dynamic condition</th><th>Confidence in effectiveness</th></tr>
<tr><td>High flows/floods</td><td rowspan="2">Unknown. Reduced capacity of estuary will alter hydrology however unknown whether this will influence pH conditions.

Will not address upstream flows.</td></tr>
<tr><td>Low flows</td></tr>
</table>
Management of ASS at Coogoorah Park
High confidence – can be designed to maintain saturation of ASS under all conditions and avoid formation of acidity which would exacerbate the issue
</td>
<td>
Capital: $2.2 million
Operation and maintenance (annual cost): $140,000
Cost Assumptions
Moveable inlet and outlet weirs.
Estimate including engineering, procurement, construction and contingency.
Actual cost would depend on required water level and design.
</td>
<td>
The construction of the weirs would require the following legislative and permit requirements:

Approval from CCMA required for works and activities within the bed and banks of the Anglesea River estuary.
Compliance with Surf Coast Community Amenity Local Law 2021
Compliance with the Aboriginal Heritage Act 2006 as all of the site is in an area of cultural heritage sensitivity.
Compliance with Surf Coast Shire – Planning scheme:

Special Use Zone – Section 2;
Public Park and Recreation Zone; and
Environmental Significance Overlay

Additional permits would be required if vegetation removal is required.

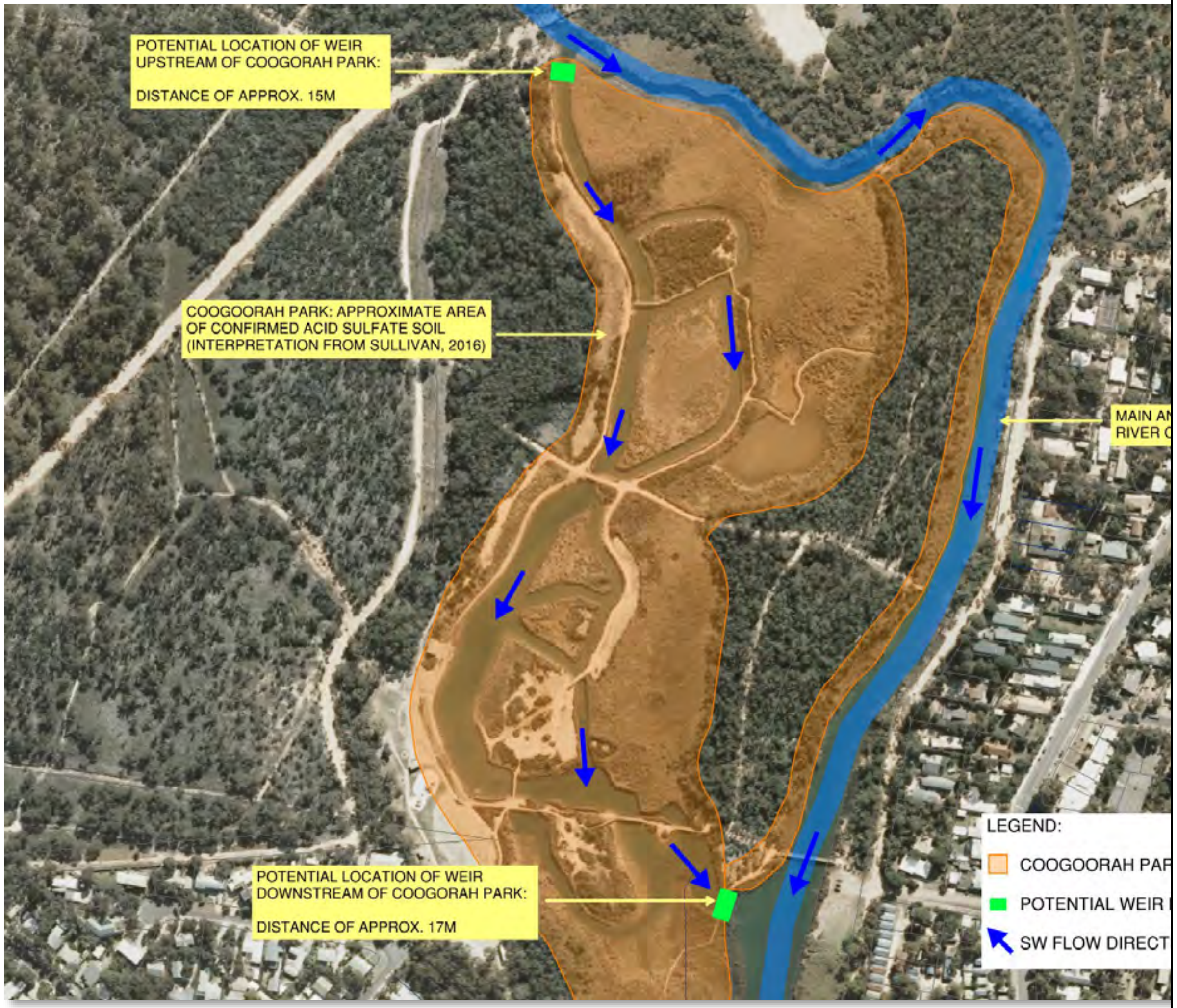
</td>
<td>
Weirs would have signficant impact on water based activities that use a circuit through the channels as well as natural amenity of Coogoorah Park, which businesses and the Anglesea tourism economy rely on. Coogoorah Park provides an important recreational and educational area. Design could incorporate features such as canoe beaches however would likely still have an impact on the use of the river and visual setting.
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).
If extended periods of low flow in the river, evaporation within closed Coogoorah Park channels would result in a need for addition of another water source to avoid oxidation of ASS; alternative water sources (recycled water, potable water and groundwater) are currently not considered practicable.
This option may impact on Traditional Owner values in areas of cultural significance.
Construction and design would need to consider disturbance of ASS, fish and eel movements and breeding cycles, and water quality.
</td>
</tr>
</table>

Comment: This option is a preventative measure to manage ASS at Coogoorah Park (one potential source of acid), based on the hazard represented if soils were to oxidise and form acid that is not readily reversed or managed (Sullivan et al, 2016). A separate option would need to be implemented to address low pH flows from the upper catchment in the broader estuary. The effectiveness of this option would not vary with future water level fluctuations; however, the future sea level is expected to rise by up to 0.8 m (Water Technology, 2011), therefore future management of ASS at Coogoorah Park potentially may not be required due to inundation. Further investigation would be required prior to the construction of the weirs at Coogoorah Park including:

- Study into the weir's ability would be able to adequately maintain ASS saturation in Coogoorah Park.
- Hydrological, geotechnical, and environmental assessment to inform the design of the weirs.

Option 5: Maintain water levels to manage ASS at Coogoorah Park with moveable weir/sluice gate weir system

Potential location



Example

Source: Adobe Stock Images

Section 4 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 keypotential or actual sources of acidity have been identified: ASS containing sulfidic material in the mid and upper catchment (within Salt and Marshy Creek) 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 under a range of different conditions. This was established 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.
- It is unlikely however that any option will be completely effective at avoiding acid events or fish death events altogether.
- 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.

4.1 Management of ASS and resulting acidic surface water from the mid and 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, including the potential changing of 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.

4.2 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 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).

4.3 Future Considerations

All recommended options require additional knowledge to inform the design and effective implementation. Additional investigation and refinement 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. The below should be considered to improve knowledge to inform the design and effective implementation of each of the recommended options.

- 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 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.
- 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 to estuarine organisms (e.g. clogging of gills or coating leaves of photosynthetic plants). It will also help to inform the design of any option, including establishing treatment rates and potential sizing of infrastructure.
- 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 mid and upper catchment, or estuary entrance conditions) should consider this study and related previous studies to understand and minimise potential influence on the issue.

4.5 Assumptions and limitations

This project has 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. 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.

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