ANGLESEA RIVER ACID FLUSH EVENT
November 2025 – Part A

Artificial Estuary Opening and Environmental Impact.

(Claringbold, E.,2025)

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Technical Report No: 137

November 2025

How to cite this report:
V. Pettigrove, and M. Walpitagama (2025), Anglesea River Acid Flush Event October 2025 – Part A – Estuary Opening and Environmental Impact, Aquatic Environmental Stress Research Group, Technical Report No. 137, RMIT University, Victoria, Australia.

RMIT University acknowledges the people of the Woi wurrung and Boon wurrung language groups of the eastern Kulin Nations on whose unceded lands we conduct the business of the University. RMIT University respectfully acknowledges their Ancestors and Elders, past and present. RMIT also acknowledges the Traditional Custodians and their Ancestors of the lands and waters across Australia where we conduct our business.

Report produced by: Aquatic Environmental Stress Research Group including the
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Revision	Date issued	Reviewed by	Approved by	Date approved	Revision type
Internal	01/10/25	CCMA			Received comments on 6/10/25
Final	21/11/25	CCMA	CCMA	25/11/25	Finalised

Printed:	
Last saved:	26 November 2025 09:20 AM
File name:	Anglesea River Acid Flush Event October 2025 – Part A – Estuary Opening and Environmental Impact
File saved location	
Author:	Milanga Walpitagama and Vincent Pettigrove
Project manager:	Vincent Pettigrove
Name of	Aquatic Environmental Stress Research group, RMIT University
Name of project:	Anglesea River Acid Flush Event October 2025
Name of document:	Anglesea River Acid Flush Event October 2025 – Part A – Estuary Opening and Environmental Impact
Document version:	1.0
Project number:	

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The authors would like to acknowledge the contributions from Corangamite Catchment Management Authority (CCMA), The Great Ocean Road Coast and Parks Authority (GORCAPA), Arthur Rylah Institute, ALS lab for analysis of water samples, Anglesea River EstuaryWatch, Parks Victoria, Barwon Water, Surf Coast Shire Council, and the Anglesea River Advisory Group (ARAG) for information and progress of this report.

Executive Summary

The Anglesea River experienced a substantial acid-flush event during July–August 2025, following more than fifteen months of below-average rainfall. This prolonged dry period promoted the oxidation of acid sulphate soils (ASS) across Marshy Creek, Anglesea Swamp, Salt Creek, and other tributaries in the upper catchment. With the return of winter rainfall, rewetting of these oxidised soils resulted in the mobilisation of hydrogen ions, aluminium, iron, and manganese, consistent with known geochemical behaviours of pyritic substrates under drought-break conditions (Golab & Indraratna, 2009; Angel et al., 2015; EPA Victoria, 2021). Water quality monitoring conducted by Australian Laboratory Services (ALS), the Corangamite CMA (CCMA), the Arthur Rylah Institute (ARI), and EstuaryWatch volunteers captured a rapid and severe decline in pH values throughout the river system, with several monitoring locations reporting pH values well below 4.0 and Marshy Creek recording readings between 2.8 and 3.3. These acidic conditions were accompanied by a corresponding increase in dissolved metals, low alkalinity, and characteristic iron flocculation, reflecting well-established patterns in the Anglesea catchment during previous acid-flush episodes (CCMA, 2013; GHD, 2021).

Biological responses observed during the ARI fish survey on 13th August 2025 were consistent with the deteriorating water quality conditions. Fish assemblages displayed low species diversity, minimal movement, and multiple instances of mortality or severe stress, particularly in the mid and upper estuary reaches. These observations align with known toxicity pathways where aluminium and other metals become more soluble and bioavailable under low-pH conditions, adversely affecting gill function, osmoregulation, and respiration (Gensemer & Playle, 1999; Atkinson et al., 2007; ANZG, 2018). The near absence of macroinvertebrates in key locations provides further evidence of ecological disruption, consistent with past assessments of acid-impacted waterbodies in the region (Nixdorf et al. 2003; EPA Victoria, 2021).

In response to the escalating acidity and ecological stress, the estuary mouth was artificially opened on 20th August 2025 by GORCAPA at the request of CCMA. The intention was to induce tidal exchange to dilute acidic inflows, increase salinity buffering, and improve dissolved oxygen concentrations. However, post-opening monitoring demonstrated that the intervention did not yield measurable improvements to water quality. The breach modified local water levels but failed to establish sufficient depth or persistence to support sustained marine inflow. Consequently, pH levels remained below 4.5 following the opening, and dissolved metal concentrations, including aluminium, manganese, and nickel continued to rise. Conductivity and turbidity also remained high, indicating that riverine inputs continued to dominate estuarine conditions. These outcomes show that shallow artificial openings are unlikely to be effective during periods of acid flush events (CCMA, 2013; Claringbold, 2025).

Historical data spanning more than a decade (Part A Section 4.4) demonstrate that the 2025 event is part of a recurring pattern of acid-flush episodes in the Anglesea catchment. Acid pulses typically originate from Marshy Creek and adjacent ASS hotspots, propagate downstream during rainfall events, and produce system-wide declines in water quality and ecological health. The long-term pH record at Marshy Creek, for example, has ranged between 2.8 and 3.8 for more than a decade, confirming persistent acidity in this landscape (CCMA, 2025). These conditions are frequently exacerbated following prolonged dry periods,

emphasising the sensitivity of the system to climatic variability and catchment hydrology (BOM 2025a; BOM 2025b).

The findings of this investigation reaffirm the dominant role of catchment processes in driving estuary acidification and highlight the limitations of estuary-mouth management interventions during severe acidic pulses. The 2025 assessments underline the need for strengthened real-time monitoring networks, particularly at strategic upstream sites such as Coalmine Road and Marshy Creek, as well as improved communication frameworks to support early public-health warnings during future events. This event also reinforces the importance of integrating ecological, hydrological, and geochemical observations into decision-making processes to ensure effective management of environmental and public-health risks.

1. Introduction

The Anglesea River catchment, covering about 125 km², comprises the Salt Creek (51 km²) and Marshy Creek (65 km²) sub-catchments, which converge around 1 km upstream of the estuary (CCMA, 2013; GHD, 2021). While Salt Creek produces higher peak flows during flood events, they are short-lived compared to the longer but lower flows of Marshy Creek. Both systems are highly ephemeral, with Salt Creek flowing only 35% of the time and Marshy Creek 50%, due to extended cease-to-flow periods linked to local swampland hydrology (GHD, 2021). The Anglesea River estuary is a dynamic coastal system that is highly vulnerable to episodes of acidification, commonly referred to as "acid flush events." These events occur when prolonged dry periods are followed by heavy rainfall, mobilising acidic waters from coal measures, pyritic soils, and tea tree marshes into the river and estuary (Maher, 2011). The catchment frequently experiences acid flows with pH as low as 3–4, primarily from coal deposits and tea tree marshes, which provide significant acid-generating potential. This could result in extensive ecological damage, including fish kills, flocculant formation, and the mobilisation of toxic metals. Historical studies have highlighted that both Salt Creek and Marshy Creek, the dominant tributaries of the Anglesea River, experience frequent low pH flows, contributing significantly to downstream acidification (CCMA, 2013; GHD, 2021).

The 2025 event occurred in the context of the driest 15 months on record for parts of western Victoria (BOM, 2025a). Following intense rainfall in June (BOM, 2025b), acidic flows were observed entering the estuary from Marshy Creek in early July, with measured pH values around 3.5. Subsequent community observations confirmed the spread of acidic waters, iron and aluminium floc deposition, and widespread fish deaths by early August (CCMA, 2025). Independent monitoring undertaken by the Arthur Rylah Institute on 13 August confirmed severely degraded water quality and limited refuge habitat for fish, with poor oxygen conditions and few invertebrates to support aquatic food webs.

Given the likelihood of further ecological damage, the Corangamite Catchment Management Authority (CMA), in collaboration with the Great Ocean Road Coast and Parks Authority (GORCAPA), trialled an artificial estuary mouth opening on 20 August 2025. Initially, the estuary remained closed as it was believed that the upper 50 cm of water provided a critical refuge for aquatic fauna during low-oxygen conditions, and artificially opening the mouth could remove this remaining habitat. However, subsequent assessments indicated that fish within the estuary were severely food-limited and unlikely to survive if conditions persisted. In light of this, the decision was re-evaluated, and a trial artificial opening was undertaken. This action aimed to investigate whether partial exchange with the ocean could improve water quality parameters, particularly pH and dissolved oxygen, acknowledging that while ecological risks were minimal due to already poor conditions, there were potential implications for recreational and aesthetic values. This marked the first artificial opening in the Corangamite region to be undertaken specifically for environmental purposes, rather than flood mitigation (Lloyd, 2025). There were two main objectives of the artificial estuary opening. The first was to determine whether an artificial opening under low-flow conditions could remain sustained. The second was to assess whether, if sustained, the opening provided observable environmental benefits during an acid event. This included evaluating whether allowing tidal exchange (if achieved) could improve water quality or reduce adverse impacts associated with acid events, such as metal toxicity. While facilitating fish movement was considered a potential secondary benefit, it was not considered a measurable outcome during this event (Sharley et al., 2012; Lloyd, 2025).

This Part A report examines the environmental processes driving the acid-flush event, evaluates the data collected before and after the estuary opening, and assesses the broader ecological consequences for the Anglesea River system. The findings are intended to support more effective management strategies by clarifying when estuary opening can be beneficial and when upstream geochemical and hydrological drivers dominate system behaviour.

2. Project Aims

This project is designed with two overarching aims:

1. **Evaluate the potential ecological impact of the acid flush events.** The evaluation will compare the measured historical water quality values against established benchmarks and guidelines for aquatic ecosystem health. (Maher, 2011; Senversa, 2019a, 2020, 2022).

2. **Evaluate the ecological and water quality outcomes of the artificial estuary opening.**
   Specifically, the project will assess whether the artificial opening of 20 August 2025 improved estuarine water quality conditions in the Anglesea River. Parameters to be analysed include pH, salinity, and metal concentrations, drawing on datasets collected by the Arthur Rylah Institute, ALS laboratory analyses, CMA staff, EstuaryWatch volunteers, and hydrological monitoring stations. The evaluation will compare measured values against established benchmarks and guidelines for aquatic ecosystem health. (Maher, 2011; Senversa, 2019a, 2020, 2022).

By addressing these aims, the project will strengthen evidence-based management of the Anglesea River estuary, balancing ecological resilience in the context of recurring acid flush events.

3. Methods used in the study

Water quality assessments were carried out on 15, 22, and 29 August 2025 by ALS, and the resulting data were analysed for this report. In addition, the Corangamite Catchment Management Authority (CCMA) provided results from a fish survey conducted on 13 August 2025 by Arthur Rylah Institute (ARI), which are also presented below. Further water quality datasets collected by the ARI, CCMA staff, EstuaryWatch volunteers, and hydrological monitoring stations were made available to the RMIT team. These datasets were analysed in conjunction with the water quality and fish survey assessments to enable a comprehensive evaluation of estuarine conditions during the acid flush event.

3.1. Anglesea Fish-Survey 13/8/2025

Water quality

Water quality was taken from 6 locations within the Anglesea Estuary (Figure 1). This water quality monitoring was conducted by ARI when they conducted a fish survey in the Anglesea River.

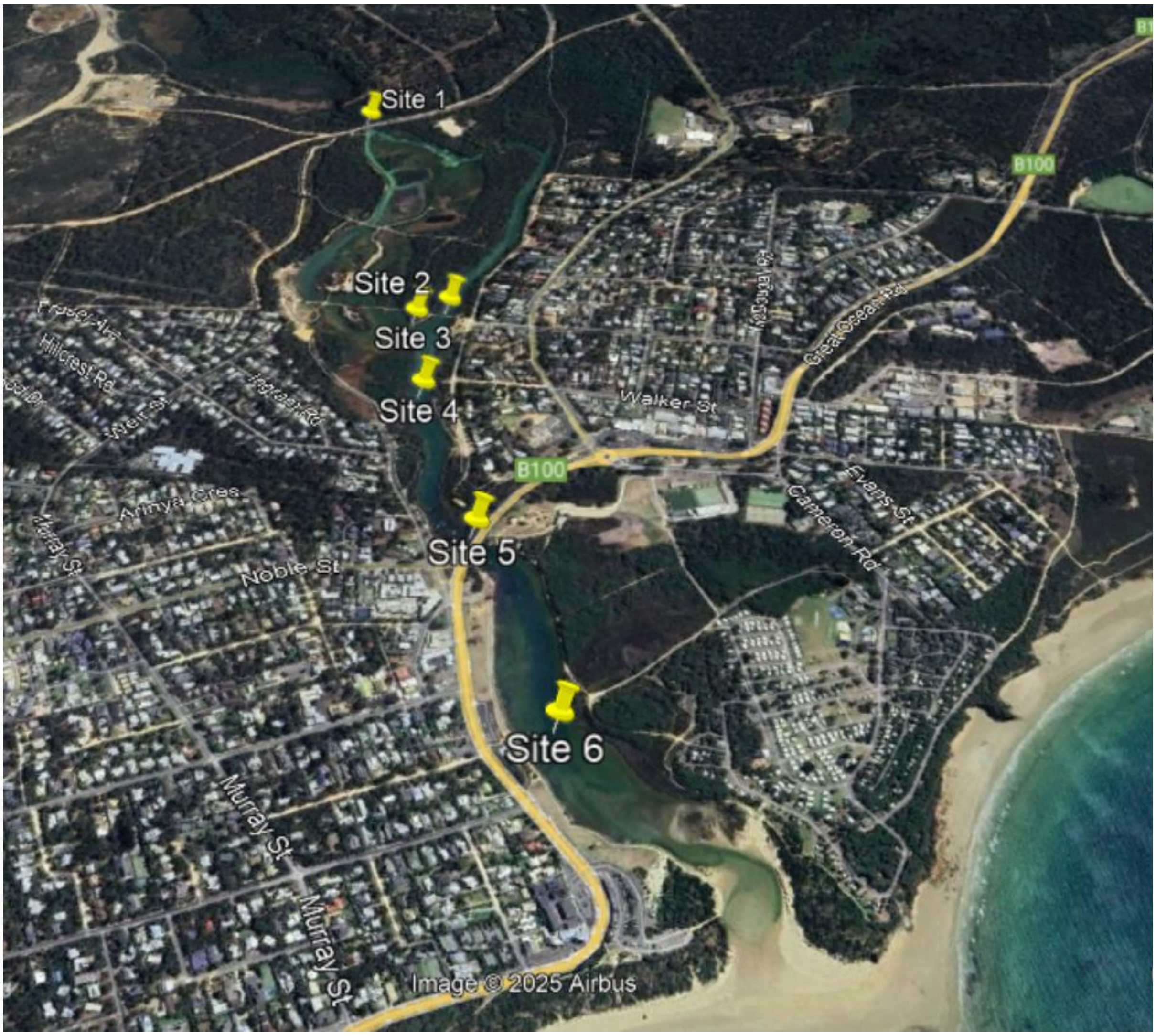

Figure 1. Water quality assessment locations.

Fish Surveys

Fish sampling was undertaken by ARI within three distinct reaches of the estuarine system corresponding to established water quality monitoring sites. The upper reach extended from Coalmine Road to the top footbridges (water quality sites 1 and 2). The mid-reach extended from the Great Ocean Road Bridge to the bottom footbridges (water quality sites 3, 4, and 5, including the lower edge of site 2). The lower reach encompassed the area between the Great Ocean Road Bridge and the estuary mouth (water quality site 6 and the downstream edge of site 5). Each section represented differing hydrological and habitat conditions along the estuarine gradient.

Boat electrofishing was employed to assess the fish assemblage across the three reaches. Sampling effort varied between sites according to accessibility and habitat conditions, with 700 seconds of electrofishing conducted at the upper reach, 520 seconds at the mid-reach, and 600 seconds at the lower reach. At the downstream site, shallow water depths near the estuary mouth limited boat operation to the upper portion of the section.

Captured fish were identified to species level and measured to the nearest millimetre total length. All live specimens were recorded. Observations of dead or failing fish were also noted, along with any apparent signs of stress to support interpretation of fish community data. No targeted sampling for macroinvertebrates was conducted; however, incidental presence or absence of visible invertebrates was noted during fish sampling activities.

3.2. Anglesea water quality assessment 15/8/2025 – 29/08/2025

The water quality assessment was undertaken at ten monitoring locations within the Anglesea River estuary (Table 1). At each site, water samples were collected and submitted to ALS Laboratories for analysis of key water quality parameters, including dissolved metals, major cations and anions, alkalinity and acidity.

Table 1. Site numbers and site names of the Anglesea water quality assessment

Site Number	Site Name
1	Upstream of Coalmine Road
2	Downstream of Coalmine Road (A5 EstuaryWatch site)
3	Cnr Bingley Parade and Wilkins Street
4	Coogoorah Park (A4 EstuaryWatch site
5	Duck pond off board walk
6	Agnes Lane Bridge (A3 EstuaryWatch site)
6A	Agnes Lane Bridge - Bottom
7	River Reserve Road (A2 EstuaryWatch site)
8	Frog area west side of River Reserve Rd
9	Anglesea Visitor Centre (A1 EstuaryWatch site)
10	River Mouth

3.3. Historical water quality data analysis

Water-quality assessment for this study was undertaken by integrating multiple complementary data sources across the Anglesea River catchment. Field measurements and observations collected by Corangamite CMA staff and the Anglesea River EstuaryWatch program were combined with continuous pH, water-level, and conductivity records from the monitoring stations at the Great Ocean Road bridge and Marshy Creek (Alcoa), accessed through the Water Measurement Information System (WMIS). Additional surface-water monitoring data from Barwon Water for Marshy Creek were incorporated to strengthen spatial coverage. To ensure accuracy and reduce the influence of isolated stagnant pools, only pH measurements taken during confirmed flowing conditions were included in the analysis. All datasets were aligned in time and evaluated collectively to characterise spatial gradients, temporal variability, and the progression of acidity throughout the catchment. This integrated approach provided a robust basis for identifying critical acid-input locations, assessing the severity of acidification, and interpreting the downstream propagation of the acid flush through the upper catchment, main channel, and estuary.

4. Observations/Comments

4.1. Fish survey water quality observations

The surface water had good levels of oxygen at all six sites (Table 2). However, oxygen levels dropped quickly and were 4.4 or less at 1 metre depth from Site 3 (Foot bridge at Coogoorah reserve) and upstream of this site. Oxygen levels appeared to be better closer to the mouth of the estuary. The pH levels were low (acidic), with the only levels above 5.5 pH below 2 metres of depth. However, this corresponded with low oxygen levels, particularly upstream the bridge at Coogoorah reserve.

Table 2. Water quality profiles at six sites in the Anglesea Estuary 13/08/2025

Site	Depth (m)	Temp (C)	EC (µS)	pH	Turbidity (NTU)	DO ppm	DO % sat
1	0.2	10.1	14510	5.2	3.5	8.27	77.4
1	1	11.6	10600	3.56	1.9	4.38	41.2
2	0.2	10.7	14513	5.07	2.22	8.85	84.2
2	1	13.6	12900	3.94	21.1	3.35	33.8
2	2	14.8	25595	6.74	6.00	2.58	28.5
2	2.4	14.9	26026	6.95	6.5	2.00	22.2
3	0.2	10.8	14926	5.16	2.07	9.09	86.6
3	1.5	14.0	13950	4.07	38.1	3.22	33.1
4	0.2	10.7	14547	5.09	2.19	9.00	85.6
4	1	10.7	14746	4.91	3.62	8.35	85.3
4	2	14.3	24100	6.00	12.97	4.7	50.2
4	2.6	14.7	26000	6.99	4.36	3.46	37.6
5	0.2	10.8	14582	5.23	2.14	9.4	89.5
5	1	10.8	14592	5.2	2.31	9.42	89.7
5	2	12.6	15400	4.51	12.08	5.9	57.8
5	2.5	14.6	24209	6.19	8.49	4.04	44.1
6	0.2	11.5	14653	5.32	2.48	10.02	96.8
6	1	11.5	14656	5.28	2.63	9.88	95.4
6	1.8	12.4	18395	4.47	25.5	5.61	57.2

4.2. Fish survey observations (ARI survey)

The Fish survey undertaken by ARI across three estuarine reaches associated with existing water quality sites produced the following results. Between Coalmine Road and the top footbridges (water quality sites 1 and 2), only five live fish were detected, comprising three Black Bream (Acanthopagrus butcheri, 192–338 mm) and two Goby species (58–64 mm). A single Flounder (Rhombosolea tapirina, 200 mm) was observed dead. No aquatic invertebrates were recorded in the water column at this site.

Within the reach extending from the Great Ocean Road bridge to the bottom footbridges (water quality sites 3, 4, and 5, including the downstream edge of site 2), 520 seconds of boat electrofishing yielded four live fish, with one additional individual observed but not captured. The live catch included one Yellow-eye Mullet (Aldrichetta forsteri, 200 mm), one juvenile Black Bream (80 mm), and two Goby species (45–55 mm). One additional Yellow-eye Mullet was observed alive but not collected. Four Australian Salmon (Arripis trutta) were found dead floating on the surface. No aquatic invertebrates were detected in this section.

Between the Great Ocean Road bridge and the estuary mouth (water quality site 6 and the downstream edge of site 5), 600 seconds of boat electrofishing were completed. The lower half of this reach, closer to the mouth, was too shallow for boat operation. Nineteen live fish were recorded, including one Flounder (150 mm), fourteen Yellow-eye Mullet (200–220 mm), one Flathead (Platycephalus sp., 300 mm), and three Gobies from two species (60–68 mm). The fourteen Yellow-eye Mullet were collected in a weakened, near-moribund state. Additionally, seven dead Yellow-eye Mullet were observed floating, along with three Flounder (250 mm) and one Black Bream (200 mm). No aquatic invertebrates were observed in the water at this site.

Nearly all the fish ARI saw were in the top 50 cm of water. The three Black Bream collected in the middle section were in deeper water and looked the healthiest of all the fish collected. All the Yellow-eye Mullet seemed in poor condition, and ARI stopped collecting them and just estimated their length at the bottom site to reduce stress. Due to the lack of invertebrates and other food, as well as the low water quality, ARI concluded that it was likely the fish were starving to death.

4.3. Anglesea water quality assessment observations

Water quality parameters observed

Three rounds of water samples were taken across the Anglesea Estuary on 15, 22, and 29 August 2025, pre, during and post estuary opening. Lab analysis of these samples revealed persistently poor conditions associated with the acid flush event. Electrical conductivity (EC) values were consistently elevated, ranging from 7,100 to 23,000 µS/cm, indicating strong saline influence well above freshwater levels. At the same time, pH values remained highly acidic, generally between 3.1 and 5.5, which is outside the recreational guideline range of 5–9. Acidity concentrations peaked during late August, with some sites recording values up to 2,900 mg/L as $CaCO_3$, while alkalinity remained extremely low (<2 mg/L at most sites), reflecting almost no buffering capacity in the system.

Metals and major ions showed clear signs of mobilisation under acidic conditions. Iron concentrations, both ferrous and ferric, were elevated throughout the sampling period, reaching as high as 19 mg/L by 29 August, far greater than initial levels on 15 August. Sulphate concentrations were also consistently high (650–4,700 mg/L), demonstrating the influence of acid sulphate soils within the catchment. Sodium and chloride levels reflected strong estuarine and saline mixing, with sodium reaching over 4,000 mg/L at some sites well above the recreational guideline of 180 mg/L. Calcium, magnesium, and hardness levels were also elevated, confirming high dissolved ion loads throughout the system.

Nutrient concentrations were consistently low, with nitrate, nitrite, and phosphate generally below detection limits (<0.1 mg/L), suggesting minimal nutrient input during this period. Fluoride was mostly low (<0.05–2 mg/L) but reached up to 7.7 mg/L at one site, temporarily exceeding guideline values. Silica concentrations were variable (5–140 mg/L), with the highest values observed on 29 August.

Overall, the monitoring results confirm that water quality in the estuary during August 2025 was dominated by strongly acidic conditions, high iron and sulphate mobilisation, with pH far exceeding recreational water quality guidelines. These findings demonstrate the combined effects of acid sulphate soil processes and saline intrusion during the acid flush event, producing conditions unsuitable for safe recreation and highly stressful for aquatic life.

A number of water-quality parameters do not have Australian and New Zealand Guideline (ANZG) numeric Default Guideline Values (DGVs) for aquatic ecosystem protection. These include Electrical Conductivity (EC), Alkalinity (as $CaCO_3$), Acidity, Carbonate, Bicarbonate, Hydroxide, Silica (SiO_2), Hardness (as $CaCO_3$), Calcium, Magnesium, Potassium, Chloride, Fluoride, Bromide, Chlorate, Nitrate (as N), Nitrite (as N), Phosphate (as P), Sulphate (as S), total Iron (Fe), and oxidation state fractions such as FERROUS_DA / FERRIC_SOL. Under the ANZG (2018) framework, these parameters should instead be managed using site- or region-specific trigger values, typically derived from reference-site percentiles, and are primarily treated as supporting physico-chemical indicators rather than direct toxicants. For nutrients, ANZG recommends deriving triggers at the catchment or physiographic scale, noting that while a 2024–25 ANZG technical brief recognises nitrate as a direct toxicant, numeric toxicant DGVs for nitrate, nitrite, and phosphate are commonly developed contextually by jurisdictions to suit local ecosystem conditions.

When deriving screening levels for aqueous contaminants where specific aquatic ecosystem values were unavailable, this assessment adopted a tiered approach following national and international guidance. First, values based on the United States Environmental Protection Agency (US EPA) Regional Screening Levels for Tap Water, November 2018 Updates were multiplied by a factor of ten, consistent with the National Health and Medical Research Council (NHMRC) 2008 guidance for deriving interim values for non-potable exposures. Second, where drinking-water values from the NHMRC (2011) were available for sum metals observed (Tables 6, 7 and 8). The 2011 NHMRC guideline ware also similarly multiplied by ten in accordance with NHMRC (2008) guidance. Although the guideline applies specifically to hexavalent chromium (Cr VI), it has been used here as an initial screening value against total chromium concentrations due to the absence of species-specific data. Finally, aquatic health screening was aligned with the Australian Guidelines for Managing Risks in Recreational Water (AGMRRW) framework to ensure consistency in assessing recreational water risks. These combined derivation pathways provide a defensible, conservative basis for screening water-quality data in the absence of parameter-specific ecosystem guideline values (Senversa. 2020).

Table 3. Water quality parameters observed in Anglesea water quality assessment on 15/08/2025

	15/08/2025											Recreation Water Quality Guideline (mg/L)	
Parameter	**1**	**2**	**3**	**4**	**5**	**6**	**6A**	**7**	**8**	**9**	**10**		Guideline
Electrical Conductivity	13000	13000	13000	14000	12000	14000		14000	11000	14000	14000		
FERROUS_DA	0.7	1.1	0.9	0.4	0.6	0.5		0.6	0.2	0.3	0.1		
FERRIC_SOL	0.5	1.5	0.7	< 0.2	3.3	0.3		0.2	0.9	< 0.2	< 0.2		
ALKALINITY AS CACO3	< 2	< 2	< 2	5	< 2	< 2		< 2	< 2	3	< 2		
CO3 AS CACO3	< 2	< 2	< 2	< 2	< 2	< 2		< 2	< 2	< 2	< 2		
HCO3 AS CACO3	< 2	< 2	< 2	5	< 2	< 2		< 2	< 2	3	< 2		
OH AS CACO3	< 2	< 2	< 2	< 2	< 2	< 2		< 2	< 2	< 2	< 2		
Bromide	15	14	16	16	13	15		15	12	16	16		
Chlorate	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1		< 0.1	< 0.1	< 0.1	< 0.1		
Chloride	4500	4200	4600	4600	4000	4400		4600	3500	4600	4600		
Fluoride	2.4	1.6	< 0.05	< 0.05	1.3	1.4		1.5	< 0.05	< 0.05	< 0.05		
Nitrate_as_N	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1		< 0.1	< 0.1	< 0.1	< 0.1		
Nitrite_as_N	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1		< 0.1	< 0.1	< 0.1	< 0.1		
Phosphate_as_P	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1		< 0.1	< 0.1	< 0.1	< 0.1		
Sulphate	1100	1200	910	900	730	1000		1100	650	920	890		
Sulphate as S	370	410	300	300	240	340		350	220	310	300		
SI-SIO2	16	22	19	7	11	11	0	12	11	7	5		
W-HARDNESS	2100	2000	2100	2000	1400	1800	0	1800	1400	2100	2000		
PH	4.2	4	4.2	4.6	3.7	4.3	0	4.4	4.8	4.6	4.7	5 to 9	(#1)
ACIDITY	200	341	301	84	78	178	0	203	24	97	56		
Calcium	180	180	180	160	120	150	0	150	130	170	170		
Potassium	120	110	120	120	97	100	0	110	87	120	120		
Magnesium	390	380	400	390	280	340	0	350	270	400	390		

Sodium	3000	2900	3000	3100	2200	2600	0	2600	2000	3200	3100	180	(#1)

#1 Australian Guidelines for Managing Risks in Recreational Water

Table 4 Water quality parameters observed in Anglesea water quality assessment on 22/08/2025

	22/08/2025											Recreation Water Quality Guideline (mg/L)	Guideline
Parameter	**1**	**2**	**3**	**4**	**5**	**6**	**6A**	**7**	**8**	**9**	**10**		
Electrical Conductivity	12000	13000	13000	14000	12000	13000	23000	13000	11000	14000	13000		
FERROUS_DA	13	9.5	5.5	1.9	0.6	1.2	< 0.1	1.6	0.1	1	0.9		
FERRIC_SOL	3	1.5	1.3	0.5	3.6	0.6	0.3	0.7	0.5	0.3	0.3		
ALKALINITY AS CACO3	< 2	< 2	3	< 2	< 2	< 2	120	< 2	< 2	< 2	4		
CO3 AS CACO3	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2		
HCO3 AS CACO3	< 2	< 2	3	< 2	< 2	< 2	120	< 2	< 2	< 2	4		
OH AS CACO3	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2		
Bromide	13	15	15	16	14	15	30	15	12	16	15		
Chlorate	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1		
Chloride	3800	4300	4500	4600	4100	4400	8800	4500	3700	4600	4400		
Fluoride	2.1	1.8	1.6	1.6	1.4	1.8	< 0.05	1.8	4.6	2.2	1.7		
Nitrate_as_N	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1		
Nitrite_as_N	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1		
Phosphate_as_P	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1		
Sulphate	1700	1200	1100	1200	770	1300	1300	1300	660	1200	1100		
Sulphate as S	570	420	360	380	260	440	450	420	220	400	360		
SI-SIO2	40	23	17	13	12	19	< 5	18	9	14	13		
W-HARDNESS	1800	1800	1800	1800	1600	1800	2800	1900	1500	1900	1700		
PH	3.7	4.1	4.4	4.3	3.6	4.2	6.7	4.2	5.4	4.3	4.5	5 to 9	(#1)
ACIDITY	477	272	169	212	75	300	29	263	43	229	226		
Calcium	180	160	160	160	130	170	230	170	140	170	160		

Potassium	89	100	110	110	100	100	180	110	93	110	100		
Magnesium	320	330	340	340	300	340	540	350	290	350	320		
Sodium	2300	2600	2800	2900	2600	2800	3800	2900	2400	2900	2700	180	(#1)

#1 Australian Guidelines for Managing Risks in Recreational Water

Table 5. Water quality parameters observed in Anglesea water quality assessment on 29/08/2025

	29/08/2025											Recreation Water Quality Guideline (mg/L)	Guideline
Parameter	**1**	**2**	**3**	**4**	**5**	**6**	**6A**	**7**	**8**	**9**	**10**		
Electrical Conductivity (EC)	7100	13000	14000	13000	12000	14000	23000	14000	11000	14000	14000		
FERROUS_DA	11	2.7	1.5	3.4	1.2	1.7	0.4	1.7	0.1	1.3	0.9		
FERRIC_SOL	19	3.3	0.9	1.6	5.7	0.9	2.5	0.8	0.7	< 0.2	0.6		
ALKALINITY AS CACO3	< 2	< 2	< 2	< 2	< 2	< 2	3	< 2	2	< 2	3		
CO3 AS CACO3	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2		
HCO3 AS CACO3	< 2	< 2	< 2	< 2	< 2	< 2	3	< 2	2	< 2	3		
OH AS CACO3	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2	< 2		
Bromide	< 0.1	13	15	14	13	15	28	16	12	15	15		
Chlorate	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1		
Chloride	1100	4000	4500	4300	4200	4500	8300	4900	3500	4600	4500		
Fluoride	7.7	3	2.1	2.7	1.6	2	< 0.05	2	< 0.05	1.8	1.8		
Nitrate_as_N	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1		
Nitrite_as_N	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1		
Phosphate_as_P	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1		
Sulphate	4700	1900	1400	1800	830	1400	1400	1500	600	1300	1200		
Sulphate as S	1600	640	470	610	280	470	450	490	200	440	410		
SI-SIO2	140	40	20	30	12	20	7	17	6	15	16		
W-HARDNESS	1600	1600	1600	1500	1400	1600	2700	1600	1100	1500	1800		
PH	3.1	3.7	4	3.8	3.4	4	5.3	4.2	5.5	4.3	4.4	5 to 9	(#1)

ACIDITY	2900	842	433	666	104	422	68	392	24	334	274		
Calcium	280	170	150	150	120	150	210	150	100	140	180		
Potassium	36	84	90	79	91	91	170	89	67	85	100		
Magnesium	230	290	310	280	260	300	540	300	210	280	340		
Sodium	530	2000	2300	2000	2200	2300	4400	2200	1700	2200	2700	180	(#1)

#1 Australian Guidelines for Managing Risks in Recreational Water

Metals observed

Lab analysis of water samples collected across the Anglesea Estuary on 15, 22, and 29 August 2025, showed metal concentrations in the Anglesea Estuary trending upward overtime, corresponding with a progressive decline in pH and increasing evidence of acid-sulphate-soil mobilisation. During the first sampling on 15 August, most metals remained well below their Recreation Water Quality Guideline limits. Aluminium ranged from 7 to 55 mg/L, iron from 0.1 to 2.2 mg/L, manganese from 0.36 to 1.1 mg/L, and zinc from 0.23 to 1.2 mg/L, all comfortably under their respective guideline values of 200, 140, 5, and 60 mg/L. Nickel, however, reached 0.43 mg/L at several sites, exceeding the 0.2 mg/L Recreation Water Quality Guideline and representing the only metal of concern in this early phase

By 22 August, metal concentrations had increased substantially. Aluminium rose to 89 mg/L, iron to 16 mg/L, and manganese to 2.1 mg/L, all still below Recreation Water Quality Guideline thresholds but showing marked enrichment. Nickel remained elevated at up to 0.72 mg/L, exceeding its 0.2 mg/L Recreation Water Quality Guideline limit at most sites, while zinc concentrations increased slightly but stayed within acceptable Recreation Water Quality Guideline limits. These changes reflected ongoing acidification and reduced redox conditions, promoting metal release from sediment sources

By the third sampling on 29 August, exceedances became widespread. Aluminium concentrations peaked at 440 mg/L, more than double the 200 mg/L Recreation Water Quality Guideline, while manganese reached 7.6 mg/L, surpassing its 5 mg/L Recreation Water Quality Guideline limit. Nickel ranged between 0.1 and 3.3 mg/L, exceeding the 0.2 mg/L Recreation Water Quality Guideline at nearly all sites. Iron and zinc remained below their respective Recreation Water Quality Guideline limits (140 mg/L and 60 mg/L) but continued to rise. These results clearly show that as acidity intensified (pH 3.1–4.0), mobilisation of aluminium, manganese, and nickel increased dramatically, signalling active release from acid-sulphate soils and associated sediments

Overall, the comparison of observed metal concentrations against guideline values indicates that nickel exceeded thresholds throughout the event, while aluminium and manganese rose above guideline levels by late August. Iron and zinc remained below guideline concentrations but exhibited consistent upward trends. The strong correlation between decreasing pH and increasing metal concentrations demonstrates the influence of acidification on metal solubility and transport. By the end of the monitoring period, water quality within the Anglesea Estuary showed clear signs of acid-driven metal contamination, posing heightened ecological and potential recreational risks.

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Table 6. Metals observed in Anglesea water quality assessment on 15/08/2025 (repeated results are shown for metal analytical accuracy)

	15/08/2025											Recreation Water Quality Guideline (mg/L)	
Parameter (mg/L)	**1**	**2**	**3**	**4**	**5**	**6**	**6A**	**7**	**8**	**9**	**10**		Guideline
Aluminium (Al)	29	55	49	12	7.3	32		34	0.46	15	8.2	200	(#1)
Arsenic (As)	< 0.001	0.001	0.001	< 0.001	0.001	< 0.001		0.001	< 0.001	< 0.001	< 0.001	0.1	(#2)
Boron (B)	1.1	1.1	1.1	0.9	0.85	1.2		1.2	0.81	0.84	0.99	40	(#2)
Chromium (Cr)	0.003	0.003	0.003	< 0.001	< 0.001	0.003		0.002	< 0.001	< 0.001	0.002	0.5	(#2)
Copper (Cu)	0.001	0.001	0.002	0.002	0.002	0.001		0.001	< 0.001	0.002	< 0.001	20	(#2)
Iron (Fe)	0.48	0.9	0.86	0.29	2.2	0.55		0.52	0.17	0.19	0.12	140	(#1)
Mercury (Hg)	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001		< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.01	(#2)
Manganese (Mn)	0.73	1.1	1	0.44	0.42	0.76		0.78	0.5	0.47	0.36	5	(#2)
Nickel (Ni)	0.27	0.43	0.37	0.13	0.065	0.27		0.28	0.028	0.14	0.12	0.2	(#2)
Zinc (Zn)	0.73	1.2	1	0.38	0.23	0.76		0.78	0.078	0.4	0.33	60	(#1)
Aluminium (Al)	29	55	49	12	7.3	33	0	34	0.46	15	8.2	200	(#1)
Arsenic (As)	0.001	0.002	0.002	0.001	0.002	0.001	0	0.001	< 0.001	0.001	< 0.001	0.1	(#2)
Boron (B)	1.1	1.2	1.1	1.1	1.1	1.2	0	1.2	1.1	1.1	1.1	40	(#2)
Chromium (Cr)	0.003	0.004	0.004	0.003	0.002	0.002	0	0.002	< 0.001	0.003	0.003	0.5	(#3)
Copper (Cu)	0.002	0.002	0.002	0.002	0.002	0.002	0	0.001	< 0.001	0.002	0.001	20	(#2)
Iron (Fe)	1.2	2.6	1.6	0.39	3.9	0.82	0	0.81	1.1	0.29	0.15	140	(#1)
Mercury (Hg)	< 0.0001	2E-04	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.01	(#2)
Manganese (Mn)	0.73	1.1	1	0.44	0.45	0.76	0	0.78	0.55	0.47	0.36	5	(#2)
Nickel (Ni)	0.27	0.43	0.37	0.15	0.079	0.28	0	0.29	0.034	0.17	0.12	0.2	(#2)
Zinc (Zn)	0.73	1.2	1	0.42	0.27	0.81	0	0.79	0.097	0.45	0.33	60	(#1)

#1 USEPA Regional Screening Level for Tap Water (November 2018 Update) multiplied by 10 in accordance with NHMRC (2008) guidance.
#2 NHMRC (2011) Health-based drinking water guideline multiplied by 10 in accordance with NHMRC (2008) guidance.
#3 Guideline is for hexavalent chromium, but has been compared to total chromium concentrations for initial screening purposes.

Table 7. Metals observed in Anglesea water quality assessment on 22/08/2025(repeated results are shown for metal analytical accuracy)

	22/08/2025											Recreation Water Quality Guideline (mg/L)	
Parameter (mg/L)	**1**	**2**	**3**	**4**	**5**	**6**	**6A**	**7**	**8**	**9**	**10**		Guideline
Aluminium (Al)	88	48	32	39	7.4	56	0.11	52	0.21	45	34	200	(#1)
Arsenic (As)	0.002	0.001	< 0.001	0.001	0.002	0.001	< 0.001	0.001	< 0.001	0.001	0.002	0.1	(#2)
Boron (B)	1.1	1.1	1.1	1.2	1.1	1.2	2	1.2	1.1	1.1	1.1	40	(#2)
Chromium (Cr)	0.002	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.5	(#2)
Copper (Cu)	0.001	< 0.001	< 0.001	0.002	0.002	0.002	0.001	< 0.001	< 0.001	0.024	0.005	20	(#2)
Iron (Fe)	14	8.9	4.9	1.7	3.2	1.2	< 0.01	1.6	0.12	0.73	0.68	140	(#1)
Mercury (Hg)	< 0.0001	< 0.0001	< 0.0001	< 0.0001	1E-04	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.01	(#2)
Manganese (Mn)	2.1	1.3	0.92	0.94	0.44	1.3	0.58	1.2	0.52	1	0.95	5	(#2)
Nickel (Ni)	0.69	0.4	0.27	0.32	0.077	0.43	0.043	0.4	0.027	0.35	0.3	0.2	(#2)
Zinc (Zn)	1.8	1	0.73	0.86	0.27	1.2	0.074	1.1	0.064	1	0.83	60	(#1)
Aluminium (Al)	89	48	33	40	7.4	57	1.7	55	0.26	47	37	200	(#1)
Arsenic (As)	0.002	0.001	0.001	0.001	0.002	0.002	< 0.001	0.002	< 0.001	0.002	0.002	0.1	(#2)
Boron (B)	1.1	1.1	1.2	1.2	1.2	1.2	2.1	1.2	1.2	1.2	1.2	40	(#2)
Chromium (Cr)	0.002	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.5	(#3)
Copper (Cu)	0.001	0.001	0.001	0.003	0.003	0.002	0.002	0.001	< 0.001	0.024	0.006	20	(#2)
Iron (Fe)	16	11	6.8	2.4	4.2	1.8	0.33	2.3	0.61	1.3	1.2	140	(#1)
Mercury (Hg)	< 0.0001	< 0.0001	< 0.0001	< 0.0001	1E-04	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	0.01	(#2)
Manganese (Mn)	2.1	1.3	0.96	0.97	0.45	1.4	0.61	1.3	0.54	1.1	0.98	5	(#2)

Nickel (Ni)	0.72	0.41	0.29	0.33	0.079	0.46	0.046	0.43	0.029	0.38	0.32	0.2	(#2)
Zinc (Zn)	1.9	1.1	0.76	0.9	0.28	1.2	0.086	1.2	0.069	1.1	0.86	60	(#1)

#1 USEPA Regional Screening Level for Tap Water (November 2018 Update) multiplied by 10 in accordance with NHMRC (2008) guidance.
#2 NHMRC (2011) Health-based drinking water guideline multiplied by 10 in accordance with NHMRC (2008) guidance.
#3 Guideline is for hexavalent chromium, but has been compared to total chromium concentrations for initial screening purposes.

Table 8 Metals observed in Anglesea water quality assessment on 29/08/2025 (repeated results are shown for metal analytical accuracy)

	29/08/2025											Recreation Water Quality Guideline (mg/L)	
Parameter (mg/L)	**1**	**2**	**3**	**4**	**5**	**6**	**6A**	**7**	**8**	**9**	**10**		Guideline
Aluminium (Al)	440	130	ND	ND	10	68	12	60	< 1	53	53	200	(#1)
Arsenic (As)	< 1	< 1	ND	ND	< 1	< 1	< 1	< 1	< 1	< 1	< 1	0.1	(#2)
Boron (B)	1	1.1	ND	ND	1.2	1.2	2	1.1	1	1.1	1.3	40	(#2)
Chromium (Cr)	< 0.1	< 0.1	ND	ND	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.5	(#2)
Copper (Cu)	< 0.1	< 0.1	ND	ND	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	20	(#2)
Iron (Fe)	30	6	ND	ND	6.9	2.6	2.9	2.5	0.8	1.4	1.5	140	(#1)
Mercury (Hg)	< 1	< 1	ND	ND	< 1	< 1	< 1	< 1	< 1	< 1	< 1	0.01	(#2)
Manganese (Mn)	7.6	2.6	ND	ND	0.5	1.6	0.9	1.4	0.5	1.3	1.4	5	(#2)
Nickel (Ni)	3.3	1	ND	ND	0.1	0.6	0.2	0.5	< 0.1	0.5	0.5	0.2	(#2)
Zinc (Zn)	7.9	2.5	ND	ND	0.3	1.4	0.4	1.3	< 0.1	1.2	1.3	60	(#1)
Aluminium (Al)	440	130	71	100	9	68	2	60	< 1	53	47	200	(#1)
Arsenic (As)	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	0.1	(#2)
Boron (B)	0.9		1.2	1.1	1.1	1.2	1.9	1.1	1	1.1	1.2	40	(#2)
Chromium (Cr)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.5	(#3)
Copper (Cu)	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	20	(#2)
Iron (Fe)	24	0.8	< 0.5	< 0.5	1.8	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	140	(#1)
Mercury (Hg)	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	0.01	(#2)
Manganese (Mn)	7.6	2.4	1.6	2.1	0.5	1.6	0.9	1.4	0.5	1.3	1.3	5	(#2)

Nickel (Ni)	3.2	1	0.6	0.8	0.1	0.6	0.2	0.5	< 0.1	0.5	0.4	0.2	(#2)
Zinc (Zn)	7.9	2.5	1.5	2	0.3	1.4	0.3	1.3	< 0.1	1.2	1.1	60	(#1)

#1 USEPA Regional Screening Level for Tap Water (November 2018 Update) multiplied by 10 in accordance with NHMRC (2008) guidance.
#2 NHMRC (2011) Health-based drinking water guideline multiplied by 10 in accordance with NHMRC (2008) guidance.
#3 Guideline is for hexavalent chromium, but has been compared to total chromium concentrations for initial screening purposes.

Tables 3–8 show acid-flush chemistry (very low pH) coinciding with elevated dissolved metals (notably Al, Mn, Ni). That pattern matches estuarine process studies showing that lower pH and mixing along the salinity gradient increase metal solubility, shift speciation, and can transiently raise bioavailable fractions to ecologically important levels (Mosley & Liss, 2020). In Victorian systems, biomonitoring from the Gippsland Lakes demonstrates that metal exposure is environmentally meaningful. Metals in sessile invertebrates integrate water-column pulses and reflect biologically available loads in this region (Willems et al., 2019). Together, these studies indicate that the ranges seen in data (acidic pH with concurrent Al/Mn/Ni peaks) lie within the envelope associated with elevated exposure risk to estuarine biota in south-eastern Australia (Mosley & Liss, 2020; Willems et al., 2019).

Co-occurring low dissolved oxygen in late-event samples is also critical. Estuarine reviews consistently treat ≤ ~2 mg L^{-1} DO as hypoxic for fish and zooplankton, with strong temperature-dependence of impacts (Vaquer-Sunyer & Duarte, 2011; Deutsch et al., 2020; Zhang et al., 2019; synthesis in Gouraud et al., 2019). Under such DO, behavioural avoidance, impaired ventilation/ion regulation, and survival declines are expected. Effects that intensify when Al is bioavailable at low pH (mechanistic link via gill irritation and ion regulatory stress) (Mosley & Liss, 2020). Regionally, prolonged low inflows and weak flushing in south-eastern estuarine lagoons (e.g., the Coorong) are associated with hyper salinity, eutrophication and oxygen stress, underscoring that poor flushing can push systems into the same stressor space your results document (Mosley et al., 2023). In short, the chemistry in Tables 3–8 aligns with known Victorian/south-eastern Australian exposure ranges for aquatic life, where a combination of acidification, metals, and low DO elevates risk of reduced environmental conditions and episodic mortality.

Comparison of Table 9 freshwater aquatic ecosystem 95% species-protection DGVs of ANZG (2018), with Tables 6–8 and pH of tables 3,4 and 5 shows that measured metal concentrations in the Anglesea Estuary consistently exceeded aquatic ecosystem protection guidelines throughout the acid-flush event. Nickel (Ni) was the most persistent exceedance, with concentrations well above the ANZG (2018) DGV of 0.011 mg/L across all sites and sampling dates. As acidity intensified (pH < 4.5) by 29 August, aluminium (Al) and manganese (Mn) also exceeded their DGVs (0.055 mg/L and 1.9 mg/L respectively), particularly at upstream sites, reflecting strong pH-driven mobilisation from acid-sulfate soils. Copper, chromium, mercury and zinc remained below guideline levels but showed upward trends consistent with declining pH. Overall, comparison with Table 9 confirms increasing ecological risk over the monitoring period, driven by low pH and rising bioavailable metals, indicating conditions unsuitable for aquatic life and consistent with field observations of fish stress and absence of invertebrates.

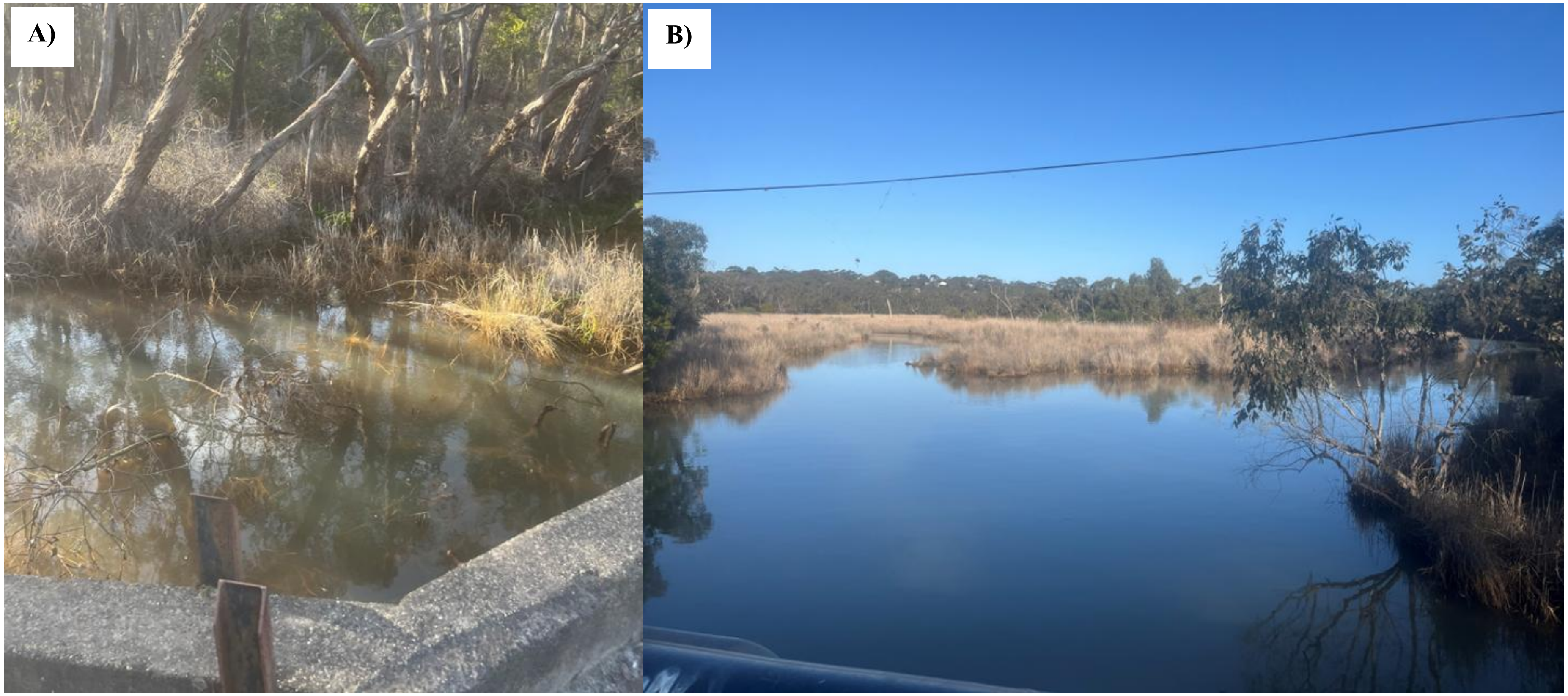
Table 9. ANZG (2018) Freshwater Aquatic Ecosystem DGVs (95% Species Protection)

Analyte	DGV
Aluminium (Al)*	0.055 mg/L (when pH > 6.5)
Arsenic (As V)	0.013 mg/L
Chromium (Cr VI)	0.001 mg/L
Copper (Cu)	0.0014 mg/L
Manganese (Mn)	1.9 mg/L
Mercury (Hg)	0.00006 mg/L
Nickel (Ni)	0.011 mg/L
Zinc (Zn)	0.008 mg/L
pH (guideline range)	6.5 – 8.0

Notes *- The Aluminium DGV applies only where pH > 6.5 due to changes in toxicity and solubility under more acidic conditions.

Values above reflect ANZG (2018) freshwater 95% species-protection DGVs, as compiled in an EPA table that cites ANZG; always confirm site context, salinity, and bioavailability (e.g., hardness, DOC, pH) per ANZG method.

Figure 2. Images taken of the **Gum Flats Road** monitoring station on the Anglesea River upstream (A) and downstream (B) on 23 August 2025 during the opening of the estuary, this stream was found to be dried up with no water flow.


A)
B)

(Claringbold, E.,2025)

Figure 3. Images taken of upstream (A) and downstream (B) of Coalmine Road on 23 August 2025 during the opening of the estuary, and image C. the state of the Anglesea River about 70 metres upstream from Coalmine Road (Claringbold, E.,2025), demonstrating discolouration of the water, indicating high acidity event.

Figure 4. Images taken of the **Anglesea River on Agnes Road** (A) and (B) on 23 August 2025 during the opening of the estuary, showing reddish soil in the riverbank and discoloured water indicating low pH in the water.

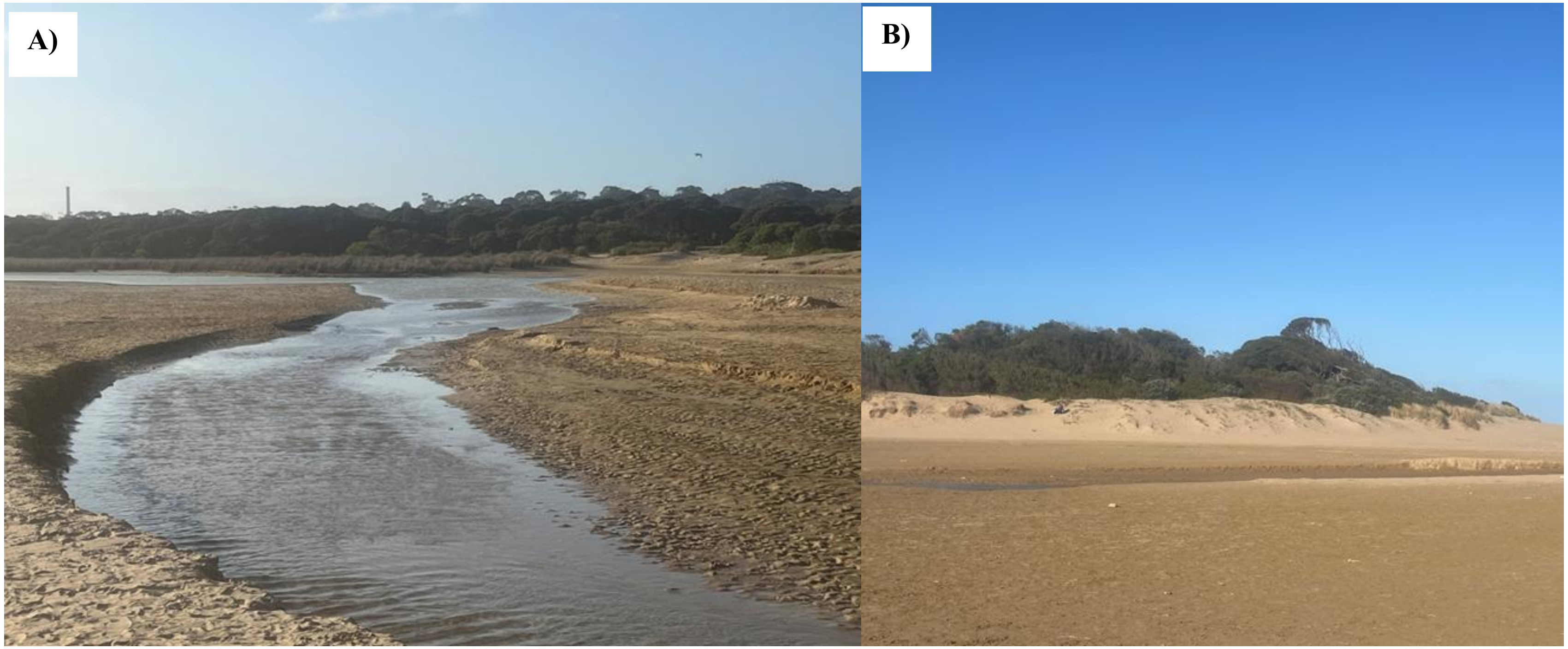


Figure 5. Images taken of the river mouth (A) and (B) on 23 August 2025 after the estuary was artificially opened, image A showing the estuary in the background and shallow opening, Image B shows the shallow water flow after the estuary opening in 2025.

Figure 6. During an estuary opening, water from the estuary discharges into the ocean through the **Anglesea River estuary mouth**, and the image shows the shallow water flow. The image was taken on 23 August 2025 after the estuary was artificially opened.

4.4. Acidity evaluation in Anglesea River catchment

Water quality data and field observations collected by Corangamite CMA staff and the Anglesea River EstuaryWatch program were combined with water quality and water level records from the Anglesea River monitoring stations at the **Great Ocean Road Bridge (Site No. 235278)** and **Marshy Creek at Alcoa (AV2 or Site No. 235260A)** available through the Water Measurement Information System. Additional surface water monitoring data from Barwon Water on Marshy Creek were also included in the analysis. To ensure accuracy, only pH measurements taken when sites were reported to be flowing were used, providing a more reliable representation of conditions within the waterway.

Monitoring across the Anglesea River catchment highlight significant spatial and temporal variability in pH and flow conditions across key sites. The upper tributaries show distinct differences, with **Breakfast Creek (SV1 or WMIS Site No. 235273A)** (a tributary of Salt Creek) generally maintaining near-neutral to slightly acidic conditions (pH 5–6), though occasional lower values of 4.5–4.8 have been recorded during 2025. In contrast, **Salt Creek (Encoder Pool) (SV2 or Site No. 235222A)** is more consistently acidic, with pH values near 4 and periods of both flow and extended dry phases. Flow resumed in early 2025 with neutral pH (7.3) before rapidly declining again to more acidic conditions (pH 4.4 by September). The **Anglesea Marsh near Alcoa (AV2 or Site No. 235260A)** exhibits the most acidic and prolonged records, with long-term monitoring since 2011 consistently showing values in the range of pH 2.8–3.8, only occasionally approaching neutral conditions. This site reflects the strongest influence of acid sulphate soils and marsh processes, with chronic acidity persisting across years.

Other monitoring locations provide complementary context. **Gum Flats (Site No. 235277)** typically shows pH values between 4 and 5, while **Breakfast Creek** is less acidic (pH 5–6). **Anglesea Swamp (ASP7 or Site No 235280A.)** remains highly acidic, usually in the range of pH 3–3.5 and is unaffected by inputs from Curum Flats. Downstream, the **main channel of the Anglesea River** flows toward the ocean outlet, with estuarine conditions strongly influenced by upstream acidic inflows. Water quality snapshots from **Marshy Creek at Alcoa (AV2 or Site No. 235260A)** during flowing periods recorded pH values around 3.1–3.3, with moderate conductivity (2,750–3,300 µS/cm), total dissolved solids (1,723–1,790 mg/L), and good dissolved oxygen at both surface and bottom waters.

Hydrological records reinforce the ephemeral nature of the system. The **Anglesea River at Gum Flats Rd (AV3 or Site No. 235277A)** ceased flowing between October 2024 and August 2025, while long-term monitoring at the **Australian Automotive Research Centre (AARC)** extends back to 2010. Historical pH records from the monitoring station above AARC (AV1 or Site No. 235270A) on the Anglesea River further illustrates the variability between stagnant and flowing conditions, with stagnant waters ranging from pH 5.1–7.9 and flowing waters typically between 5.2–6.9. However, during specific events between 2012 and 2022, more acidic conditions (pH 3–4) were observed, pointing to localised acid flush impacts.

Monitoring conducted across ten sites within the Anglesea Estuary on 15, 22, and 29 August 2025 indicated relatively stable pH conditions at most locations, with values generally ranging between 3.7 and 4.8. Two exceptions were recorded: Site 1 (upstream of Coalmine Road), where pH declined to 3.1, and Site 8 (Frog area west side of River Reserve Rd), where pH increased to 5.5 by 29 August. Overall, the results demonstrate that pH remained consistently low across the estuary during the monitoring period, well below thresholds considered safe for aquatic ecosystems and human use.

Spatial trends along the waterway reveal pronounced changes in acidity. At the upper sampling point near the Australian Automotive Research Centre (AARC), pH values remained within the 5–6 range, decreasing slightly to 4–5 around Gum Flats Road. Breakfast Creek and Salt Creek also recorded pH values between 5 and 6. However, a sharp decline was observed downstream at Marshy Creek (Alcoa), where pH levels dropped abruptly to between 2.9 and 3.2. This marked reduction coincides with the location of the former coal mine and indicates a significant acid input. Downstream of this point, the Anglesea Swamp consistently recorded pH values of 3.0–3.5, with levels stabilising at around 4.0 closer to the Great Ocean Road bridge.

The data suggest that Marshy Creek at Alcoa represents a critical hotspot for acidification within the estuary. Notably, this sharp decline in pH was observed even during periods when neither Breakfast Creek nor Salt Creek were contributing flow, strengthening the inference that localised inputs near Marshy Creek are responsible for the sudden acidification. These findings highlight the need for further investigation to identify and characterise the specific sources of acidity entering the system at this location.

Governance and management notes highlight that coordination during past events involved agencies such as Department of Energy, Environment and Climate Action, GORCAPA, Corangamite Catchment Management Authority (CCMA), Parks Victoria, Barwon Water, Surf Coast Shire Council, and the Anglesea River Advisory Group (ARAG). Communication gaps with licence holders were noted, and reliance on reports from emergency and catchment agencies has been common. Collectively, these records demonstrate that while certain tributaries such as Breakfast Creek provide near-neutral inflows, sites like Anglesea Marsh and Salt Creek represent persistent sources of acidity, driving estuary-wide water quality challenges.

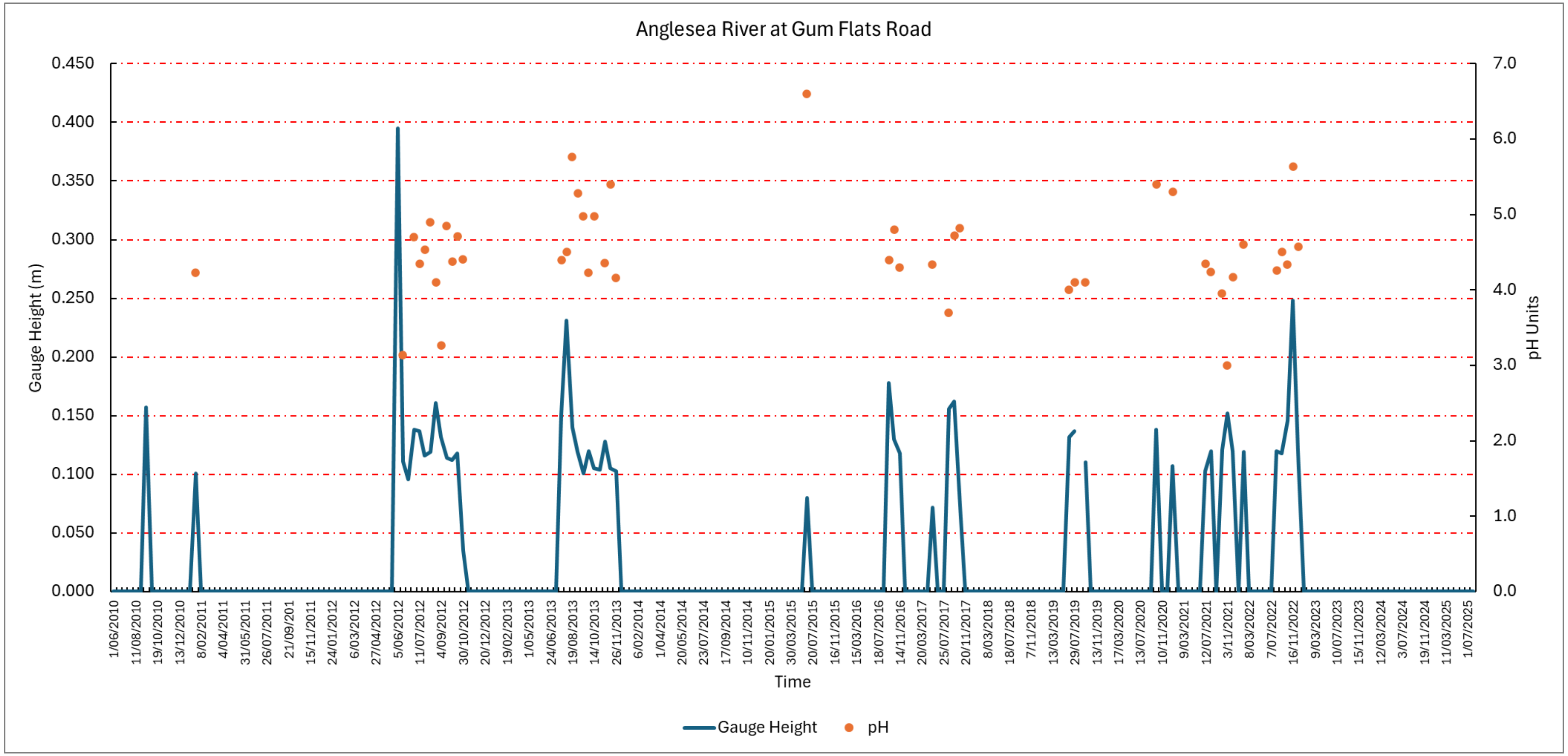


Figure 7. Water availability according to gauge height and pH in the Anglesea River at Gum Flats Road

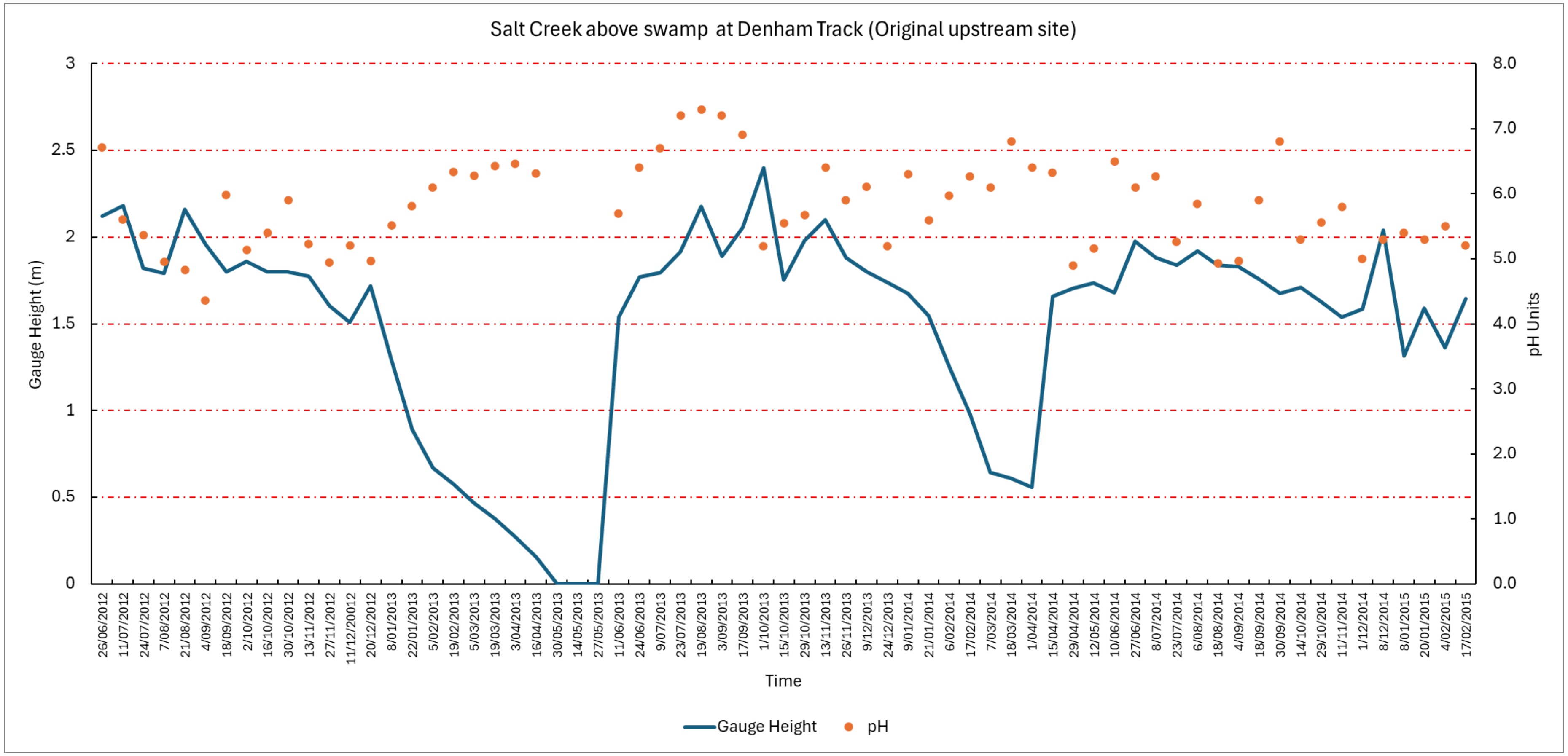


Figure 8. Water availability according to gauge height and pH in the Salt Creek above the swamp at Denham Track (Original upstream site)

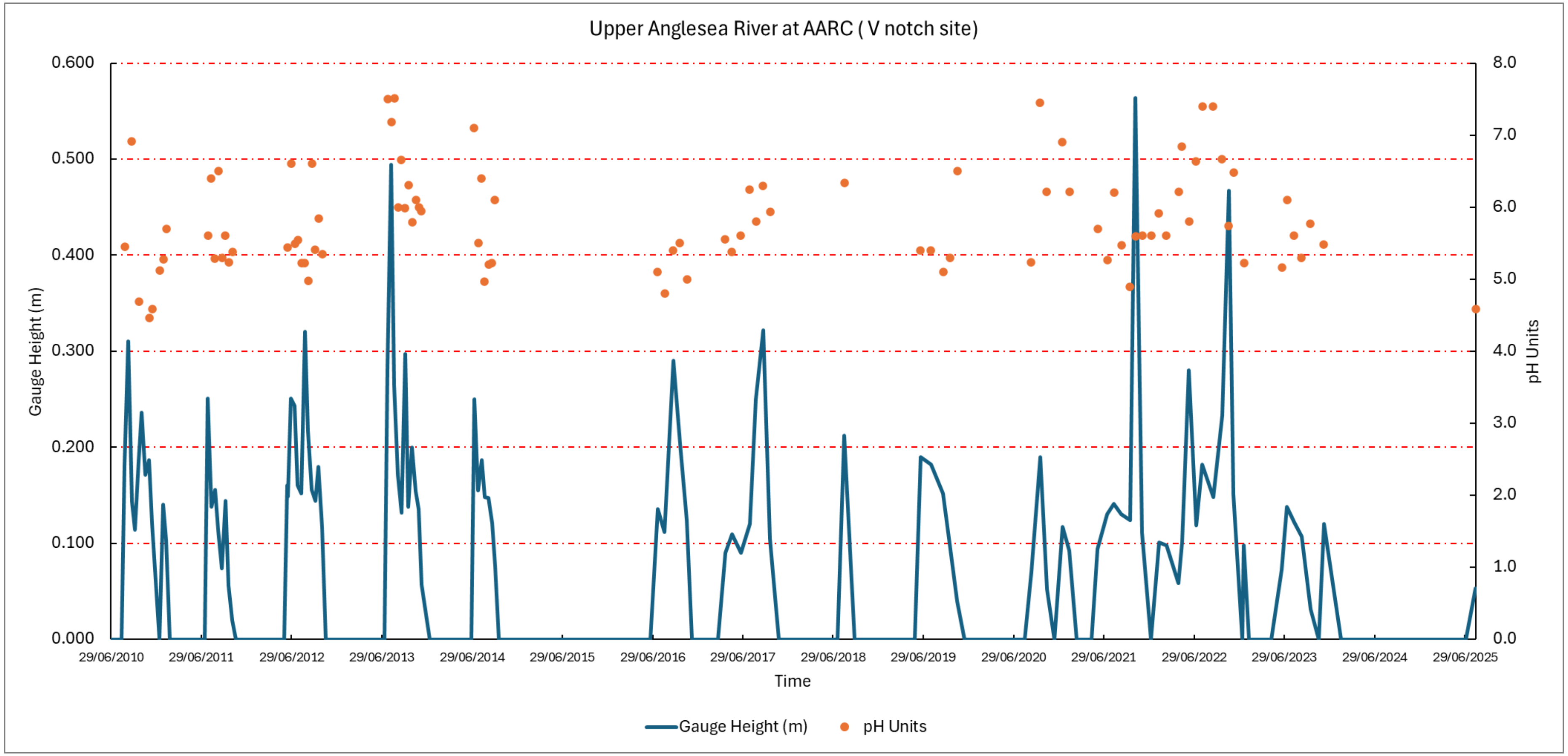


Figure 9. Water availability according to gauge height and pH in the Upper Anglesea River at AARC (V notch site)

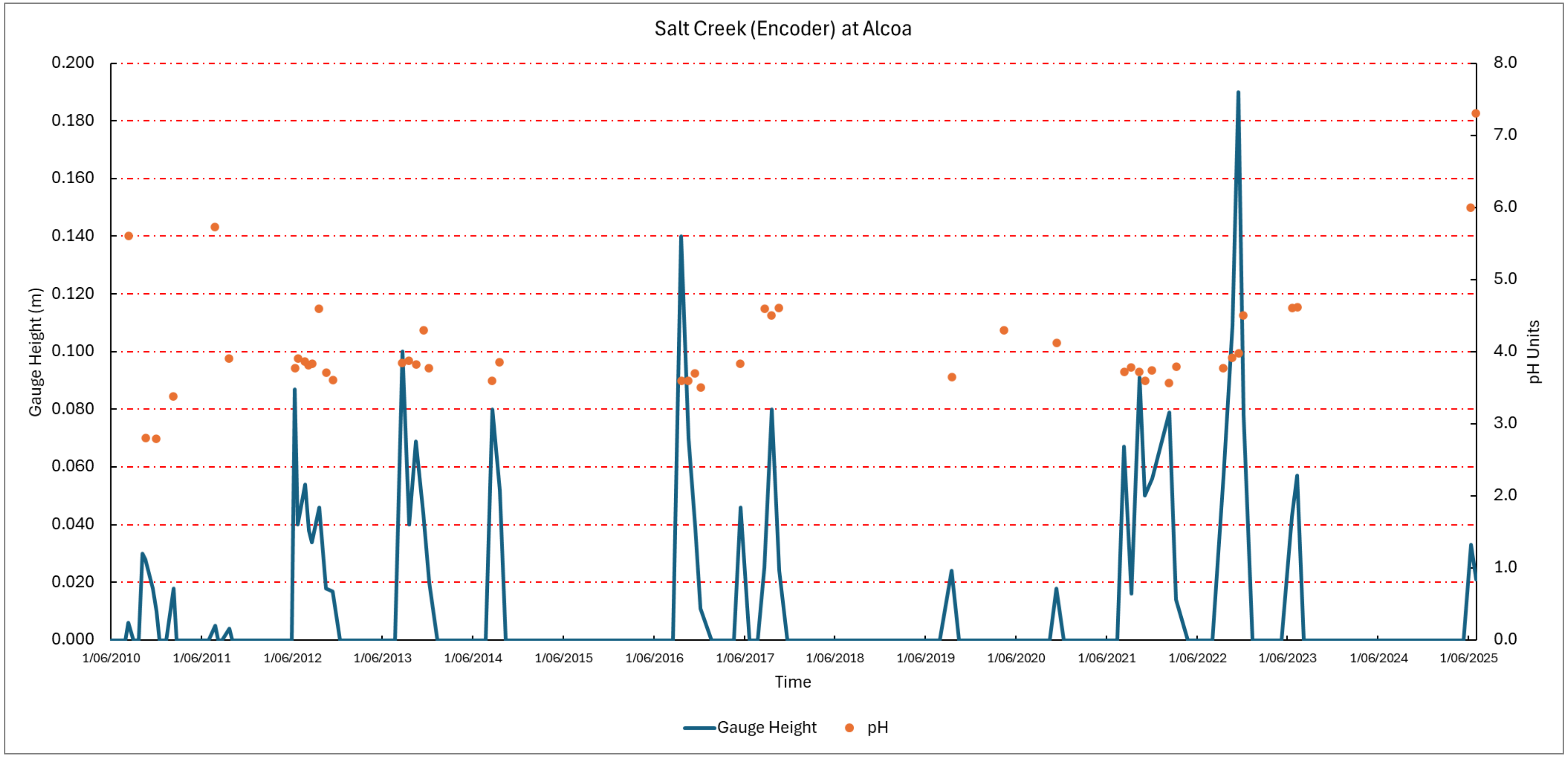


Figure 10. Water availability according to gauge height and pH in Salt Creek (Encoder) at Alcoa site

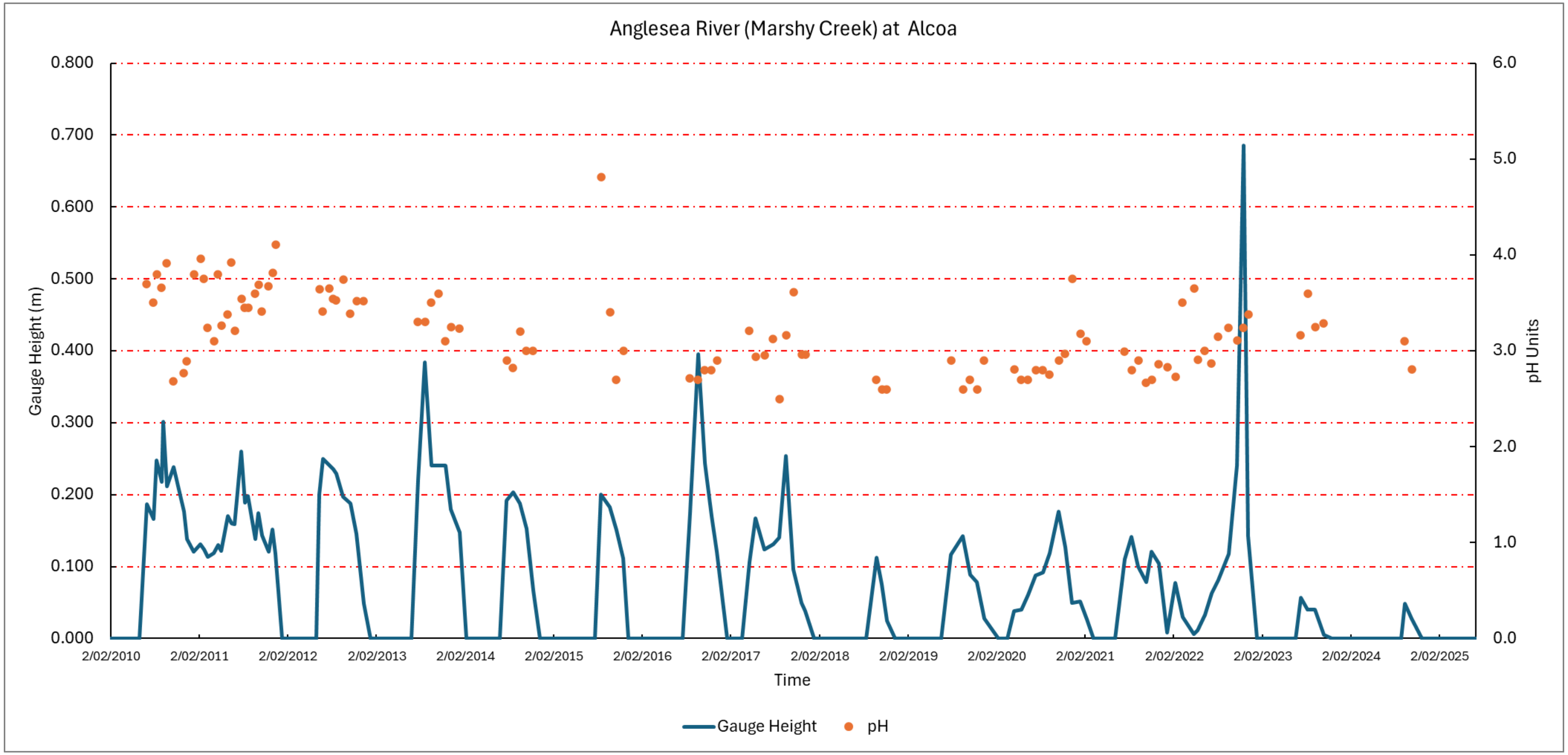


Figure 11. Water availability according to gauge height and pH in the Anglesea River (Marshy Creek) at Alcoa site

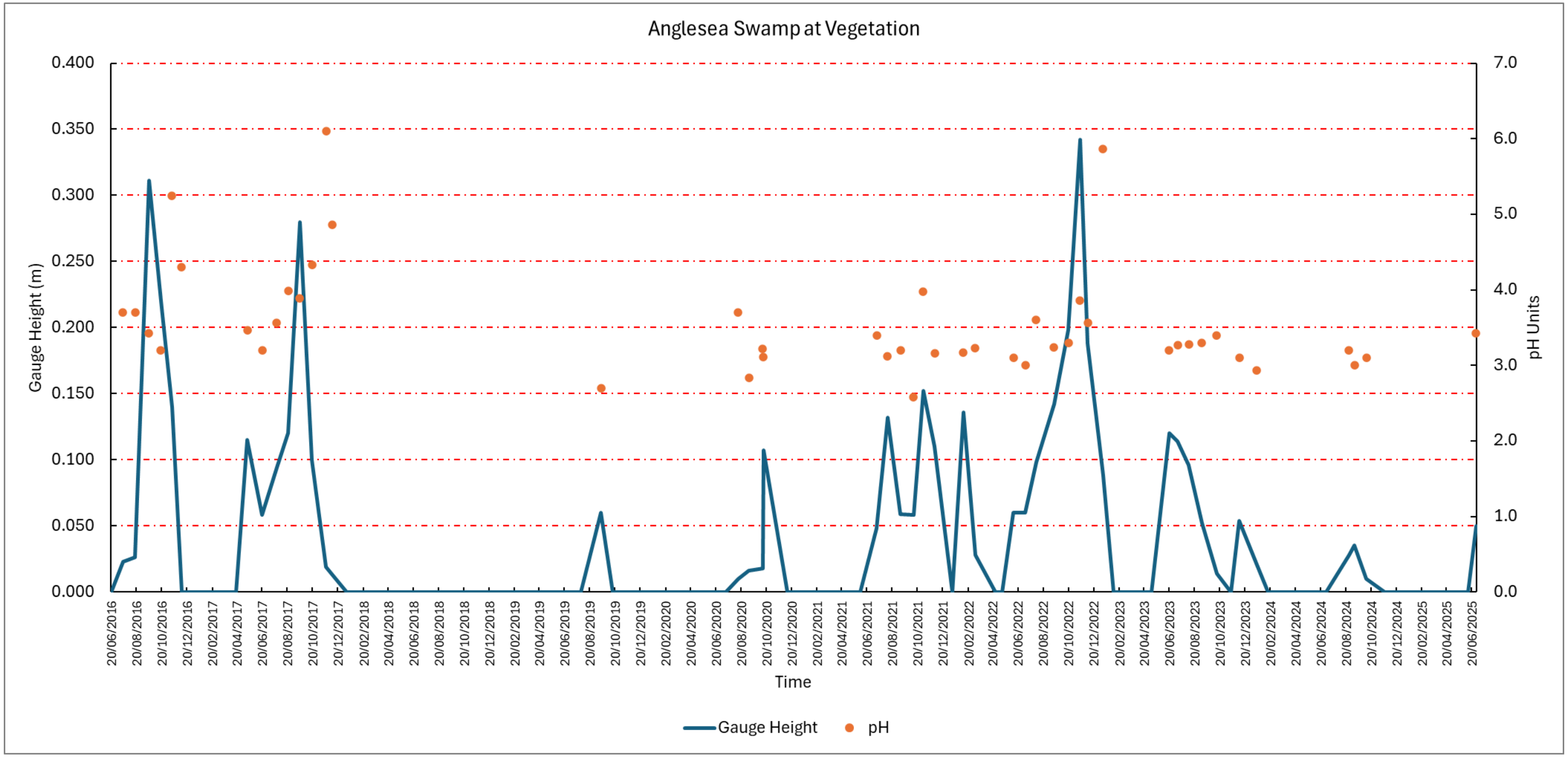


Figure 12. Water availability according to gauge height and pH in the Anglesea Swamp at Vegetation Site

Based on Figures 7 to 12, the pH trend in the freshwater reaches, over a longer time scale, clearly shows a progressive decline in pH from upstream to downstream when the stream is flowing, confirming the spatial propagation of the acid flush through the catchment.

At the upstream sites (Figure 7 – Gum Flats Road and Figure (AV3) 8 – Salt Creek above the swamp (SGP2-A)), pH values were typically around 4.5 - 6.0, indicating mildly acidic but still tolerable conditions for some aquatic life. Moving downstream through the Upper Anglesea River at AARC (AV1) (Figure 9) and Salt Creek at Alcoa (SV2) (Figure 10), pH levels dropped sharply to 3.5–4.0, reflecting the onset of strong acidification linked to acid-sulfate soil mobilisation. The most severe acidity occurred at Marshy Creek (Alcoa AV2) (Figure 11), where pH values fell to 2.9–3.2, identifying this area as a critical hotspot of acid input likely influenced by legacy mine drainage and pyritic soil oxidation. Further downstream in the Anglesea Swamp (ASP7) (Figure 12), acidity remained high (pH ~ 3.0–3.5) but showed slight buffering closer to the estuary outlet (~ 4.0), suggesting limited neutralisation through mixing with tidal waters.

Overall, these figures illustrate a distinct downstream gradient of increasing acidity when the waterway is active, originating near Marshy Creek and propagating through the estuary, resulting in conditions (pH < 4.5) that exceed biological tolerance thresholds for most fish and invertebrates and necessitate public health warnings during acid-flush events.

5. Potential impact of the low pH/high acidity aquatic environment.

Aquatic systems are highly sensitive to pH changes, and conditions within the range of 3–5 can have profound ecological, chemical, and societal consequences (Gensemer & Playle, 1999; Kwong et al., 2014). Acidification directly stresses aquatic organisms, alters biodiversity, and disrupts ecological processes, while also mobilising metals from sediments and water columns (Atkinson et al., 2007; Riba et al., 2003). Estuaries are particularly vulnerable due to the influence of acid sulphate soils and tidal dynamics, which amplify these impacts (Sammut et al., 1996; Tuukkanen et al., 2007).

5.1. Biological effects of high acidity

Aquatic organisms are highly sensitive to departures from circumneutral pH. At levels around 3–5, fundamental physiological processes are disrupted. In fish, acidic water causes pronounced ion regulatory stress at the gills, with sodium and chloride efflux, increased mucous production, and epithelial damage (Kwong et al., 2014). Reduced plasma electrolytes lead to hemoconcentration and impair oxygen uptake, while endocrine stress responses divert energy away from growth and reproduction. Mortality risk is particularly elevated in soft waters with low calcium concentrations, where buffering of gill membranes is absent (Gensemer & Playle, 1999).

Macroinvertebrates also display marked thresholds of tolerance. Taxa richness typically declines below pH 5, with sensitive groups such as Ephemeroptera, Plecoptera, and molluscs disappearing from assemblages (Ganong et al., 2021). Acid-tolerant taxa such as chironomids persist, leading to simplified food webs and altered detrital processing. Amphibian eggs and larvae are particularly vulnerable, with low hatching success and developmental abnormalities under acidic conditions (Horne & Dunson, 1994).

Phytoplankton communities shift as well. Acidic mining lakes and streams exhibit reduced diatom abundance, dominance of acidophilic green algae and cyanobacteria, and lower overall primary productivity (Nixdorf et al., 2003). These shifts cascade upwards, reducing food quality for grazers and altering nutrient cycling. Thus, acidity is a pervasive driver of biodiversity loss and ecological restructuring.

During August 2025 the Anglesea estuary experienced very low pH (to ~3.1) with negligible alkalinity, conditions associated with acute stress to gill-breathing fauna and increased risk when low dissolved oxygen co-occurs (e.g., ventilation and ionoregulatory disruption, reduced survival). Monitoring notes these extremely acidic conditions and severe biological impacts during the event, consistent with experimental and review evidence that hypoxia and acidification together drive sublethal impairment and mortality in fishes (Wang et al., 2023).

5.2. Geochemical and metal mobilisation impacts

Acidification strongly modifies geochemical equilibria. Proton competition for binding sites reduces metal sorption to organic matter and clays, increasing dissolved fractions of Zinc, Copper, Lead, and Cadmium (Riba et al., 2003). Acidic conditions also dissolve Iron and Manganese oxyhydroxides in sediments, releasing previously sequestered metals into porewaters. Experimental studies show that pH decreases to 5 or below can trigger substantial mobilisation of these trace elements, particularly when combined with low redox conditions (Atkinson et al., 2007).

Aluminium dynamics are central. At pH < 5.5, Aluminium speciation shifts toward labile monomeric and polymeric forms that precipitate onto fish gills and disrupt osmoregulation, contributing to mass fish mortality during acid events (Gensemer & Playle, 1999). Dissolved organic carbon can chelate Al and mitigate toxicity, but this depends on dissolved organic carbon concentration and quality.

In estuarine systems, cyclic changes in pH and salinity, mimicking tidal cycles, induce episodic releases of Zinc, Cadmium, Manganese, and Fe from sediments (Hong & Reible, 2014). These transient peaks coincide with low-pH pulses, amplifying ecological exposure. Metal mobilisation thus operates both as a chronic background pressure and as an acute episodic hazard.

Anglesea data show strong acid-sulfate signatures, high sulphate, elevated Iron, and pulses of Aluminium, Manganese and Nickel, indicating acid-driven mobilisation and estuarine mixing effects; this aligns with estuarine geochemical theory where low pH and changing ionic strength shift metal speciation and increase bioavailable fractions (Angel et al., 2015; Mosley & Liss, 2020). Tables 6-8 in the document show rising metals across August (e.g., Al and Ni exceedances), matching these mechanisms, and opening the estuary seems to have no immediate impact on the metal mobilisation as observed in the results.

5.3. Ecosystem-level responses

Beyond individual physiology and metal toxicity, acidification alters whole-ecosystem processes. Acidic conditions reduce invertebrate diversity, simplify trophic interactions, and suppress fish recruitment, shifting energy pathways toward microbial decomposition. Acid-induced mobilisation of Iron and Aluminium also modifies nutrient cycling by co-precipitating phosphorus, reducing primary productivity in lakes and estuaries. In wetlands, acidity slows the decomposition of organic matter, reduces macrophyte growth, and weakens nutrient retention functions, thereby diminishing their buffering role against downstream contamination (Nixdorf et al., 2003).

Sulphur cycling is also reshaped. In acid sulphate soils, sulphide oxidation generates sulfuric acid, driving further acidification. In estuarine sediments, alternating redox conditions govern whether sulphides sequester metals or release them upon oxidation (Jørgensen & Nelson, 2004). These processes highlight the coupling of acidification, nutrient limitation, and contaminant fluxes at the ecosystem scale.

When flushing is weak and acidity persists, estuaries can tip toward degraded states (oxygen stress, altered communities). Regional syntheses from south-eastern Australia show long-term low inflows amplify eutrophication/oxygen stress and heighten susceptibility to metal pulses (Mosley et al., 2023). In Anglesea, managers trialled an artificial mouth opening (20 Aug 2025) to enhance seawater exchange and dilute acidic, metal-rich water, explicitly balancing ecological risks and potential benefits under already poor conditions.

5.4. Estuarine context

Estuaries are particularly vulnerable to acidification. Runoff from acid sulphate soils can reduce pH to 3–5, delivering high loads of Fe, Al, and Mn (Tuukkanen et al., 2007). Such plumes have been linked to widespread fish kills, oyster die-offs, and long-term loss of seagrass habitats (Sammut et al., 1996). Mixing with seawater produces complex chemistry: Dissolved organic carbon flocculation scavenges some metals, while ionic strength enhances desorption of others (Virtasalo et al., 2023).

Field studies confirm pronounced spatial heterogeneity, with dissolved metal peaks tracking tidal mixing and seasonal discharges (Zhang et al., 2019). Climate change compounds risks by intensifying rainfall variability, increasing drought-driven oxidation of acid sulphate soils, and enhancing storm surges that mobilise acidity and metals (Cai, 2023). Estuarine acidification, therefore, represents both a chronic stress and an episodic hazard for ecosystems and human communities.

Estuaries are mixing zones where pH and salinity gradients govern particle aggregation and metal behaviour; the high Na/Cl and hardness seen at Anglesea indicate strong marine influence during the event, which can rapidly redistribute dissolved vs particulate metals (Mosley & Liss, 2020). Such context explains the observed chemistry: acid pulses from the catchment meet saline water, altering speciation and exposure near the plume margins.

6. Management Actions to Minimise the Environmental Impact During Acid Flush Events

Environmental management during an acid-flush event requires a coordinated, catchment-wide approach that recognises the primary role of acid sulfate soil mobilisation in driving rapid declines in river health. Acid flush events, such as the August 2025 episode in the Anglesea

River, occur when previously oxidised acid sulfate soils are rewetted after extended dry periods, mobilising acidity and dissolved metals into waterways (Golab & Indraratna, 2009; Jørgensen & Nelson, 2004). The resulting drop in pH, often to levels below 4, generates highly toxic conditions for aquatic organisms (Gensemer & Playle, 1999) and requires immediate environmental management actions. Under these circumstances, the priority for managers is early detection of declining pH and rapid deployment of mitigation and communication strategies to minimise ecological harm.

The most effective environmental management framework begins upstream, well before acidity reaches the estuary. Real-time monitoring at key tributary junctions such as Salt Creek, Marshy Creek, and Coalmine Road provides the earliest and most reliable indicator of an impending acid flush event (Maher, 2011; GHD, 2021). Continuous monitoring of pH, conductivity, temperature, and turbidity enables managers to identify the leading edge of acidity and initiate preparedness measures while the pulse is still contained in the upper catchment. Because acid flush events evolve rapidly, proactive monitoring tools are essential for reducing response times and guiding interventions (BOM, 2025a; CCMA, 2025).

Once acidity is detected, environmental managers should activate enhanced field assessments, including high-frequency water-quality sampling, dissolved-metal analysis, and ecological inspections. The mobilisation of metals such as aluminium, manganese, and iron is strongly influenced by pH and can reach concentrations acutely toxic to fish and macroinvertebrates (Angel et al., 2015; Atkinson et al., 2007). Visual signs such as orange-brown flocculation, turbidity spikes, and fish lethargy can serve as rapid diagnostic indicators of biological stress (Ganong et al., 2021; Mosley & Liss, 2020). These observations support decision-making regarding whether to initiate public warnings, restrict recreational access, or trigger emergency ecological interventions.

Management responses must also consider the limitations of physical interventions such as estuary openings. While mechanical breaching of sand berms can improve tidal exchange under favourable hydrological conditions, its effectiveness is greatly reduced during low-flow drought-break scenarios (CCMA, 2013; Claringbold, 2025). Without sufficient upstream discharge to maintain breach depth and allow tidal penetration, marine flushing may not occur, and estuary openings may fail to improve water quality. This was evident during the 2025 event, where weak tidal intrusion and rapid channel reshaping prevented meaningful salinity buffering, despite the breach. Therefore, estuary opening should be considered a conditional management tool requiring adequate catchment flows, suitable tidal windows, and prior modelling to predict mixing potential (Cai, 2023).

During the active phase of an acid flush event, managers should prioritise both ecological protection and risk communication. Environmental actions include prioritising sampling zones of ecological sensitivity, assessing fish refugia, and documenting the spatial extent of acidic waters. Where feasible, aeration or localised flushing may be considered in isolated pools to reduce hypoxia; however, these measures have limited effectiveness during large catchment-driven acidity pulses (Mosley et al., 2024). Management should also consider the influence of temperature, residence time, and stratification on acid propagation, particularly in slow-flowing reaches where metal floc can smother benthic habitats (Birch, 2017; Gouraud et al., 2019).

Post-event management is equally critical. Recovery monitoring should continue until pH stabilises above 6, dissolved-metal concentrations decline, and ecological indicators show signs of improvement. Habitat rehabilitation such as re-vegetation, sediment remediation, or targeted oxygenation may be required in severely impacted reaches (Lloyd, 2025). Moreover, lessons learned from each event should inform revisions to the catchment's acid-flush management plan, improving preparedness and resilience for future episodes.

Overall, effective environmental management during an acid-flush event depends on early upstream detection, evidence-based intervention, conditional use of estuary openings, and coordinated ecological monitoring. By basing decision-making on robust hydrological and geochemical understanding and by integrating real-time monitoring with adaptive management frameworks agencies can significantly reduce ecological harm and improve long-term resilience of affected waterways.

7. Discussion

The results of this investigation demonstrate that the 2025 Anglesea River acid flush event was overwhelmingly driven by catchment-scale acid generation, with the Marshy Creek, Anglesea Swamp complex acting as the primary source of acidity. The consistent observation of extremely low pH values (2.8–3.3), elevated metal concentrations, and extensive flocculation within these upstream reaches reflects the hallmark behaviour of acid sulphate soils under drought-break conditions (Golab & Indraratna, 2009; Angel et al., 2015). These findings are consistent with more than a decade of historical monitoring, which identifies the Marshy Creek system as the most chronically acidic component of the catchment (CCMA, 2013; CCMA, 2025). When rewetting occurs, oxidised pyritic materials release sulphate, iron, and acidity, which then mobilise downstream in concentrated pulses, producing the rapid deterioration in water quality observed in August 2025.

The temporal pattern of water-quality decline supports this interpretation. Early August flow events coincided with a sharp drop in pH at upstream locations, followed by declining values through the mid-reaches and estuary. These spatial gradients were consistent across all three August sampling rounds (15, 22, and 29 August) and mirrored historic acidification dynamics documented in past drought-break events (GHD, 2021). The rapid rise in dissolved aluminium, manganese, and nickel concentrations during the same period aligns with the known geochemical interactions that increase metal solubility under low pH conditions (Atkinson et al., 2007; ANZG, 2018). Conductivity, total dissolved solids, and floc formation patterns further confirm the acid-sulphate origin of the event, reinforcing the catchment-based causation rather than any short-term estuarine process.

Ecological conditions recorded during the ARI fish survey on 13th August 2025 serve as biological indicators of the severity of this acidification. Fish displayed signs of stress, including lethargy, poor escape response, and mortality consistent with exposure to high concentrations of dissolved aluminium, which interferes with gill mucus regulation and ion exchange (Gensemer & Playle, 1999). Species presence was extremely low in several reaches, and the absence of macroscale benthic invertebrates suggests acute habitat impairment. These patterns replicate known ecological effects documented in previous Anglesea acid-flush events (CCMA, 2013; EPA Victoria, 2021), underscoring the predictable and recurring nature of these stress responses.

The artificial estuary opening trial offered an opportunity to test the capacity of tidal exchange to buffer acidic inflows during active acidification. However, the results show that the shallow opening did not substantially influence water quality, reflecting well-documented constraints on managed openings during low-flow periods. The opening failed to maintain channel stability, likely due to insufficient river discharge and wave action that quickly reshaped the breach (CCMA, 2013; Claringbold, 2025). The tidal prism was too small to offset upstream inflows, and marine water penetration was minimal. Consequently, water quality parameters, including pH, conductivity, dissolved oxygen, and metals, continued to follow upstream-driven trends with no detectable benefit associated with the intervention.

These findings reinforce the conclusion that estuarine interventions should not be relied upon as primary management tools during severe acid-flush events. Instead, a catchment-first approach is required, focused on real-time monitoring, predictive modelling, and identification of high-risk periods based on rainfall patterns, soil moisture deficits, and groundwater surface water interactions (BOM 2025a; Mosley et al., 2023). Installing continuous pH sensors at Coalmine Road, Salt Creek, and Marshy Creek would provide early detection of acidic flows, enabling agencies to initiate warnings earlier and minimise ecological and public-health impacts. Strengthened cross-agency communication, including integration of monitoring data into shared dashboards, would further support timely decision-making.

Additionally, the recurrence of severe acidification events highlights long-term management challenges. Historical datasets (Part A Section 4.4) illustrate that chronic acidity in Marshy Creek and Anglesea Swamp persists during prolonged dry periods and intensifies with rewetting. This suggests a need for strategic investigations into the underlying hydrology and soil-geochemistry of this reach, including mapping of pyritic soil distributions, modelling of groundwater surface water connectivity, and assessment of legacy mine drainage pathways. Such work would align with recommendations for improving acid-sulphate soil management in Victorian coastal systems (EPA Victoria, 2021).

Overall, the 2025 acid-flush event demonstrates the vulnerability of the Anglesea River system to climate-driven hydrological variability and the limited effectiveness of estuary opening interventions under low-flow conditions. A shift toward catchment based, early warning, and predictive management frameworks supported by real time data, multi-agency coordination, and community risk communication is required to improve future responses and safeguard both ecological and public-health values.

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