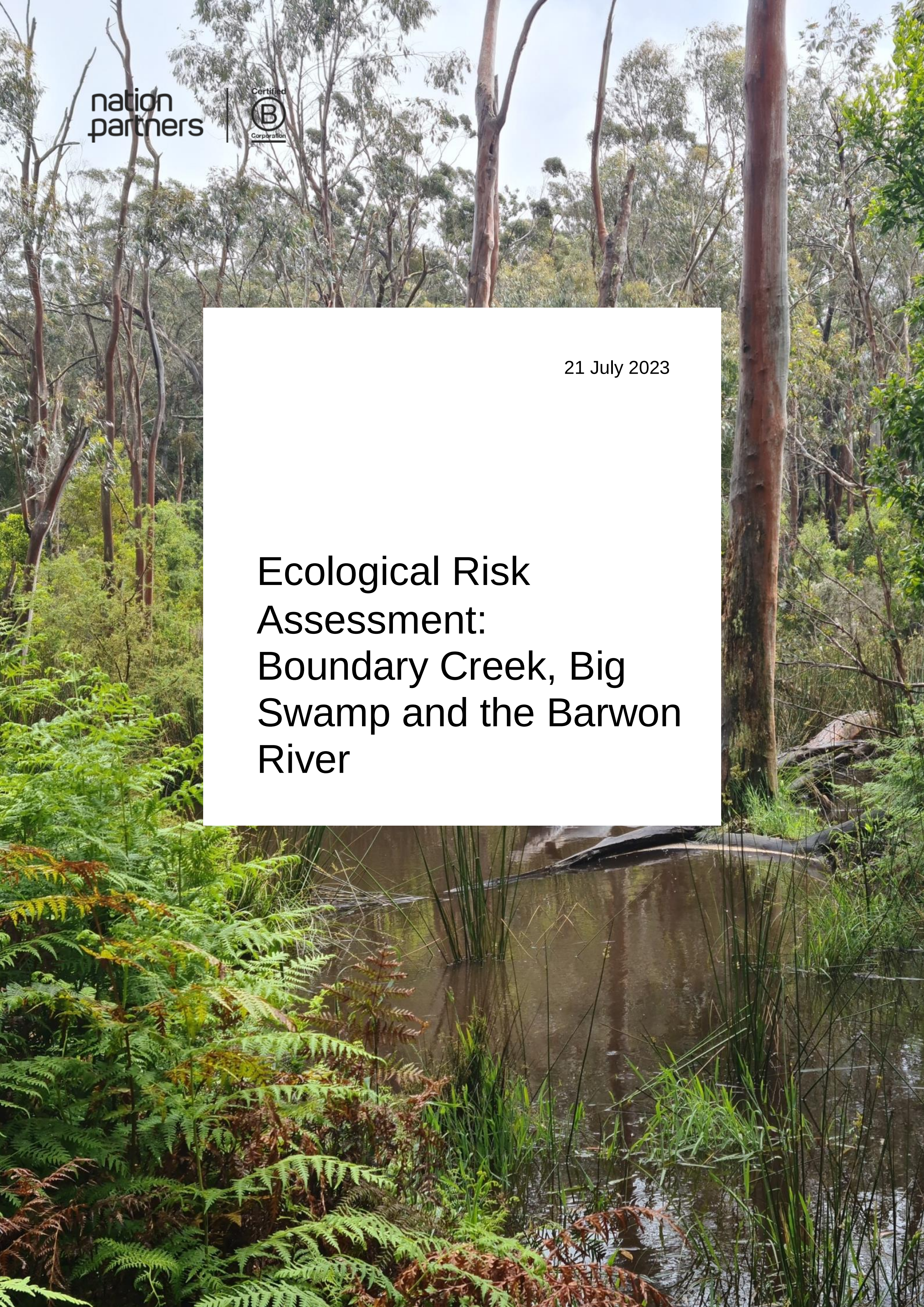

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21 July 2023

Ecological Risk Assessment: Boundary Creek, Big Swamp and the Barwon River

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Ecological Risk Assessment: Boundary Creek, Big Swamp and the Barwon River

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Executive Summary

ES1 Introduction

Nation Partners Pty Ltd (Nation Partners) was engaged by Barwon Region Water Corporation (Barwon Water) to conduct a Level 3 Ecological Risk Assessment (ERA) in accordance with Schedule B5a of the *National Environment Protection (Assessment of Site Contamination) Measure 1999* (ASC NEPM) to evaluate risks to Boundary Creek, Big Swamp and the Barwon River associated with the presence of acidity and heavy metals in water discharging to these waterways.

Big Swamp encompasses approximately 17 hectares within a privately owned portion of Otway Forest Park near the township of Yeodene, approximately 13 kilometres (km) south-east of Colac. Boundary Creek flows from west to east through Big Swamp and then discharges into the Barwon River approximately 3.6 km downstream of the eastern edge of Big Swamp.

The Boundary Creek catchment has undergone significant modification since European colonisation. A timeline of events was developed by Barwon Water which outlines the key changes in the Boundary Creek catchment between European colonisation and 2020 (**Figure E1**). This included intermittent extraction of groundwater from the Barwon Downs borefield from 1982 to 2016 to supplement conventional water supplies during dry periods, in accordance with groundwater extraction licence(s) (Barwon Water, 2023). Within this period, pumping was noted to have primarily been undertaken between 1982-1983, 1987-1990, 1997-2001, 2005-2010 and in 2016.

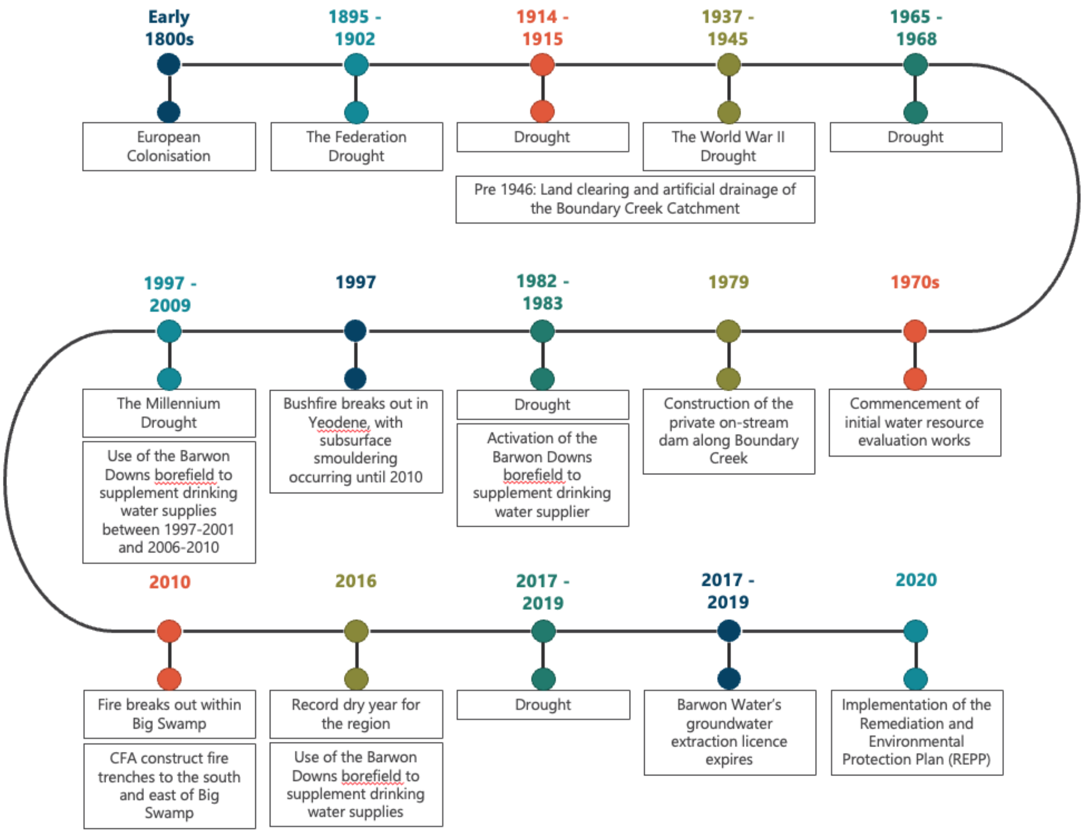

Figure E1: Timeline of Changes to Boundary Creek Catchment since 1979 (Source: Barwon Water)

In June 2017, Barwon Water acknowledged that groundwater pumping had exacerbated the oxidation of naturally occurring acid sulfate soils (ASS) and increased the discharge of acid water to the lower reaches of Boundary Creek (Barwon Water, 2023).

In September 2018, Southern Rural Water (SRW), as a delegate for the Minister for Water, issued a notice to Barwon Water under Section 78 of the Water Act 1989 (the Ministerial Notice). The notice was issued on the basis that the groundwater extraction activity undertaken by Barwon Water '*has caused a measurable negative environmental impact on Boundary Creek, Big Swamp and the surrounding environment and legal enforcement of protective works is required under s78(1).*'

In accordance with the requirements of the Ministerial Notice, Barwon Water undertook a range of environmental investigations to support an improved understanding of the current environmental conditions of Boundary Creek, Big Swamp and the surrounding environments including:

- Hydrogeological investigations – to evaluate conditions in the Lower Tertiary Aquifer (LTA) and assess/model the groundwater surface water interaction at Big Swamp and Boundary Creek;
- Hydrological investigation – including installation of stream gauges within Boundary Creek, Big Swamp and Barwon River to measure surface water flows, water levels and water quality;
- Ecological assessments – to identify groundwater dependent ecosystems, to investigate habitat conditions in Boundary Creek and the Barwon River (macroinvertebrate sampling), and assess vegetation communities in and around Big Swamp;
- Light Detection and Ranging (LIDAR) topographic mapping – to gather information about the ground conditions within Big Swamp and surrounding environments;
- Soil investigations – to assess soil chemistry and peat profile within Big Swamp;

The information gathered to date supported Barwon Water's understanding of the nature of the issue within Boundary Creek and Big Swamp, however the missing element was an understanding of the risks to ecological receptors posed by the presence of acidity and mobilisation of metals in surface waters. Barwon Water therefore commissioned Nation Partners to undertake this ERA to support an improved understanding of the level of risk to ecological receptors and to provide a holistic understanding of the current situation within Boundary Creek and Big Swamp to support future decision-making processes.

In addition to the changes that occurred since European colonisation, the natural occurrence of extended drought conditions, wildfire and flooding will have altered the ecological condition within Big Swamp over time resulting in an ever-shifting landscape. Notwithstanding these disturbances, topographic and hydraulic conditions have supported the ongoing presence of swamp (or wetland) conditions within Big Swamp over time. However, the cumulative effects of these changes have altered the landscape of Big Swamp resulting in the evolved state that Big Swamp is observed to be today.

The recent ecological surveys that have been reviewed to support an understanding of the current biological condition of Boundary Creek, Big Swamp and the Barwon River have consisted of:

- vegetation surveys (Big Swamp only) (ELA, 2020 and ELA, 2023);
- macroinvertebrate surveys (Austral, 2022 and Austral, 2023); and
- a desktop fish survey (conducted by Jacobs 2017).

ES2 Objectives

The objectives of the ERA were to:

- Review the likely condition of Boundary Creek and Big Swamp under natural conditions and confirm how the changes (e.g. drainage works, damming, groundwater pumping and climate etc.) have impacted the ecological condition/function;
- Determine the current ecological values within the lower reaches of Boundary Creek, Big Swamp and the Barwon River immediately upstream and downstream of the confluence with Boundary Creek, and the thresholds that account for the naturally occurring deposits/minerals within the region; and

- Quantify the risks associated with the metals and acidity loads to Big Swamp, Boundary Creek and the Barwon River.

This ERA was undertaken in accordance with the following Australian guidance documents:

- ASC NEPM (NEPC, 2013); and
- *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZG, 2018).

ES3 Methodology

Given the complexity of the environmental condition present within Boundary Creek and Big Swamp, this ERA adopted a multiple lines of evidence approach. To support the risk characterisation the following data was incorporated into the ERA:

- Water quality data collected from stream gauges along Boundary Creek and Barwon River, including pH, metals and discharge volume (measured in megalitres per day);
- Macroinvertebrate data from multiple survey rounds along Boundary Creek and Barwon River, and some data collected from within Big Swamp;
- Vegetation survey data collected within Big Swamp to support an understanding of the function of this area as a 'wetland' or 'swamp'; and
- Groundwater data – the current groundwater level and pH data was used to inform some elements of the ERA.

To support an evaluation of risks associated with the available water quality data, the default guideline values were reviewed and where more recent values were available these were selected as Tier 2 guideline values. The macroinvertebrate data was evaluated against the targets published in the Environment Reference Standard (ERS, 2021). The vegetation survey data was evaluated based on the species recorded to be present and the 'prevalence' of 'swamp' or waterlogging tolerant species (hydrophytic species).

ES4 Risk Characterisation

The presence of naturally occurring ASS underlying Big Swamp suggests that there has always been potential (pre-1979) for natural wet-dry cycling to have resulted in generation of acidic water within the swamp environment and discharge to Boundary Creek. The presence of acidic conditions prior to 1979 has been demonstrated by the palaeoecology study (La Trobe University, 2023) and indicates that conditions within Big Swamp and Boundary Creek have tended to be acidic-circumneutral throughout the history of this environment. Therefore, the stressors that have been noted to be present since 1979 have acted to increase the likelihood of acidic discharges from Big Swamp to Boundary Creek and the Barwon River.

Overall, the lines of evidence available suggest that under current conditions there are measurable impacts to water quality and aquatic receptors (macroinvertebrates) that may be attributable to discharge of acidity and metals from Big Swamp. However, the elevated risk profile for Boundary Creek and Big Swamp cannot be entirely attributed to the groundwater pumping activities within the Barwon Downs borefield. In addition, the elevated water quality risk profile for Boundary Creek is not inferred to be impacting on water quality in the Barwon River. Given the data limitations (Section 7.5) and the presence of a range of ecosystem stressors, it is not possible to uncouple the elevated risk profile associated with drawdown of the LTA from:

- The complexities associated with the management of the private on-stream dam and its effects on streamflow within Boundary Creek;
- The impact of the Millennium Drought on recharge, discharge, evaporation and surface water runoff-routing processes;
- The irreversible changes caused by European colonisation and subsequent drainage of the downstream swamp environment to support agricultural land uses;
- Changes in runoff patterns sediment loading and decreased water quality as a result of changing land uses in the catchment since European colonisation; and

- The ongoing surrounding land uses in the catchment that are contributing to reduced water quality.

ES5 Conclusions

The ERA has considered the available information with regard to ecological condition and water quality to evaluate risks associated with the presence of acidity and metals in surface water in Boundary Creek and the Barwon River sourced from Big Swamp.

Given the dynamic nature of the environment within Big Swamp and Boundary Creek and the range of biotic and abiotic factors that can contribute to changing conditions over time, the ERA used a multiple lines of evidence approach to support an evaluation of risks.

The outcomes of the ERA indicate:

- There are elevated risks associated with the presence of acidity and metals in surface water in Boundary Creek within and below Big Swamp; however, the available data does not indicate that these elevated risks also exist within the Barwon River. The palaeoecology study (La Trobe University, 2023) identified that acidic conditions are likely to have been present within the swamp as a result of the natural processes within this environment, and likely because of the presence of ASS. Therefore, risks associated with acidity and metals are also likely to have been present prior to 1979 that have been exacerbated by the stressors identified in the system post 1979;
- The physico-chemical parameters indicate a high potential for unacceptable risks to Boundary Creek associated with acidity and metals, whilst the macroinvertebrate surveys suggest that there is a moderate to high risk. These findings indicate that the release of acidity and metals from Big Swamp is impacting on the aquatic receptors downstream in Boundary Creek. However, there are other ecosystem stressors identified for the Boundary Creek system would prevent full recovery of the aquatic communities even if adverse impacts to water quality in Boundary Creek from Big Swamp were rectified. In addition, the identification of potential risks needs to also be considered in light of the presence of naturally acidic conditions which were reported by the palaeoecology study (La Trobe University, 2023); and
- A sufficient supply of water is needed to support the ecological value of Big Swamp. The upper groundwater system beneath Big Swamp is likely to have historically supported soil saturation conditions and thus the hydrophytic vegetation in the swamp. The continued recovery of the LTA is important for re-establishing and maintaining groundwater contributions to baseflow in Boundary Creek upstream of Big Swamp. However, if passing flows through the private on-stream dam further upstream are not appropriately managed in the future, and/or where extended drought conditions occur, extended dry conditions in Big Swamp may occur that contribute to a decline in water quality. Upstream surface water regulation and management is therefore an important factor in the ongoing protection of ecological values in Big Swamp.

Overall, these risk outcomes need to be considered in the context of the significant stressors that remain present within the system. The impacts of historical groundwater pumping and aquifer drawdown cannot be uncoupled from the impacts of these other stressors.

Given the irreversible changes in the catchment, and within Big Swamp itself, further work is needed to:

- Conduct additional vegetation and water quality monitoring to support Barwon Water in defining the new ‘natural’ conditions within Big Swamp;
- Define Barwon Water’s role in success given the limited options with regard to management actions (i.e. groundwater extraction from the Barwon Downs borefield has ceased); and
- Evaluate success targets in light of the risk outcomes, with consideration of future climate conditions and potential for identified risks to be present for a considerable time to come.

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1 Introduction

Nation Partners Pty Ltd (Nation Partners) was engaged by Barwon Region Water Corporation (Barwon Water) to conduct a Level 3 Ecological Risk Assessment (ERA) in accordance with Schedule B5a of the *National Environment Protection (Assessment of Site Contamination) Measure 1999* (ASC NEPM; NEPC, 2013) to evaluate risks to Boundary Creek, Big Swamp and the Barwon River associated with the presence of acidity and heavy metals in water discharging to these waterways.

1.1 Background

Big Swamp encompasses approximately 17 hectares within a privately owned portion of Otway Forest Park near the township of Yeodene, approximately 13 kilometres (km) south-east of Colac. Boundary Creek flows from west to east through Big Swamp and then discharges into the Barwon River approximately 3.6 km downstream of the eastern edge of Big Swamp. Boundary Creek and Big Swamp surface water catchments are located within the Gerangamete Groundwater Management Area (GMA).

The Boundary Creek catchment has undergone significant modification since European colonisation, including intermittent extraction of groundwater from the Barwon Downs borefield between 1982 and 2016 to supplement conventional water supplies during dry periods, in accordance with the groundwater extraction licence(s) (Barwon Water, 2020; Barwon Water, 2023). \ Within this period, pumping was noted to have primarily been undertaken between 1982-1983, 1987-1990, 1997-2001, 2005-2010 and in 2016.

In June 2016, local landowners observed the water in the Barwon River downstream of the confluence with Boundary Creek to become abnormally clean and clear. The landowners subsequently observed dead fish and eels to be washing onto the banks of the Barwon River in large numbers. It was suspected that the cause of the fish kill was the release of acidic water from Boundary Creek into the Barwon River.

In June 2017, Barwon Water acknowledged that groundwater extraction from Barwon Downs borefield had contributed to reductions in surface water flows within Boundary Creek and contributed to the drying out of Big Swamp. The drying out of Big Swamp resulted in activation of acid sulfate soils (ASS) and ongoing release of acidic water to the lower reach of Boundary Creek (Barwon Water, 2020; Barwon Water, 2023). In response Barwon Water established a community and stakeholder working group in May 2018 and committed to developing a remediation plan for Boundary Creek and Big Swamp.

In September 2018, Southern Rural Water (SRW), as a delegate for the Minister for Water, issued a notice to Barwon Water under Section 78 of the *Water Act 1989* (the Ministerial Notice). The notice was issued on the basis that the groundwater extraction activity undertaken by Barwon Water '*has caused a measurable negative environmental impact on Boundary Creek, Big Swamp and the surrounding environment and legal enforcement of protective works is required under s78(1).*'

The Ministerial Notice required Barwon Water to:

a) Continue no groundwater extraction, other than for maintenance and emergency response;

b) Prepare a plan for the remediation of Boundary Creek, Big Swamp and the surrounding environment impacted by groundwater pumping at Barwon Downs; and

c) Describe the environmental outcomes for the waterways to be achieved by the remediation plan.

In December 2019, Barwon Water prepared a Remediation and Environmental Protection Plan (REPP) (Barwon Water, 2020) was submitted to address the requirements of the Ministerial Notice and provide an open and transparent form of communication of the remediation intent. The REPP includes eight (8) key principles that underpin the investigation and remediation actions. The key principles are:

1. No further groundwater extraction from the Barwon Downs borefield by Barwon Water;
2. Barwon Water supports the recovery of groundwater levels in the Lower Tertiary Aquifer (LTA), as intended under the current Permissive Consumptive Volume (PCV) set for the Gerangamete and Gellibrand Groundwater Management Areas;

3. Remediation actions which may be required to be carried out by Barwon Water must directly relate to material harm caused by historical groundwater pumping activities by Barwon Water at the Barwon Downs borefield in order to meet the requirements of the s78 notice;
4. Barwon Water highly values its partnerships with Traditional Owners and is committed to working with, and learning from them, to ensure that cultural history and values are considered during the implementation of the REPP;
5. Barwon Water is committed to continuing an open and transparent relationship with the community and stakeholders including local environmental groups during the implementation of the REPP;
6. The Boundary Creek and Big Swamp Remediation Plan will prioritise actions and controls that minimise the need for ongoing active intervention and enable the system and its ecological values to improve progressively over time. This does not preclude the implementation of engineered interventions if they are deemed to be required;
7. The REPP is based on an adaptive management approach, and
8. Barwon Water and Southern Rural Water will both carry out their relevant statutory obligations and regulatory functions to ensure supplementary flows are delivered to Boundary Creek and that these flows are given every opportunity to reach Big Swamp.

In accordance with the requirements of the Ministerial Notice, Barwon Water has completed a range of environmental investigations to support an improved understanding of the current environmental conditions of Boundary Creek, Big Swamp and the surrounding environments. The information and data gathered from these investigations has informed a comprehensive understanding of environmental and ecological conditions at Boundary Creek and Big Swamp. Barwon Water is now seeking to extend this understanding to characterise the risks to ecological receptors posed by the presence of acidity, and corresponding mobilisation of dissolved metals, in surface water at Big Swamp, Boundary Creek and the Barwon River.

Barwon Water has commissioned Nation Partners to undertake this ERA to support an improved understanding of the risks to ecological receptors, and to provide a holistic understanding of the current situation within Boundary Creek and Big Swamp to support future decision-making processes.

1.2 Stakeholders

The ASC NEPM identifies a need to consult with relevant stakeholders to support the problem identification element of the ERA process. As part of its commitment to developing a remediation plan for Boundary Creek and Big Swamp, Barwon Water established a community and stakeholder working group in May 2018. The following key stakeholder groups have provided input into the investigations and remediation planning undertaken at Big Swamp and Boundary Creek to date, and provided input into the development of this ERA:

- Barwon Water (BW);
- Southern Rural Water (SRW);
- Remediation Reference Group (RRG);
- Independent Technical Review Panel (ITRP); and
- Local land owners and community members (mostly as part of either RRG or Southern Rural Water's (SRW's) Community Leaders Group).

1.3 Objectives

The objectives of the ERA were defined by Barwon Water and comprised:

- Review the likely condition of the Boundary Creek and Big Swamp under natural conditions and confirm how the changes (e.g. drainage works, damming, groundwater pumping and climate etc.) have impacted the ecological condition/function;

- Determine the current ecological values within the lower reaches of Boundary Creek, Big Swamp and the Barwon River immediately upstream and downstream of the confluence with Boundary Creek and the thresholds that account for the naturally occurring deposits/minerals within the region; and
- Quantify the risks associated with the metals and acidity loads to Big Swamp, Boundary Creek and the Barwon River.

Barwon Water requested a Level 3 Ecological Risk Assessment in line with Schedule B5a of the ASC NEPM to achieve the above listed objectives. The original ASC NEPM, published in 1999, outlined three (3) tiers of ERA which consisted of the same basic principles but incorporated increasing degrees of complexity and site specificity from Level 1 to Level 3. The current ASC NEPM (as amended in 2013) adjusted the ERA framework to include a Preliminary and Definitive ERA, which merged the previous tiers of ERA into two levels instead of three (3), as described in **Section 1.4**.

1.4 Regulatory Framework and Methodology

This ERA was undertaken in accordance with the following Australian guidance documents:

- ASC NEPM (NEPC, 2013); and
- *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZG, 2018).

Schedule B5a of the ASC NEPM (NEPC, 2013) sets out the recommended framework for conducting an ERA, which is further enhanced by the risk-based hierarchical approach adopted in the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZG, 2018). The framework utilises a tiered approach comprising a Preliminary ERA to allow screening of sites where environmental risks are minimal (equivalent to a Level 1 ERA under the previous ASC NEPM (1999 version, since replaced)), and a Definitive ERA for sites with greater potential risks where more detailed evaluation is required (equivalent to a Level 2 and 3 ERA under the previous ASC NEPM (1999 version)). Both Preliminary and Definitive ERAs consist of the same five (5) basic components, with the primary difference being the type, quantum and level of analysis of site-specific data, and correspondingly greater time and resource commitment required, when undertaking a Definitive ERA.

Table 1.1 summarises the components of the ERA process, along with the data inputs and assessment requirements for both Preliminary and Definitive ERAs, noting that Definitive ERAs are typically required only where contamination is considered to present a risk to ecological receptors. In undertaking this ERA, Nation Partners followed the data inputs and requirements for a Preliminary ERA, while incorporating elements of a Definitive ERA where risks were identified and site-specific data were available. The data inputs and assessment requirements incorporated into this ERA are those elements identified in **bold** in **Table 1.1**. Some elements of the Definitive ERA were not able to be completed due to site-specific information not being available. However, further data collection was not considered to be necessary for this ERA as the available data was considered sufficient to meet the objectives set out by Barwon Water.

Table 1.1: ERA Components and Assessment Methodology (from ASC NEPM (NEPC, 2013))

ERA Component	Data Inputs and Assessment Requirements	
	Preliminary ERA	Definitive ERA
Problem Identification *Purpose:* To establish the objectives, scope and data inputs required, including stakeholder inputs	• **Site history, contamination and environmental (e.g. ecological survey) data** • **Evaluation of quantity and quality of data available for use in the ERA** • **Identification of contaminants of concern (COCs) and corresponding ecological investigation levels (EILs) or default guideline values (DGVs)** • **Development of an ecological conceptual site model (CSM)**	• **Site-specific data addressing data gaps and uncertainties identified in Preliminary ERA** • **Review and refinement of CSM**

ERA Component	Data Inputs and Assessment Requirements	
	Preliminary ERA	Definitive ERA
	• **Identification of data gaps and uncertainties that may require more detailed investigation and/or site-specific assessment**	
Receptor Identification *Purpose:* Identify the ecological species and values that may be at risk and/or require protection, including defining what is considered an acceptable risk	• **Identification of sensitive receptors, habitats and ecological values, typically based on desktop review of habitat and species present or likely to be present**	• **Site-specific investigations of sensitive receptors, habitats and ecological values**
Exposure Assessment *Purpose:* Definition of exposure mechanisms, pathways and factors	• **Determination of potential exposure scenarios and corresponding exposure pathways**	• **Contaminant fate and transport evaluation** • Species specific inhalation, ingestion and absorption rates* • Bioavailability factors* • **Biota data (e.g. macroinvertebrate sampling)** • **Determination of exposure point concentrations and/or intake calculations**
Toxicity Assessment *Purpose:* Determine concentrations of contaminants at which harmful effects are caused, and/or concentrations at which an ecosystem can be exposed with acceptable risk	• **Toxicity data for COCs** • **Identify factors that may influence toxicity (e.g. environmental conditions, contaminant age)** • **Toxicological basis of EILs / DGVs for applicability**	• Site-specific field or laboratory toxicity tests
Risk Characterisation *Purpose:* Determine the risk to ecological receptors based on the exposure and toxicity assessments	• **Evaluate risks to identified receptors through comparison of site contamination data to adopted EILs / DGVs and other lines of evidence** • **Evaluate data uncertainties and assumptions for influence on risk characterisation.**	• **Determination of site-specific EILs / DGVs based on exposure and toxicity assessment outputs** • **Evaluate risks to identified receptors through comparison of site contamination data to site-specific EILs / DGVs and other lines of evidence**

Note: Elements identified in **bold** represent the data inputs and assessment requirements incorporated into this ERA.

* These data types are relevant for terrestrial environments, however have limited application in aquatic and semi-aquatic environments.

1.5 Scope of Work

To achieve the objectives of this project, Nation Partners undertook the following scope of work:

- Attended a project inception meeting;
- Reviewed reports and data provided by Barwon Water;
- Conducted a desktop review of available site-specific information;
- Undertaken a site visit to observe key locations relevant to the ERA;
- Facilitated a workshop with key Barwon Water stakeholders to discuss the findings of the desktop review and align thinking with regard to environmental values;
- Defined the ecological values that were included in the ERA (noting that this step focused on evaluation of current and desired ecosystem conditions to enable agreement on the level of protection applied by the ERA);
- Developed a Preliminary/Definitive ERA in accordance with the ASC NEPM;
- Facilitated a workshop with key Barwon Water stakeholders to discuss the findings of the Definitive ERA; and

- Delivered a Definitive ERA report (this report) that incorporated feedback from Barwon Water and all relevant stakeholder groups.

1.6 Risk Management Decisions

It is not the role of this ERA to determine the most appropriate management options for Big Swamp and Boundary Creek. Risk management is a separate process to risk assessment. The outcomes of this ERA will however inform the risk management decision-making process, by identifying:

- The key risk driving processes present and how these processes contribute to the overall risk profile for the site and surrounding areas; and
- The data gaps, uncertainties and sensitivities inherent in the risk assessment process, which will further inform the decision-making process with regard to the need for management and/or further monitoring.

2 Site Description and Environmental Setting

2.1 Site Features

Boundary Creek is approximately 18 km long and flows from Barongarook to Yeodene where it joins the Barwon River, thus forming part of the Barwon River catchment. Big Swamp forms part of the Boundary Creek watercourse, approximately four (4) km upstream of the confluence of Boundary Creek and the Barwon River, as shown in **Figure 2.1**.

Over the last five (5) years, Boundary Creek and Big Swamp have been the subject of a number environmental of investigations. For the purposes of this ERA, and consistent with these previous investigations, the creek has been divided into reaches based on surface water features, hydrology and operational considerations as shown in **Figure 2.1** (Barwon Water, 2020; Barwon Water, 2023). The reaches are defined as follows:

- Reach 1 is the upper reach of Boundary Creek commencing near the township of Barongarook and flowing east towards a private onstream dam located in Yeodene. Supplementary flows by Barwon Water are released into a small tributary that joins Boundary Creek in Reach 1, upstream of the dam. This reach is further divided into sub-reaches as follows:
  - Reach 1a, represents the section of the creek from Barongarook to ~500m upstream of the private on-stream dam. The Quaternary Sediments within this reach are predominantly underlain by outcropping bedrock comprised of impermeable Paleozoic sandstone, siltstone and mudstone. The Quaternary Sediments within this reach are expected to receive a minor contribution of upward vertical flow from the underlying basement rock; and
  - Reach 1b, represents the section from Reach 1a through to the downstream end of the private on-stream dam. Approximately 50% of this reach has been heavily modified by the construction of the private on-stream dam, with only the upper ~500m stretch being consistent with its historical condition. The Quaternary Sediments within this reach are underlain by the LTA. This reach is within the groundwater recharge zone and is classified as a losing stream;
- Reach 2 flows east south-east from the outlet of the private onstream dam (previously known as McDonalds Dam) to the eastern (downstream) end of Big Swamp. This reach is further subdivided as follows:
  - Reach 2a – a likely artificial channelised section immediately downstream of the private onstream dam;
  - Reach 2b – a densely vegetated and marshy area known as the 'damplands' characterised by highly braided flow pathways and waterlogged conditions; and
  - Reach 2c – corresponding to Big Swamp, a large swamp[1] covering an area of approximately 11 hectares; and
- Reach 3 flows east north-east between the eastern (downstream) end of Big Swamp and the confluence with the Barwon River. This reach is understood to have been modified to support agricultural activity.

This ERA has focused on evaluating risks within Reach 2c and Reach 3.

[1] For the purposes of this ERA, Big Swamp will be referred to as a peat swamp, noting that it also falls within the definition of a wetland. Historical reports have described Big Swamp as a peat swamp with the definition of a peatland or peat swamp being the presence of terrestrial sediments with >20% organic carbon. This ERA does not aim to test the definition of Big Swamp as a peat swamp, as it is outside the scope of work.

2.1.1 Boundary Creek

Boundary Creek rises south of Colac, near Barongarook West, and flows in an easterly direction for approximately 18 km, before joining the Barwon River east of Yeodene (Barwon Water, 2020). The Boundary Creek catchment has been highly modified over the last century which has significantly altered the natural and hydrological flow of the creek (Barwon Water, 2020). Land use changes claimed about 324 hectares (ha) of low-lying land for agricultural production and resulted in the removal of large sections of lowland forest and grassy woodlands.

Figure 2.1: Boundary Creek, Big Swamp and Barwon River Features

Barwon Water - Ecological Risk Assessment Boundary Creek, Big Swamp and the Barwon River

Legend

Stream Gauges
Private Onstream Dam
Big Swamp Boundary

Boundary Creek Reaches
Reach 1
Reach 2a
Reach 2b
Reach 2c
Reach 3

DATA SOURCES
Barwon Water, 2023; Imagery: Google Satellite, 2023

SCALE 1:30,000
250 0 250 500 750 m

nation partners

Much of the lower reach of Boundary Creek was cleared over the past century (some evidence provided by aerial imagery suggests this occurred in approximately the 1940s) to support agriculture and farming practices, changing runoff patterns and therefore streamflow (Barwon Water, 2020). The upper part of the catchment retains a largely unmodified channel structure; however, the lower part of the catchment, near the confluence with Barwon River, has been channelised (Jacobs, 2017). Prior to European colonisation it is likely that the lower part of the creek would have been a broad, undefined marsh that subsequently became channelised in the early years of colonisation to improve drainage to the Barwon River and to open up the area for agricultural development (Jacobs, 2017). Channelisation changed the hydrology of the lower part of Boundary Creek by conveying flows efficiently to the Barwon River and drying the lower Boundary Creek marshland (Jacobs, 2017).

The Boundary Creek catchment has a number of private diverters and farm dams which collect runoff before it reaches the creek. In 1979, a private onstream dam (previously referred to as 'McDonalds Dam') was constructed in the central reach of Boundary Creek, which subsequently altered the downstream hydrology of Boundary Creek. The dam has a storage capacity of 160 ML and has a surface area of approximately 11 ha, which is similar to the total area of Big Swamp, and continues to influence the flows into the lower reaches of Boundary Creek (Barwon Water, 2023).

2.1.2 Big Swamp

Big Swamp is present along Boundary Creek, approximately four (4) km upstream from the confluence of Boundary Creek and the Barwon River (Barwon Water, 2020; Barwon Water, 2023). The swamp covers an area of approximately 11 hectares and is understood to be a groundwater dependent ecosystem that was historically fed by both discharge from underlying groundwater systems and surface inflow from Boundary Creek (Barwon Water, 2023).

The land downstream of the swamp was historically cleared for agriculture, which partially drained the swamp and left the eastern end of the swamp to dry, allowing terrestrial vegetation and trees to establish. **Figure 2.2** is an aerial image from 1946 and shows the drainage channel (highlighted by the red box) which still exists today.

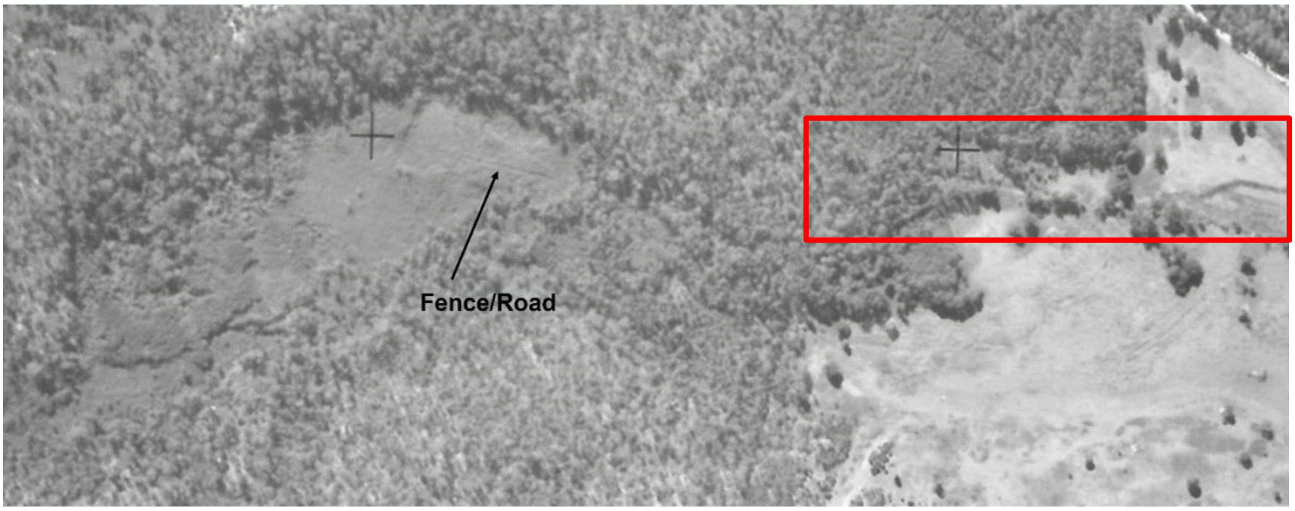

Figure 2.2: Historical Aerial Image of Big Swamp from 1946 (Source: Dr Darren Baldwin pers comms)

To date Big Swamp has been referenced as being a peat swamp; however, the organic carbon content of sediment within Big Swamp does not meet the definition of peatlands[2]. Whilst it is hypothesised that Big Swamp has transitioned to its current state (CDM Smith, 2021), whether or not it was a peat swamp in the

2 Terrestrial sediments in which organic matter exceeds 20% dry weight, and with a depth generally greater than 0.3 m (Glover, 2014)

past matters less than the fact that it is underlain by ASS that are likely to have experienced some wet-dry cycling over time.

To support the understanding of what Big Swamp should look like with regard to its ability to function as a swamp, it is important to define what it means for an environment to be a swamp (or wetland). According to the Department of Climate Change, Energy, the Environment and Water (DCCEEW) wetlands are areas of land where water covers the soil – all year or just at certain times of the year. They include[3]:

- Swamps, marshes
- Billabongs, lakes, lagoons
- Saltmarshes, mudflats
- Mangroves, coral reefs
- Bogs, fens and peatlands

The Victorian Department of Energy, Environment and Climate Action (DEECA, formerly Department of Environment, Land, Water and Planning (DEWLP)) defines wetlands as '*areas, whether natural, modified or artificial, subject to permanent or temporary inundation, that hold static or very slow moving water and develop, or have the potential to develop biota adapted to inundation and the aquatic environment. They may be fresh or saline[4].'*

Internationally, the US Department of Agriculture (USDA) defines a wetland as land that:

1) Has a predominance of hydric (saturated) soils
2) Is inundated or saturated by surface or groundwater at a frequency and duration sufficient to support a prevalence of hydrophytic vegetation typically adapted for life in saturated soil conditions and
3) Under normal circumstances does support a prevalence of such vegetation.[5]

Regardless of the specific definition used for Big Swamp, the key is that this environment is an area of land inundated or saturated by water at least part of the time and has characteristics of both dry land and aquatic environments.

2.2 Environmental Setting

In accordance with the requirements of the Ministerial Notice, Barwon Water has undertaken a range of environmental investigations to support an improved understanding of the current environmental conditions of Boundary Creek, Big Swamp and the surrounding environments. These investigations have included:

- Hydrogeological investigations to evaluate groundwater conditions and assess/model groundwater surface water interactions at Big Swamp and Boundary Creek;
- Hydrological investigation, including installation of stream gauges within Boundary Creek, Big Swamp and Barwon River to measure surface water flows, water levels and water quality;
- Ecological assessments to identify groundwater dependent ecosystems, investigate habitat conditions in Boundary Creek and the Barwon River (macroinvertebrate sampling), and assess vegetation communities in and around Big Swamp;
- Light Detection and Ranging (LIDAR) topographic mapping to characterise ground conditions and topography within Big Swamp and surrounding environments; and
- Soil investigations to assess soil chemistry, ASS and peat profile within Big Swamp.

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3 https://www.dcceew.gov.au/water/wetlands/about

4 https://www.environment.vic.gov.au/__data/assets/pdf_file/0025/91267/Biodiversity-information-explanatory-document-Measuring-value-when-removing-or-.pdf

5 https://www.ers.usda.gov/webdocs/publications/40845/32653_aer765c_002.pdf?v=0#:~:text=Wetland%E2%80%94Land%20that%20(1),normal%20circumstances%20does%20support%20a

The following sections summarise relevant findings and outcomes from these investigations in relation to hydrological and hydrogeological conditions and soil chemistry, specifically in relation to ASS and acidity, at Big Swamp and Boundary Creek. **Section 2.3** summarises historical influences and stressors that have impacted these conditions over time, and **Section 2.4** presents a summary of current ecological conditions.

2.2.1 Hydrology and Hydrogeology

The hydrology and hydrogeology of Big Swamp and Boundary Creek are complex, interconnected systems, and understanding of these systems has evolved as more information has been obtained. The current conceptualisation of hydrological and hydrogeological conditions has been taken from CDM Smith (2022) and is presented in **Figure 2.3**, with key features summarised as follows:

- Reach 1 of Boundary Creek (refer **Figure 2.1**) is characterised by Quaternary-aged alluvial sediments underlain by Paleozoic sandstone, siltstone and mudstone bedrock in the upper section of the creek, and by the Mepunga/Dilwyn Formation, also known as the Lower Tertiary Aquifer (LTA), for the approximately 500 metre (m) stretch preceding the private onstream dam. The alluvial sediments within Reach 2a, downstream of the private onstream dam, are also underlain by the LTA. The lower section of Reach 1 and Reach 2a are both considered losing sections of Boundary Creek, with surface water from the creek and via surface infiltration recharging the underlying LTA.
- The Quaternary-aged alluvial sediments within Reach 2b of Boundary Creek, the damplands section immediately upstream of Big Swamp, are also underlain and surrounded by the LTA. The marshy, waterlogged conditions along this section indicate it was likely a gaining stream, with groundwater discharge from the underlying LTA contributing to creek baseflow.
- Big Swamp (Reach 2c) occupies a narrow valley containing the same shallow, Quaternary-aged alluvial sediments associated with Boundary Creek. The thickness of alluvial sediments has been inferred to increase along the course of Boundary Creek from less than 8 m at the private onstream dam to around 14 m at the lower end of Big Swamp (GHD, 2021).
- Sediments within Big Swamp are underlain by older strata comprising the Gellibrand Marl (an Upper Middle Tertiary Aquitard), the Narrawaturk Marl (Lower Middle Tertiary Aquitard) and the LTA (GHD, 2021). The alluvial sediments and Gellibrand Marl comprise the “upper groundwater flow system”, and the Narrawaturk Marl, which acts as a regional confining layer, separates and limits connectivity between the upper groundwater flow system and the underlying LTA at and downstream of Big Swamp.
- Groundwater levels indicate an upward hydraulic gradient between the LTA and the overlying upper groundwater flow system, however hydrographs for the upper system indicate that upward vertical leakage from the LTA is limited by the interceding confining layer. Based on this conceptualisation impacts from changes to groundwater levels / pressures in the partially confined LTA, such as from historical pumping from the Barwon Downs borefield, on Boundary Creek were likely restricted to reductions in baseflow upstream of Big Swamp along Reach 2b.
- Changes in groundwater levels in Big Swamp’s upper groundwater flow system are closely linked to the stream flow in Boundary Creek, with rapid rises in swamp groundwater level corresponding with increases in stream flow (GHD, 2021; CDM Smith, 2021). The minimal lag time in groundwater response indicates a small unsaturated zone preceding the flow events (GHD, 2021).
- Within Big Swamp groundwater-surface water interaction with the upper groundwater flow system varies seasonally and results in both groundwater recharge and groundwater discharge. In the western portion of Big Swamp groundwater in the swamp sediments is deeper, and the creek is likely to be losing most of the time. In the eastern portion of Big Swamp sediments are typically fully saturated and discharge to the creek. Although the creek is net losing through this reach, there is a component of baseflow from the swamp sediments to the creek.

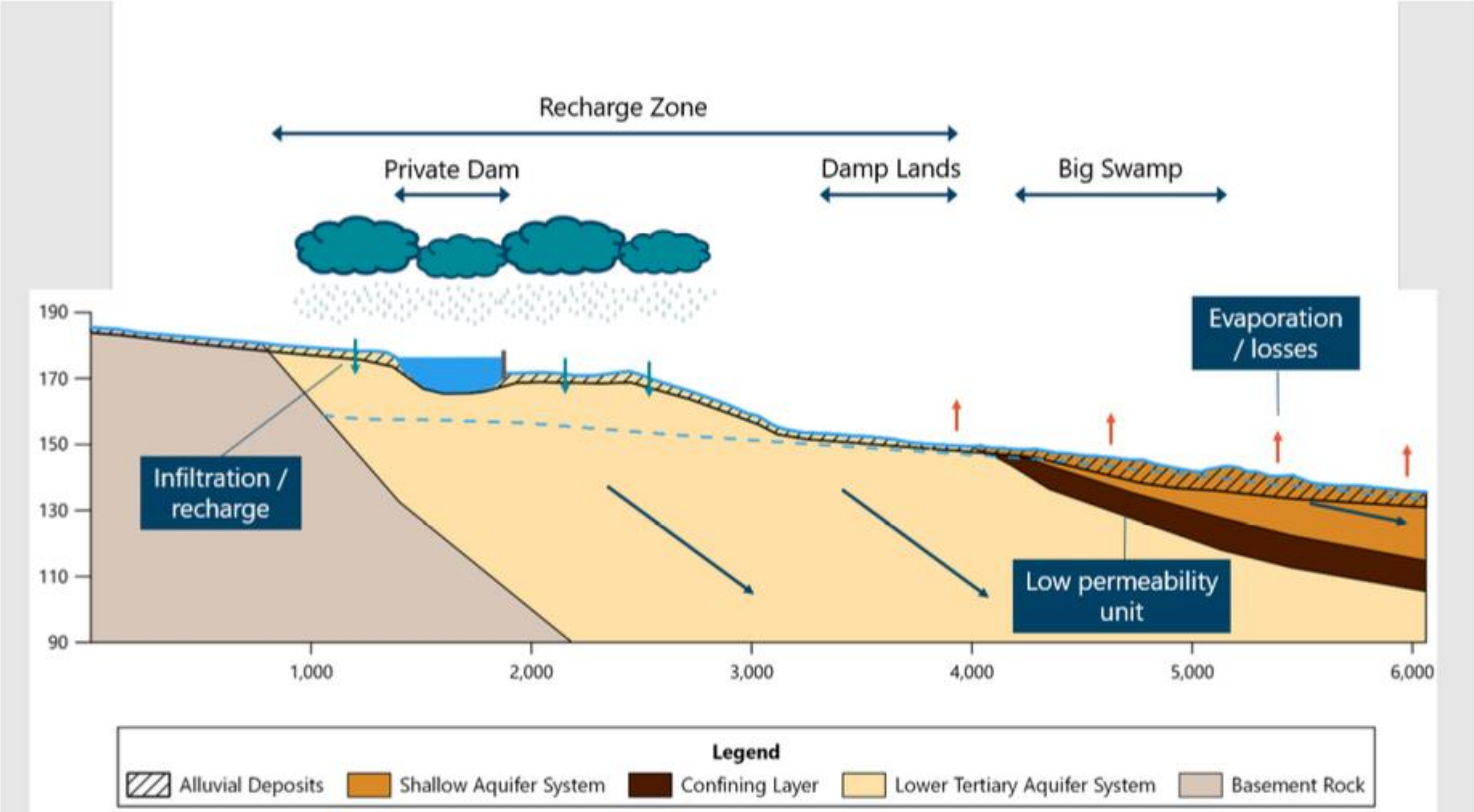

Figure 2.3: Hydrogeological Conceptualisation of Boundary Creek and Big Swamp (Barwon Water (as published in the CDM Smith (2022) report)

2.2.2 Swamp Soil Conditions

Acid Sulfate Soils and Soil Acidity

At Big Swamp the local topography and perched nature of the upper groundwater flow system resulted in the saturation of alluvial sediments and associated humic rich substrates (ELA, 2019), leading to the formation of actual and potential ASS. Soil samples collected by both Jacobs (2018) and Cook and Wong (2020) identified the presence of ASS to occur variably in surface sediments across the swamp plain, with stored potential acidity present in deeper sediments in the form of reduced sulfides. The highest concentrations of net and potential acidity were recorded in the central and lower lying areas of Big Swamp (Jacobs, 2018).

The ASS study conducted by Cook and Wong (2020) identified that Big Swamp contains significant quantity of net acidity (greater than 10,000 mol H+ / tonne) heterogeneously deposited throughout the swamp, making it difficult to target and treat (neutralise) ASS hot spots. To date a small percentage of this material has been oxidised to release actual acidity in the upper two (2) m of swamp sediments, though further drying of the swamp would substantially increase the generation and release of acidity upon re-wetting. Based on their findings Cook and Wong (2020) recommended that Big Swamp be maintained in a saturated state indefinitely, and that exposure and release underlying groundwater be minimised, to prevent further release of stored net acidity.

Given the presence of ASS and the potential for natural wet-dry cycling to have resulted in oxidation of sediments in some portions of the swamp over time, it is likely that Big Swamp is a naturally acidic environment that contains ecological communities adapted to such conditions. Whilst no historical data is available to support this hypothesis, it is supported by the preliminary results of a diatom assessment undertaken by Dr Peter Gell (La Trobe University, 2023):

> '*Broadly, the diatom assemblages reflect persistent acidic-circumneutral conditions likely driven by organic acids derived from the swamp vegetation*.'
>
> '*Acid conditions have prevailed at Big Swamp for some time and there is no evidence that recent water management has exacerbated water acidity. There were only single counts of planktonic species suggesting that Big Swamp has never sustained deep waters. Also, there were few aerophilous species or indicators of saline waters suggesting that the site has not dried appreciably in the past. The most likely cause of the diatom shifts recorded are small increases in nutrient and sediment loads on account of the clearance and farming of the upper catchment*.' (La Trobe University, 2023).

Swamps and Peatlands

Freshwater peatlands or peat swamps are defined as organic wetlands characterised by a living plant layer and thick accumulations of organic material, in which waterlogged conditions prevent plant material from fully decomposing. Consequently, the organic production is in excess of decomposition (Warburton et al., 2004, Grover et al., 2005, Glover, 2014). The anaerobic conditions provided by the permanent waterlogging along with the presence of both organic and inorganic sulfur provide ideal environments for the accumulation of iron sulfides and the formation of acid sulfate soils. Organic sulfur comes from decomposing plant material and inorganic sulfur is provided from a range of sources including by rainfall, surface water or groundwater (Warburton et al., 2004, Grover et al., 2005, Glover, 2014).

Peat is defined as a biogenic deposit that consists of partially decomposed organic matter, derived mostly from plant matter, that has accumulated under saturated conditions and oxygen deficiency. Saturated peat consists of about 90-95% water and 5-10% solid material. Water is an important factor to the natural processes which control how peatlands function, particularly changes in the composition of the soil or sediment (Warburton et al., 2004, Grover et al., 2005, Glover, 2014).

Swamp Formation in the Barwon River System

Boundary Creek drains the northern slopes of the Otway Ranges before flowing into the West Barwon. To the north of the creek, basaltic lavas of the Newer Volcanics erupted around 2.31 Ma and infilled the lowest points of the topography and dammed the Barwon River, allowing the formation of extensive swamps upstream. The present course of the river has diverted along the edge of the basalt flows. The many swamps and wetlands throughout the Barwon River catchment were mostly drained for agriculture by the artificial deepening of the stream channels in the early 1900s. Big Swamp is one of the few remaining swamps.

Buckley Swamp in the Glenelg-Hopkins region formed in a similar manner to Big Swamp, as it consists of a valley infilled by an earlier lava flow, with the blockage of the drainage line resulting in peat accumulation. The area has been drained and burnt at various times in the past, resulting in some decomposition and loss of peat. The key profile features are strongly acidic topsoil (0-60 cm, loam/peat, pH ~5.5) and strongly acidic subsoil (60-90 cm, light clay, pH 5.1)[6].

General Acidity of Peat Swamps

Studies conducted on peat swamps across Australia and New Zealand are summarised in Table A. The acidity levels depend on the type of swamp, i.e., bog or fen. Bogs are considered to be more acid and nutrient poor while fens are mildly acidic and contain mineral matter that provide better nutrients. Bogs and fens rely on groundwater baseflows and are sensitive to changes to groundwater flows or discharge[7]. Table A indicates that peatlands are typically acidic, with Buckley Swamp being the best indicator of what the expected pH would be for Big Swamp.

Table 2.1: pH ranges of some swamps in South-Eastern Australia and New Zealand

Site and Location	Classification	pH range reported in study	Reference
The Snowy Mountains, NSW	Mire (equivalent to peatland)	4.5 – 6.5	Peat-forming bogs and fens of the Snowy Mountains of NSW: Technical Report, 2012, pg. 40 www.environment.nsw.gov.au/-/media/OEH/Corporate-Site/Documents/Parks-reserves-and-protected-areas/Types-of-protected-areas/peat-forming-bogs-and-fens-snowy-mountains-technical-report-120257.pdf
Bogong High Plains, VIC	Alpine peatland	4.2 - 6.3 for "good wetlands" 4.7 - 6.7 for "poor wetlands"	NESP Threatened Species Recovery Hub, 2021, Characterising alpine peatland water quality on the Bogong High Plains, Victoria, Project 1.2.3 Research findings factsheet. www.nespthreatenedspecies.edu.au/media/12jlnkmn/1-2-3-characterising-alpine-peatland-water-quality-on-the-bogong-high-plains-victoria-ff_v5.pdf
The Wellington Plains Bog, South Gippsland Alps, VIC	Bog	3.76 – 4.77	Chemical characterisation of bog peat and dried peat of the Australian Alps, 2005, Grover et al., *Australian Journal of Soil Research* 43(8) 963-971 www.publish.csiro.au/sr/sr04014
Woronora Plateau, NSW	Upland swamp (eq. to peatland)	3.8 – 4.4	Floristics and soil relations of upland swamp vegetation near Sydney, 1993, Keith, D.A.; Myerscough, P.J., *Australian Journal of Ecology* onlinelibrary.wiley.com/doi/abs/10.1111/j.1442-9993.1993.tb00460.x
Buckley Swamp, Glenelg-Hopkins, VIC	Peatland	5.1-5.5	Victorian Resources Online, Glenelg-Hopkins vro.agriculture.vic.gov.au/dpi/vro/glenregn.nsf/pages/glenelg_soil_mm726
New Zealand	Swamps	4.8 – 6.3	The Peatlands of the Australasian Region, 2005, Whinam, J., and Hope, G., *Stapfia* https://www.researchgate.net/publication/259800339_The_Peatlands_of_the_Australasian_Region

6 https://vro.agriculture.vic.gov.au/dpi/vro/glenregn.nsf/pages/glenelg_soil_mm726

7 https://www.dcceew.gov.au/sites/default/files/documents/draft-recovery-plan-alpine-sphagnum-bogs.pdf

2.3 Historical Environmental Stressors

The Boundary Creek catchment has been highly modified since European colonisation, with some changes to the catchment resulting in permanent and irreversible alterations to the natural hydrological flow regime of Boundary Creek (Jacobs, 2018; ELA, 2020). These changes include:

- Land clearing and construction of drainage lines across the catchment to facilitate agriculture in the early 1900s;
- Construction of the private onstream dam in 1979 which has a licence to extract 160 ML/year;
- Other private diversions and farm dams that have been installed along the length of Boundary Creek;
- Groundwater extraction from the Barwon Downs borefield; and
- Extended drought conditions, including the Millennium Drought that contributed to the drying of Big Swamp and subsequent fires.

Figure 2.4 shows a timeline of events developed by Barwon Water which outlines the key changes in the Boundary Creek catchment between 1979 and 2017, and the following sections summarise impacts from changes to hydrological and natural conditions.

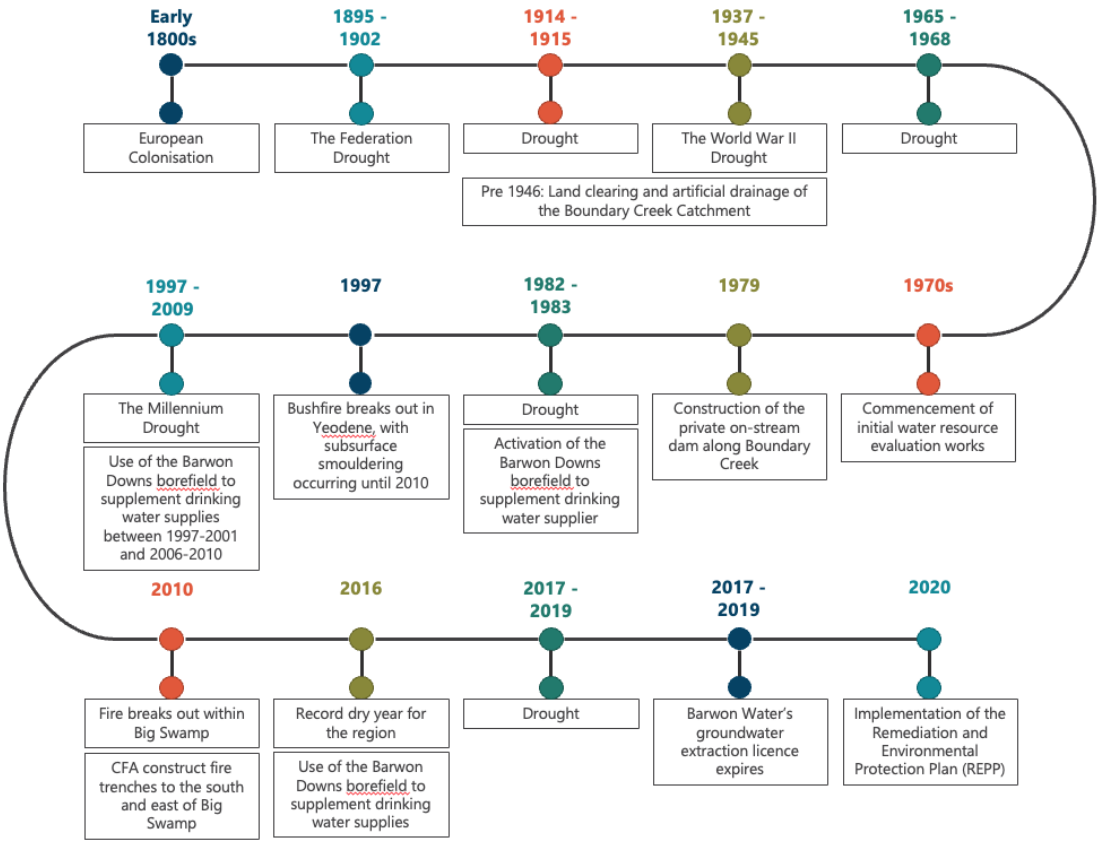

Figure 2.4: Timeline of Changes to Boundary Creek Catchment since 1979 (Source: Barwon Water)

2.3.1 Hydrological Changes

In 1979, a stream gauge (number 233228) was installed to monitor flows and water quality in Boundary Creek downstream of Big Swamp following the installation of the private onstream dam upstream of Big Swamp. In 1990, Boundary Creek was reported to have no flows for the first time since the stream gauge was installed. Between 1998 and 2016, Boundary Creek (at stream gauge 233228) was reported to have cease to flow events each year.

Barwon Water extracted groundwater from the Barwon Downs borefield intermittently from 1983 to 2016 to supplement urban water supplies during dry periods (Barwon Water, 2020). Approximately 119,000 ML in total was extracted over the 30+ year period in accordance with groundwater extraction licence (Barwon Water, 2020). The Barwon Downs borefield is located south of the confluence between Boundary Creek and the Barwon River, and its extraction bores target the LTA.

Groundwater extraction from the Barwon Downs borefield led to a decrease in groundwater pressure in the confined section, beneath the Narrawaturk Marl underlying Big Swamp, and groundwater levels in the unconfined section (the recharge zone shown in **Figure 2.3**) of the LTA. This reduction in groundwater levels led to a decrease in baseflow contributions from the LTA to Boundary Creek along Reach 2b, upstream of Big Swamp.

In 2004, the groundwater extraction licence was amended to include environmental provisions, including a requirement for Barwon Water to release two (2) ML/day of supplementary flows to Boundary Creek under certain conditions during groundwater extraction periods (Barwon Water, 2023). The intent of this provision was to offset the loss of baseflow to Boundary Creek as a result of extraction from the LTA. In compliance with this condition Barwon Water released two (2) ML/day of supplementary flows (under certain conditions) to Boundary Creek upstream of the private onstream dam. However, due to complexities associated with the management and regulation of the dam and a range of other contributing factors, the supplementary flows were identified to be insufficient to offset the baseflow reductions in Boundary Creek downstream of the private on-stream dam (Barwon Water, 2023). Following expiry of the groundwater extraction licence, Barwon Water continued to release supplementary flows (where required) to maintain a minimum flow of 2 ML/Day into Reach 2 of Boundary Creek (Barwon Water, 2023).

These complexities were highlighted in the hydrogeological assessment undertaken by BlueSphere (2023). Bluesphere (2023) identified that after 2009 the 10th percentile of mean daily flow (also referred to as the Q90) recorded at gauges 233231 and 233229 (upstream and downstream of the private onstream dam, respectively, as shown in **Figure 2.1**) was higher than prior to 1997, likely due to the influence of supplementary flows released by Barwon Water to Boundary Creek. However, the influence of supplementary flows was only partly evident in Q90 data recorded at gauge 233228 at the bottom end of the Boundary Creek catchment at gauge 233228. The data indicate that since 2009 Q90 has reduced from 1.95 ML/day to 0.97 ML/day, a reduction of ~50%. By comparison, prior to groundwater extraction (and supplementary flows) a 65% reduction in Q90 streamflow was evident downstream of the private onstream dam; supplementary flows have therefore increased the proportion that is evident downstream of the dam by ~15% compared to prior to supplementary flows. This indicates that supplementary flows released up-stream are either captured by the private onstream dam or presumably are lost to either evaporation or infiltration/recharge. This highlights the complexities associated with the management and regulation of the dam.

A combination of decreases in baseflow to Boundary Creek due to groundwater extraction, the complexities associated with regulation of passing flow conditions through the private on-stream dam, and naturally occurring climatic conditions (refer **Section 2.3.2**), led to a lowering of groundwater levels within the upper groundwater flow system at Big Swamp. The decrease in groundwater levels and reduced surface water flows in Boundary Creek resulted in more frequent dry periods within Big Swamp, exposing actual and potential ASS to a depth of two (2) m, and consequently releasing acidic (low pH) surface water and corresponding elevated dissolved metal concentrations into Boundary Creek (Barwon Water, 2020). Downstream the Barwon River, which is recognised as a major asset that requires protection, has also been impacted from acidic discharge from the swamp, which was suspected to be the cause of the fish kill observed in the Barwon River in June 2016 (Barwon Water, 2020).

A fire was reported in the swamp on October 10, 1997, with an area of approximately one hectare of the swamp involved in wildfire (Country Fire Authority, 2010). The swamp continued to smoulder subsurface until it ignited in 2010, when fire once again broke out in Big Swamp and burnt an area of approximately 80 hectares to the north of Boundary Creek (Barwon Water, 2023). The latter fire resulted in an almost complete loss of vegetation cover across the swamp, significantly altering the structure of the vegetation communities

(ELA, 2022). As a prevention measure against further ignition of peat deposits, a one (1) km long trench, up to three (3) m deep, was excavated in 2010 along the southern boundary of the swamp (Barwon Water, 2023). **Figure 2.5** shows the changes in vegetation condition over time following the fires in 2010.

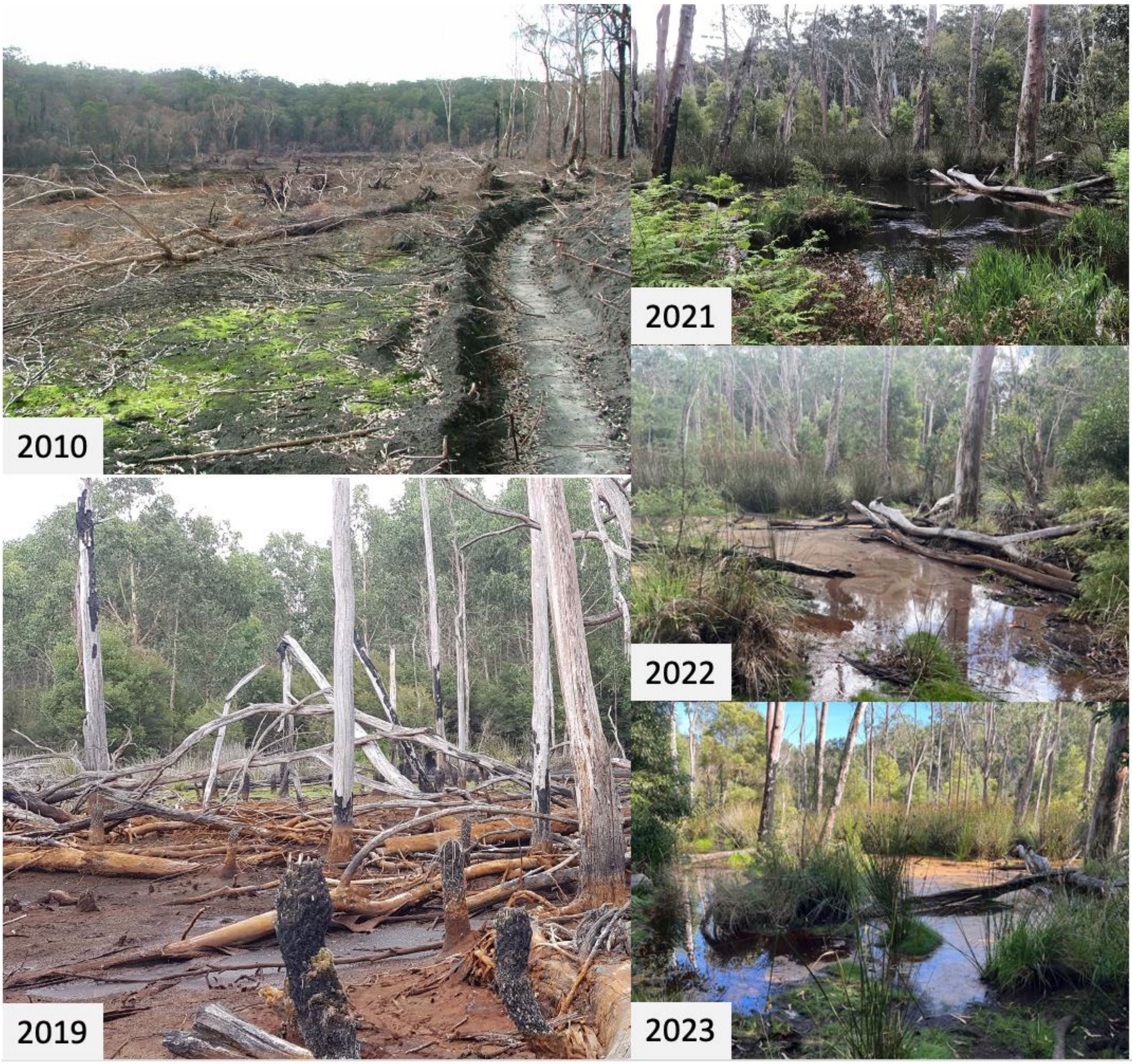

Figure 2.5: Changes in Big Swamp Vegetation Condition Over Time (Source: Barwon Water pers coms)

The palaeoecology study (La Trobe University, 2023) identified a long history of fire in the region dating back to pre-European colonisation. The drying of Big Swamp during the Millennium Drought resulted in increased susceptibility to fire, however the charcoal evaluation undertaken during the palaeoecology study identified a similar fire event is likely to have occurred within the swamp environment pre-European colonisation (La Trobe University, 2023).

2.3.2 Drought Conditions

Whilst the drawdown of the LTA as a result of groundwater extraction is likely to have exacerbated the drying out of Big Swamp and contributed to the oxidation of ASS, the activity cannot be uncoupled from the extreme drought conditions experienced during the Millennium Drought (between 1997 and 2009[8]). In addition, Australia has a long history of drought with extended dry periods recorded on a national scale over several time periods since weather records began. **Table 2.2** provides a summary of significant drought events that have occurred since the Federation Drought (1895 – 1902) until the Millennium Drought and the potential for drying, and consequent oxidation of ASS, to have occurred at Big Swamp. **Figure 2.6** shows the recorded extent of the Black Friday bushfires that extended into the Big Swamp area.

Table 2.2: Summary of Key Droughts in Australia History and Implications for Big Swamp

Date Range	Description	Implications for Big Swamp
1895 - 1902	**Federation Drought:** The Federation drought was one of Australia's worst droughts. It began in the mid-1890s with the most extreme conditions recorded in late 1901 and 1902.	Given the duration of drought conditions there is potential for drought conditions to have resulted in drying out of Big Swamp.
1937 - 1945	**World War II Drought:** The drought conditions during this event were not as continuous as the Federation Drought. However the BOM has described this drought as having more periods of intense dryness. Conditions deteriorated in 1937 over NSW, Victoria, most of QLD and parts of WA. In Victoria, extreme dry weather between August 1938 and January 1939 lead to the Black Friday bushfires. By April 1945, most of Victoria's water storages were empty, and the Murray River was recorded to have stopped flowing at Echuca.	The Black Friday bushfires were recorded to have passed across the Big Swamp area (**Figure 2.6**). Therefore it is considered likely that the vegetation in Big Swamp was burned at that time. Given the extended duration of this drought it is possible that the extreme dry may have resulted in drying out of Big Swamp and thus potential for oxidation of ASS.
1982 - 1983	This drought resulted from a very strong El Nino weather event. The extremely low rainfall resulted in a Total Fire Ban being declared on 24 November 1982, which is the earliest a Total Fire Ban had been implemented since approx. 1942. During this drought the upper Murrumbidgee River had ceased to flow and by the end of 1982 water storage reservoirs were extremely low. The Ash Wednesday fires began in Victoria on 16 February 1983 and burned for most of the month.	The recorded extent of the Otways portion of the Ash Wednesday fires is not inferred to have extended into the Big Swamp area. However given the severity of the drought conditions, there is potential for surface soils within Big Swamp to have dried out at the peak of the drought.
1997 - 2009	**Millennium Drought:** Conditions in the densely populated southeast and southwest portions of Australia were highly impacted by drought conditions. The Millennium Drought was considered by BOM to be the first major Australian drought that interacted significantly with influences of climate change. This resulted in much hotter recorded temperatures than during other droughts, with annual average temperatures in the Murray-Darling Basin in 2005, 2006, 2007 and 2009 being higher than anything previously recorded. These higher temperatures, combined with below average rainfall results in increased evaporation and increased impacts on the ecological health.	The duration and severity of the Millennium Drought is likely to have resulted in impacts to the ecological values of Big Swamp and Boundary Creek. However, these impacts cannot be uncoupled from the drawdown of the LTA which resulted from the need to supplement drinking water supplies to the Greater Geelong region during this drought.

Note: Information presented in this table has been sourced from BOM[7]

[8] http://www.bom.gov.au/climate/drought/knowledge-centre/previous-droughts.shtml

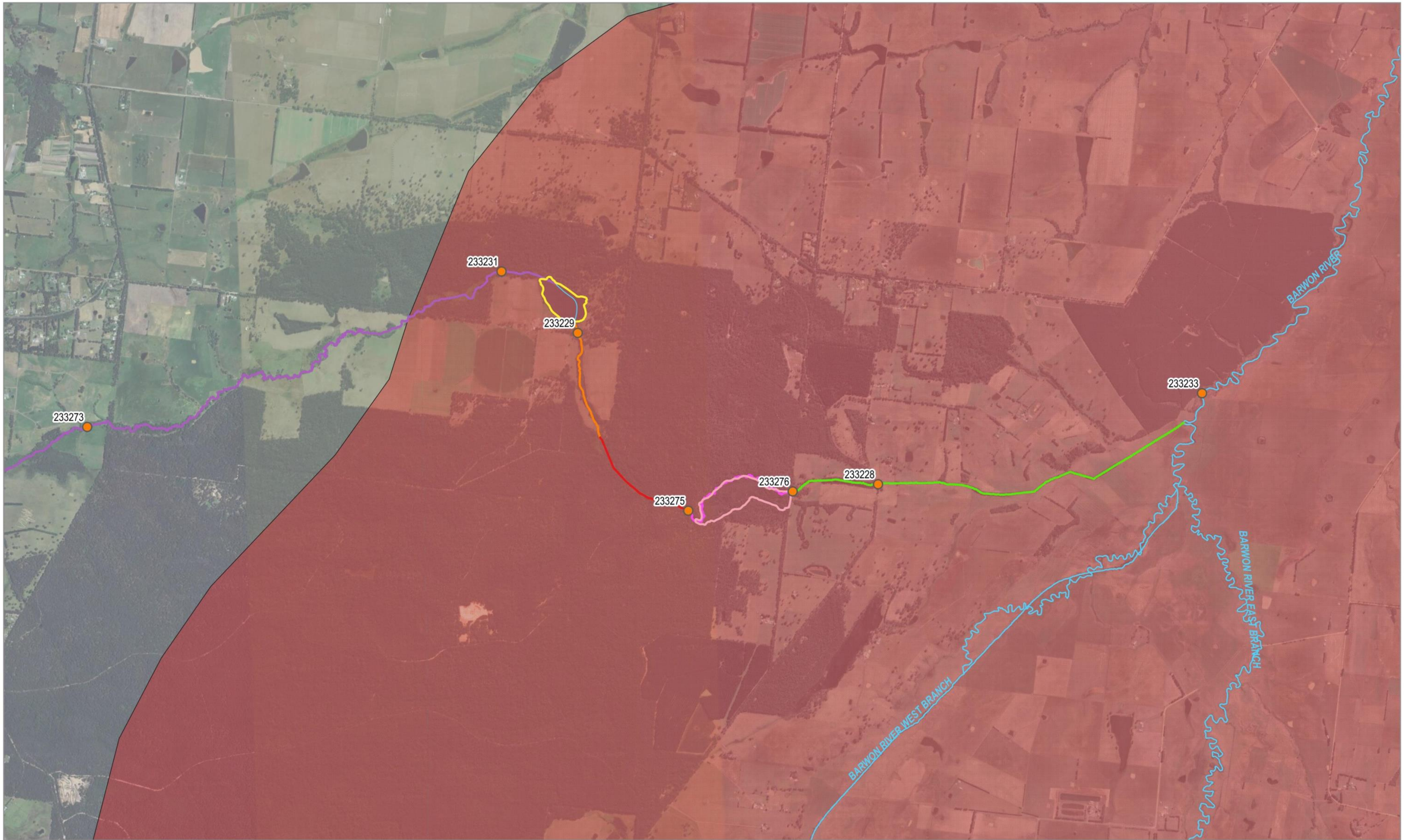

Figure 2.6: Extent of Black Saturday Bushfires (1939)

Barwon Water - Ecological Risk Assessment Boundary Creek, Big Swamp and the Barwon River

Legend

Stream Gauges
Private Onstream Dam
Big Swamp Boundary
Black Saturday Bushfire Extent

Boundary Creek Reaches
Reach 1
Reach 2a
Reach 2b
Reach 2c
Reach 3

DATA SOURCES
DSE and CFA, 2023; Imagery: Google Satellite, 2023

SCALE 1:30,000
250 0 250 500 750 m

nation partners

2.4 Ecological Condition

The natural and anthropogenic environmental stressors identified in **Section 2.3** have resulted in hydrological and water quality impacts, as well as impacts to ecological conditions at Big Swamp over time, resulting in an ever shifting landscape. **Figure 2.7** provides an overview of key events and their impact on the ecological conditions at Big Swamp and Boundary Creek. These impacts, the majority of which are irreversible or ongoing, have cumulatively changed the landscape and ecological condition of Big Swamp.

To date, the ecological surveys undertaken to support an understanding of the biological condition of Boundary Creek, Big Swamp and the Barwon River have comprised:

- vegetation surveys (Big Swamp only) (ELA, 2020 and ELA, 2023);
- macroinvertebrate surveys (Austral, 2022 and Austral, 2023); and
- a fish survey (Jacobs, 2017).

Whilst there are some reports available (e.g. Turnbridge, 1988; Jacobs, 2017) that provide an indication of historical conditions in Boundary Creek, and the palaeoecology study (La Trobe University, 2023) provides some insights through charcoal, diatom and pollen records, there is no site-specific data available that can support a robust understanding of swamp conditions pre-1979, the following sections provide an understanding of the current ecological condition in Big Swamp, Boundary Creek and the Barwon River that have been used support the risk characterisation in this ERA.

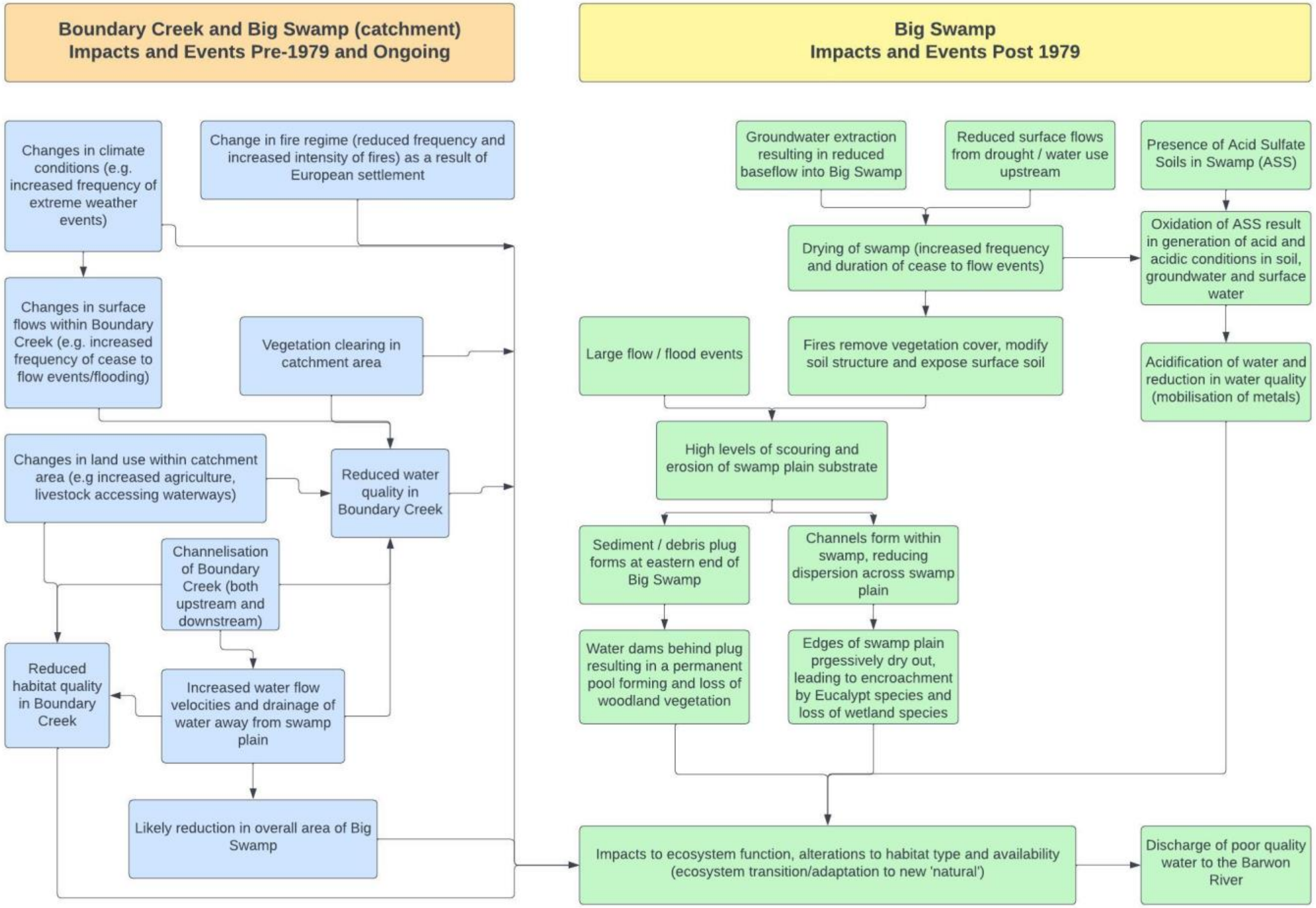

Figure 2.7: Key Events and Impacts on Ecological Conditions (Source: adapted from ELA (2019))

2.4.1 Vegetation Survey Outcomes

Big Swamp and Boundary Creek are present within the Otways Plain Bioregion[9] which is defined as having soils within the upper terrain areas that support Lowland Forest and Heathy Woodland ecosystems. Soils in the western half of the Otways Plain Bioregion are recorded to be 'generally acidic and of variable fertility'[8].

The ecology of Big Swamp is complex and intricately linked to the hydrology of the site (ELA, 2023). The hydrology of Big Swamp is in turn influenced by a range of factors such as soils, topography, climate, surface water flows, upstream water uses and conditions/recharge within the upper aquifer system (ELA, 2023). In addition to the range of stressors identified within the Boundary Creek and Big Swamp catchment (refer **Section 2.3**), erosion within the swamp plain driven by large rainfall events following the 1998 and 2011 fires has concentrated surface water flows into a secondary channel that now bisects the swamp plain (ELA, 2023). **Figure 2.8** shows the likely inundation areas of Big Swamp based on a range of site-specific factors, including changes in topography within the swamp plain.

The assessment of historical and current swamp conditions undertaken by ELA (2019) identified three (3) main ecohydrological zones to be present within Big Swamp:

1. the Swamp Plain - dominated by the Riparian Fern Scrub (EVC A120) ecological vegetation class (EVC) which is noted to be endangered and restricted within the Otway Ranges. This EVC is described by Department of Energy, Environment and Climate Action (DEECA) as:

   'Dense tall shrubby vegetation with a primarily ferny ground-layer, associated with waterlogged and inundation-prone soils with a substantial organic content. Distinguished from Riparian Scrub (EVC 191) and Riparian Thicket (EVC 59) by greater height and more open and diverse ferny understorey. Distinguished from Swam Scrub (EVC 53) by being dominated by Scented Paperbark as well as by understorey character.'[10]

2. Woodland areas – this consists of the eastern portion of the swamp and the communities immediately bordering the swamp plain (in areas generally unlikely to experience inundation). In these areas ELA (2023) noted the presence of woodland and damp woodland vegetation communities, dominated by Swamp Gum (*Eucalyptus ovata*). The slopes surrounding Big Swamp (in areas unaffected by water-logging or inundation) are dominated by Messmate Stringybark (*Eucalyptus obliqua*) and Manna Gum (*Eucalyptus viminalis)*.
3. Main Channel – This community, located along the northern boundary of the swamp plain, consists of a Swampy Riparian Woodland community that is reliant on surface water flows along the main channel and the associated infiltration of water into the root zone. The Swampy Riparian Woodland is dominated by Swamp Gum (*Eucalyptus ovata*), Brooker's Gum (*Eucalyptus brookeriana*) and Manna Gum (*Eucalyptus viminalis*). In the more elevated areas adjacent to the main channel, where inundation is more limited, a variety of ground, scrambling and tree ferns were noted to be common. The main channel was noted to support a range of aquatic and semi-aquatic forbs and sedges.

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9 https://www.environment.vic.gov.au/biodiversity/bioregions-and-evc-benchmarks

10 https://iwc.vic.gov.au/docs/IWC%20Wetland%20EVC%20benchmarks%20-%20August%202022.pdf

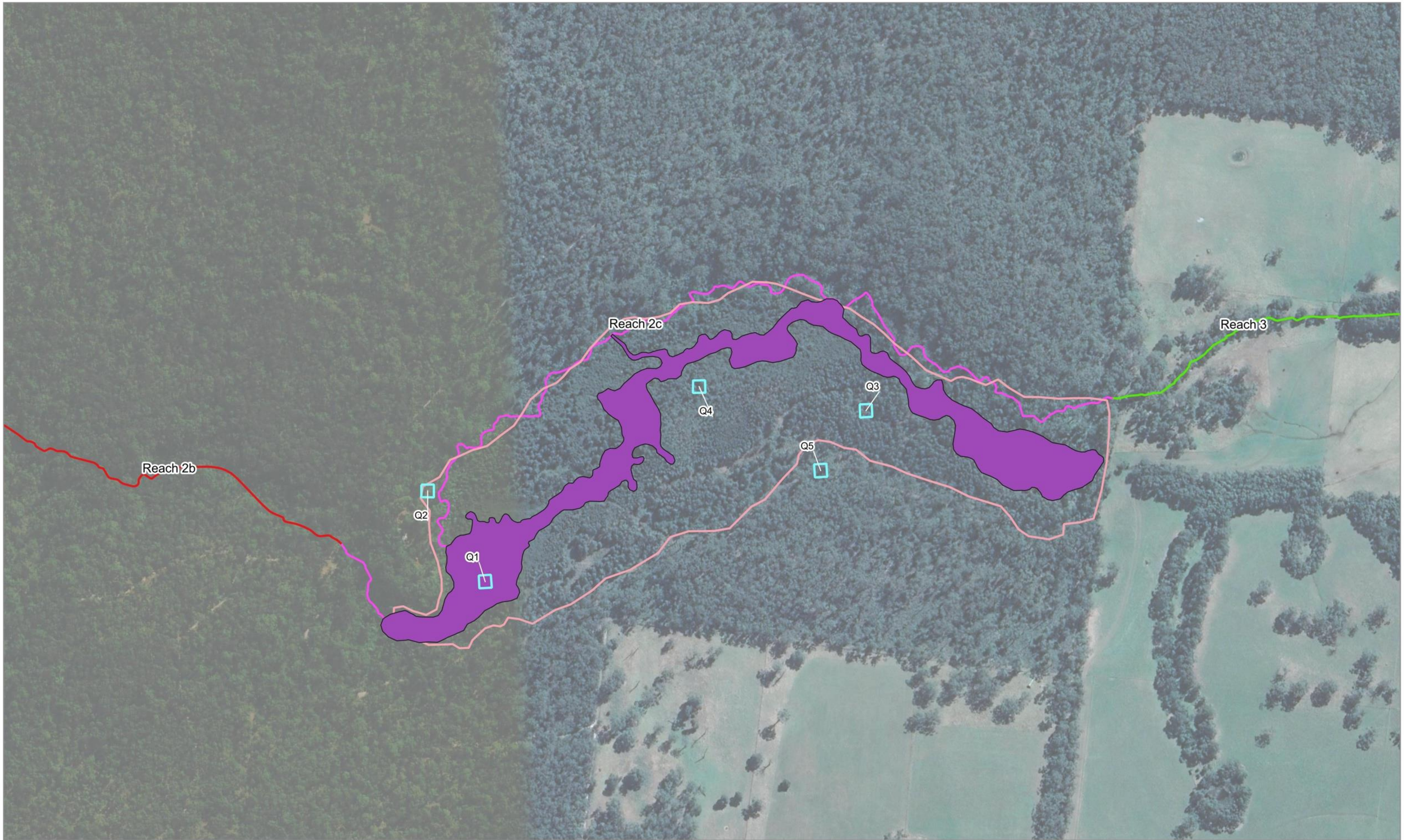

Figure 2.8: Big Swamp Inundation Area and Vegetation Survey Quadrats

Barwon Water - Ecological Risk Assessment Boundary Creek, Big Swamp and the Barwon River

Legend

- Big Swamp Inundation Area
- Private Onstream Dam
- Big Swamp Boundary
- Vegetation Monitoring Quadrats

Boundary Creek Reaches

- Reach 1
- Reach 2a
- Reach 2b
- Reach 2c
- Reach 3

DATA SOURCES
ELA, 2020 and 2023; Imagery: Google Satellite, 2023

SCALE 1:4,000
25 0 25 50 75 100 m

nation partners

To evaluate the health of the vegetation communities, ELA (2020 and 2023) evaluated the species and structural diversity using flora species quadrats. Five (5) quadrats were assessed within Big Swamp and the surrounding vegetation as follows:

- Two quadrats within the swamp plain (Q1 and Q4);
- Two quadrats within the woodland areas (Q3 and Q5); and
- One quadrat within the main channel (Q2).

The location of these quadrats is presented in **Figure 2.8** along with the location of eight (8) survey transects that were utilised to evaluate vegetation association boundaries considered to align with environmental gradients or features. These vegetation survey transects were designed to monitor changes in the extent of vegetation communities over time. However, given the dynamic nature of the swamp environment and the potential for seasonal changes to occur which may influence the more sensitive species in these communities, it is difficult to interpret this data relative to the objectives of the ERA. It was considered that the quadrat data provides an appropriate indication of the species diversity and abundance to support evaluation of risks within Big Swamp. Therefore, the transect data has not been further considered.

For each 8 m x 8 m quadrat, species diversity was measured by calculating the sum of the total number of species present, and structural diversity was calculated using the Simpsons Index of Diversity which measures the probability of selecting two individuals at random that belong to the same lifeform. To evaluate the structural diversity, the scale presented in **Table 2.3** was used by ELA (2020 and 2023).

Table 2.3: Structural Diversity Interpretation

Score	Abundance Interpretation
0	Low structural diversity
0.5	Moderate structural diversity
1	High structural diversity

Table 2.4 provides a summary of the species and structural diversity results as reported by ELA (2020) and ELA (2023). Based on this information it was observed that the number of species observed did not change significantly for Q3 and Q2, whilst there was some change for Q5 (noting that the location markers for Q5 could not be found during the 2022 monitoring event so this change may not be representative of actual change) and a significant change for Q1. The structural diversity was reported to be above 50% of the adopted scale (**Table 2.3**) for all locations except for Q4.

Table 2.4: Quadrat Monitoring Results (ELA, 2023)

Ecohydrological Zone	Species Diversity (number of species)		Structural Diversity (Simpsons Index of Diversity - Table 2.3)	
	2020	2022	2020	2022
Swamp Plain				
Q1	43	9	0.68	0.59
Q4	5	8	0.3	0.45
Woodlands				
Q3	18	14	0.61	0.55
Q5	33	19	0.81	0.65
Main Channel				
Q2	42	42	0.72	0.75

Further evaluation of the ecosystem structure, relative to the definition of a wetland/swamp environment, was made by assessing the a prevalence of vegetation that is adapted to wet or inundated soils. For the purposes of this ERA the term ‘prevalence’ has been interpreted to mean that >50% of the vegetation species recorded to be present have a preference for moist to wet soils or are aquatic/semi-aquatic in nature. **Table 2.5** presents a breakdown of the types of vegetation recorded to be present in four (4) of the five (5) quadrats within Big Swamp. Noting that Q5 was located within the woodland (Lowland Forest) environment on the southern slope of the swamp area in a location that is unlikely to be inundated, and thus is not representative of swamp habitat.

The observations from Q1 and Q2 (located at the western end of the swamp) indicated a prevalence of hydrophytic species with the species with highest reported coverage being those that prefer moist to wet conditions (Prickly Tea-tree (*Leptospermum continentale*), Tassel Sedge (*Carex fescicularis*) and Forest Wire-grass (*Tetrarrhena juncea*). This indicates that in this portion of the swamp the vegetation confirms the presence of suitable moisture and inundation to support this environment functioning as a swamp/wetland. The observations for Q3 (in the woodland area to the east) and Q4 (in the swamp plain) indicate that conditions in this portion of Big Swamp are drier and may be less prone to inundation under normal conditions, with a predominance of Australian Bracken present. It is noted that the presence of Australian Bracken may also be due to its tolerance of highly acidic soils[11].

Table 2.5: Recorded Vegetation Species in Swamp Plain Quadrats (2022 monitoring only) (ELA, 2023)

	Number of Species		% of Species Recorded	
	2020	**2022**	**2020**	**2022**
Q1 – Swamp Plain - Western Portion				
Total species recorded	43	9	-	-
Hydrophytic species	26	7	60%	78%
Non-hydrophytic species	15	2	35%	22%
Species of Highest Observed Coverage:	**2020:** The species recorded to have the greatest coverage was Prickly Tea-tree (*Leptospermum continentale*). This species is a shrub that is identified to be widespread in woodland, heathland and beside watercourses. With a preference for poorly drained soils such as seepages.		**2022:** The species recorded to have the greatest coverage was the Tassel Sedge (*Carex fescicularis*). This species is a large tufted graminoid (sedge) that prefers moist to wet soil on stream and swamp edges.	
Outcome:	The vegetation monitoring at this location indicates that whilst the assemblage of species has changed between monitoring periods, the area described by Q3 has maintained a prevalence of 'wetland' species or species that have a preference for moist to wet soils.			
Q2 Main Channel – Western Portion				
Total species recorded	42	42	-	-
Hydrophytic species	28	28	67%	67%
Non-hydrophytic species	13	13	31%	31%
Species of Highest Observed Coverage:	**2020:** The species recorded to have the greatest coverage in this quadrat was Forest Wire-grass (*Tetrarrhena juncea*) was recorded to have a coverage of 50-75%. This species has a preference for moist soils with a preference for moist-wet forests and heathy woodlands. Also of note is that Blackwood (Acacia melanoxylon), Prickly Tea-tree (*Leptospermum continentale*), Slender Tussock-grass (*Poa tenera*), Hazel Pomaderris (*Pomaderris aspera*), and Australian Bracken (*Pteridium esculentum subsp. Esculentum*) were all recorded to have a coverage between 25 – 50% across this quadrat. With the exception of the Australian Bracken, these species also have a preference for moist to wet soils.		**2022:** During the 2022 monitoring two species were recorded to be present at equal prevalence within this quadrat: Forest Wire-grass (*Tetrarrhena juncea*), Australian Bracken (*Pteridium esculentum subsp. Esculentum*) both recorded with 50 – 75% coverage. Whilst the Forest Wire-grass is noted to be a species that prefers moist to wet soils, the Australian Bracken does not. In addition, the species noted in 2020 to have 25 – 50% coverage remained the same, whilst the Tall Sedge (*Carex appressa*) increased in coverage from 2 – 25% coverage in 2020.	
Outcome:	Whilst a number of woodland species were noted to be present within this quadrat in both 2020 and 2022, there remained a prevalence of species that prefer moist-wet or inundated soils.			

[11] https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/316261/Bracken-fern.pdf

	Number of Species		% of Species Recorded	
	2020	**2022**	**2020**	**2022**
Q3 – Woodland – Eastern End of Big Swamp				
Total species recorded	18	14	-	-
Hydrophytic species	7	6	39%	43%
Non-hydrophytic species	10	8	56%	57%
Species of Highest Observed Coverage:	**2020:** The species noted to be most prevalent in this quadrat was Australian Bracken (*Pteridium esculentum subsp. Esculentum*) with an observed coverage of 75 – 100%. The next most prevalent species was observed to be the Swamp Gum (*Eucalyptus ovata*) with 50 – 75% coverage. Whilst neither of these species are reported to be wetland species, it is noted that the Swamp Gum does have a preference for poorly drained clay soils, and does tolerate inundation which indicates that it is well suited for swamp fringe areas.		**2022:** The Australian Bracken (*Pteridium esculentum subsp. Esculentum*) (75 – 100% cover) and Swamp Gum (*Eucalyptus ovata*) (50 – 75% cover) were also observed to be the most prevalent species in this quadrat during the 2022 monitoring event.	
Outcome:	The prevalence of non-hydrophytic species in this area indicates that it is likely to be drier with a lower likelihood of inundation. However, there were still some species observed that prefer moist environments which indicates that there is still some availability of water to support them. Given the location of this quadrat within the woodland portion of Big Swamp it is considered appropriate that this area may support a lower proportion of 'wetland' or inundation tolerant species.			
Q4 Swamp Plain – Central Eastern Portion				
Total species recorded	5	8	-	-
Hydrophytic species	3	5	60%	63%
Non-hydrophytic species	2	3	40%	38%
Species of Highest Observed Coverage:	**2020:** The species noted to be most prevalent in this quadrat was Australian Bracken (*Pteridium esculentum subsp. Esculentum*) with an observed coverage of 75 – 100%. Prickly Tea-tree (*Leptospermum continentale*) was observed to be present at 5 – 25% coverage during this monitoring event. With a number of other species that have a preference for moist to wet conditions were recorded.		**2022:** The species noted to be most prevalent in this quadrat was Australian Bracken (*Pteridium esculentum subsp. Esculentum*) with an observed coverage of 75 – 100%. Prickly Tea-tree (*Leptospermum continentale*) was observed to be present at 5 – 25% coverage during this monitoring event. With two additional species that prefer moist to wet conditions were observed during 2022 (Annual Fireweed (*Senecio glomeratus*) and Yorkshire Fog (*Holcus lanatus*)) which were not previously observed.	
Outcome:	This quadrat was noted to have a greater presence of Australian Bracken than the western portion of the swamp plain. It was also noted to have a lower species diversity than the other quadrats, however the presence of some species that are indicated to be 'swamp' or 'wetland' suitable species indicates that there is likely to be some inundation or elevated soil moisture in these areas some of the time.			

2.4.2 Macroinvertebrate Survey Outcomes

Macroinvertebrate communities have been assessed in Big Swamp, Boundary Creek and the Barwon River as part of the monitoring work undertaken by Barwon Water since 2019 (noting that some locations have only been added during the autumn 2022 monitoring round, thus only have two (2) rounds of data available). The macroinvertebrate monitoring locations are presented in **Figure** 2.9 and **Figure 2.10**.

Macroinvertebrate community condition can be measured using rapid bioassessment methodologies as recommended by EPA Victoria (EPA Publication 604.2, June 2021). The rapid bioassessment methodology includes collection of two biological samples, a stream bed or benthic sample (collected in fast flowing waters) and an edge or littoral sample (collected in slow flowing habitats). The parameters collected during this biological sampling are then used in the final assessment process, in which a range of invertebrate indices (including Australian Rivers Assessment System (AusRivAS) scores) are calculated to enable an assessment of stream health. The following biotic indices were used by Austral (2022 and 2023):

- AusRivAS – the identified band for each sample location was reported by Austral (2022 and 2023). The bands indicate an observed stream condition relative to a reference site (relatively free from environmental impacts). Band A = conditions are reported to be comparable to the reference site, Band B = conditions are reported to be significantly impaired, Band C = conditions are reported to be severely impaired, and Band D = conditions are reported to be extremely impaired.
- SIGNAL2 (Stream Invertebrate Grade Number – Average Level) – this index provides information about the tolerance or intolerance of macroinvertebrate species to water pollution. Sites with high SIGNAL2 scores are indicated to be high quality sites with low levels of pollution, whilst sites with low scores are low quality sites that may be impacted by pollution. It is noted that this particular index is identified to be good for evaluating impacts associated with organic pollutants (e.g. those from sewage effluent), but its usefulness for toxic impacts or other types of disturbances is identified to be less certain.
- Taxa richness (number of families) – the number of families reported at a site can provide a reasonable representation of the ecological health of a stream. Healthy streams generally support a larger number of families than less healthy streams.

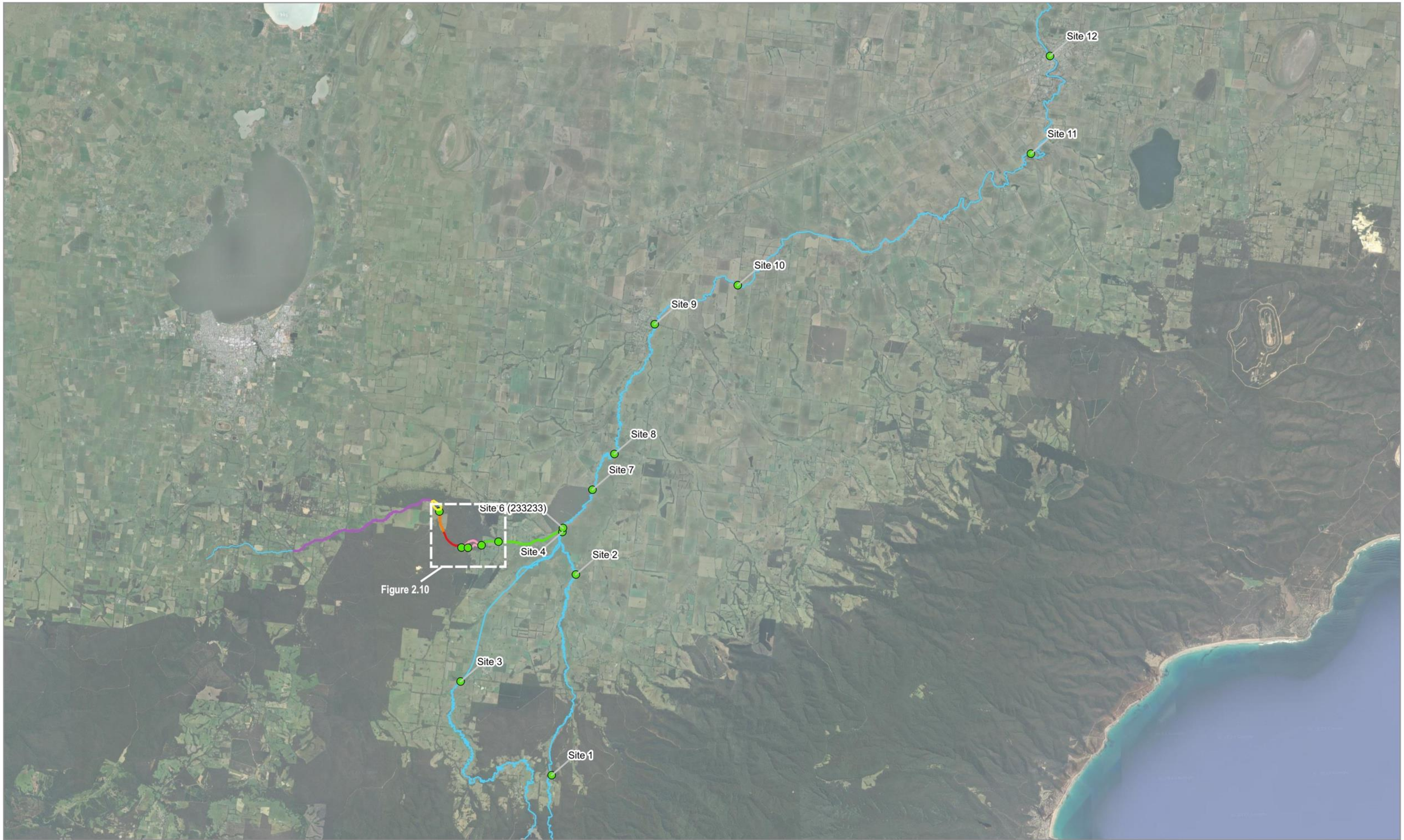

Figure 2.9: Macroinvertebrate Survey Locations - All Locations

Barwon Water - Ecological Risk Assessment Boundary Creek, Big Swamp and the Barwon River

Legend

- Macroinvertebrate Survey Locations (Stream Gauge ID)
- Private Onstream Dam
- Big Swamp Boundary

Boundary Creek Reaches

- Reach 1
- Reach 2a
- Reach 2b
- Reach 2c
- Reach 3

DATA SOURCES
Barwon Water, 2023; Imagery: Google Satellite, 2023

SCALE 1:150,000
1 0 1 2 3 4 km

nation partners

Figure 2.10: Macroinvertebrate Survey Locations - Big Swamp Area

Barwon Water - Ecological Risk Assessment Boundary Creek, Big Swamp and the Barwon River

Legend

- Macroinvertebrate Sampling Locations (Stream Gauge ID)
- Private Onstream Dam
- Big Swamp Boundary

Boundary Creek Reaches
- Reach 1
- Reach 2a
- Reach 2b
- Reach 2c
- Reach 3

DATA SOURCES
Barwon Water, 2023; Imagery: Google Satellite, 2023

SCALE 1:10,000
100 0 100 200 m

nation partners

To interpret the findings from the macroinvertebrate sampling, each of the above indices was compared to the targets for the Central Foothills and Coastal Plains region, as set out in the ERS (2021). Findings from the macroinvertebrate study conducted by Austral Research and Consulting (Austral, 2022 and Austral, 2023) in the Boundary Creek catchment have been summarised in **Table 2.6**.

Table 2.6: Summary of Macroinvertebrate Survey Results

Location	Number of families[1]		SIGNAL2 Index Score[2]		AusRivAS Band[3]		Habitat Assessment Score (Low Gradient Streams)	
	Target	**20**	**Target**	**3.4**	**Target**	**A**	**Target**	**140**
Site 4 – Barwon River 100 m upstream of Boundary Creek confluence	Spring 2019	18	Spring 2019	2.7	Spring 2019	A	2019	79
	Autumn 2020	13	Autumn 2020	3.1	Autumn 2020	B	-	-
	Spring 2020	25	Spring 2020	3.5	Spring 2020	A	-	-
	Autumn 2021	14	Autumn 2021	3.1	Autumn 2021	B	-	-
	Spring 2021	21	Spring 2021	3.6	Spring 2021	A	-	-
	Autumn 2022	14	Autumn 2022	3.25	Autumn 2022	B	2022	99
Site 6 – Barwon River 100 m downstream of Boundary Creek confluence (233233)	Spring 2019	17	Spring 2019	4.0	Spring 2019	B	2019	70
	Autumn 2020	19	Autumn 2020	3.4	Autumn 2020	B	-	-
	Spring 2020	20	Spring 2020	2.65	Spring 2020	B	-	-
	Autumn 2021	8	Autumn 2021	3.25	Autumn 2021	B	-	-
	Spring 2021	15	Spring 2021	3.7	Spring 2021	B	-	-
	Autumn 2022	16	Autumn 2022	4.05	Autumn 2022	A	2022	71
	Spring 2022	16	Spring 2022	3.36	Spring 2022	A	-	-
Site 5.1 – Boundary Creek downstream of private onstream Dam (Reach 2a) (233229)	Autumn 2022	16	Autumn 2022	3.95	Autumn 2022	A	2014	87
	Spring 2022	17	Spring 2022	3.94	Spring 2022	A	2022	91
Site 5.2 - Boundary Creek upstream of Big Swamp (Reach 2b) (233275)	Autumn 2022	18	Autumn 2022	4.3	Autumn 2022	A	-	-
	Spring 2022	21	Spring 2022	4.69	Spring 2022	A	2022	130
Big Swamp (BS1 and BS2 Average) (Reach 2c)	Autumn 2022	3	Autumn 2022	2.35	Autumn 2022	C	-	-
	Spring 2022	8	Spring 2022	2.94	Spring 2022	C	-	-
Site 5 – Boundary Creek at Colac-Forrest Rd (233288) (Reach 3)	Spring 2019	5	Spring 2019	2.75	Spring 2019	-	2019	81
	Autumn 2020	6	Autumn 2020	2.55	Autumn 2020	-	-	-
	Spring 2020	6.5	Spring 2020	3.05	Spring 2020	-	-	-
	Autumn 2021	7	Autumn 2021	3.4	Autumn 2021	-	-	-
	Spring 2021	8	Spring 2021	3.8	Spring 2021	C	-	-
	Autumn 2022	5.5	Autumn 2022	3.25	Autumn 2022	-	2022	81
	Spring 2022	9	Spring 2022	3.45	Spring 2022	B	-	-

Note: no AusRivAS band was reported by Austral (2022) for site 5 during 2019, 2020 and Autumn 2021/22 sampling events. Austral (2022) indicated that this may be due to the 'low alkalinity at the site' taking the results for this site outside of the experience of the AusRivAS model.

1. Taxa richness is measured by the number of macroinvertebrate families collected, and can give a good overview of the health of the waterway.
2. SIGNAL2 is a biotic index based on the tolerance or intolerance of biota (macroinvertebrates) to water pollution.
3. Band A = Reference condition, Band B = significantly impaired, Band C = Severely impaired - where no result is listed this is because none was provided by Austral (2022)

The macroinvertebrate sampling outcomes indicate the following:

- The sampling locations within the Barwon River do not generally meet the target biological index scores both up and downstream of the Boundary Creek confluence, indicating that a range of catchment level influences are present that have resulted in impacts to macroinvertebrate communities (e.g. impacted stormwater entering the waterway, impacts from land clearing and agricultural land uses, etc). The consistency between upstream and downstream survey outcomes indicates that discharges of acidic waters and associated dissolved metals from Big Swamp are not significantly impacting on macroinvertebrate communities within the Barwon River.
- The sample locations upstream of Big Swamp in Boundary Creek (but downstream of the private onstream dam) indicate good quality habitat with water quality that is relatively unimpacted by pollution, whilst the sample locations downstream of Big Swamp suggest that the habitat is impacted and water quality is reduced. However, whilst the number of families was reported to be lower downstream of Big Swamp compared to upstream, the observed presence of macroinvertebrate families within this section of the creek provides an indication that this section is inhabitable. The presence of macroinvertebrates in the lower reaches of Boundary Creek indicates there are aquatic species that have adapted to inhabit this reach of the creek.

2.4.3 Fish Survey Outcomes

In 2017, Jacobs used available information to evaluate the presence of a range of fish species expected to be present based on anecdotal evidence provided by stakeholders. Jacobs (2017) noted that direct field surveys can have problems in a system like Boundary Creek for taxa such as fish, frogs and platypus because the creek is relatively small. It is likely to only support low numbers of aquatic animals and, therefore, field surveys may not record many of the expected taxa (Jacobs, 2017). The failure to record a certain species during a field survey does not mean that it can confidently be inferred that the species is not present. Jacobs (2017) assembled a specialist panel to conduct a systematic background review and habitat assessment on which to base an estimate of the ecological values currently supported by the creek. The approach adopted is therefore subjective, but also regarded as the most suitable approach given the issues with direct surveys in systems like Boundary Creek (Jacobs, 2017). Fish species identified in the survey have been summarised in **Table 2.7** (Jacobs, 2017).

Table 2.7: Review of records and targeted fish survey from Boundary Creek (source: Jacobs, 2017)

Victorian Biodiversity Atlas (VBA) Records[1]	Turnbridge (1988)[2]
Native	Native
• Mountain Galaxias (Galaxias olidus) • Southern Pygmy Perch (Nannoperca australis) • Short-finned Eel (Anguilla australis) • River Blackfish (Gadposis marmoratus)	• Dwarf Galaxias (Galaxiella pusilla) • Southern Pygmy Perch (Nannoperca australis) • Short-finned Eel (Anguilla australis) • River Blackfish (Gadposis marmoratus)
Introduced	Introduced
• Brown Trout (Salmon trutto) • Redfin Perch (Perca fluviatilis)	• Brown Trout (Salmon trutto)

1. The vast majority of records are from the early 1990s or before
2. Archival material provided by Southern Rural Water to Jacobs (2017)

The findings of Jacobs (2017) aquatic habitat assessment are reproduced below.

Reach 1 – Upstream of private onstream dam

There was a high amount of fringing and aquatic vegetation that would provide good quality habitat for a range of fish species. The water depth was not observed to be very high, with some pools up to 50 cm in some sections, so historically it is likely that small-bodied fish would have been dominant. This includes the species listed in **Table 2.7**, as well as the fish surveyed in nearby catchments (River Blackfish, Dwarf

Galaxias, Southern Pygmy Perch, Yarra Pygmy Perch, Flathead Gudgeon, Mountain Galaxias Common Galaxias, Australian Smelt and Short-finned Eel). The Common Galaxias and Australian Smelt noted in nearby catchments are diadromus, meaning they need to migrate to the ocean or to lakes to complete their life cycles, but they are unable to overcome large fish barriers like the private onstream dam. The pools in Reach 1 would have probably become unsuitable during extreme low flows, such as during the Millennium Drought; however, Jacobs (2017) noted that the two (2) hardy, small-bodied species, the Flathead Gudgeon and Mountain Galaxias, could probably have found refuge habitat in dry times and do not need to migrate, so therefore there is a moderate probability that these species could be supported. It is unlikely that River Blackfish, Southern Pygmy Perch, Yarra Pygmy Perch and Dwarf Galaxias could be supported in Reach 1.

Reach 2 – Private onstream dam to eastern end of Big Swamp

Due to the shallow depth of the channel in this area, the ‘dampland’ and Big Swamp are unlikely to represent high quality habitat for fish. Most fish species would be unable to migrate upstream due to the private onstream dam. Jacobs (2017) reported that there is a low probability for Southern Pygmy Perch and Dwarf Galaxias to find suitable habitat.

Reach 3 – Downstream of Big Swamp to confluence with Barwon River

Reach 3 of Boundary Creek was channelised following European colonisation, and the increase in flow meant that fish may have been able to pass through. The aquatic habitat was rated good, particularly in the areas where the riparian zone has been revegetated (approx. 20-30% of this reach). Pools of 40 cm depth with aquatic and fringing vegetation and woody debris would have been suitable to support all of the species that have been recorded as occurring in Boundary Creek by Turnbridge (1988). However, as the water quality is at times highly acidic and sometimes dry in the summer there may be inadequate habitat to support resident fish populations.

2.4.4 Evaluation of the Presence of Species of Interest - Platypus

It is understood that some stakeholders are interested to see platypus return to Boundary Creek. Box 2.1 provides some information on the habitat and feeding requirements of platypus, and also demonstrates that some of the stressors present in Big Swamp and Boundary Creek are not conducive to the presence of platypus (regardless of water quality). Jacobs (2017) also evaluated whether there is potential for platypus to reside within Boundary Creek, and provided the following conclusions:

- There is a low probability that Reach 1 supports platypus, however the shallow pools with connecting flow most of the time could provide sufficient resources to support platypus.
- It is unlikely that Reaches 2 and 3 would support resident platypus populations.

Overall, the available information suggests that regardless of the water quality issues present downstream of Big Swamp, it is unlikely that platypus would return to Boundary Creek unless there is rehabilitation of the creek to provide suitable habitat and removal of some of the significant stressors identified in the catchment (e.g. livestock accessing the waterway, presence of the private onstream dam, etc).

Box 2.1: Platypus Habitat Summary

Distribution

The species' distribution is largely based on historical records and anecdotal sightings. Taking this into account, the platypus appears to have been relatively widely distributed in waterways throughout Victoria (apart from the drier northwest region, Mornington Peninsula and Wilsons Promontory). This species' broad geographical distribution in Victoria does not seem to have changed significantly since European colonisation, except for the lower Murray River downstream of Echuca, where it no longer exists. This broad distribution however fails to depict localised declines or localised extinctions and reduced abundance. Platypus is endemic to Australia and is dependent on rivers, streams, and bodies of freshwater[1].

Habitat

Platypus tend to occur in a variety of water bodies including rivers, creeks, lakes, as well as man-made dams and reservoirs and it favours areas that have stable banks for burrowing, intact streamside vegetation, aquatic invertebrates for food and reliable water flows[2]. A study conducted by Serena et al. (2001) found habitats that showed a significant positive relationship with the occurrence of platypus activity included the number of medium and large *Eucalyptus*, *Acacia* and *Populus* trees growing along the bank, presence of gravel, pebbles, cobbles, large rocks and coarse particulate organic matter in the channel substrate; amount of riffle habitat; amount of large woody debris in the channel; and undercut banks[3]. Habitats that showed a significant negative relationship with platypus activity included the number of medium and large *Salix* trees growing along the bank; the presence of silt, solid clay and *Salix* roots in the channel substrate; the amount of pool habitat; and the maximum channel depth[3].

The platypus feeds exclusively in the water so it is highly unlikely that this species relies directly on the presence of streamside plants in the sense that arboreal mammals depend on trees[3]. On the other hand, it is believed that perennial riparian vegetation generally contributes to the integrity and productivity of aquatic ecosystems, e.g. by controlling bank and channel erosion, generating and helping to retain allochthonous organic matter, reducing the transport of sediment and pollutants from adjoining terrestrial systems, and moderating temperature variation in the water[3].

Diet

On the basis of studies undertaken along rivers in New South Wales, the platypus' diet mainly comprises benthic insects, although ostracods, decapod shrimp, bivalve and gastropod molluscs, nematomorph worms, salmonid eggs and small frogs are also eaten[2]. The presence of logs, twigs, and roots, as well as cobbled or gravel water substrate result in increased microinvertebrate fauna (a main food source), and the platypus also tends to be more abundant in areas with pool-riffle sequences[4].

Threats

The primary threat to platypuses appears to be reduction in surface water and flows due to drought, altered flow regimes and water extraction for domestic, industrial and agricultural purposes. Habitat modification due to bank erosion and stream sedimentation (as a result of poor land management practices in agriculture, forestry, and urbanization) threatens platypus nesting and foraging habitats[2]. Modified land-use for agriculture and urbanization, and widespread clearing of native vegetation along waterways has led to degradation of platypus habitat. Fragmentation of populations due to in-stream structures (e.g. weirs, dams), reduced surface water, or poor habitat quality results in small, isolated populations that are prone to loss of genetic diversity and an increased risk of local extinctions after events such as floods and bushfires[2]. A negative influence of stormwater on platypus and aquatic macroinvertebrates (their food source) occurrence has also been established[1].

1. https://www.environment.vic.gov.au/__data/assets/pdf_file/0030/484086/01-Platypus-PRR-FinalSign-1.pdf
2. https://www.ari.vic.gov.au/research/threatened-plants-and-animals/helping-platypus-recover

3. Serena, M., Worley, M., Swinnerton, M., & Williams, G. A. (2001). Effect of food availability and habitat on the distribution of platypus ( ) foraging activity. *Australian Journal of Zoology*, *49*(3), 263–277. https://doi.org/10.1071/ZO00089
4. https://australian.museum/learn/animals/mammals/platypus/?gclid=EAIaIQobChMI_-SY_8qq_gIV4YBLBR2wdAUhEAAYAiAAEgJGTvD_BwE

2.5 Potential Ecological Receptors

Based on the information presented in the previous sections, the following broad ecological communities are considered to have the potential to be impacted by acidity and dissolved metals in and discharging from Big Swamp:

- Swampland vegetation and water dependent ecosystems within the swamp environment;
- Aquatic organisms in Boundary Creek (Reach 2c and 3); and
- Aquatic organisms in the Barwon River, downstream of the confluence of Boundary Creek.

2.6 Ecological Values

In accordance with guidance provided in the ASC NEPM (NEPC 2013), identification of site-specific ecological values requires gathering information about the biota (plants, animals and fungi) and supporting ecological functions that are expected to be present in the area under investigation. The Environment Reference Standard (ERS) is a tool under the Victorian *Environment Protection Act* 2017 that sets out the Environmental Values that the Victorian community want to achieve and maintain. An Environmental Value is defined as '*an aspect of the environment and how we use it that is important to us*.' The ERS provides indicators and objectives to assess the Environmental Values of different environmental matrices (e.g., land, water, air, etc).

There are several Environmental Values in the reference standards for land and water that directly relate to ecology[12]; Those Environmental Values considered most relevant to Big Swamp, Boundary Creek and the Barwon River, in the context of this ERA are:

- Land dependent ecosystems and species (Land quality that is suitable to protect soil health and the integrity and biodiversity of natural ecosystems, modified ecosystems and highly modified ecosystems); and
- Water dependent ecosystems and species (Water quality that is suitable to protect the integrity and biodiversity of water dependent ecosystems. This integrity and biodiversity includes:
  - The integrity of riparian vegetation as it contributes to the health of water dependent ecosystems and bank stability;
  - Groundwater quality that does not adversely affect surface water ecosystems;
  - Groundwater quality that does not adversely affect natural ecosystems that require access to groundwater to meet all or some of their water requirements on a permanent or intermittent basis to maintain their communities of organisms, ecological processes and ecosystem services. This includes wetlands, rivers and streams reliant on groundwater baseflow, some terrestrial vegetation and some estuarine and near-shore marine systems, stygofauna and troglofaunal
  - Maintenance of fish passage).

These Environmental Values are defined in the ERS as follows:

[12] Other environmental values include those related to human heath, buildings and structures and production of food.

Based on the available guidance, and the environmental values that need to be protected in accordance with the *Environment Protection Act* 2017**,** a range of key factors needs to be considered when identifying and defining the ecological values relevant to Boundary Creek (Reach 2c and Reach 3) and the Barwon River (downstream of Boundary Creek confluence). Suter (2007) identified the follow key factors to support development of ecological endpoints or values:

- Stressor characteristics
- Ecosystem and receptor characteristics
- Management goals
- Stakeholder input
- Policies or precedents

The outcomes of considering these factors is presented in **Table 2.8**.

Table 2.8: Key Consideration for Development of Ecological Values

Information	Question	Outcome
Stressor characteristics	What is susceptible to the stressor?	The specific stressors under consideration for this ERA include: • Human influenced increases in water level variability in Boundary Creek (Reach 2c and 3); • Reduced soil moisture in Big Swamp; • Increased frequency and duration of wet-dry cycling within Big Swamp resulting in increased release of acidity (low pH) into Boundary Creek (Reach 2c and 3); • Mobilised heavy metals in pore water and surface water in Big Swamp and Boundary Creek (Reach 2c and 3); and • Acidity and mobilised heavy metals in surface water in the Barwon River resulting from discharge of impacted water from Boundary Creek. The primary ecological receptors that are susceptible to the above listed stressors include: • Swampland vegetation and water dependent ecosystems within the swamp environment; • Aquatic organisms in Boundary Creek (Reach 2c and 3); and • Aquatic organisms in the Barwon River, downstream of the confluence of Boundary Creek.
Ecosystem and receptor characteristics	What is present and ecologically relevant?	Based on the ecological surveys that have been conducted in Boundary Creek, Big Swamp and the Barwon River, the following ecosystem communities are considered to be relevant to the ERA: • Macroinvertebrate communities that occupy the littoral and benthic environments; • Fish and other aquatic organisms that occupy the water column environment; and • Riparian vegetation communities that straddle the interface between the aquatic environment and the terrestrial environment. This includes the Riparian Fern Scrub vegetation and the Swampy Riparian Woodland communities within Big Swamp that are reliant on continuous waterlogging of soils and/or surface flows along the main channel of Boundary Creek. In addition to the ecosystem communities, there are a range of ecosystem processes that have also been considered in the development of ecological values for Big Swamp, Boundary Creek and the Barwon River, these include: • Surface water flows and the natural frequency of wet-dry cycling; • Waterlogging of soils and groundwater extrusion; • Carbon and nutrient cycling, including deposition and decomposition of organic matter; and • Sulfide oxidation and acid generation resulting from natural wet-dry cycling. These are not an exhaustive list of aquatic organisms or ecosystem processes. However, the key communities and processes have been included as they are considered relevant, and for which data is available, to support the ERA outcomes.
Management goals	What is relevant to the management goals?	The following remedial objectives have been identified in the REPP (Barwon Water, 2022):

Information	Question	Outcome
		1. Facilitate groundwater level recovery and enable groundwater-surface water interaction to return 2. Reduce the severity of wet-dry cycling processes and the occurrence of ‘acid flush’ events in Boundary Creek 3. Control/manage oxidation of naturally occurring acid sulfate soils 4. Preserve/improve the ecological values of Big Swamp and Boundary Creek 5. Reduce the fire risk in Big Swamp
Input from stakeholders	What is of concern?	Based on discussions with key stakeholders and information provided by Barwon Water, project stakeholders are understood to be concerned about: • Groundwater management such that they want to prevent future extraction of water from the Barwon Downs Borefield; • The health of Boundary Creek and the Barwon River waterways as it relates to the ability for livestock to access the water and for species of interest to ‘return’ to the area (e.g. platypus); • Prevention of future fish kills in the Barwon River; • The ongoing presence of a functional wetland swamp; and • Ongoing ability for use of the Big Swamp area for recreational activities (e.g. riding motorbikes, camping and picnicking).
Policies or precedents	What is supported by policy or precedent?	In accordance with the *Environment Protection Act* 2017 there is a requirement for entities undertaking activities to minimise risks of harm to human health and the environment so far as reasonably practicable. The ERS outlines the need to protect the integrity and biodiversity of land and water dependent ecosystems and species.

Based on the factors considered in **Table 2.8**, the ecological values for Big Swamp, Boundary Creek (Reach 2c and 3) and the Barwon River (downstream of the Boundary Creek confluence) are presented in **Box 2.2**.

Box 2.2: Ecological Values Relevant to the ERA:

Natural soil saturation within Big Swamp is supported such that species diversity and abundance of swamp vegetation communities are able to be sustained.

- Biological/habitat indicator: Maintenance of swamp vegetation in the swamp plain
- Water level indicator: Groundwater monitoring in piezometers and stream gauge monitoring (at the upstream gauge 233275) against management goals

Natural water quality within Boundary Creek (Reach 2c and 3) is supported such that abundance and diversity of aquatic communities (including those within receiving environments (e.g. the Barwon River)) are not impacted.

- Biological indicator[13]: Macroinvertebrate monitoring against site-specific targets
- Water level indicator: Monitoring of flows in Boundary Creek (stream gauge 233228) against management goals

[13] It is noted that macroinvertebrate monitoring was listed as a biological indicator because there are relevant targets published in the ERS that can be used to support interpretation of macroinvertebrate sample data. Whilst other biological indicators may be relevant to the site (e.g. food web dynamics or community respiration), there was no data available to support evaluation of these indicators and no benchmarks to support interpretation of risks in the ERA.

- Physico-chemical indicator: Monitoring of contaminant concentrations against relevant water quality objectives (as defined by the ERA)

2.7 Preliminary Conceptual Site Model

A conceptual site model (CSM) provides a description of site-related information with regard to source(s) of contamination, receptors and the exposure pathways that link the sources with the receptors (ASC NEPM, 2013). The ASC NEPM (2013) lists the CSM as being an essential component of site assessments and risk assessments as it helps provide a clear understanding of the source-pathway-receptor linkages that are present and that require further evaluation.

Based on the available information, the primary source of contamination considered for this ERA is the generation of acidity and mobilisation of metals present in the sediments/soils within Big Swamp, and discharge of impacted water to Boundary Creek and the Barwon River. **Table 2.9** presents the source-pathway-receptor linkages identified for assessment in this ERA, and **Figure 2.11** provides an overview of the conceptual understanding of groundwater-surface water interaction and the source of surface water impacts in Big Swamp and Boundary Creek.

Table 2.9: Summary of Source-Pathway-Receptor Linkages

Waterway/Reach	Big Swamp	Boundary Creek (Reach 2c and 3)	Barwon River (Downstream of Boundary Creek Confluence)
Source	▪ Acidity stored in solid phase as minerals in the soils themselves ▪ Acidity stored in groundwater resulting from the infiltration of acidic recharge/seepage ▪ Acidity stored in the pore water of soils in the unsaturated zone	Leaching of acidity and heavy metals from soil and groundwater in Big Swamp	Impacted surface water from Boundary Creek
Pathway	Discharge of acidity and metals in groundwater into surface water within Big Swamp	Discharge of impacted surface water from Big Swamp to Boundary Creek	Discharge of impacted surface water from Boundary Creek to the Barwon River
Receptor	Swampland vegetation and water dependent ecosystems within the swamp environment Aquatic organisms present in the surface water channels (Boundary Creek) within the swamp footprint	Aquatic organisms in Boundary Creek (Reach 2c and 3)	Aquatic organisms in the Barwon River, downstream of the confluence of Boundary Creek

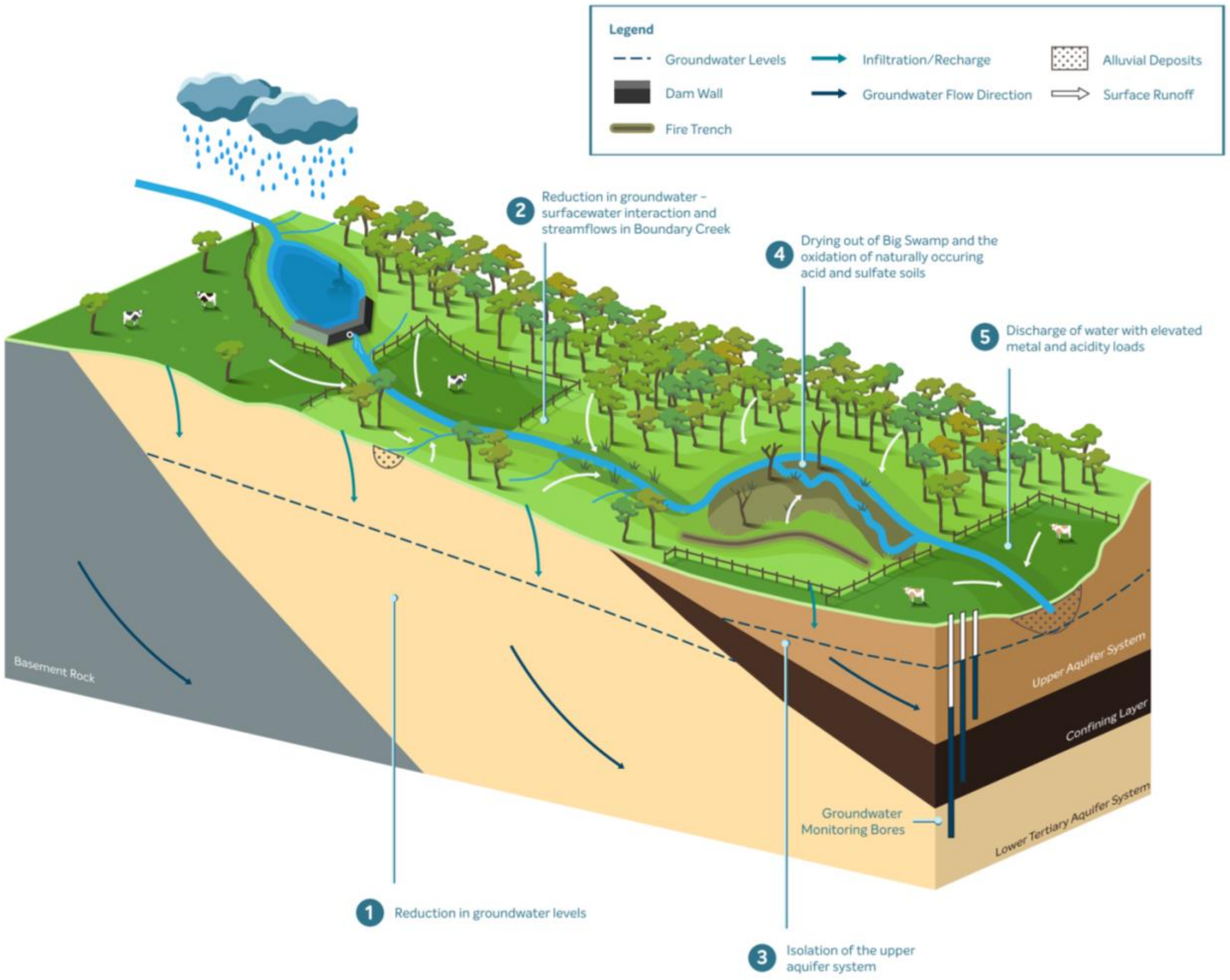

Figure 2.11: Conceptual Site Model (Source: Barwon Water, 2022c)

3 Data Evaluation

3.1 Data Sources

As outlined in **Section 1.1**, a range of environmental investigations have been undertaken in the Boundary Creek / Big Swamp area to support an improved understanding of the environmental conditions at Big Swamp and in Boundary Creek and to inform the development of the REPP. Nation Partners drew upon information and data presented in the reports, or referenced within these reports, listed in **Section 9**.

The information, data, interpretations and conclusions presented in these reports are referenced throughout this ERA.

In addition to these reports, water quality and water flow data collected by Barwon Water as part of the real time stream gauge monitoring program (refer to **Section 3.2** for more information) currently in place within Big Swamp, Boundary Creek and the Barwon River was provided for inclusion in the ERA.

3.2 Stream Gauges

Stream flow gauges[14] have been present within Boundary Creek since 1979, with the number of gauging stations and analytes evaluated increasing over time. The current Boundary Creek stream gauge network consists of seven (7) stream gauges, including a stream gauge installed in the Barwon River to monitor water quality and flow downstream of the confluence with Boundary Creek. The details of each gauge are presented in **Table 3.1**, with the stream gauge locations presented in **Figure 2.1**.

Table 3.1: Stream Gauge Summary

Gauge ID	Description	Monitoring Parameters	Monitoring Period
233273	Reach 1: Boundary Creek at Barongarook	Flow, water level, temperature, electrical conductivity (EC)	June 2014 to present
233231	Reach 1: Boundary Creek Upstream of McDonald's Dam	Flow, water level, Temperature, EC	December 1989 to present June 2014 to present
233229	Reach 2a: Boundary Creek Downstream of McDonald's Dam	Flow, water level, Temperature, EC, pH	December 1989 to present June 2014 to present
233275	Reach 2b: Boundary Creek Upstream of Big Swamp	Flow, water level, temperature, EC, pH Analytical data (water chemistry e.g. metals)	June 2019 to present August 2019 to present
233276	Reach 3: Boundary Creek Downstream of Big Swamp	Flow, water level, EC, pH Weather data, analytical data (water chemistry e.g. metals)	June 2019 to present August 2019 to present
233228	Reach 3: Boundary Creek at Yeodene	Mean daily flow Flow, water level, temperature, EC, pH Analytical data (water chemistry e.g. metals)	June 1979 to March 1985 March 1985 to present August 2019 to present
233233	Barwon River Downstream of Boundary Creek	Mean daily flow, Flow, water level, temperature, EC, pH, analytical data (water chemistry e.g. metals)	November 2022

14 For the purposes of the ERA the term 'stream flow gauge' is considered to be interchangeable with the designation of 'sites' for the relevant sample locations as listed in the Victorian Water Measurement Information System (WMIS).

Stream gauge 233273 is located upstream of the area under assessment in this ERA; therefore, data from this stream gauge has not been considered herein.

The stream gauge structure/setup differs between stream gauge locations as a result of the location and timing of installation. Overall, the water level data obtained from the stream gauges is measured from the base of the creek bed to the top of the standing water. However, some water levels are calculated based on the amount of standing water at the stream gauge location, whilst some gauges have acoustic sensors installed that measure the water level. There are also v-notch structures installed at some locations that are used to calculate water level, but these structures are not present at all stream gauges. Therefore, whilst the water level data is useful, the potential variability and uncertainty created by the different methods of measuring water level and the different structure types in place at each location indicate that it is more useful to rely on the trends in water level data rather than absolute water level differences across the network.

3.3 Data Quality, Quantity and Limitations

Samples of surface water and sediment have been collected from Boundary Creek, Big Swamp (surface water only) and the Barwon River to support evaluation of impacts from environmental stressors. The location, period of record, number of samples and analytical suite (including water quality data for surface water samples) are presented in **Table 3.2** to **Table 3.5**, noting that **Table 3.3** and **Table 3.4** provide a more detailed breakdown of the number of samples analysed for soluble and total metals. The sample locations presented in **Table 3.2** to **Table 3.5** are a combination of stream gauge locations and locations sampled during the macroinvertebrate sampling conducted by Austral Research and Consulting (**Figure 2.9** and **Figure 2.10**).

It is noted that no analytical data has been collected from stream gauge 233231 (Boundary Creek upstream of the private onstream dam) to date; therefore no comparison of metals concentrations to adopted screening values could be undertaken.

Table 3.2: Summary of Quantity of Surface Water Data

Location	Total number of samples	Number of samples that have results for these measurements										No. of samples per metal analyte		
		Water level	Discharge	pH	Temp	EC	Acidity (as CaCo3)	Alkalinity (as CaCO3)	Dissolved Oxygen (DO)	Turbidity (field)	Organics (N, P, C)	Soluble Metals[1]	Total Metals[2]	Assess against guideline values
Boundary Creek														
Gauge 233231 Boundary Creek upstream of Private Onstream Dam (1989 – 2022)	4431	4431	4414	-	2713	2576	-	-	-	-	-	-	-	N
Gauge 233229; ME 5.1 Boundary Creek downstream of Private Onstream Dam (1989 – 2022)	4481	4481	4451	2947	2743	2742	-	1	1	1	-	1	-	Y
Gauge 233275; ME 5.2 Boundary Creek upstream of Big Swamp (2019 – 2022)	1169	1168	1167	1158	1097	1109	69	36	1	34	35-36	34-35	2	Y
Big Swamp (BS) (2022)	1	-	-	1	1	1	-	1	1	1	-	1		Y
Gauge 233276 Boundary Creek downstream of Big Swamp (2019 – 2022)	1183	1182	1163	1066	92	923	69	35	35	34	35	35	2-35	Y
233228_5_B79_BCY_BCatForrestRd Boundary Creek Yeodene (1979 – 2022)	16235	13117	13595	2961	2547	2467	27	14	84	14	14	14-82	7-19	Y
Barwon River														
ME 4 Barwon River upstream Boundary Creek (2019 – 2022)	6	-	-	6	6	6	-	6	6	6	-	6	-	Y
Gauge 233233; ME 6; Barwon River 100 m downstream Boundary Creek Confluence	6	-	-	6	6	6	-	6	6	6	-	6	-	Y

(2019 – 2022)														
ME 7 Barwon River at north boundary of plantation (2019 – 2022)	6	-	-	6	6	6	-	6	6	6	-	6	-	Y
ME 1-3; Barwon River upstream Boundary Creek (2016 – 2022)	118	-	-	115	116	49	-	2	83	18	--	23-105	5-7	Y
ME 8-12; Barwon River downstream Boundary Cree (2016 – 2022)	522	-	-	511	511	511	-	36	351	30	-	54-460	24	Y

EC = Electrical Conductivity; N = Nitrogen, P = Phosphorus, C = Calcium

1. Expanded in Table 3.3.
2. Expanded in Table 3.4.

Table 3.3: Summary of Quantity of Surface Water Data - Dissolved/Soluble Metals

Location	Al[1]	**Al**	**Sb**	**As**	Ba	Be	Bo	**Cd**	**Cr**	Co	**Cu**	**Fe**	**Pb**	**Mn**	**Hg**	Mo	Ni	**Se**	**Ag**	Sr	Sn	Th	Ti	Va	**Zn**
Boundary Creek																									
Gauge 233229; ME 5.1 Boundary Creek downstream of Private Onstream Dam	-	1	1	1	-	-	-	1	1	-	1	1	1	1	1	-	-	1	1	-	-	-	-	-	1
Gauge 233275; ME 5.2 Boundary Creek upstream of Big Swamp	-	36	36	36	35	35	35	36	36	35	36	35	36	36	36	35	35	36	36	35	35	35	35	35	36
Big Swamp	-	1	1	1	-	-	-	1	1	-	1	1	1	1	1	-	-	1	1	-	-	-	-	-	1
Gauge 233276 Boundary Creek downstream of Big Swamp	-	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35	35
233228_5_B79_BCY_BCatForrestRd Boundary Creek Yeodene	82	28	21	21	14	14	14	21	21	14	21	44	21	37	21	14	14	21	21	14	14	14	14	14	28
Barwon River																									
ME 4 Barwon River upstream Boundary Creek	-	6	6	6	-	-	-	6	6	-	6	6	6	6	6	-	-	6	6	-	-	-	-	-	6
Gauge 233233; ME 6; Barwon River 100 m downstream Boundary Creek Confluence	-	6	6	6	-	-	-	6	6	-	6	6	6	6	6	-	-	6	6	-	-	-	-	-	6

Location	Al[1]	Al	Sb	As	Ba	Be	Bo	Cd	Cr	Co	Cu	Fe	Pb	Mn	Hg	Mo	Ni	Se	Ag	Sr	Sn	Th	Ti	Va	Zn
ME 7 Barwon River at north boundary of plantation	-	6	6	6	-	-	-	6	6	-	6	6	6	6	6	-	-	6	6	-	-	-	-	-	6
ME 1-3; Barwon River upstream Boundary Creek	-	105[2]	23	23	-	-	-	23	23	-	23	105[2]	23	104[2]	23	-	-	23	24	-	-	-	-	-	24
ME 8-12; Barwon River downstream Boundary Creek	430	54	54	54	-	-	-	54	54	-	54	460	54	455	54	-	-	54	54	-	-	-	-	-	57

1. Acid soluble.
2. 82 samples collected between 05/07/2016 and 26/10/2022 metal analysis consisted of only Al, Fe and Mn.

Table 3.4: Summary of Quantity of Surface Water Data - Total Metals

	Al	Sb	As	Ba	Be	Bo	Cd	Cr	Co	Cu	Fe	Pb	Li	Mn	Hg	Mo	Ni	P	Se	Si	Ag	Sr	Sn	Th	Ti	Va	Zn	St1[1]	St2[2]	St3[3]
Gauge 233275; ME 5.2 Boundary Creek upstream of Big Swamp	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	36		
Gauge 233276 Boundary Creek downstream of Big Swamp	2	2	2	2	2	2	2	2	2	2	35	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	35		
233228_5_B79_BCY_BCatForrestRd Boundary Creek Yeodene	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	14		
ME 1-3; Barwon River upstream Boundary Creek				5	5	5			5				5			5	5	5		5		5	5	5	5	5			2	5
ME 8-12; Barwon River downstream Boundary Creek				24	24	24			24				24			24	24	24		24		24	24	24	24	24			6	24

1. St1 – Analysis suite which includes Ca, Na, Mg, K, Cl, SO_4 , reactive phosphorus, ammonia as N, nitrate as N, nitrite as N, alkalinity (bicarbonate, carbonate, hydroxide, total (as $CaCO3$)), biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved organic carbon (DOC), total dissolved solids (TDS), total kjedhal nitrogen, total nitrogen as N, total organic carbon (TOC), total oxidised nitrogen, total phosphorus as P
2. St2– Analysis suite which includes Cl, SO_4, alkalinity (bicarbonate, carbonate, hydroxide, total (as $CaCO3$)), sulfur.
3. St3– Analysis suite which includes Ca, Na, Mg, K, SO_4,

Table 3.5: **Summary of Quantity of Sediment Data**

Location	Number of Samples		Analytical Suite
Boundary Creek	**0 – 20 cm below surface**	**20 – 40 cm below surface**	
233228_5_B79_BCY_BCatForrestRd Boundary Creek Yeodene	1	1	pH, aluminium, antimony, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, selenium, silver, zinc
Barwon River			
ME 1-4; Barwon River upstream Boundary Creek	4	4	pH, aluminium, antimony, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, selenium, silver, zinc
Gauge 233233; ME 6; Barwon River 100 m downstream Boundary Creek Confluence	1	1	
ME 7-12; Barwon River downstream Boundary Creek	6	6	

The data obtained from the sample locations listed for Boundary Creek, Big Swamp and the Barwon River provide suitable spatial coverage of the area of interest in this ERA. However, it is noted that water quality data is not available for Boundary Creek and Big Swamp prior to the installation of the private onstream dam and extraction of groundwater from the Barwon Downs borefield.

Given the timeframes over which stressors and impacts have occurred there is limited data to support temporal trends across the range of climate scenarios that may have occurred or that may occur in the future. Therefore, the outcomes of the ERA are considered to provide an indication of current and short-term risks, but may not reflect risks under climatic conditions that may occur in the future.

Whilst there are limited sediment samples collected from Boundary Creek, variability in sediment quality is likely to be much lower than that of the surface water within Boundary Creek and the Barwon River. Therefore, this ERA has focused primarily on evaluating the potential for unacceptable risks to ecological receptors associated with surface water impacts, with sediment data providing a secondary line of evidence to support an understanding of potential metals deposition. Therefore, despite the limitations the available sediment data are considered suitable to support the ERA outcomes.

Whilst noting the limitations identified in the data, and the absence of site-specific toxicity data (considered necessary for a Definitive ERA), overall the quantity of data available is considered to be suitable to support the outcomes of this ERA for the exposure scenarios considered herein.

The data quality was evaluated to determine if it was suitable for use in the ERA. The findings of the data quality evaluation was as follows:

- Flow, water level, temperature, EC and pH were measured at the stream gauges every 15 minutes, then daily averages were collected and verified by ALS Laboratories (ALS) and uploaded to the Water Measurement Information System (WMIS);
- Monthly sampling was (and continues to be) conducted from the stream gauges by ALS and analysed for analytes as listed in Table 3.2;
- Water quality data was collected during the biannual macroinvertebrate sampling conducted by Austral Research and Consulting (Austral, 2022 and Austral, 2023). The reports provided by Austral Research and Consulting do not indicate what data quality assurance and quality control analysis was undertaken, and no laboratory reports are provided, therefore no evaluation of the quality of the analytical data can be undertaken herein. However, Austral Research and Consulting do state that samples were preserved and kept refrigerated prior to delivery to ALS; and
- Sediment sampling was conducted by Austral Research and Consulting during macroinvertebrate sampling. Whilst no report has been provided, it is understood that Austral Research and Consulting are likely to have followed the same sample handling protocol (e.g. sample refrigeration prior to delivery to the laboratory) as reported for surface water sampling and provided the samples to ALS for analysis.

The water and sediment quality data provided by Barwon Water has not been verified for its quality. However, as the analytical data has been verified and reported by ALS Laboratories, which is a National Association of Testing Authorities (NATA) accredited laboratory for the analyses conducted, it is considered that the surface water and sediment quality data is of acceptable quality and is representative of the conditions in Boundary Creek, Big Swamp and the Barwon River at the time of sampling. Therefore, the data were considered to be suitable for use in the ERA.

It is noted that there are some data limitations that have potential to impact on the outcomes of the ERA. The data limitations are summarised in Table 3.6, along with a description of the method used to address these data limitations in the ERA.

Table 3.6: Data Limitations

Data Limitation	Potential Impact on Risk Assessment Outcome	Approach Adopted in the ERA
Limited sediment chemistry data within Boundary Creek, Big Swamp and the Barwon River	Increased uncertainty associated with sediment impacts and potential risks to ecological receptors.	The ERA will assume: • That the reported concentrations in sediment provide an indication as to potential exposures for ecological receptors.
No metals and acidity (pH) data was available for Boundary Creek, Big Swamp and the Barwon River prior to the Millennium Drought, construction of the private onstream dam, and groundwater extraction from the Barwon Downs borefield.	Uncertainty as to what 'natural' water quality conditions were present prior to the introduction of significant environmental stressors.	Evaluation of the degree of change between pre-disturbance and post-disturbance water quality will need to be based on theoretical data for peat swamps and other waterways in the region (where available and relevant).
No reference data for a similar Victorian environment (e.g. pH, water quality)	Limited ability to evaluate what 'natural' conditions look like in Big Swamp	The ERA will evaluate the available data and make assumptions about 'natural' conditions.
No recent fish survey data (it is understood that no fish survey has been completed within the last 20+ years)	Some increased uncertainty in risk outcomes	A multiple lines of evidence approach will be adopted to evaluate: • Habitat availability for fish and other aquatic species. • Potential impacts associated with metals and acidity/pH on aquatic organisms (including fish) • Impacts of physical stressors present (including fish migration impediments)
Limited water flow data from prior to construction of the private onstream dam	Increased uncertainty in risk outcomes associated with physical disturbances to the aquatic environment	The ERA will assume that the construction of the private onstream dam has contributed to the physical disturbance of Boundary Creek and Big Swamp, and to the increased frequency of cease to flow events in the system.

Overall, based on the data quality review, a number of data limitations were identified, including the limited number of sediment samples collected to date. However, despite the identified data limitations, the available data was considered to be of suitable quality and quantity to support evaluation of risks to Big Swamp, Boundary Creek (downstream of Big Swamp) and the Barwon River (downstream of Boundary Creek confluence) associated with the presence of acidity (low pH) and dissolved metals.

3.4 Surface Water Flows

Surface water flow data has been collected at the various stream gauges within Boundary Creek upstream and downstream of Big Swamp. **Table 3.7** provides a summary of the flow readings available for each relevant stream gauge. The data has been split into pre- and post-2019 as stream gauges 233275 and 233276 were installed more recently and thus there is no flow data available for these gauges for pre-2029.

Table 3.7: Summary of Available Flow Data

	233231	233229, ME 5.1	233275, 5.2	233276	233228, ME5
Pre 2019					
Total Number of Flow Readings	3122	3148	No data available	No data available	12409
Minimum Recorded Flow (ML)	0.01	0.01			0.01
Maximum Recorded Flow (ML)	583.56	463.05			484.28
Date of Maximum Recorded Flow	14/09/2016	14/09/2016			14/09/2016
Flow Recording - 10th Percentile (ML)	0.43	0.387			0.32
Flow Recording - 50th Percentile (ML)	2.875	2.87			2.85
Flow Recording - 90th Percentile (ML)	23.909	24.52			24.98

	233231	233229, ME 5.1	233275, 5.2	233276	233228, ME5
2019 onwards					
Total Number of Flow Readings	1292	1304	1167	1163	1186
Minimum Recorded Flow (ML)	1.08	0.06	0.01	0.01	0.01
Maximum Recorded Flow (ML)	185.51	126.6	63.55	92.45	258.61
Date of Maximum Recorded Flow	9/10/2020	9/10/2020	9/10/2020	23/08/2020	9/10/2020
Flow Recording - 10th Percentile (ML)	1.70	1.13	0.41	0.19	0.57
Flow Recording - 50th Percentile (ML)	2.98	3.11	2.45	2.43	4.41
Flow Recording - 90th Percentile (ML)	13.94	15.10	18.28	17.02	23.53

Note: A rainfall event of 42mm was recorded on 14 September 2016

The surface water flow data has been used in the ERA as part of a multiple lines of evidence approach. This data provides an understanding of the presence of surface water within Boundary Creek and Big Swamp and enables an evaluation of the impact of the presence of the private onstream dam on Boundary Creek and Big Swamp.

3.5 Biological Data

The ERA considered macroinvertebrate, vegetation and fish survey data collected from Boundary Creek, Big Swamp and the Barwon River (macroinvertebrate data only).

The vegetation survey outcomes are presented in Section 2.4.1, the macroinvertebrate survey outcomes are presented in Section 2.4.2 and the available fish survey data is presented in Section 2.4.3. The following conclusions are provided with regard to the quality and quantity of biological data for use in the ERA:

- Macroinvertebrate sampling has been conducted during spring and autumn between spring 2019 and spring 2022 (four (4) years of monitoring). Whilst some additional sites have been added during the most recent spring sampling event, the remaining sampling locations have multiple (seven (7)) rounds of data available to support an understanding of conditions at each sampling location over time.
- Vegetation survey data from Big Swamp has been collected by ELA in 2019, 2020 and 2022. However, ELA only established the quadrat sample locations during the 2020 survey to enable measurement of diversity of understorey species across the swamp plain. Therefore, only two (2) rounds of quadrat data was available for use in the ERA.
- Fish survey data compiled by Jacobs (2017) provided an indication of the potential presence of fish species within Boundary Creek. However, no field based fish survey data was collected by Jacobs to validate the findings of their assessment.

Overall, the quantity of biological data available to support the ERA is limited, but it provides an indication of the current health of Boundary Creek and Big Swamp.

4 Chemicals of Potential Concern

4.1 Tier 1 Guideline Values

To support selection of chemicals of potential concern (CoPC) for inclusion in the ERA, reported chemical concentrations in surface water and sediment were screened against default guideline values (DGV) published in the *Australian and New Zealand Water Guidelines for Fresh and Marine Water Quality* (ANZG, 2018). Based on the site setting information (Section 2) and the level of protection of waterways in the Central Foothills and Coastal Plains segment in accordance with the ERS, 95% species protection was adopted for DGV selection, unless otherwise recommended by ANZG (2018), as noted in **Table** 4.1.

Table 4.1: Tier 1 Guideline Values

Chemical	Guideline value (mg/L unless otherwise stated)	Level of Protection Adopted – Reliability of DGV
pH	≥6.8 - ≤8.0 (pH units)	Environment Reference Standard (ERS) central foothills and coastal plains
Aluminium	0.055 (pH >6.5) 0.0008 (pH <6.5)	Freshwater 95% Species Protection – low reliability (pH >6.5), unknown reliability (pH <6.5)
Arsenic	0.024 (AsIII) 0.013 (AsV)	Freshwater 95% Species Protection – moderate reliability
Barium	No DGV available	-
Beryllium	0.00013	Indicative interim working level recommended in ANZECC/ARMCANZ (2000) based on an environmental concern level from USEPA.
Boron	0.94	Freshwater 95% Species Protection – very high reliability
Cadmium	0.0002	Freshwater 95% Species Protection – very high reliability
Chromium	0.001 (CrVI) 0.0033 (CrIII)	Freshwater 95% Species Protection – very high reliability (CrVI), unknown reliability for CrIII value.
Cobalt	0.0014	Freshwater, unknown level of species protection – unknown reliability
Copper	0.0014	Freshwater 95% Species Protection – very high reliability
Iron	0.3	CCREM (1987 – as recommended by ANZG (2018)
Lead	0.0034	Freshwater 95% Species Protection – moderate reliability
Manganese	1.2	Freshwater 99% Species Protection – adopted to protect more sensitive species as recommended by ANZG (2018)
Mercury	0.0001	Freshwater 99% species protection (inorganic mercury) – higher level of protection adopted to account for bioaccumulation of this compound – moderate reliability
Molybdenum	0.034	Freshwater, unknown level of species protection – unknown reliability
Nickel	0.011	Freshwater 95% species protection – low reliability
Selenium	0.005 (0.011 – 95% species protection)	Freshwater 99% species protection – higher level of protection adopted to account for bioaccumulation of this compound – moderate reliability
Silver	0.00005	Freshwater 95% Species Protection – high reliability
Strontium	No DGV available	-
Thallium	0.00003	Freshwater, unknown level of species protection – unknown reliability
Titanium	No DGV available	-
Vanadium	0.006	Freshwater, unknown level of species protection – unknown reliability
Zinc	0.008	Freshwater 95% Species Protection – very high reliability

4.2 Sediment

There is limited available sediment data for Big Swamp, Boundary Creek and the Barwon River (**Table 4.2**). What data were available were screened against available sediment quality guideline values in ANZG (2018). There are no sediment quality guideline values in ANZG (2018) for aluminium, cobalt, iron and manganese.

Of the detected metals in sediment, only arsenic was reported to exceed its DGV in four (4) of 24 samples. The arsenic exceedances (21 – 27 mg/kg) were only marginally above the default guideline value (20 mg/kg), with two (2) samples from downstream in Barwon River outside the likely influence of Boundary Creek (sites 8 and 10 which are greater than 2 km downstream of the confluence on Boundary Creek). Mercury was also detected marginally above the adopted default guideline value in the deeper sediment sample collected from Boundary Creek.

Given the low reported metals concentrations in available metals samples and lack of exceedances of adopted guideline values, it was considered appropriate to base the evaluation of risks on the available surface water data without further consideration of sediment data.

Table 4.2: Summary of Sediment Data and Default Guideline Values

	Reported Concentration Range (mg/kg) (sediment sampled from 0 – 40 cm depth)		Default Guideline Value (mg/kg)
	Boundary Creek (n = 2)	Barwon River (n = 22)	
Aluminium	32,000	7,000 – 46,000	None available
Antimony	<10	<10	None available
Arsenic	**23 – 27**	3.2 - 25	20
Cadmium	<0.4	<0.4	1.5
Chromium	43 - 44	11 - 40	80
Copper	10 - 12	<5 - 26	65
Iron	40,000 – 73,000	14,000 – 60,000	None available
Lead	12 - 43	7.1 - 23	50
Manganese	50 - 58	180 – 1,300	None available
Mercury	0.1 – **0.3**	<0.1 – 0.1	0.15
Selenium	<2	<2	None available
Silver	<0.2	<0.2	1
Zinc	81 - 120	24 - 100	200

4.3 CoPC Selection

Based on the available information, the key chemical group of interest is metals, which appear to be mobilised from stream sediments and underlying soils by the acidity being generated in Big Swamp. To evaluate which metals may be present as a result of the acidity in Big Swamp, the proportion of samples in which each of the metals detected above the laboratory limit of reporting (LOR) was evaluated and is presented in **Table 4.3**. Based on this evaluation, it was observed that aluminium, arsenic, barium, beryllium, boron, cobalt, iron, manganese, nickel, selenium, strontium and zinc are present at concentrations above the laboratory's LOR in greater than 20% of samples collected from downstream of Big Swamp (at stream gauges 233276 and 233228). Whilst some of these metals are also present at concentrations above the laboratory's LOR in more than 20% of samples within Boundary Creek both upstream and downstream of Big Swamp, and in the Barwon River both upstream and downstream of the confluence with Boundary Creek, evaluation of the reported metals concentrations against the DGVs was undertaken to determine which metals should be carried through the ERA process.

Based on comparison with the Tier 1 guideline values and consideration of upstream detections of metals, the following metals were identified as being present at elevated concentrations:

- Aluminium
- Cobalt
- Iron
- Manganese
- Nickel
- Zinc

Figure 4.1 presents the average concentrations of these metals both upstream and downstream in Boundary Creek and the Barwon River.

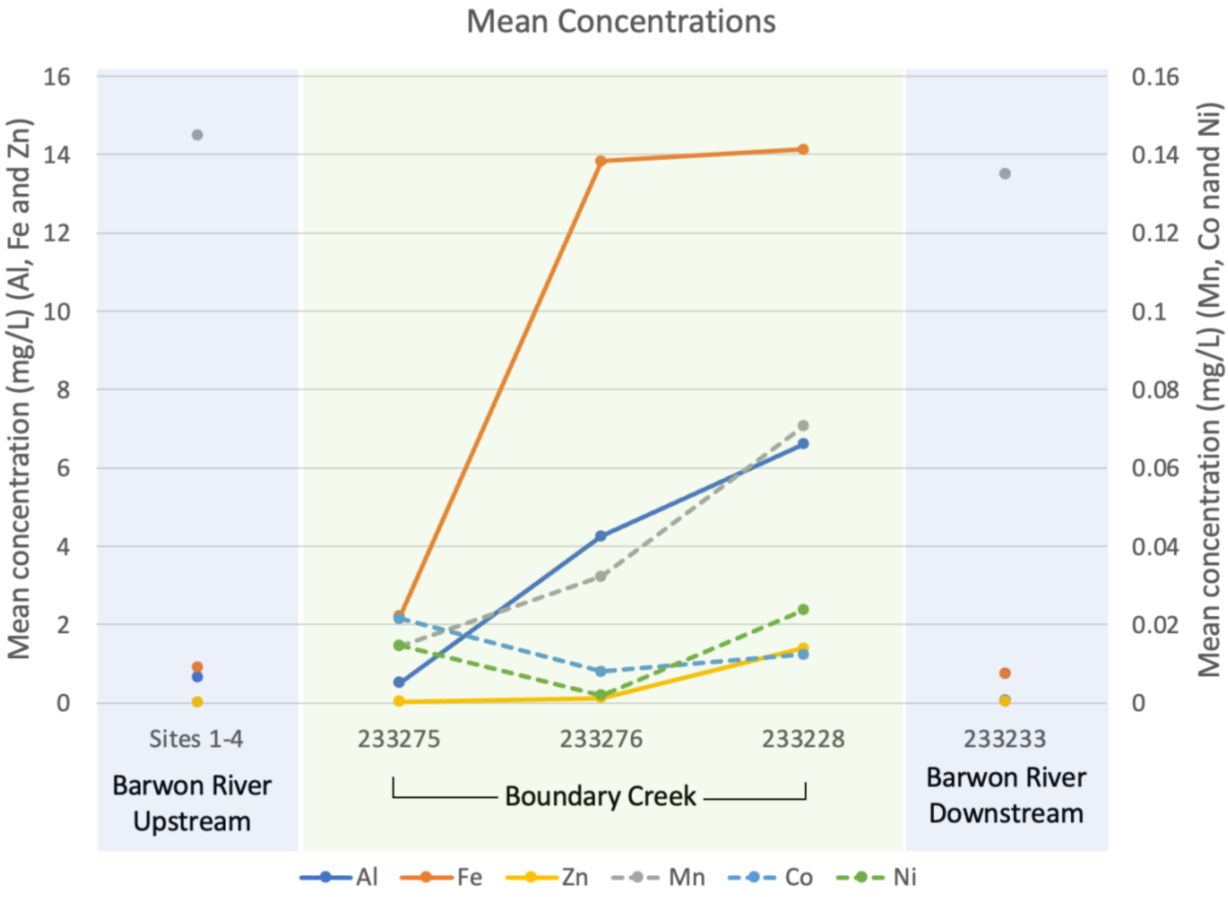

Figure 4.1: Average Key Metals Concentrations in Barwon River and Boundary Creek

A number of metals were detected but not considered further as part of the ERA for the following reasons:

- No Tier 1 guideline values are available for barium and strontium in the *Australian and New Zealand Water Guidelines for Fresh and Marine Water Quality* (ANZG, 2018). In addition, no upstream data exists for these metals in Boundary Creek and the Barwon River to enable an understanding of catchment wide impacts. Therefore, these metals have not been considered further in the ERA.
- Comparison of the range of detected arsenic and boron concentrations in surface water samples with ANZG (2018) 95% species protection values did not identify any exceedances.
- The DGV for beryllium is less than the laboratory LOR, however beryllium was only detected in ten (10) of 35 samples. Less than 30% of samples returned a result above the LOR (refer **Table 4.3**) at stream gauge 233276, directly downstream of Big Swamp, and it was not detected at stream gauge 233228 (Boundary Creek at Colac Forrest Road). Therefore, it is unlikely to contribute to increased risks to ecological receptors in Boundary Creek.
- Selenium was reported above the adopted DGV in only three (3) of 35 samples at stream gauge 233276, and it was not reported above the DGV at stream gauge 233228. In addition, selenium was detected above the LOR in samples at stream gauge upstream and downstream of Big Swamp (refer **Table 4.3**), indicating some catchment inputs of selenium into Boundary Creek.

Appendix B contains a summary of the sample numbers and reported concentration ranges for the key metals identified to be carried through the ERA process.

Groundwater data was not analysed and screened against Tier 1 guideline values as the surface water DGVs apply to aquatic receptors within the surface water environment. In addition, based on the current understanding of the shallow groundwater – surface water interactions that occur within Big Swamp, it was considered most relevant to evaluate risks based on surface water and sediment data as it characterises the actual conditions to which surface water receptors are exposed.

The reported metals of concern in surface water have also been evaluated in sediments within Boundary Creek and the Barwon River is presented in **Table 4.4**. No exceedances of adopted DGVs (ANZG, 2018) were identified for the surface water metals of concern. Whilst DGVs were not available for aluminium, iron and manganese, concentrations between upstream and downstream of the Boundary Creek confluence in the Barwon River were comparable (i.e within the same order of magnitude).

Table 4.3: Occurrence of metal detection above limit of detection (percent) when the number of samples is greater than 5

	Percent (%) of samples above limit of detection																							
Location	**Al**	**Sb**	**As**	Ba	Be	Bo	**Cd**	**Cr**	Co	**Cu**	**Fe**	**Pb**	**Mn**	**Hg**	Mo	Ni	**Se**	**Ag**	Sr	Sn	Th	Ti	Va	**Zn**
ME 1-3; Barwon River upstream Boundary Creek	85.5	17.4	4.3	-	-	-	4.3	4.3	-	0.0	99.0	4.3	99.0	0.0	-	-	0.0	0.0	-	-	-	-	-	62.5
ME 4; Barwon River upstream Boundary Creek	33.3	16.7	0.0	-	-	-	0.0	0.0	-	16.7	100	0.0	100	0.0	-	-	0.0	0.0	-	-	-	-	-	66.7
Gauge 233275; ME 5.2 Boundary Creek upstream of Big Swamp	74.3	2.86	11.4	100	2.86	22.9	2.86	5.71	5.71	5.71	100	2.86	94.3	0.00	0.00	34.3	8.57	14.3	100	5.71	5.71	28.6	14.3	51.4
Gauge 233276 Boundary Creek downstream of Big Swamp	100	5.71	45.7	100	28.6	22.9	17.1	11.4	85.7	14.3	100	8.57	100	0.00	2.86	91.4	42.9	14.3	100	8.57	0.00	5.71	11.4	97.1
Gauge 233228; ME 5 Boundary Creek at Forrest Rd, Yeodene	99.1	9.52	38.10	100	0.00	35.7	4.76	4.76	92.9	4.76	97.7	14.3	97.3	0.00	7.14	92.9	38.1	9.52	92.9	0.00	0.00	7.14	14.3	100
Gauge 233233; ME 6; Barwon River 100 m downstream Boundary Creek Confluence	66.7	16.7	0.0	-	-	-	0.0	0.0	-	16.7	100	0.0	100	0.0	-	-	0.0	0.0	-	-	-	-	-	66.7
ME 7; Barwon River at north boundary of plantation	83.3	16.7	0.0	-	-	-	0.0	0.0	-	33.3	100	0.0	100	0.0	-	-	0.0	0.0	-	-	-	-	-	83.3
ME 8-12; Barwon River downstream Boundary Creek	96.1	5.6	5.6	-	-	-	0.0	0.0	-	9.3	98.9	0.0	99.3	0.0	-	-	0.0	1.9	-	-	-	-	-	68.4

Table 4.4: Data Summary for CoPC – Sediment (0-20cm)

Metal of interest	Number of samples	Number of detects	Number in exceedance	Guideline Value (mg/kg) **	Range (Min – Max)	Mean
ME 1-4; East Barwon and West Barwon River upstream of Boundary Creek						
Aluminium (mg/kg)	4	4	0	N/A	14,000 – 22,000	13,850
Arsenic (mg/kg)	4	4	0	20	3.2 - 4.9	3.8
Copper (mg/ kg)	4	4	0	65	9.6 - 15	12.6
Iron (mg/ kg)	4	4	0	N/A	23,000 – 30,000	27,750
Manganese (mg/kg)	4	4	0	N/A	540 – 1,300	857.5
Zinc (mg/kg)	4	4	0	200	56 - 74	64.3
Gauge 233228; ME 5; Boundary Creek at Forrest Rd, Yeodene						
Aluminium (mg/kg)	1	1	0	N/A	32,000	32,000
Copper (mg/kg)	1	1	0	65	12	12
Iron (mg/kg)	1	1	0	N/A	73,000	73,000
Manganese (mg/ kg)	1	1	0	N/A	50	50
Zinc (mg/ kg)	1	1	0	200	120	120
Gauge 233233; ME 6; Barwon River 100 m downstream Boundary Creek Confluence						
Aluminium (mg/ kg)	1	1	0	N/A	26,000	26,000
Copper (mg/ kg)	1	1	0	65	12	12
Iron (mg/ kg)	1	1	0	N/A	33,000	33,000
Manganese (mg/ kg)	1	1	0	N/A	470	470
Zinc (mg/ kg)	1	1	0	200	78	78
ME 7-12; Barwon River downstream of Boundary Creek Confluence						
Aluminium (mg/ kg)	6	6	0	N/A	7,000 - 37,000	15,883
Copper (mg/ kg)	6	5	0	65	6.7-26	11.3

Metal of interest	Number of samples	Number of detects	Number in exceedance	Guideline Value (mg/kg) **	Range (Min – Max)	Mean
Iron (mg/ kg)	6	6	0	N/A	14,000 - 56,000	33,500
Manganese (mg/ kg)	6	6	0	N/A	280 - 860	476.7
Zinc (mg/ kg)	6	6	0	200	24 - 75	47.5

Note: No cobalt and nickel analysis were conducted on sediment samples collected to date

** Values from ANZG (2018) Default Guideline Values (DGV)

5 Exposure Assessment

5.1 Exposure Point Concentration Selection

An exposure point concentration (EPC) is the concentration of a contaminant in the medium to which a receptor population is exposed, at the point of exposure (NEPC, 2013). The ASC NEPM (NEPC, 2013) sets out a number of approaches for estimating EPCs using sample data obtained from environmental investigations. For the purposes of this ERA, the available data set was analysed and the rules as presented in **Box 5.1** were applied to develop a set of EPCs considered to represent the concentration to which ecological receptors may be exposed within each reach of Boundary Creek and the Barwon River.

Box 5.1: EPC Selection Rules:

Where a compound was detected above Tier 1 guideline values it was included as a CoPC.

Where a CoPC was detected more than or equal to ten (10) times at any given sample location or waterway reach, the 95% upper confidence limit of the mean (95% UCL) was selected as the EPC.

Where a CoPC was detected less than ten (10) times at any given sample location or waterway reach, the maximum reported concentration was selected as the EPC.

The exception to the above rules was for pH, where it was considered important to evaluate risks based on both the minimum and maximum values

The basis for each EPC is presented in Appendix C, with a summary of the EPC for each location presented in **Table 5.1**. The Big Swamp location only contained one set of data (one (1) sample collected from a single location), and as such was not considered representative of the variability likely to be observed at this location. Stream gauge 233233 was only recently installed (November 2022) and thus there was only data available from the macroinvertebrate survey sampling events (six (6) samples) from that location.

ANZG (2018) recommends consideration of the 95th percentile value to evaluate risks to the aquatic environment from the presence of toxicants. The use of the 95th percentile is protective of pulse exposures to high concentrations, however for the Boundary Creek environment it was considered more relevant to understand the reasonable average exposures (95% UCL - in line with guidance provided in the ASC NEPM) given the ongoing nature of acidity and metals flushing from the Big Swamp environment. Further evaluation of the impact of the EPC selection process is provided in **Section 7.5**.

Table 5.1: Summary of EPCs

Metal of interest	pH (pH units)	Aluminium (mg/L)	Cobalt (mg/L)	Copper (mg/L)	Iron (mg/L)	Manganese (mg/L)	Nickel (mg/L)	Zinc (mg/L)
ME 1-4; East Barwon and West Barwon River upstream of Boundary Creek	5.26 8.67	0.086	N/A	N/A	1.02	N/A	N/A	0.012
Gauge 233275; Boundary Creek upstream of Big Swamp	4.00 7.84	1.12	N/A	N/A	3.48	N/A	0.0119	0.037
Big Swamp (based on	5.48	0.26	N/A	0.002	48	0.024	N/A	0.023

Metal of interest	pH (pH units)	Aluminium (mg/L)	Cobalt (mg/L)	Copper (mg/L)	Iron (mg/L)	Manganese (mg/L)	Nickel (mg/L)	Zinc (mg/L)
one sample collected in March 2022)								
Gauge 233276; Boundary Creek downstream of Big Swamp	2.9 7.0	5.86	N/A	0.003	33.55	N/A	0.05	0.17
Gauge 233228; ME 5; Boundary Creek at Forrest Rd, Yeodene	2.72 7.80	8.42	0.024	0.005	37.29	N/A	0.0306	0.15
Gauge 233233; ME 6; Barwon River 100 m downstream Boundary Creek Confluence	6.88 7.48	0.073	N/A	N/A	1.37	N/A	N/A	0.035
ME 7-12; Baron River downstream of Boundary Creek Confluence	4.3 8.1	0.36	N/A	0.01	1.74	0.149	N/A	0.018

5.2 Exposure Pathways

The hydrogeochemical model for Big Swamp (Barwon Water, 2021) describes the primary source of acidified water in Boundary Creek as the oxidation of reduced sulfides over the last 30 years, which has resulted in the movement of acidity into a number of secondary sources, including:

- Acidity stored in solid phase as minerals in the soils themselves;
- Acidity stored in groundwater resulting from the infiltration of acidic recharge/seepage; and
- Acidity stored in the pore water of soils in the unsaturated zone.

The hydrogeochemical model (Barwon Water, 2021) estimated that there are approximately 810 tonnes of acidity (as calcium carbonate ($CaCO_3$) equivalent) in the top 0.24 m of surface soils, 126 tonnes of acidity as $CaCO_3$ equivalent in groundwater and 11 tonnes of acidity as $CaCO_3$ equivalent stored in the unsaturated zone.

Based on this information, there are three (3) potential pathways for mobilisation of acidity into Boundary Creek from Big Swamp (Barwon Water, 2021):

- Acidic runoff from surface soils;
- Groundwater discharge to surface water; and
- Flushing of acidity from the unsaturated zone.

The available data with regards to the timing of acidic discharges from Big Swamp suggests that the primary mechanism by which acidity discharges to Boundary Creek is groundwater discharge from the upper groundwater flow system present in Big Swamp (Barwon Water, 2021).

Surface water sampling was undertaken within Big Swamp to evaluate water quality changes as water passed through the swamp on 7 April 2021 (Barwon Water, 2021). This study identified that the greatest increase in surface water acidity occurred in the eastern portion of Big Swamp, suggesting that increased groundwater discharge in the eastern end of the swamp was the primary pathway for acidity mobilisation into surface water at the time of the study (Barwon Water, 2021). In addition, Barwon Water have undertaken a review of acidic discharges when overland runoff was measured to be negligible (e.g. summer 2020-2021) and identified that where surface runoff contributes less than 20% of streamflow, acidity loads from Big Swamp into Boundary Creek remain high (Barwon Water, 2021). The data supported conclusions of previous studies with regard to groundwater discharges at the eastern end of Big Swamp.

Whilst the acidity discharges for Big Swamp to Boundary Creek can be attributed largely to groundwater discharges, additional factors are involved in understanding the exposure pathways for the Barwon River. This includes consideration of the proportion of inputs from Boundary Creek relative to flows in the Barwon River. Based on the available data, including conditions that occurred during the fish kill in the Barwon River, there were identified to be two key factors necessary to create high risk conditions within Barwon River (Barwon Water, 2021), these conditions were:

- Greater than 40% of the flows in the Barwon River coming from Boundary Creek AND
- Greater than 4 months of cease to flow events within Boundary Creek prior to a first flush event

Based on the review of the available data for Big Swamp and Boundary Creek, the preliminary CSM (**Section 2.3.2**) has been updated with additional detail from the data evaluation and selection of CoPCs (Chapters 3 and 4 of this report). The key exposure pathways for ecological receptors in Big Swamp, Boundary Creek and the Barwon River are related to direct exposure to CoPC derived from groundwater discharging to Big Swamp. **Figure 5.1** provides a summary of the key exposure pathways for ecological receptors.

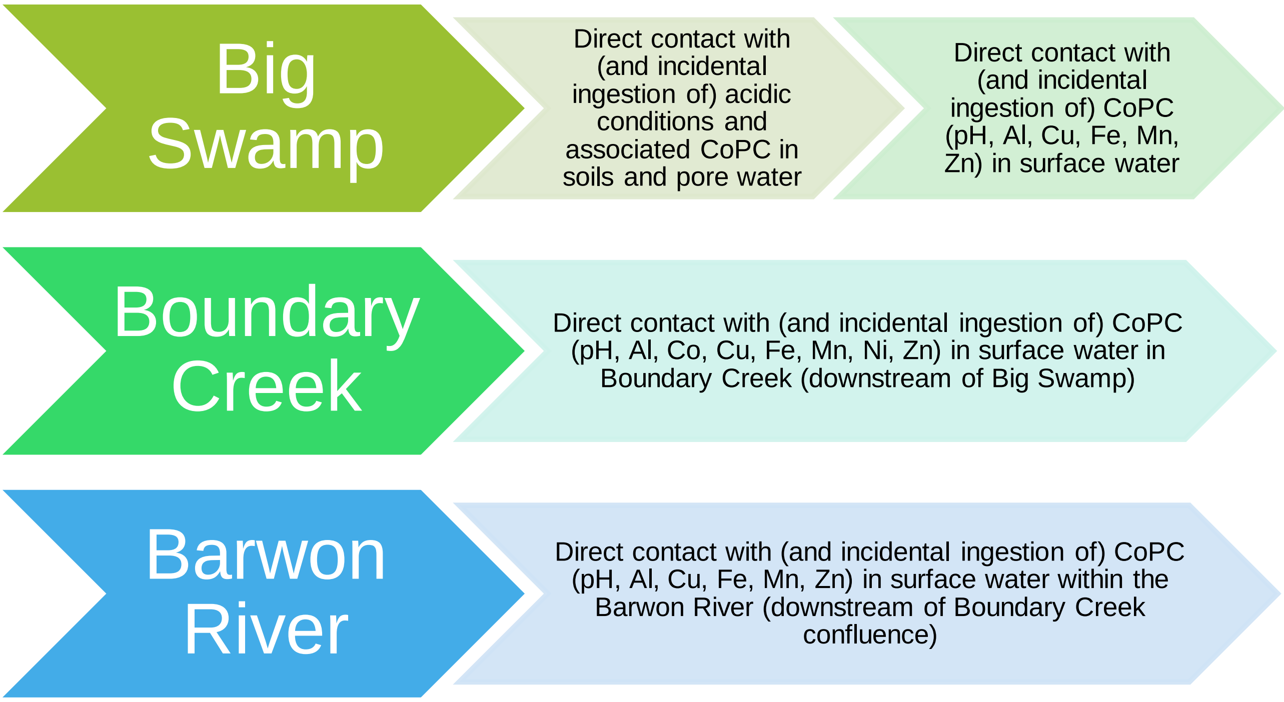

Figure 5.1: Exposure Pathway Summary

6 Toxicity Assessment

The toxicity assessment stage of an ERA involves estimating the maximum concentrations of contaminants at which no harmful effects will be experienced by species and ecological functions. To inform this evaluation, a review of the key hazards associated with each CoPC (hazard identification) has been undertaken.

6.1 Hazard Identification

Table 6.1 provides a summary of the ecological toxicity information published in ANZG (2018), but based on ANZECC & ARMCANZ (2000). This information is provided to demonstrate the types of ecologically relevant toxic effects that have been noted for the CoPCs reported in surface water in Boundary Creek, Big Swamp and the Barwon River. This information has been obtained directly from ANZG (2018), and no review of primary literature was conducted to determine where the understanding of some elements of toxicity may have changed over time.

Table 6.1: Hazards for CoPC (source: ANZG, 2018)

Metal	Key ecological toxicity points	Factors affecting toxicity
Al	• Toxicity to fish and invertebrates is increased at low (e.g. <5.5) and high pH (e.g. >9). • Aluminium is a gill toxicant to fish, causing both ionoregulatory and respiratory effects. • Among freshwater aquatic plants, single-celled plants are generally the most sensitive to aluminium. • Fish are generally more sensitive to aluminium than aquatic invertebrates	• Toxicity reduced by complexing with fluoride, citrate and humic substances. The effect of organic complexation requires experimental determination. • Toxicity is reduced in presence of silicon. • Toxicity reduced at high water hardness (high calcium concentrations). • Increased temperature may increase aluminium toxicity.
Co	• A freshwater moderate reliability trigger value could be derived for cobalt (90 µg/L with 95% protection) using the statistical distribution method, where both the 95% and 99% (30 µg/L) values were well above some experimental chronic figures, particularly for *D. magna* (between NOEC of 2.8 µg/L and LC50 of 27 µg/L). • Hence, a low reliability freshwater trigger value was derived by dividing the lowest chronic figure (2.8 µg/L) by an assessment factor (AF) of 2 (cobalt is an essential element).	• Cobalt is adsorbed to suspended particles and sediment but its solubility may be increased by complexing with organic matter, such as from sewage works. • Some aquatic organisms may accumulate cobalt, particularly some aquatic plants and benthic organisms.
Cu	• Acute toxicity of copper for ten Australian species ranged from 200 µg/L to 7800 µg/L. • Toxicity for Australian species ranged from 40 µg/L to 21,000 µg/L. • The concentrations of copper reported to cause a 50% decrease in algal growth ranged from 5 to 58,000 µg/L. The large range could be explained by the use of culture media that contain chelators and absorbents, which reduce copper toxicity. • Invertebrates, particularly marine crustaceans, corals and sea anenomes, are sensitive to copper, with concentrations of copper as low as 10 µg/L causing sublethal effects. • In general, embryos of marine fish are more sensitive than their larvae whereas larvae of freshwater fish are more sensitive than embryos. • Acute LC50 values for prawns, crabs and amphipods ranged from 100 to 1000 µg/L, with chronic values from 10 to 300 µg/L	• Copper is an essential trace element required by many aquatic organisms. • Levels of dissolved organic matter found in most freshwaters are generally sufficient to remove copper toxicity but often not in very soft waters. Speciation measurements can account for this. • Copper is adsorbed strongly by suspended material. Filtration and speciation measurements should account for this. • Copper complexing is increased at higher pH, but the relationship to toxicity is complex. • Copper toxicity in algae, invertebrates and fish generally increases as salinity decreases. • Copper can bioaccumulate in aquatic organisms but, as it is an essential element, it is commonly regulated by the organisms.
Fe	• In the presence of oxygen, iron is often found as colloidal suspensions of ferric hydroxide, which may remain	• Iron is an essential trace element for both plants and animals, required by most organisms for essential growth and

	suspended in water or settled and harden. Suspended flocs can cause problems with turbidity, decreased light penetration and smothering of benthic organisms. • Iron precipitates act as an indirect or physical stress on organisms and ecosystems rather than direct chemical toxicity. • Acute toxicity to aquatic insects has been reported at iron concentrations ranging from 320 to 16,000 µg/L.	development, and iron deficiency could cause adverse biological effects.
Mn	• Manganese is an essential trace element for microorganisms, plants and animals. It is present in natural waters in suspended form although soluble forms may persist at low pH or low DO.	• Manganese toxicity is low compared to other trace metals and toxicity to brown trout (*Salmo trutta*) decreased significantly with increasing hardness.
Ni	• Nickel is moderately toxic to freshwater organisms, with acute LC50 values ranging from 510 µg/L for a cladoceran to 43,000 µg/L for fish at low hardness. • The lowest acute toxicity to fish was 2480 µg/L. • For five (5) species of freshwater green algae, significantly decreased growth was observed at 100 µg/L at pH 7.2 • Reduced growth was noted in several freshwater algae at concentrations as low as 50 µg/L. In general, blue-green algae were more tolerant to nickel at pH 7, possibly due to production of extracellular organic compounds that bind nickel outside the cell.	• Nickel toxicity decreases with increased hardness and a hardness algorithm is available. • Toxicity of nickel increases as pH decreases. This is accounted for in the hardness algorithm. • Nickel is weakly complexed by dissolved organic matter and is less bioavailable when adsorbed to suspended material. • Bioconcentration of nickel is not a significant problem in aquatic environments. • At pH > 6, nickel adsorbs/co-precipitates with iron and manganese (oxy)hydroxides and can also adsorb to suspended organic matter. • At pH < 6, sorption is minor and nickel is considered to be highly mobile.
Zn	• Acute toxicities for Australian freshwater species exposed to zinc ranged from 140 µg/L to 6900 µg/L. • Toxicity associated with zinc exposure range from 340 to 9600 µg/L for ten Australian species. • Zinc was found to bioaccumulate in freshwater animal tissues 50 to 1130 times but bioaccumulation is not generally considered a problem for zinc. • Zinc is likely to build up in fish and other organisms, but unlikely to build up in plants.	• Zinc is an essential trace element required by many aquatic organisms. • Zinc toxicity is hardness–dependent (also alkalinity) and a hardness algorithm is available. Toxicity decreases with increasing hardness and alkalinity. • Levels of dissolved organic matter found in most freshwaters are generally sufficient to remove zinc toxicity but often not in very soft waters. Speciation measurements can account for this. • Zinc forms complexes with dissolved organic matter, the stability of which depends on pH. • Zinc is adsorbed by suspended material. Filtration and speciation measurements should account for this. There is conflicting evidence on its bioavailability after adsorption. • Zinc toxicity generally decreases with decreasing pH, at least below pH 8. Trends are complex above pH 8. • .

6.2 Acidity (pH)

This section presents the available information that was used to select a pH value to be used as a target for evaluation of risks.

Based on the available information, swamp environments tend to be more acidic than streams, creeks and rivers (refer to pH information presented in **Section 2.2.2**). In addition, the data from the palaeoecology study suggests that '*Acid conditions have prevailed at Big Swamp for some time and there is no evidence that recent water management has exacerbated water acidity.'* (La Trobe University, 2023) This information, and the presence of oxidised ASS which has generated acidity that has discharged from the upper groundwater system beneath Big Swamp, means that aquatic organisms present within Big Swamp and downstream in Boundary Creek are likely to have been exposed to variably acidic conditions in this environment for some time.

Review of the scientific literature (including a review conducted for the European Union[15] and a review by Fromm (1980)) suggests that direct toxic effects associated with acidic conditions (i.e., low pH) are the primary risk driving factor at pH <5, and with toxic effects occurring for more sensitive species between pH 5 and pH 6[16]. Fromm (1980) indicated that most fish species remain unaffected by pH as low as 5.5. Given that acidic conditions are likely to have prevailed in Big Swamp, and the potential for this acidity to discharge to Boundary Creek, the aquatic organisms in this environment are likely to have some level of acclimatisation to low pH conditions. Based on this literature information and the 75th percentile pH at stream gauge 233276 (downstream of Big Swamp, **Table 6.2**), a pH of 5.5 was used to evaluate risks to ecological receptors in Big Swamp and Boundary Creek downstream of Big Swamp. A higher pH of 6 for Barwon River was selected as:

1. biota in this reach are presumably less adapted to low pH conditions than those in the swamp, and
2. it encompasses over 90% of the reported pH conditions in Barwon River both upstream and downstream of the confluence of Boundary Creek (**Figure 6.1**).

Table 6.2: Percentiles for Surface Water pH Data

Gauge Location	Percentiles					
	90	75	50	25	10	5
233229 (downstream private onstream dam)	7.27	7.06	6.87	6.65	6.43	6.25
233275 (upstream Big Swamp)	7.35	7.07	6.79	6.41	6.12	5.93
233276 (downstream Big Swamp)	5.90	5.59	5.11	3.64	3.47	4.73
233228 (Colac Forrest Road)	5.68	4.47	3.81	3.57	3.39	3.29
Barwon River Upstream BC	7.20	7.00	6.90	6.70	6.60	6.53
Barwon River Downstream BC	7.55	7.40	7.20	6.90	6.60	6.21

15 https://www.sciencedirect.com/science/article/abs/pii/0043135469900487

16 https://www.sciencedirect.com/science/article/abs/pii/0043135469900487

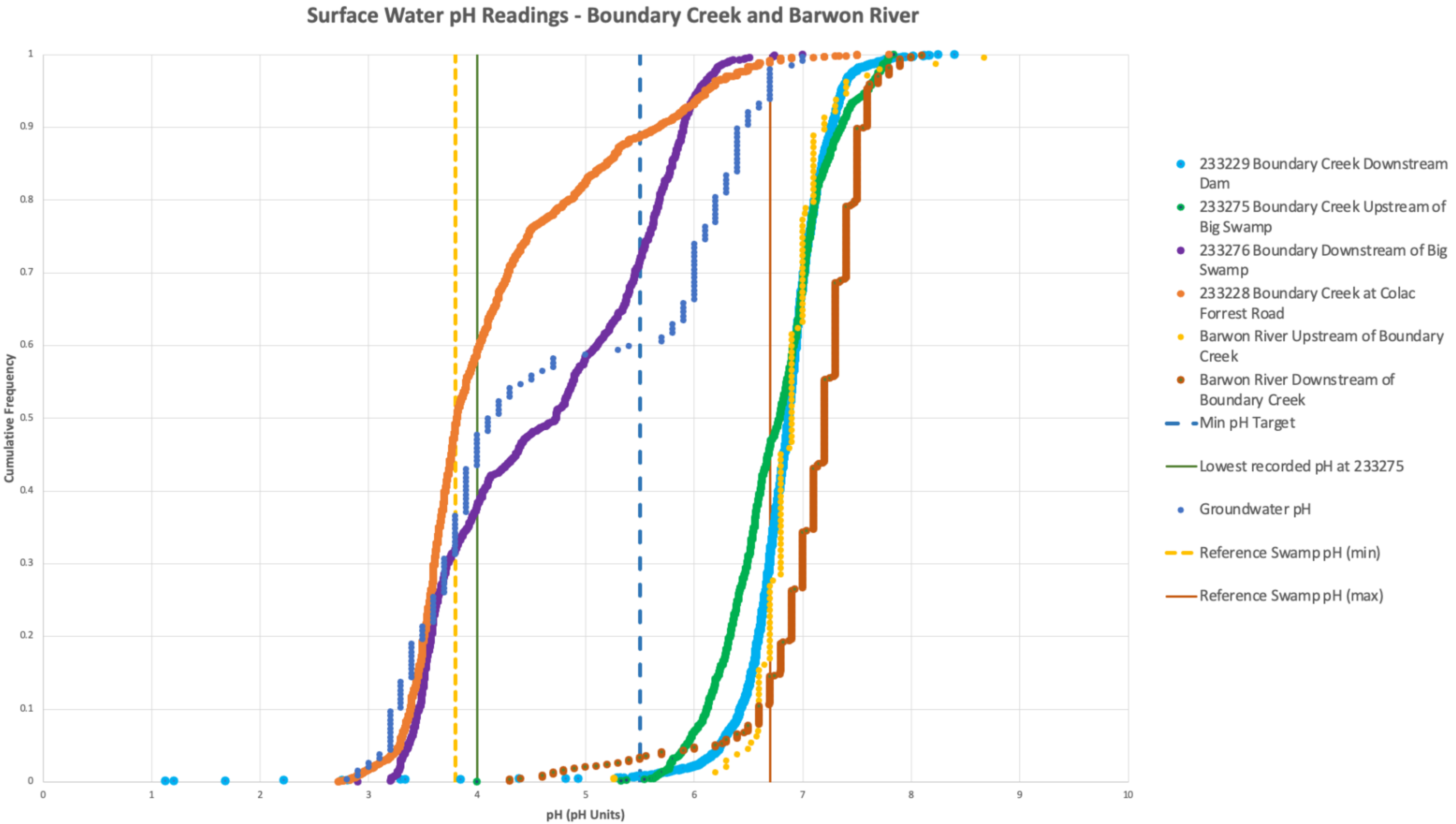

Figure 6.1: Surface Water pH Readings Boundary Creek and Barwon River

6.3 Tier 2 Guideline Values

The NEPM (NEPC, 2013) sets out a tiered approach to undertaking an ERA, with the first tier comprising the assessment of measured contaminant concentrations against DGVs. For the purposes of this ERA, the Tier 1 screening was undertaken using DGVs to support the selection of CoPC for inclusion in the ERA (Section 5.1). A review of the DGVs and recent literature with regards to guideline value derivations that incorporate more recent knowledge on metal bioavailability and toxicity was undertaken to support evaluation of risks to ecological receptors within Big Swamp, Boundary Creek and the Barwon River. **Table 6.3** presents the DGVs for each CoPC and a set of proposed Tier 2 guideline values that have been selected based on more recent literature.

Table 6.3: Tier 2 guideline values for key contaminants – surface water

CoPC	Relevant Default Aus/NZ guideline value (DGV) [a]	Relevance and justification	Tier 2 Guideline Value	Relevance and justification
pH	ERS (2021) ≥6.8 - ≤8.0	This pH range is considered to be protective of the environmental value of water dependent ecosystems and species in the Central Foothills and Coastal Plains region.	≥5.5 for Boundary Creek ≥6.0 for the Barwon River	Refer to information presented in **Section 6.2**, noting that toxic effects associated with acidity are generally observed at pH <5.
Aluminium	ANZG (2018): 0.055 mg/L (pH >6 .5) 0.0008 mg/L (pH < 6.5) • Guideline derivation is based on dissolved aluminium concentration.	These DGVs originate from ANZECC/ARMCANZ (2000) and are outdated. The DGV for pH >6.5 is based on acute toxicity data, while the DGV for pH <6.5 is based on the assessment factor method due to a lack of available data. Apart from the binary pH split, the DGVs do not account for the influence of toxicity modifying factors (TMFs) (e.g. dissolved organic carbon (DOC), hardness). In addition, neither DGV accounts for the fact that colloidal/precipitated forms of aluminium also contribute to toxicity.	ECCC (2022): 0.17 mg/L (as total Aluminium) • Guideline derivation is based on total aluminium concentration. • Representative of high bioavailability conditions, and can be adjusted depending on local water pH, hardness and DOC	The recent Canadian Guideline Value (GV) for aluminium (ECCC, 2022) accounts for (i) pH, hardness and DOC as TMFs, and (ii) the fact that both dissolved and colloidal/precipitated forms of aluminium contribute to toxicity. This is an enormous advantage over the existing DGVs for Australia/New Zealand. The Canadian approach is similar to the recent USEPA (2018) GV for aluminium, except that EC10 toxicity data were used rather than EC20 toxicity data. This makes the Canadian GV more appropriate for Australia/New Zealand. Limitations include: • No Australian species included in the derivation of the GVs; however, data for Australian species fall within the sensitivity range of the species used for the derivation; thus, the derivation can be considered to be representative of freshwater species in Australia. • The algorithms used to adjust the DGV have not been validated below pH 6.0. • Aluminium in natural freshwaters may contain a significant amount of mineralised, non-bioavailable aluminium and, thus, a total measurement will overestimate the toxic fraction. However, conversely, a dissolved

CoPC	Relevant Default Aus/NZ guideline value (DGV) [a]	Relevance and justification	Tier 2 Guideline Value	Relevance and justification
				(0.45 um filtered) sample will underestimate the toxic fraction because it does not capture bioavailable precipitated forms. Notwithstanding these limitations, the ECCC (2022) GVs are considered the most recent and most relevant GVs for aluminium in freshwater. They are applicable down to pH 6.0, so should be used with caution at pH <6.0.
Cobalt	ANZG (2018) 0.0014 mg/L	This value is an unknown reliability trigger value originating from ANZECC/ARMCANZ (2000) that was considered at the time to not be suitably representative of 95% and 99% species protection as some chronic toxicity values were below this value.	Stubblefield et al (2020) 0.0018 mg/L	Revised cobalt value derived based on acute and chronic freshwater toxicity assays performed for the purpose of deriving a guideline value. The guideline value was derived though application of the species sensitivity distribution (SSD) methodology as per ANZG (2018) and is considered to represent the most up to date value for cobalt in freshwater ecosystems.
Copper	ANZG (2018): 0.0014 mg/L Based on dissolved concentration.	Value originates from ANZECC/ARMCANZ (2000) and is outdated in that it does not capture past 20 years of knowledge nor does it account for relevant TMFs. Although a water hardness correction did originally accompany this DGV, this is no longer recommended.	Revised draft ANZG Guidelines: 0.00047 mg/L Based on dissolved concentration. Representative of high bioavailability conditions, and can be adjusted depending on local DOC	A revised ANZG DGV for copper is currently in draft, and applies a correction for DOC only. Although overseas derivations also account for pH and hardness (e.g. USEPA 2007, ECCC 2021), they have been shown to have a minor influence on copper chronic toxicity relative to DOC, within the ranges assessed. The draft ANZG DGV has been approved by the relevant technical and policy-level committees and is currently awaiting final editing before being released for public comment. Moreover, a technical report detailing the derivation and proposed DGVs has been published at https://docs.niwa.co.nz/library/public/2017105HN.pdf. The draft DGVs have not changed from the values presented in the technical report. The ANZG derivation has considered Australian freshwater species. Limitations include: • The pH range for the DGV derivation is 6.0-8.5 and, thus, it doesn't necessarily reflect low pH conditions. However, the overall effect of low pH on copper toxicity can vary (i.e. increasing or decreasing effect on toxicity) between species, making it difficult to account for in GV derivations. Notwithstanding this limitation, the ANZG (2018) draft is considered to capture the most recent knowledge on copper toxicity and has incorporated a correction for the most important TMF, DOC. They are applicable down to pH 6.0, so should be used with extreme caution at pH <6.0.
Iron	ANZECC/ARMCANZ (2000): 0.3 mg/L	Value was taken at the time from a Canadian GV and is now outdated. ANZECC/ARMCANZ (2000) recommended it only as an interim value.	Revised draft ANZG Guidelines: 0.7 mg/L	The revised draft ANZG DGV (2018) accounts for the fact that both dissolved and colloidal/precipitated forms of iron contribute to toxicity. However, it does not account for TMFs. The recent Canadian GV for iron (ECCC, 2018) does

CoPC	Relevant Default Aus/NZ guideline value (DGV) [a]	Relevance and justification	Tier 2 Guideline Value	Relevance and justification
	Based on dissolved concentrations.	Updated ANZG draft DGVs for iron have been released for public comment but have not yet been finalised and published.	Based on total concentration. Supported by ECCC (2018): 0.6 mg/L Can be adjusted depending on local water pH and DOC. Based on total concentration.	account for pH and DOC as key TMFs, and could be used to support the draft ANZG DGV. Limitations include: • The pH ranges for the draft ANZG DGV and Canadian GV are 6 – 9 and 6.5 – 8, respectively. • Iron in natural freshwaters may contain a significant amount of mineralised, non-bioavailable iron and, thus, a total iron measurement will overestimate the toxic fraction. However, conversely, a dissolved (0.45 um filtered) sample will underestimate the toxic fraction because it does not capture bioavailable precipitated forms. Because the draft ANZG and ECCC (2018) GVs are similar, the ECCC (2018) GVs can probably be used because it accounts for two key TMFs (pH, DOC) within a limited range.
Manganese	ANZG (2018): 1.9 mg/L (95% species protection) 1.2 mg/L (99% species protection) Based on dissolved concentration.	Values originate from ANZECC/ARMCANZ (2000). While they are outdated, no more recent formal GVs exist from elsewhere. The 95% species protection DGV of 1900 µg/L is accompanied by a caveat that it may not protect key test species from chronic toxicity. To address this, the 99% species protection DGV of 1,200 µg/L could be used.	None proposed	Not applicable
Nickel	ANZG (2018) 0.011 mg/L	Values originate from ANZECC/ARMCANZ (2000). New guidelines values have been proposed by Stauber et al. (2021) based on more recent toxicity data.	Stauber et al (2021) 0.003 – 0.005 mg/L Site specific water quality dependent values	The current freshwater nickel guideline value for 95% species protection is based on just 7 species from 4 taxonomic groups (as defined in Warne et al. 2018), however there is now a larger database of nickel effects both tropical and temperate freshwater biota (Scientific Committee on Health and Environmental Risks, 2011). A study conducted by Stauber et al. (2021) used the combined tropical and temperate dataset in a trophic level-specific multiple linear regressions (MLRs) model to derive a new bioavailability-based guideline values for nickel for be submitted for adoption as default guideline values for Australia and New Zealand. The study (doi.org/10.1002/etc.4885) is considered to represent the most up to date value.
Zinc	ANZG (2018): 8 µg/L	Value originates from ANZECC/ARMCANZ (2000) and includes a correction for water hardness. However, water hardness is not the key TMF for Big Swamp/Boundary Creek. This DGV is outdated and	None proposed	Not applicable

CoPC	Relevant Default Aus/NZ guideline value (DGV) [a]	Relevance and justification	Tier 2 Guideline Value	Relevance and justification
	Based on dissolved concentration. Can be adjusted to account for water hardness.	there are other more recent derivations (based on more data/knowledge) that are likely to be more appropriate. A revised ANZG zinc freshwater DGV is currently being developed, but is in too early a stage to be used. It will include corrections for key TMFs but the final details are as yet unclear. Canada derived a GV of 7 µg/L for zinc in 2018 that accounted for the key TMFs, pH, DOC and hardness. However, the TMF corrections are based on data for just one species, the rainbow trout. This would not be considered appropriate in Australia (i.e. such data should be available for multiple species) and, therefore, it is not advisable to use the Canadian GV. For zinc, it is recommended to use the ANZG (2018) DGV of 8 µg/L, corrected for hardness if necessary. However, this DGV should be used with caution for pH values <6.0.		

7 Risk Characterisation

Rick characterisation is the stage of the ERA process where the available information is compiled to support a multiple lines of evidence evaluation of the likelihood for unacceptable risks to be occurring in the environment of interest.

For this ERA the risk characterisation has considered:

- Physico-chemical conditions in Big Swamp, Boundary Creek and the Barwon River relative to selected Tier 2 guideline values;
- Biological indicators that include evaluation of vegetation communities in Big Swamp and assessment of macroinvertebrate communities in Big Swamp, Boundary Creek and the Barwon River; and
- Water level indicators in Big Swamp and Boundary Creek.

The following sections describe the outcomes of these elements as part of the risk characterisation.

7.1 Physico-Chemical Screening Outcomes

Table 7.1 provides a summary of the EPC compared to the adopted Tier 2 guideline values. Where the EPC is reported to be greater than the Tier 2 screening value there is potential for unacceptable risks to aquatic ecological receptors. The following risk outcomes are noted based on the Tier 2 screening:

- Exceedances of Tier 2 guideline values were noted at upstream sample locations in the Barwon River and Boundary Creek. This indicates that there are catchment level inputs of metals that are resulting in water quality impacts in the Barwon River and Boundary Creek that are not associated with discharges from Big Swamp. Though it should be noted that the available data does not support a conclusion as to whether the catchment level inputs are naturally elevated due to geological inputs or whether they are as a result of anthropogenic activity.
- Water quality appears to drop between macroinvertebrate sample location 6 and 7 (and beyond) within the Barwon River, however it should be noted that there are only 6 sample results available for site 6 whilst site 7 through 12 have more than 60 sample results. Therefore, it is unclear whether the results indicate a source of metals other than Boundary Creek, or if it is just an artefact of the sample size differences.
- The risk outcomes for Big Swamp are also highly uncertain given that there was only one surface water sample collected at this location.

pH within the Barwon River both upstream and downstream of the confluence with Boundary Creek has been reported to drop below 6.0 pH units (**Table 7.1**). It is unclear whether this is based on the input of natural organic acids or anthropogenic influences in the catchment; however, the presence of low pH conditions in the Barwon River suggests that the aquatic organisms may be tolerant to pH variability. As noted in **Section 2.1.2**, Big Swamp was likely an acidic environment and without any pH data from prior to the installation of the private onstream dam and the Millennium Drought, it is not possible to understand the extent to which these acidic conditions were exacerbated by the drying of the swamp over the past several decades.

Comparison of EPCs with Tier 2 Guideline Values has identified potential for unacceptable risk in the Barwon River upstream of the confluence of Boundary Creek, as well as in Boundary Creek upstream of Big Swamp ((**Table 7.1**). The available data does not enable interpretation of the source of the elevated metals concentrations in Boundary Creek and the Barwon River, however this indicates that aquatic organisms within these waterways may be adapted to elevated metals concentrations in surface water.

Table 7.1: Summary of Tier 2 Screening Outcomes

Metal of interest	Selected EPC	Tier 2 Guideline Values	Potential for Unacceptable Risk
ME 1-4; East Barwon and West Barwon River upstream of Boundary Creek			
pH (pH units)	5.26 8.67	≥6.0 – ≤8.0	Potential
Aluminium (mg/L)	0.086	0.17	Potential
Iron (mg/L)	1.0	0.7	Potential
Zinc (mg/L)	0.012	0.008	Potential
Gauge 233275; Boundary Creek upstream of Big Swamp			
pH (pH units)	4.00	≥5.5	Potential
Aluminium (mg/L)	1.1	0.17	Potential
Iron (mg/L)	3.5	0.7	Potential
Nickel (mg/L)	0.012	0.005	Potential
Zinc (mg/L)	0.037	0.008	Potential
Big Swamp			
pH (pH units)	5.5	≥5.5	Potential (based on limited data set)
Aluminium (mg/L)	0.26	0.17	Potential
Copper (mg/L)	0.002	0.00047	Potential
Iron (mg/L)	48	0.7	Potential
Manganese (mg/L)	0.024	1.2	Unlikely
Zinc (mg/L)	0.023	0.008	Potential
Gauge 233276; Boundary Creek downstream of Big Swamp			
pH (pH units)	2.9	≥5.5	Potential
Aluminium (mg/L)	5.9	0.17	Potential
Cobalt (mg/L)	0.015	0.0018	Potential
Copper (mg/L)	0.003	0.00047	Potential
Iron (mg/L)	33.6	0.7	Potential
Nickel (mg/L)	0.05	0.005	Potential
Zinc (mg/L)	0.17	0.008	Potential
Gauge 233228; ME 5; Boundary Creek at Forrest Rd, Yeodene			
pH (pH units)	2.7	≥5.5	Potential
Aluminium (mg/L)	8.4	0.17	Potential
Cobalt (mg/L)	0.016	0.0018	Potential
Copper (mg/L)	0.005	0.00047	Potential
Iron (mg/L)	37.3	0.7	Potential
Nickel (mg/L)	0.03	0.005	Potential
Zinc (mg/L)	0.15	0.008	Potential

Metal of interest	Selected EPC	Tier 2 Guideline Values	Potential for Unacceptable Risk
Gauge 233233; ME 6; Barwon River 100 m downstream Boundary Creek Confluence			
pH (pH units)	6.88	≥6.0	Unlikely
Aluminium (mg/L)	0.073	0.17	Unlikely
Iron (mg/L)	1.37	0.7	Potential
Zinc (mg/L)	0.035	0.008	Potential
ME 7-12; Barwon River downstream of Boundary Creek Confluence			
pH (pH units)	4.3	≥6.0	Potential
Aluminium (mg/L)	0.36	0.17	Potential
Copper (mg/L)	0.01	0.00047	Potential
Iron (mg/L)	1.74	0.7	Potential
Manganese (mg/L)	0.15	1.2	Unlikely
Zinc (mg/L)	0.018	0.008	Potential

Table 7.2 provides a summary of the number of guideline exceedances of Tier 1 vs Tier 2 guideline values. This comparison demonstrates that whilst the Tier 2 guideline values are based on more up to date science, overall the comparison doesn't generally change the risk outcomes, with the majority of sample locations reported to have a similar number of exceedances as a result of the range of reported metals concentrations. **Figure 7.1** and **Figure 7.2** provide a visual representation of the proportion of samples (as a percentage) in Boundary Creek and the Barwon River above the Tier 1 and 2 guideline values. For Boundary Creek it can be observed that there is a profile of elevated metals concentrations in the Boundary Creek catchment, however iron does not seem to increase after Big Swamp as significantly as the other detected metals. The data also indicates that Boundary Creek is not having an observable impact on the metals concentrations in surface waters of the Barwon River.

Table 7.2: Comparison of Guideline Values

Metal of interest	Number of samples	Number of detects	Tier 2 Guideline Value (mg/L)	Number in exceedance (Tier 2)	Tier 1 Guideline Value (mg/L)	Number in exceedance (Tier 1)
ME 1-4; East Barwon and West Barwon River upstream of Boundary Creek						
pH (pH units)	121	121	≥6.0	18	≥6.8	87
Aluminium (mg/L)	111	100	0.17	18	0.055	57
Copper (mg/L)	29	1	0.00047	1	0.0014	0
Iron (mg/L)	111	110	0.7	69	0.3	97
Manganese (mg/L)	110	109	n/a[1]	-	1.2	0
Zinc (mg/L)	30	19	n/a[1]	-	0.008	11
Gauge 233275; Boundary Creek upstream of Big Swamp						
pH (pH units)	1158	1158	≥5.5	3	≥6.8	594
Aluminium (mg/L)	35	26	0.17	2	0.055	13
Cobalt (mg/L)	35	2	0.0018	2	0.09	2
Copper (mg/L)	35	2	0.00047	2	0.0014	0
Iron (mg/L)	34	34	0.7	17	0.3	23
Manganese (mg/L)	35	33	n/a[1]	-	1.2	0

Metal of interest	Number of samples	Number of detects	Tier 2 Guideline Value (mg/L)	Number in exceedance (Tier 2)	Tier 1 Guideline Value (mg/L)	Number in exceedance (Tier 1)
Nickel (mg/L)	35	12	0.005	2	0.011	2
Zinc (mg/L)	35	18	n/a[1]	-	0.008	3
Big Swamp						
pH (pH units)	1	1	≥5.5	1	≥6.8	1
Aluminium (mg/L)	1	1	0.17	1	0.055	1
Copper (mg/L)	1	1	0.00047	1	0.0014	1
Iron (mg/L)	1	1	0.7	1	0.3	1
Manganese (mg/L)	1	1	n/a[1]	-	1.2	0
Zinc (mg/L)	1	1	n/a[1]	-	0.008	1
Gauge 233276; Boundary Creek downstream of Big Swamp						
pH (pH units)	1066	1066	≥5.5	765	≥6.8	1065
Aluminium (mg/L)	35	35	0.17	32	0.055	33
Cobalt (mg/L)	35	30	0.0018	30	0.09	0
Copper (mg/L)	35	5	0.00047	5	0.0014	4
Iron (mg/L)	34	34	0.7	30	0.3	34
Manganese (mg/L)	35	35	n/a[1]	-	1.2	0
Nickel (mg/L)	35	32	0.005	29	0.011	23
Zinc (mg/L)	35	34	n/a[1]	-	0.008	32
Gauge 233228; ME 5; Boundary Creek at Forrest Rd, Yeodene						
pH (pH units)	2961	2961	≥5.5	2629	≥6.8	2945
Aluminium (mg/L)	120	119	0.17	18	0.055	21
Cobalt (mg/L)	14	13	0.0018	13	0.09	8
Copper (mg/L)	21	1	0.00047	1	0.0014	1
Iron (mg/L)	44	43	0.7	39	0.3	41
Manganese (mg/L)	37	36	n/a[1]	-	1.2	0
Nickel (mg/L)	14	13	0.005	13	0.011	10
Zinc (mg/L)	28	28	n/a[1]	-	0.008	28
Gauge 233233; ME 6; Barwon River 100 m downstream Boundary Creek Confluence						
pH (pH units)	6	6	≥6.0	0	≥6.8	0
Aluminium (mg/L)	6	4	0.17	0	0.055	3
Copper (mg/L)	6	1	0.00047	1	0.0014	0
Iron (mg/L)	6	6	0.7	2	0.3	3
Manganese (mg/L)	6	6	n/a[1]	-	1.2	0
Zinc (mg/L)	6	4	n/a[1]	-	0.008	4
ME 7-12; Barwon River downstream of Boundary Creek Confluence						
pH (pH units)	517	517	≥6.0	20	≥6.8	100
Aluminium (mg/L)	470	451	0.17	240	0.055	390
Copper (mg/L)	60	7	0.00047	7	0.0014	2

Metal of interest	Number of samples	Number of detects	Tier 2 Guideline Value (mg/L)	Number in exceedance (Tier 2)	Tier 1 Guideline Value (mg/L)	Number in exceedance (Tier 1)
Iron (mg/L)	466	461	0.7	335	0.3	410
Manganese (mg/L)	461	458	n/a[1]	-	1.2	2
Zinc (mg/L)	63	44	n/a[1]	-	0.008	35

4. At this stage there are no tier 2 guideline values for manganese or zinc.

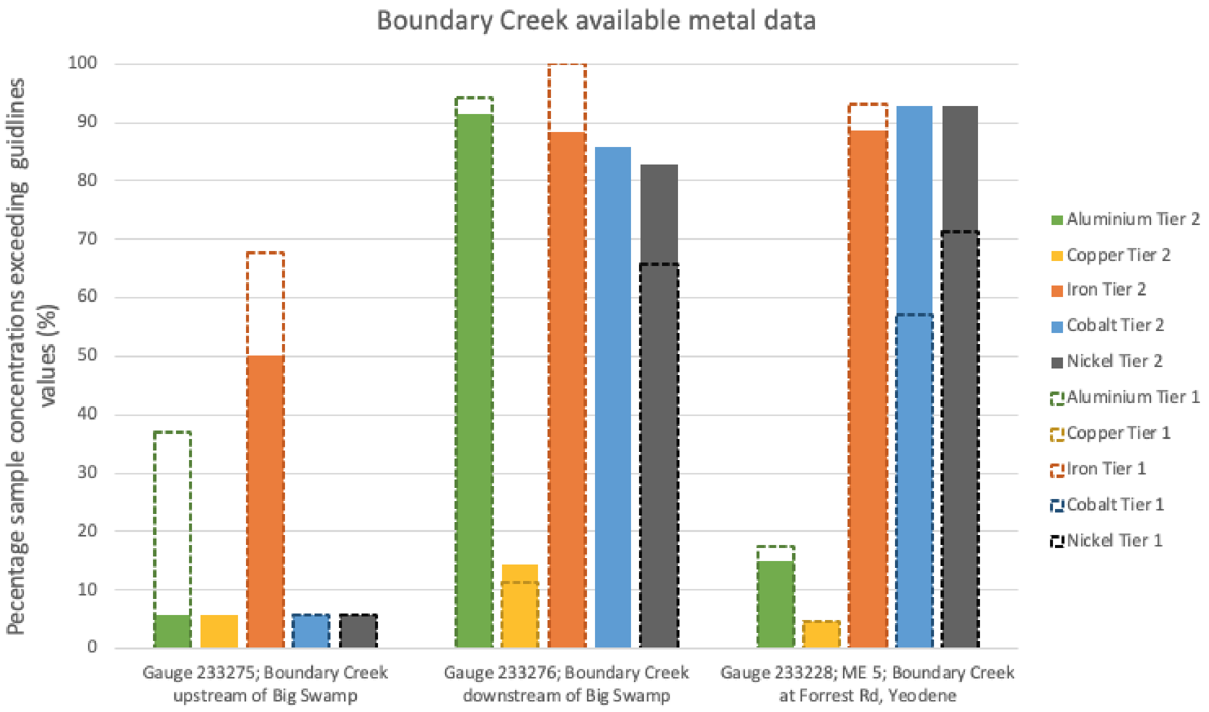

Figure 7.1: Exceedances of Guideline Values in Boundary Creek

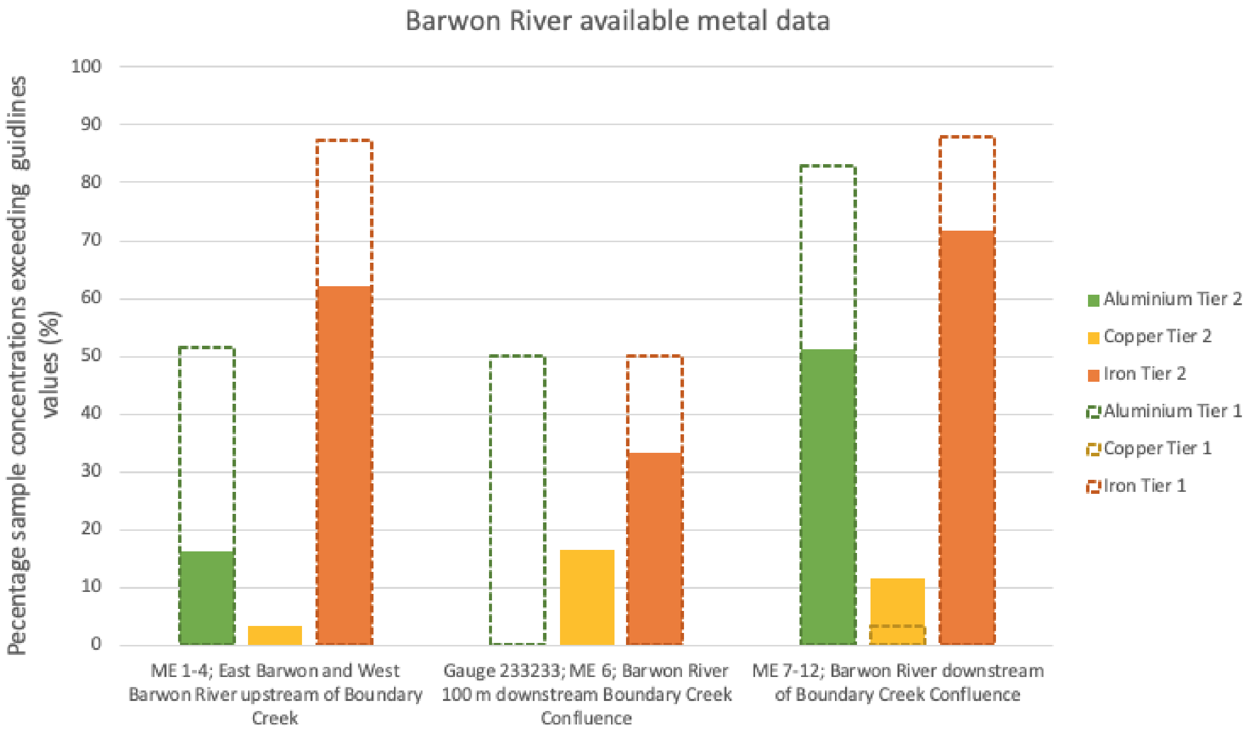

Figure 7.2: Exceedances of Guideline Values in Barwon River

7.2 Biological Indicator Outcomes

The outcomes of the vegetation quadrat surveys (Section 2.4) undertaken within Big Swamp have been summarised as follows:

- The observations from Q1 and Q2 (located at the western end of the swamp) indicated a prevalence of hydrophytic species with the species with highest reported coverage being those that prefer moist to wet conditions (Prickly Tea-tree (*Leptospermum continentale*), Tassel Sedge (*Carex fescicularis*) and Forest Wire-grass (*Tetrarrhena juncea*). This indicates that in this portion of the swamp the vegetation confirms the presence of suitable moisture and inundation to support this environment functioning as a swamp/wetland.
- The observations for Q3 (in the woodland area to the east) and Q4 (in the swamp plain) indicate that conditions in this portion of Big Swamp are drier and may be less prone to inundation under normal conditions, with a predominance of Australian Bracken present. The presence of Australian Bracken may also be due to its tolerance of highly acidic soils[17].

In addition, ELA (2023) concluded that the transect data indicate that the structure and composition of vegetation in the swamp is shifting, with a move towards drier, woodland dominated communities along the southern edge and eastern half of the swamp. ELA indicate that this is not impacting on the ecological value of Big Swamp, but rather that the ecosystem is adapting to a new environmental state as a result of the changed hydrological regime in the region. This transition process will see an improvement in ecological values of the swamp as the vegetation communities mature and stabilise (ELA, 2023).

[17] https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/316261/Bracken-fern.pdf

Macroinvertebrate survey outcomes were used to support evaluation of the biological health of Boundary Creek, Big Swamp and the Barwon River. While it is unclear how relevant macroinvertebrate survey outcomes are for Big Swamp, given that it may not always have standing water, this information was used to provide a comparison point with data collected from Boundary Creek. Overall, the data indicates that the ecological health of Boundary Creek declines downstream of Big Swamp, but it is unclear based on the available data whether there is some resilience in the system downstream of Colac-Forrest Road before the confluence with Barwon River. The data also indicates that Boundary Creek is not having a measurable impact on the health of the Barwon River (Table 7.3).

Table 7.3: Waterway Health Indicator Outcomes for macroinvertebrates (Austral, 2022 and Austral, 2023)

Location	No. Families	Signal2 Score	AusRivAS Band
Target	20	3.4	A
Barwon River – Upstream of Boundary Creek Confluence	13 - 25	2.7 – 3.6	B – A
Boundary Creek Upstream of Big Swamp	16 - 21	3.94 – 4.69	B – A
Big Swamp	3 - 8	2.35 – 2.94	Not reported
Boundary Creek Downstream of Big Swamp	5 - 9	2.55 – 3.8	C – B
Barwon River Downstream of Boundary Creek Confluence	8 - 20	3.25 – 4.05	B – A

Ecological stressors that contribute to the low scores presented in Table 2.6 and Table 7.3 were discussed by the Austral Macroinvertebrate study (Austral, 2023) and are summarised below in Table 7.4. Overall, this information supports that there are a range of physical stressors present within the Boundary Creek and Barwon River catchments that suggest impacts to the waterway are not entirely attributable to the acidic water discharging from Big Swamp.

Table 7.4: Likely ecological stressors gathered from the Austral Macroinvertebrate study (Austral, 2023)

	Likely Ecological Stressor
Site 4 – Barwon River 100 m upstream of Boundary Creek confluence	Stock access to watercourses is known to cause ecological stress. Tramping by cattle, for example, can impact soil structure by breaking up aggregates which results in compaction. Compacted soil reduces vegetation growth because the densely compacted soil layer restricts the movement of water, air and roots through the soil. Over grazing can degrade soil health and biodiversity.
Site 5 – Boundary Creek at Colac-Forrest Rd (233288 BCFRY)	European farming practices have allowed pasture grass to establish and encroach on aquatic and riparian vegetation, reducing access and resources required to support native vegetation.
Site 6 – Barwon River 100 m downstream of Boundary Creek confluence (233233 BRDSBC)	Stock access at this location is likely to be causing ecological stress.
Site 5.1 – Boundary Creek downstream of McDonalds Dam (233229 BCDSMD)	Intensive agriculture surrounding the riparian zone may lead to erosion of the zone and negatively impact water quality. Invasive weeds dominating the area and its management control through poisoning has resulted in a loss of native species biodiversity.
Site 5.2 - Boundary Creek upstream of Big Swamp (233275 BCUSBS)	An extensive riparian zone is preserved at this location which supports ecological health.
Big Swamp (BS1 and BS2)	Iron floc noted in Big Swamp is presumably iron (oxy)hydroxides, which the precipitation of is an acid producing reaction. $Fe^{3+} + H_2O \rightarrow Fe(OH)_3 + 3H^+$ (simplistic reaction) Hence a large amount of iron precipitation most likely driven by evaporation during dry events can result in a significant decrease in pH. Iron floc settlement can smother benthic macroinvertebrates.

7.3 Water Level Outcomes

The ecological value of Big Swamp is linked to the presence of saturated soils which support the growth of hydrophytic plants. The hydrogeological modelling indicated that keeping the ASS within Big Swamp inundated will minimise the generation of acidity. It is also important to support continuous flows in Boundary Creek to the extent possible to minimise the 'first flush' events that may cause a pulse of acidity and metals to wash through the system and cause increased short term stress to downstream aquatic communities.

To evaluate the potential impacts of inadequate water flows into Boundary Creek and Big Swamp, the available water discharge data was compiled (refer to **Section 3.4**). **Figure 7.3** shows the cumulative frequency discharges for the stream gauges upstream and downstream of Big Swamp. The discharge volumes both upstream and downstream of the private onstream dam equalise after approximately 2.5 ML/day. However, it should be noted that there are periods of the year where the dam licence does not require release of passing flows, thus no flows are occurring through Boundary Creek from the downstream end of the dam during these times unless the spillway is overtopping. This further emphasises the importance of the appropriate management of passing flows through the private on-stream dam and indicates that the presence of the dam is a risk factor under low flow conditions in the system.

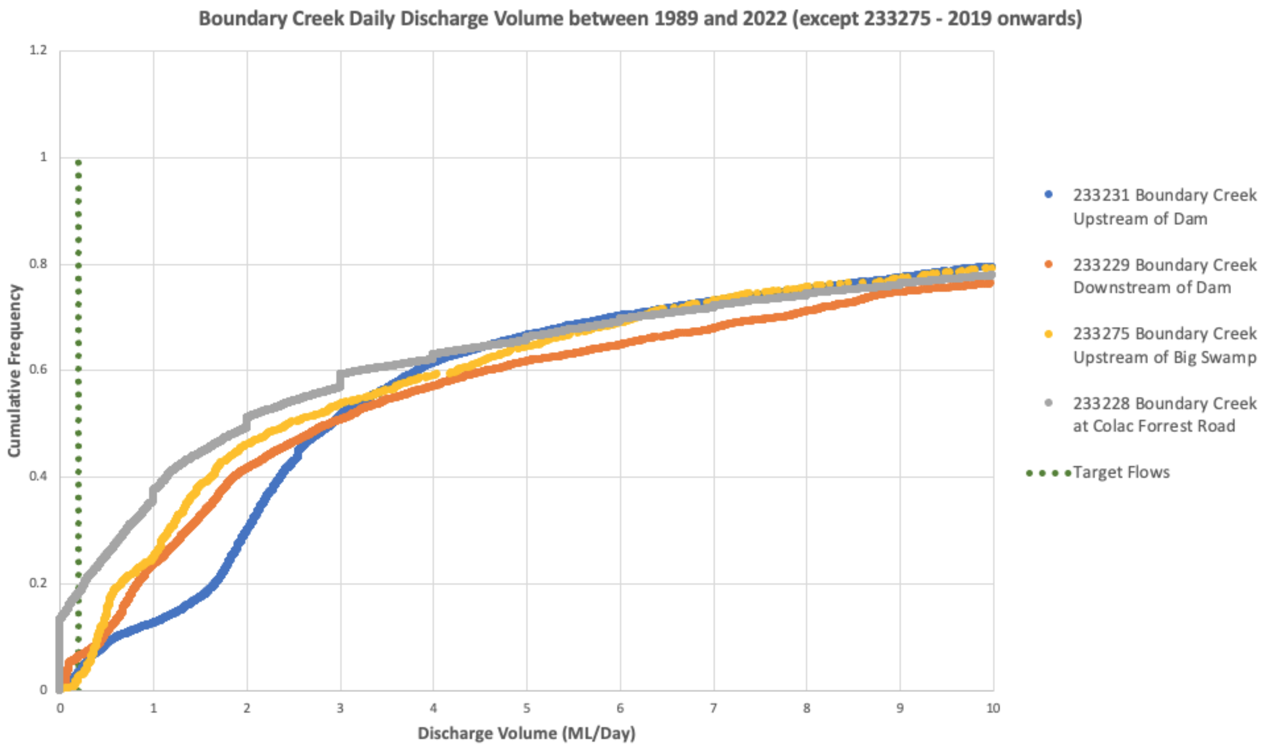

Figure 7.3: Recorded Discharge Volumes (ML/Day) at Key Stream Gauges

7.4 Risk Characterisation Summary

To enable evaluation of the risks to the identified ecological values, the physico-chemical data, biological data and water level data was categorised based on the risk ratings presented in Table 7.5 and Table 7.6. The outcomes of the risk characterisation are presented in Table 7.7 and summarised in Figure 7.4 and Figure 7.5.

The presence of naturally occurring ASS underlying Big Swamp suggests that there has always been potential (pre-1979) for natural wet-dry cycling to have resulted in generation of acidic water within the swamp environment and discharge to Boundary Creek. The presence of acidic conditions prior to 1979 has been demonstrated by the palaeoecology study (La Trobe University, 2023) and indicates that conditions within Big Swamp and Boundary Creek have tended to be acidic-circumneutral throughout the history of this environment. Therefore, the stressors that have been noted to be present since 1979 have acted to increase the likelihood of acidic discharges from Big Swamp to Boundary Creek and the Barwon River.

Overall, the lines of evidence available suggest that there are measurable impacts to water quality and aquatic receptors (macroinvertebrates) in Boundary Creek that may be attributable to discharge of acidity and metals from Big Swamp. However, the elevated risk profile for Boundary Creek and Big Swamp cannot be entirely attributed to the groundwater pumping activities within the Barwon Downs borefield. Given the data limitations (Section 7.5) and the presence of a range of ecosystem stressors it is not possible to uncouple the elevated risk profile associated with drawdown of the LTA from:

- The irreversible changes caused by European colonisation and subsequent drainage of the downstream swamp environment to support agricultural land uses;
- The impact of the Millennium Drought;
- The inadequate management of flows from the private onstream dam located upstream of Big Swamp; and
- The ongoing surrounding land uses in the catchment that are contributing to reduced water quality.

Table 7.5: Summary of Adopted Risk Ratings – Physico-chemical indicators

Risk Rating	Physico-chemical indicator – metals and pH
Negligible/ Low Risk	Exceedance of guideline value 0 - 5% of samples
Minor Risk	Exceedance of guideline value 6 – 20% of samples
Moderate Risk	Exceedance of guideline value 21 – 50% of samples
High Risk	Exceedance of guideline value 51 – 80% of samples
Extreme Risk	Exceedance of guideline value >80% of samples

Table 7.6: Summary of Adopted Risk Ratings – Biological and Water Level Indicators

Risk Rating	Biological indicator – Macroinvertebrate monitoring	Biological Indicator – Vegetation Surveys	Water level indicator – Surface Water
Negligible/ Low Risk	AusRivAS Band A SIGNAL2 Score and Number of Families >targets	Quadrat survey results indicate a predominance (>50%) hydrophytic species in inundated areas	Water level <0.2 ML/day 0 - 10% of the time
Minor Risk	Two (2) of three (3) indicators >targets	Quadrat survey results indicate hydrophytic species make up between 30 – 50% of vegetation species present	Water level <0.2 ML/day 11 – 50% of the time
Moderate Risk	Two (2) of three (3) indicators <target	Quadrat survey results indicate hydrophytic species make up between 5 – 29% of vegetation species present	Water level <0.2 ML/day 51 – 75% of the time

Risk Rating	Biological indicator – Macroinvertebrate monitoring	Biological Indicator – Vegetation Surveys	Water level indicator – Surface Water
High Risk	All three (3) indicators <targets	Quadrat survey results indicate hydrophytic species make up <5% of vegetation species present	Water level <0.2 ML/day 76 – 100% of the time

Table 7.7: Risk Characterisation Summary

Line of Evidence	Outcome	Risk Rating
Physico-chemical outcomes	**Boundary Creek – Upstream of Big Swamp:** A considerable number of surface water samples have been analysed for metals and pH from Boundary Creek upstream of Big Swamp. Based on these results pH, aluminium, cobalt, copper, iron, nickel and zinc were reported at concentrations above the guideline values adopted in the ERA (Table 7.2). This indicates that there are catchment related inputs of these metals and acidity within Boundary Creek. The overall risk rating assigned to this location based on physico-chemical outcomes varies depending on which parameter is evaluated. The low pH values, and the elevated aluminium, cobalt, copper and nickel indicate a minor risk to aquatic organisms, whilst the iron exceedances indicate a moderate risk to aquatic organisms.	Minor – Moderate
	Big Swamp: There was limited surface water data available from within Big Swamp. The available data suggests that there is a high risk to aquatic receptors. However, this is based on very limited surface water data (Table 7.2). The pH data obtained from the shallow groundwater system beneath Big Swamp suggests that groundwater discharging to the swamp environment generally has a pH <5.5 (Figure 6.1). This contributes to the overall elevated risk profile for the aquatic environments within Big Swamp.	High
	Boundary Creek – Downstream of Big Swamp: The surface water results from downstream of Big Swamp indicate that there is aluminium, cobalt, copper, iron, nickel and zinc present at concentrations above the guideline values at a relatively high frequency (>50% of the time). In addition, the pH is reported to be less than the target 5.5 in approximately 75% of the collected surface water samples.	High
	Barwon River – Upstream of Boundary Creek Confluence: The overall risk rating assigned to this location based on physico-chemical outcomes varies depending on which parameter is evaluated. The low pH values, and the elevated aluminium, copper and zinc indicate a minor risk to aquatic organisms, whilst the iron exceedances indicate a moderate risk to aquatic organisms.	Minor - Moderate
	Barwon River – Downstream of Boundary Creek Confluence: Directly downstream of the Boundary Creek confluence, the surface water was reported to contain elevated concentrations of copper, iron and zinc. Whilst further downstream aluminium and zinc were also reported to increase, and there was an increased detection of pH below 6. This indicates that there are other sources of metals to the Barwon River, and that the influence of metals and pH from Boundary Creek is not detectable at the sample locations along the Barwon River.	Minor – Moderate
Macroinvertebrate survey outcomes	**Boundary Creek – Upstream of Big Swamp:** In Boundary Creek upstream of Big Swamp it was reported that macroinvertebrates were at or above the target levels for 2 – 3 of the measured indices.	Low – Minor
	Big Swamp: The macroinvertebrate sampling in Big Swamp did not identify any indices for which the results met the target. However, it is noted that given the dynamic nature of the swamp it is unclear whether the outcomes of the macroinvertebrate sampling should be interpreted in the same way as for standard waterways such as Boundary Creek and the Barwon River.	High

Line of Evidence	Outcome	Risk Rating
	Boundary Creek – Downstream of Big Swamp: Downstream of Big Swamp the macroinvertebrate sampling results reported the indices to be below the target for two (2) to three (3) of the measures used.	Moderate – High
	Barwon River – Upstream of Boundary Creek Confluence: Whilst the macroinvertebrate sampling indicated that there are some regional influences that are impacting on water quality (e.g. livestock access and impacted riparian vegetation), the macroinvertebrate communities were indicated to be in reasonable condition.	Low - Minor
	Barwon River – Downstream of Boundary Creek Confluence: Downstream of the Boundary Creek confluence there was varying macroinvertebrate outcomes, however the greatest variables were recorded as a result of seasonal variations rather than spatial variations relative to the confluence of Boundary Creek.	Low - Minor
Vegetation Survey Outcomes	**Big Swamp:** The quadrat surveys conducted by ELA (2022 and 2023) have identified the presence of hydrophytic vegetation species across the swamp plain. The location of these quadrats is not specifically designed to evaluate the extent of the swamp plain and does not align with the inundation area (Figure 2.8). Therefore, the reduced detection of hydrophytic species in Q3 and Q4 is unlikely to indicate reduced function of the swamp ecosystem but is more likely to reflect the reduced frequency of inundation as expected based on the topography of the swamp plain.	Low
Water Level Outcomes – Groundwater	**Big Swamp:** Groundwater is reported to be present beneath Big Swamp at variable depths between <1 m bgl and >2 m bgl. The LTA is reported to be recovering and the rainfall over the past two (2) years has supported increased groundwater expression to the surface within the eastern portion of Big Swamp.	Minor
Water Level Outcomes – Surface water	**Boundary Creek – Upstream of Big Swamp:** The water level records from Boundary Creek upstream of Big Swamp, suggest that flows are <0.2 ML per day approximately <5% of the time. This indicates that where passing flows are appropriately managed through the private onstream dam, there should be sufficient flows the majority of the time to support Big Swamp in remaining sufficiently wet.	Low
	Boundary Creek – Downstream of Big Swamp: The water level data collected from downstream of Big Swamp suggests that there is reduced flow occurring, however the target of 0.2 ML/day is being met approximately 80% of the time. This decreased water level is likely the result of a combination of factors.	Minor

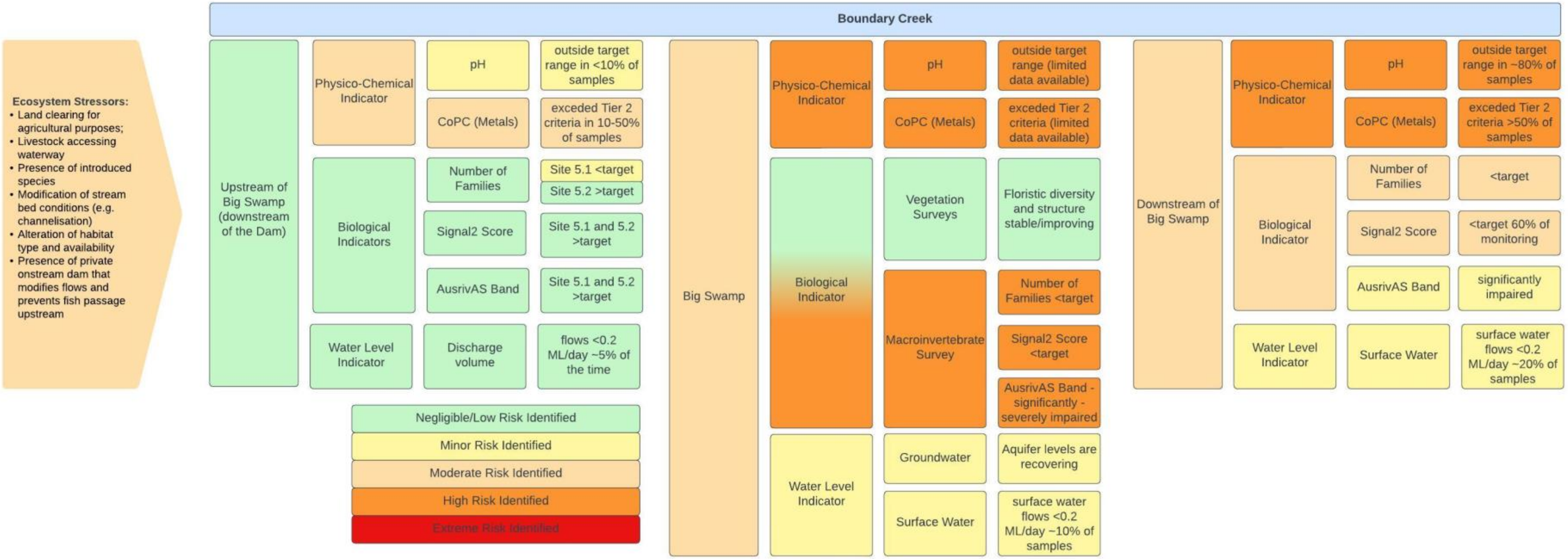

Figure 7.4: Risk Characterisation Overview – Boundary Creek and Big Swamp

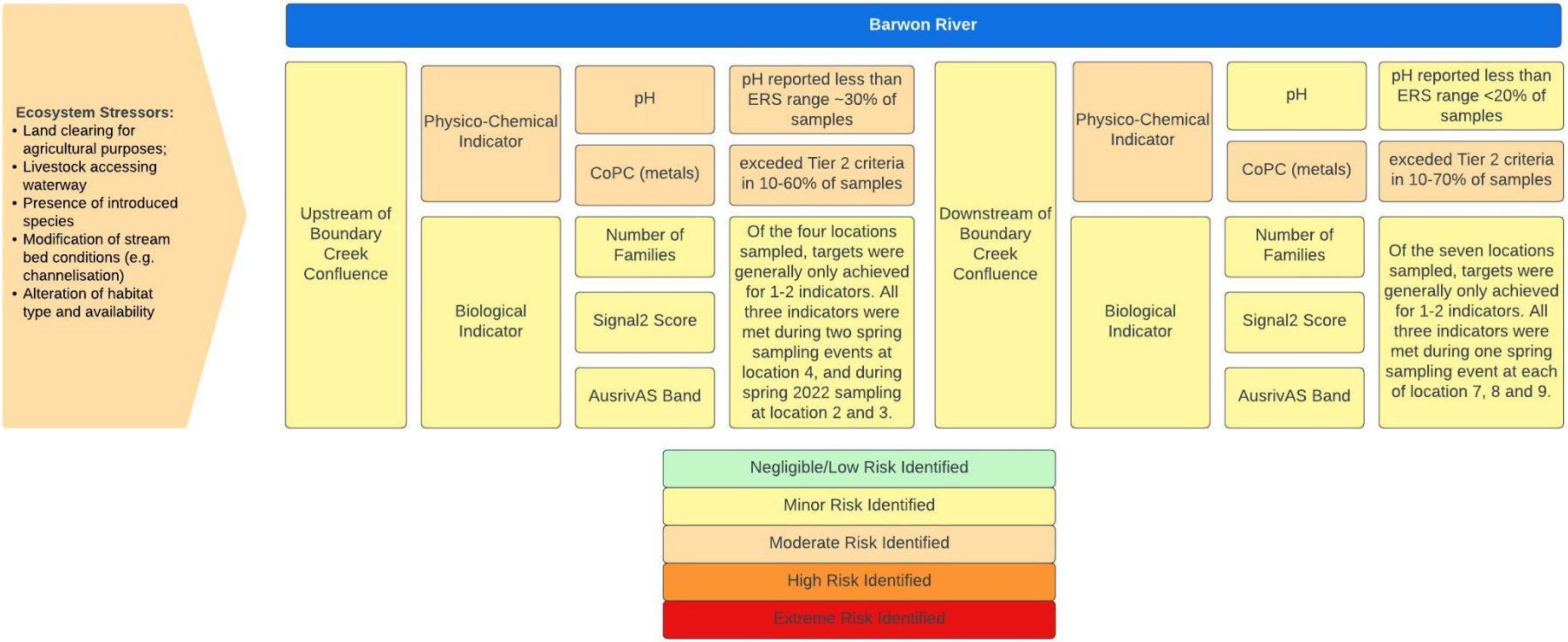

Figure 7.5: Risk Characterisation Overview – Barwon River

7.5 Uncertainties and Limitations

The outcomes of the ERA should be interpreted with the following uncertainties and limitation in mind:

- There was no water quality data available to support evaluation of hydrological and ecological conditions prior to construction of the private onstream dam or groundwater extraction from the LTA;
- The water quality data available was collected under conditions supported by supplementary flows; therefore, risk outcomes are considered to represent, in part, post-mitigated risks. Water quality data (measured or modelled) in the absence of supplementary flows was not available at the time of preparation of this report.
- Water quality data was not available for hydrological conditions inferred to pose the greatest risk to the Barwon River (i.e. where >40% of flows in Barwon River are contributed by Boundary Creek inputs (Barwon Water, 2021). It is therefore unclear whether the risk outcomes also cover high risk water flow conditions.
- To support risk characterisation outcomes, the ERA has adopted EPCs based on 95% UCL (where the data supports this approach). This is a less conservative approach than that recommended by ANZG (2018), where the 95th percentile is recommended. To support an understanding of the impact of this decision on the outcomes of the ERA, a comparison of 95% UCL values and 95th percentile values for location 233276 (downstream of Big Swamp) is presented in **Table 7.8**. Given the risk outcomes, and the use of a multiple lines of evidence approach, the use of 95% UCL has resulted in an appropriate interpretation of risks to ecological receptors, and that the use of 95th percentile data would not change the risk outcomes.

Table 7.8: Comparison of 95% UCL EPC vs 95th Percentile for select metals at 233276

Metal	Tier 2 Guideline Value (mg/L)	EPC (mg/L)	95th Percentile (mg/L)
Aluminium	0.71	5.86	11.3
Iron	0.7	33.55	49.6
Nickel	0.005	0.05	0.11
Zinc	0.008*	0.17	0.39

* No Tier 2 value was adopted for zinc

Although risks of toxicity due to metals were based on the best available guideline values that incorporated bioavailability where possible, there are likely to be other factors that have not been accounted for that will influence metal toxicity. Unfortunately, there was no data from direct toxicity assessments of Boundary Creek (including Big Swamp) and Barwon River ambient waters to help inform the risk predictions.

This ERA has been prepared based on the information available at the time of preparation as supplied by Barwon Water. The outcomes of the ERA are unable to take into account future conditions that may occur within Boundary Creek, Big Swamp and the Barwon River, including future climate conditions.

8 Conclusions

The ERA has considered the available information with regard to ecological condition and water quality to evaluate risks associated with the presence of acidity and metals in surface water in Boundary Creek and the Barwon River sourced from Big Swamp.

Given the dynamic nature of the environment within Big Swamp and Boundary Creek and the range of biotic and abiotic factors that can contribute to changing conditions over time, the ERA used a multiple lines of evidence approach to support an evaluation of risks.

The outcomes of the ERA indicate:

- There are elevated risks associated with the presence of acidity and metals in surface water in Boundary Creek within and below Big Swamp; however, the available data does not indicate that these elevated risks also exist within the Barwon River. The palaeoecology study (La Trobe University, 2023) identified that acidic conditions are likely to have been present within the swamp as a result of the natural processes within this environment, and likely because of the presence of ASS. Therefore, risks associated with acidity and metals are also likely to have been present prior to 1979 that have been exacerbated by the stressors identified in the system post 1979;
- The physico-chemical parameters indicate a high potential for unacceptable risks to Boundary Creek associated with acidity and metals, whilst the macroinvertebrate surveys suggest that there is a moderate to high risk. These findings indicate that the release of acidity and metals from Big Swamp is impacting on the aquatic receptors downstream in Boundary Creek. However, there are other ecosystem stressors identified for the Boundary Creek system would prevent full recovery of the aquatic communities even if adverse impacts to water quality in Boundary Creek from Big Swamp were rectified. In addition, the identification of potential risks needs to also be considered in light of the presence of naturally acidic conditions which were reported by the palaeoecology study (La Trobe University, 2023); and
- A sufficient supply of water is needed to support the ecological value of Big Swamp. The upper groundwater system beneath Big Swamp is likely to have historically supported soil saturation conditions and thus the hydrophytic vegetation in the swamp. The continued recovery of the LTA is important for re-establishing and maintaining groundwater contributions to baseflow in Boundary Creek upstream of Big Swamp. However, if passing flows through the private on-stream dam further upstream are not appropriately managed in the future, and/or where extended drought conditions occur, extended dry conditions in Big Swamp may occur that contribute to a decline in water quality. Upstream surface water regulation and management is therefore an important factor in the ongoing protection of ecological values in Big Swamp.

Overall, these risk outcomes need to be considered in the context of the significant stressors that remain present within the system. The impacts of historical groundwater pumping and aquifer drawdown cannot be uncoupled from the impacts of these other stressors.

Given the irreversible changes in the catchment, and within Big Swamp itself, further work is needed to:

- Conduct additional vegetation and water quality monitoring to support Barwon Water in defining the new 'natural' conditions within Big Swamp;
- Define Barwon Water's role in success given the limited options with regard to management actions (i.e. groundwater extraction from the Barwon Downs borefield has ceased); and
- Evaluate success targets in light of the risk outcomes, with consideration of future climate conditions and potential for identified risks to be present for a considerable time to come.

In addition, the outcomes of the ERA should be used to inform adjustments to the macroinvertebrate and vegetation survey programs to enable a more robust data set to be collected into the future. The following considerations should be made during planning for future field surveys:

- Include additional quadrat survey locations within the swamp plain areas inferred to be most frequently inundated to enable assessment of the presence of swamp/wetland plant species.
- Include additional macroinvertebrate monitoring locations between Site 5 and the Barwon River to understand how water quality recovers with distance from Big Swamp.
- Include a macroinvertebrate monitoring location upstream of the private onstream dam to enable evaluation of water quality in a section of the creek that is more heavily influenced by surrounding land use.

The following conclusions are provided with respect to the three (3) key objectives of the ERA:

Objective 1: Review the likely condition of the Boundary Creek & Big Swamp (a peat swamp) under natural conditions and confirm how the changes (e.g. drainage works, damming, groundwater pumping and climate etc.) have impacted the ecological condition/function

The Boundary Creek catchment has been subject to considerable change since European colonisation, with a range of key factors resulting in irreversible changes to the system:

- Land clearing and construction of drainage lines across the catchment to facilitate agriculture in the early 1900s
- Channelisation of sections of Boundary Creek (most obviously Reach 3)
- Construction of a private onstream dam in 1979 which has a licence to extract 160 ML/year
- Other private diversions and farm dams that have been installed along the length of Boundary Creek
- Groundwater extraction from the Barwon Downs borefield
- The Millennium Drought (and other historical droughts) contributing to the drying of Big Swamp and subsequent fires
- The likely burning of the swamp that occurred during the Black Friday bushfires in 1939 following the World War II drought.

Given the timeframe of these changes and the significant impacts that these activities have made to the Boundary Creek system it is difficult to uncouple these impacts from those associated with groundwater extraction from the Barwon Downs borefield. It is therefore not possible to predict what Boundary Creek and Big Swamp would have looked like under natural conditions. The results of the palaeoecology study (La Trobe University, 2023) indicate that the current swamp conditions are unlikely to be significantly different to historical conditions with regard to inundation and vegetation assemblages. However, indicators of disturbance were noted in the sediment record associated with activities related to European colonisation and changes in surrounding land uses over time (La Trobe University, 2023). It can therefore be concluded that although the natural state of these environments is likely to have been altered as a result of the above listed factors and stressors that have been introduced to the system, the environment within Big Swamp remains similar to historical conditions.

Objective 2: Determine the current ecological values within the lower reaches of Boundary Creek, Big Swamp and the Barwon River immediately upstream and downstream of the confluence with Boundary Creek and the thresholds that account for the naturally occurring deposits/minerals within the region

Consideration of a range of factors was undertaken to enable the ecological values of Big Swamp and Boundary Creek to be defined as follows:

- *Natural soil saturation within Big Swamp is supported such that species diversity and abundance of swamp vegetation communities are able to be sustained.*
- *Natural water quality within Boundary Creek (Reach 2c and 3) is supported such that abundance and diversity of aquatic communities (including those within receiving environments (e.g. the Barwon River)) are not impacted.*

Biological, physico-chemical and water level indicators were used to evaluate risks to these ecological values in the ERA.

It should be noted, that the ecological value of Big Swamp and Boundary Creek cannot be protected without appropriate management and regulation of passing flows through the private onstream dam constructed upstream of Big Swamp in 1979. In addition, the presence of this dam precludes the environmental value of fish passage through the Boundary Creek system which further impacts on the ecological value of Boundary Creek.

Objective 3: Quantify the risks associated with the metal and acidity loads to Big Swamp, Boundary Creek and the Barwon River

The presence of increased acidity and metals concentrations in surface water discharging from Big Swamp into Boundary Creek are considered to be posing a high risk to ecological receptors in Reach 2c and Reach 3. However, the available data indicates that the presence of metals and acidity in water discharging from Boundary Creek into Barwon River is not increasing the risk profile of the Barwon River. The presence of metals in the Barwon River catchment is resulting in a moderate risk based on screening against guideline values, however the biological indicators in the Barwon River indicate a minor risk. These risk outcomes are the same for sample locations both upstream and downstream of the Boundary Creek confluence.

Previous assessments suggested that risks to the Barwon River associated with acidity and metals in surface water from Boundary Creek are noted to be extreme under the following flow conditions:

- Greater than 40% of the flows in the Barwon River coming from Boundary Creek AND
- Greater than 4 months of cease to flow events within Boundary Creek prior to a first flush event

However, no data for such conditions were available to be assessed for the ERA.

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Appendices

A Vegetation Species Reported by ELA 2020 and 2023

Species Name	Common Name	Lifeform	% Cover		Habitat Preference (a)	Hydrophytic (H) / Non-Hydrophytic (NH)
			2020	2022		
Q1 – Swamp Plain - Western Portion						
Acacia spp.	-	Shrub (S)	<1% (+)	Not observed	Unknown	Unknown
Alternanthera denticulate s.l	Lesser Joyweed	Medium Herb (MH)	5 – 25% (2)	5 – 25% (2)	Aquatic / semi-aquatic – moist areas on margins of swamps and other wet areas in lowlands.	H
Anthoxanthum odoratum	Sweet Vernal-grass	-	<1% (+)	Not observed	Widespread weed found in many natural settings, tolerates almost any soil. Can occur in riparian vegetation and freshwater wetland environments.	H
Ascaena novae-zelandiae	Bidgee-widgee	MH	<1% (+)	Not observed	Widespread in moist to dry sites in clay and sandy soils.	NH
Asperula conferta	Common Woodruff	MH	<1% (+)	Not observed	Moist well drained soils in moist forests	NH
Bursaria spinosa	Sweet Bursaria	S	<1% (+)	Not observed	Moist to dry well drained soils in forests of foothills and mountains.	NH
Carex appressa	Tall Sedge	Large Tufted Graminoid (LTG)	25 – 50% (3)	5 – 25% (2)	Wet soils beside or along margins of water areas. Will tolerate some drying out.	H
Carex fescicularis	Tassel Sedge	LTG	1 - 5% (1)	50 – 75% (4)	Moist to wet soil on stream and swamp edges.	H
Carex sp.	-	Tufted Graminoid (TG)	<1% (+)	Not observed	Sedges that tolerate moist to wet conditions	H
Centaurium erythraea	Common Centaury	S	<1% (+)	Not observed	Wet, seasonally inundated soils and wet verges of water areas.	H
Centipeda spp.	-	Herb (H)	<1% (+)	Not observed	Perennial herbs that tolerate inundated to wet soils.	H
Cerastium glomeratum s.l.	Sticky Mouse-ear Chickweed	-	<1% (+)	Not observed	Introduced species, usually indicative of freshwater environments and occurs along water courses.	H
Cirsium vulgare	Spear Thistle	-	<1% (+)	Not observed	Noxious weed that grows well under irrigation.	NH
Cotula spp.	-	Small or Prostrate Herb/ Medium Herb (SH/MH)	25 – 50% (3)	Not observed	Moist soil in grassy forests.	NH
Eucalyptus ovata	Swamp Gum	Understorey Tree or Large Shrub (T)	1 - 5% (1)	1 - 5% (1)	Poorly drained infertile and clay soils which may dry out in summer.	H

Species Name	Common Name	Lifeform	% Cover		Habitat Preference (a)	Hydrophytic (H) / Non-Hydrophytic (NH)
			2020	2022		
Galium aparine	Cleavers	-	1 – 5% (1)	Not observed	Introduced species – widespread in gardens and disturbed sites (c)	NH
Galium ciliare subsp. terminale	-	Herb (H)	<1% (+)	Not observed	Herb that grows well in moist soil in sheltered position in open forests	H
Holcus lanatus	Yorkshire Fog	Large Non-Tufted Graminoid (LNG)	50 – 75% (4)	Not observed	Common on seasonally wet freshwater and saline swamp and lake margins. Very tolerant of waterlogging (b).	H
Hydrocotyle hirta	Hairy Pennywort	Small or Prostrate Herb (SH)	<1% (+)	Not observed	Widespread in moist to wet open to closed forests and rainforests.	H
Hydrocotyle pterocarpa	Wing Pennywort	SH	1 – 5% (1)	Not observed	Moist soil in sedgelands and on mossy rocks.	H
Hypochaeris radicata	Flatweed	SH	5 – 25% (2)	Not observed	Introduced species (also known as False Dandelion)	NH
Isolepis spp.	Club Sedge	Medium to Tiny Non-tufted Graminoid (MNG)	<1% (+)	<1% (+)	Moist soil in swamp scrubs	H
Juncus pauciflorus	Loose-flower Rush	Medium Tufted Graminoid (MTG)	<1% (+)	Not observed	Moist boggy soils in forests and swamp scrubs	H
Juncus procerus	Tall Rush	LTG	<1% (+)	Not observed	Semi-aquatic, wet soils on margins of water areas or poorly drained soils within riparian forests.	H
Juncus spp.	-	TG	<1% (+)	Not observed	Semi-aquatic, in wet soil on margins of water areas or poorly drained soils within riparian forests.	H
Lepidosperma elatius	Tall Sword-Sedge	LTG	<1% (+)	Not observed	Moist to heavy soils in forests	H
Leptospermum continentale	Prickly Tea-Tree	Shrub (S)	50 – 75% (4)	5 – 25% (2)	Well drained to moist sandy and light clay soils, Widespread in woodland, heathland and beside watercourses.	H
Leptospermum myrsinoides	Silky Teatree	S	5 – 25% (2)	Not observed	Moist sandy soil in heathlands, tolerates poor drainage, good for boggy environments.	H
Lobelia beaugleholei	Snowy Lobelia	SH	1 – 5% (1)	Not observed	Unknown	Unknown
Lobelia prateoides	Poison Lobelia	SH	<1% (+)	Not observed	Seasonally inundated to waterlogged soils along swamp margins and drainage lines.	H
Lycopus australis	Australian Gipsywort	Large Herb (LH)	25 – 50% (3)	1 – 5% (1)	Moist to wet soil on edges of swamps and water areas.	H
Maleluca squarrosa	Scented Paperbark	S	1 – 5% (1)	Not observed	Moist to wet swampy soils.	H
Mentha australis	Australian Mint	SH	1 – 5% (1)	Not observed	Moist to wet soils on edges of watercourses and swamps	H

Species Name	Common Name	Lifeform	% Cover 2020	% Cover 2022	Habitat Preference (a)	Hydrophytic (H) / Non-Hydrophytic (NH)
Oxalis spp.	Shady Wood-sorrel	SH	<1% (+)	<1% (+)	Widespread in heavy soils through most plant communities.	NH
Poa annua	Annual Meadow-Grass	Grass	<1% (+)	Not observed	Introduced grass species that will grow wherever there is sufficient moisture	NH
Poa sp.	-	Grasses	<1% (+)	Not observed	Grasses that occur in pastures, some species are considered weeds	NH
Poaceae sp.	-	Grasses	1 – 5% (1)	Not observed	-	NH
Prunus spp.	-	Trees/Shrubs	<1% (+)	Not observed	-	NH
Pteridium esculentum subsp. esculentum	Australian Bracken	Ground Fern (GF)	1 – 5% (1)	Not observed	Very common in all but poorly drained soils and heavily shaded sites. Found below 1,200 m, especially in disturbed areas. Prevalent after fires.	NH
Rumex sp.	-	Herb (H)	<1% (+)	Not observed	Aquatic or semi aquatic on margins of lakes and billabongs, moist to wet soils in low lying areas and along watercourses.	H
Senecio minimus	Shrubby Fireweed	MH	<1% (+)	<1% (+)	Moist well drained soils in cool forests. Coloniser of disturbed places especially along tracks and after fires.	NH
Senecio prenanthoides	Beaked Fireweed	Herb (H)	<1% (+)	Not observed	Moist well drained soils in forests and woodlands in the foothills.	NH
Sonchus oleraceus	Sow-thistle	LH	<1% (+)	Not observed	Very common weed of disturbed areas, also found on swamps, lake edges and coastal dunes provided moisture is adequate (b).	H
Q2 - Main Channel – Western Portion						
Acacia melanoxylon	Blackwood	Shrub (S)	25 - 50% (3)	25 - 50% (3)	Prefers moist fertile soils in valleys of wet mountain forests. Can tolerate dry conditions once established	H
Acacia verticillata	Prickly Moses	Shrub (S)	1 - 5% (1)	1 - 5% (1)	Moist sandy or clay soils of foothill forests, can withstand periods of waterlogging	H
Alternanthera denticulata	Lesser Joyweed	Medium Herb (MH)	<1% (+)	<1% (+)	Aquatic / semi-aquatic – moist areas on margins of swamps and other wet areas in lowlands.	H
Anthoxanthum odoratum	Sweet Vernal-grass	-	<1% (+)	5 – 25% (2)	Widespread weed found in many natural settings, tolerates almost any soil. Can occur in riparian vegetation and freshwater wetland environments.	H
Blechnum nudum	Fishbone Water-fern	GF	1 - 5% (1)	1 - 5% (1)	Moist alluvial soils along margins of watercourses and shaded gullies in riparian, moist and wet forests. Tolerates periods of flooding	H

Species Name	Common Name	Lifeform	% Cover		Habitat Preference (a)	Hydrophytic (H) / Non-Hydrophytic (NH)
			2020	2022		
Blechnum spp.	-	-	<1% (+)	1 - 5% (1)	Ferns that live in moist to wet conditions	H
Carex appressa	Tall Sedge	Large Tufted Graminoid (LTG)	5 – 25% (2)	25 – 50% (3)	Wet soils beside or along margins of water areas. Will tolerate some drying out.	H
Carex fascicularis	Tassel Sedge	LTG	1 - 5% (1)	5 – 25% (2)	Moist to wet soil on stream and swamp edges.	H
Centaurium erythraea	Common Centaury	S	<1% (+)	<1% (+)	Wet, seasonally inundated soils and wet verges of water areas.	H
Cerastium glomeratum s.l.	Sticky Mouse-ear Chickweed		<1% (+)	<1% (+)	Introduced species, usually indicative of freshwater environments and occurs along water courses.	H
Coprosma quadrifida	Prickly Currant-bush	Shrub (S)	1 - 5% (1)	5 – 25% (2)	Moist well drained soils in open forest, rainforest and gullies.	NH
Cycnogeton procerum s.s.	Common Water-ribbons	Herb (H)	1 - 5% (1)	1 - 5% (1)	Aquatic plant that grows in slow-flowing water to 2m deep, permanent swamps and streams or in areas that dry out briefly.	H
Eucalyptus brookeriana	-	Tree	5 – 25% (2)	5 – 25% (2)	Grows on slopes and ridge tops but also near watercourses in wet forest and sometimes in or near rainforest.	H
Gahnia sieberiana	Red-fruit Saw-sedge	Sedge	5 – 25% (2)	5 – 25% (2)	Moist to wet alluvial soil in low areas of mountain and foothill forests.	H
Galium aparine	Cleavers	-	1 - 5% (1)	1 - 5% (1)	Introduced species – widespread in gardens and disturbed sites (c)	NH
Galium ciliare subsp. terminale	-	Herb (H)	<1% (+)	<1% (+)	Herb that grows well in moist soil in sheltered position in open forests	H
Gonocarpus tetragynus	Common Raspwort	Small or Prostrate Herb (SH)	<1% (+)	<1% (+)	Widespread in moist to dry well drained soils in dry forests, scrubs and heaths	NH
Gynatrix pulchella	Hemp Bush	Shrub (S)	5 – 25% (2)	5 – 25% (2)	Moist well drained soil in forests and scrubs beside watercourses	NH
Holcus lanatus	Yorkshire Fog	Large Non-Tufted Graminoid (LNG)	1 - 5% (1)	5 – 25% (2)	Common on seasonally wet freshwater and saline swamp and lake margins. Very tolerant of waterlogging (b).	H
Hydrocotyle hirta	Hairy Pennywort	Small or Prostrate Herb (SH)	<1% (+)	<1% (+)	Widespread in moist to wet open to closed forests and rainforests.	H
Hydrocotyle pterocarpa	Wing Pennywort	SH	<1% (+)	<1% (+)	Moist soil in sedgelands and on mossy rocks.	H
Hypochaeris radicata	Flatweed	SH	<1% (+)	<1% (+)	Introduced species (also known as False Dandelion)	NH
Juncus pauciflorus	Loose-flower Rush	Medium Tufted Graminoid (MTG)	<1% (+)	<1% (+)	Moist boggy soils in forests and swamp scrubs	H

Species Name	Common Name	Lifeform	% Cover 2020	% Cover 2022	Habitat Preference (a)	Hydrophytic (H) / Non-Hydrophytic (NH)
Lepidosperma elatius	Tall Sword-Sedge	LTG	5 – 25% (2)	5 – 25% (2)	Moist to heavy soils in forests	H
Leptospermum continentale	Prickly Tea-Tree	S	25 – 50% (3)	25 – 50% (3)	Well drained to moist sandy and light clay soils, Widespread in woodland, heathland and beside watercourses.	H
Lobelia beaugleholei	Snowy Lobelia	SH	<1% (+)	<1% (+)	Unknown	Unknown
Lobelia pratioides	Poison Lobelia	SH	<1% (+)	<1% (+)	Seasonally inundated to waterlogged soils along swamp margins and drainage lines.	H
Melaleuca squarrosa	Scented Paperbark	S	<1% (+)	<1% (+)	Moist to wet swampy soils.	H
Microlaena stipoides var. stipoides	Weeping Grass	MNG	5 – 25% (2)	1 – 5% (1)	Very extensive in moist well drained soil in heathlands, woodlands and forests.	NH
Olearia lirata	Snowy Daisy-Bush	S	1 – 5% (1)	<1% (+)	Moist well drained clay soil, widespread moist forests.	NH
Oxalis spp.	Shady Wood-sorrel	SH	<1% (+)	<1% (+)	Widespread in heavy soils through most plant communities.	NH
Poa spp.	-	Grasses	<1% (+)	<1% (+)	Grasses that occur in pastures, some species are considered weeds	NH
Poa tenera	Slender Tussock-grass	MNG	25 – 50% (3)	25 – 50% (3)	Moist soils in shady forests and riparian scrubs along watercourses.	H
Pomaderris aspera	Hazel Pomaderris	Shrub (S)	25 – 50% (3)	25 – 50% (3)	Moist, well drained humus rich and acidic soils in sheltered forests.	H
Pteridium esculentum subsp. esculentum	Australian Bracken	Ground Fern (GF)	25 – 50% (3)	50 – 75% (4)	Very common in all but poorly drained soils and heavily shaded sites. Found below 1,200 m, especially in disturbed areas. Prevalent after fires.	NH
Rubus anglocandicans	Common Blackberry		<1% (+)	<1% (+)	Introduced species, usually found in moist riparian or other mesic habitats (c)	H
Senecio minimus	Shrubby Fireweed	MH	<1% (+)	<1% (+)	Moist well drained soils in cool forests. Coloniser of disturbed places especially along tracks and after fires.	NH
Senecio prenanthoides	Beaked Fireweed	Herb (H)	<1% (+)	<1% (+)	Moist well drained soils in forests and woodlands in the foothills.	NH
Sonchus oleraceus	Sow-thistle	LH	<1% (+)	<1% (+)	Very common weed of disturbed areas, also found on swamps, lake edges and coastal dunes provided moisture is adequate (b).	H
Tetrarrhena juncea	Forest Wire-grass	LNG	50 – 75% (4)	50 – 75% (4)	Moist soils, tolerating drying out in summer, in gullies and moist to wet forests and heathy woodlands.	H
Todea barbara	Austral King-fern	GF	<1% (+)	1 – 5% (1)	Moist to wet organic soil, tolerating waterlogging, in shaded gullies,	H

Species Name	Common Name	Lifeform	% Cover		Habitat Preference (a)	Hydrophytic (H) / Non-Hydrophytic (NH)
			2020	2022		
					along watercourses and in swamps of mountain and foothill forests.	
Viola hederacea	Ivy-leaf Violet	SH	1 – 5% (1)	1 – 5% (1)	Widespread in drying to moist well drained soils in forests.	NH
Q3 – Woodland – Eastern End of Big Swamp						
Anthoxanthum odoratum	Sweet Vernal-grass	-	<1% (+)	Not observed	Widespread weed found in many natural settings, tolerates almost any soil. Can occur in riparian vegetation and freshwater wetland environments.	H
Ascaena novae-zelandiae	Bidgee-widgee	MH	<1% (+)	<1% (+)	Widespread in moist to dry sites in clay and sandy soils.	NH
Asperula conferta	Common Woodruff	MH	<1% (+)	Not observed	Moist well drained soils in moist forests	NH
Asteraceae sp.	-	-	<1% (+)	Not observed	Unknown	Unknown
Australina pusilla	-	-	<1% (+)	Not observed	Moist soil in subalpine grassland and woodland	NH
Eucalyptus ovata	Swamp Gum	T	50 – 75% (4)	50 – 75% (4)	Poorly drained infertile and clay soils which may dry out in summer.	H
Galium aparine	Cleavers	-	1 - 5% (1)	1 - 5% (1)	Introduced species – widespread in gardens and disturbed sites (c)	NH
Holcus lanatus	Yorkshire Fog	Large Non-Tufted Graminoid (LNG)	1 – 5% (1)	Not observed	Common on seasonally wet freshwater and saline swamp and lake margins. Very tolerant of waterlogging (b).	H
Hydrocotyle hirta	Hairy Pennywort	Small or Prostrate Herb (SH)	<1% (+)	1 – 5% (1)	Widespread in moist to wet open to closed forests and rainforests.	H
Hypochaeris radicata	Flatweed	SH	1 – 5% (1)	<1% (+)	Introduced species (also known as False Dandelion)	NH
Microlaena stipoides var. stipodes	Weeping Grass	MNG	<1% (+)	1 – 5% (1)	Very extensive in moist well drained soil in heathlands, woodlands and forests.	NH
Olearia lirata	Snowy Daisy-Bush	S	1 – 5% (1)	1 – 5% (1)	Moist well drained clay soil, widespread moist forests.	NH
Pteridium esculentum subsp. esculentum	Australian Bracken	Ground Fern (GF)	75 – 100% (5)	75 – 100% (5)	Very common in all but poorly drained soils and heavily shaded sites. Found below 1,200 m, especially in disturbed areas. Prevalent after fires.	NH
Rubus anglocandicans	Common Blackberry		<1% (+)	<1% (+)	Introduced species, usually found in moist riparian or other mesic habitats (c)	H
Senecio glomeratus	Annual Fireweed	MH	1 – 5% (1	<1% (+)	Moist soil in forests and woodlands, sometimes near water.	H
Senecio minimus	Shrubby Fireweed	MH	5 – 25% (2)	1 – 5% (1)	Moist well drained soils in cool forests. Coloniser of disturbed places especially along tracks and after fires.	NH
Senecio prenanthoides	Beaked Fireweed	Herb (H)	1 – 5% (1)	Not observed	Moist well drained soils in forests and woodlands in the foothills.	NH

Species Name	Common Name	Lifeform	% Cover 2020	% Cover 2022	Habitat Preference (a)	Hydrophytic (H) / Non-Hydrophytic (NH)
Sonchus oleraceus	Sow-thistle	LH	<1% (+)	<1% (+)	Very common weed of disturbed areas, also found on swamps, lake edges and coastal dunes provided moisture is adequate (b).	H
Q4 – Swamp Plain – Central Eastern Portion						
Asperula conferta	Common Woodruff	MH	Not observed	5 – 25% (2)	Moist well drained soils in moist forests	NH
Eucalyptus ovata	Swamp Gum	T`	<1% (+)	<1% (+)	Poorly drained infertile and clay soils which may dry out in summer.	H
Holcus lanatus	Yorkshire Fog	Large Non-Tufted Graminoid (LNG)	Not observed	<1% (+)	Common on seasonally wet freshwater and saline swamp and lake margins. Very tolerant of waterlogging (b).	H
Hypochaeris radicata	Flatweed	SH	<1% (+)	<1% (+)	Introduced species (also known as False Dandelion)	NH
Leptospermum continentale	Prickly Tea-Tree	S	5 – 25% (2)	5 – 25% (2)	Well drained to moist sandy and light clay soils, Widespread in woodland, heathland and beside watercourses.	H
Maleluca squarrosa	Scented Paperbark	S	1 – 5% (1)	1 – 5% (1)	Moist to wet swampy soils.	H
Pteridium esculentum subsp. esculentum	Australian Bracken	Ground Fern (GF)	75 – 100% (5)	75 – 100% (5)	Very common in all but poorly drained soils and heavily shaded sites. Found below 1,200 m, especially in disturbed areas. Prevalent after fires.	NH
Senecio glomeratus	Annual Fireweed	MH	Not observed	<1% (+)	Moist soil in forests and woodlands, sometimes near water.	H

Large Tufted Graminoid (LTG) – tussock grass or grass like plant. A robust grass, sedge, rush or similar

Non-tufted graminoid – non-tussock grass of frass like plant

(a) https://www.yarraranges.vic.gov.au/PlantDirectory/Home

(b) https://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/sip_salt_common_sow_thistle , https://vro.agriculture.vic.gov.au/dpi/vro/vrosite.nsf/pages/sip_yorkshire_fog

(c) https://vicflora.rbg.vic.gov.au/flora/taxon/390a7b22-b707-45b2-8ac5-6750bfaf4b12 https://vicflora.rbg.vic.gov.au/flora/taxon/a44b2334-eac3-4a51-b38d-f6451bc9d7a5

B CoPC Data Summary – Surface Water

Table 10.1: Data Summary for CoPC – Surface Water

Metal of interest	Number of samples	Number of detects	Number in exceedance	Guideline Value **	Range (Min – Max)	Mean	Standard Deviation	95% UCL
ME 1-4; East Barwon and West Barwon River upstream of Boundary Creek								
pH (pH units)	121	121	≤6.8: 87 ≥8.0: 2	≥6.8 - ≤8.0	5.26 – 8.67	6.89	-	-
Aluminium (mg/L)	111	100	57	0.055	0.01 – 34.78	0.651	3.925	1.259
Iron (mg/L)	111	110	97	0.3	0.05 – 5.4	0.902	0.746	1.02
Manganese (mg/L)	110	109	0	1.2	0.005 – 0.57	0.145	0.098	0.16
Zinc (mg/L)	30	19	11	0.008	0.002 – 0.051	0.012	0.009	0.0124
Gauge 233275; Boundary Creek upstream of Big Swamp								
pH (pH units)	1158	1158	≤6.8: 594 ≥8.0: 0	≥6.8 - ≤8.0	4.00 – 7.84	6.75	-	-
Aluminium (mg/L)	35	26	12	0.055	0.01 – 12	0.51	2.137	1.124
Cobalt (mg/L)	35	2	0	0.09	0.011 – 0.032	-	-	-
Iron (mg/L)	34	34	23	0.3	0.08 – 24	2.209	5.267	3.48
Manganese (mg/L)	35	33	0	1.2	0.002 – 0.054	0.0146	0.0111	0.0183
Nickel (mg/L)	35	12	1	0.011	0.001 – 0.043	0.0057	0.0208	0.0119
Zinc (mg/L)	35	18	3	0.008	0.001 – 0.38	0.0221	0.0666	0.0374
Big Swamp								
pH (pH units)	1	1	1	≥6.8 - ≤8.0	5.48	-	-	-
Aluminium (mg/L)	1	1	1	0.055	0.26	-	-	-
Iron (mg/L)	1	1	1	0.3	48	-	-	-
Manganese (mg/L)	1	1	0	1.2	0.024	-	-	-
Zinc (mg/L)	1	1	1	0.008	0.023	-	-	-
Gauge 233276; Boundary Creek downstream of Big Swamp								

Metal of interest	Number of samples	Number of detects	Number in exceedance	Guideline Value **	Range (Min – Max)	Mean	Standard Deviation	95% UCL
pH (pH units)	1066	1066	≤6.8: 1065 ≥8.0: 0	≥6.8 - ≤8.0	2.9 – 7.0	4.64		
Aluminium (mg/L)	35	35	33	0.055	0.02 – 13	4.262	4.201	5.863
Cobalt (mg/L)	35	30	0	0.09	0.002 – 0.038	0.0113	0.0106	0.0154
Iron (mg/L)	34	34	34	0.3	0.55 – 66	13.83	17.08	33.55
Manganese (mg/L)	35	35	0	1.2	0.007 – 0.091	0.0323	0.0195	0.0379
Nickel (mg/L)	35	32	23	0.011	0.002 – 0.16	0.0351	0.0377	0.05
Zinc (mg/L)	35	34	32	0.008	0.001 – 0.42	0.122	0.125	0.17
Gauge 233228; ME 5; Boundary Creek at Forrest Rd, Yeodene								
pH (pH units)	2961	2961	≤6.8: 2945 ≥8.0: 0	≥6.8 - ≤8.0	2.72 – 7.80	4.16		
Aluminium (mg/L)	120	119	21	0.055	0.05 – 71	6.607	13.08	8.42
Cobalt (mg/L)	14	13	8	0.09	0.003 – 0.024	0.0123	0.00716	0.0158
Iron (mg/L)	44	43	41	0.3	0.13 – 96	14.13	21.55	43.97
Manganese (mg/L)	37	36	0	1.2	0.019 – 0.24	0.0707	0.0585	0.0872
Nickel (mg/L)	14	13	10	0.011	0.005 – 0.047	0.0237	0.014	0.0306
Zinc (mg/L)	28	28	28	0.008	0.015 – 36	1.395	6.783	3.578
Gauge 233233; ME 6; Barwon River 100 m downstream Boundary Creek Confluence								
pH (pH units)	6	6	0	≥6.8 - ≤8.0	6.88 – 7.48	7.19		
Aluminium (mg/L)	6	4	3	0.055	0.02 – 0.09	0.0467	0.0281	0.0733
Iron (mg/L)	6	6	3	0.3	0.13 – 2.0	0.747	0.762	1.373
Manganese (mg/L)	6	6	0	1.2	0.01 – 0.29	0.135	0.0964	0.214
Zinc (mg/L)	6	4	4	0.008	0.012 – 0.057	0.0182	0.0179	0.0351
ME 7-12; Baron River downstream of Boundary Creek Confluence								
pH (pH units)	517	517	≤6.8: 100	≥6.8 - ≤8.0	4.3 – 8.1	7.09		

Metal of interest	Number of samples	Number of detects	Number in exceedance	Guideline Value **	Range (Min – Max)	Mean	Standard Deviation	95% UCL
			≥8.0: 3					
Aluminium (mg/L)	470	451	390	0.055	0.01 – 6.3	0.327	0.597	0.362
Iron (mg/L)	466	461	410	0.3	0.010 – 14	1.622	1.476	1.742
Manganese (mg/L)	461	458	2	1.2	0.005 – 1.4	0.138	0.148	0.149
Zinc (mg/L)	63	44	35	0.008	0.003 – 0.13	0.016	0.019	0.018

** pH range based on Environment Reference Standard (ERS) range for Central Foothills and Coastal Plains, all other values based on 95% species protection values as published by ANZ WQG (2018).

Note: No cobalt or nickel data is available for samples collected in the Barwon River.

C Exposure Point Concentration Selection

Table 10.2: Summary of EPC Selection

Metal of interest	Selected EPC	Basis	Justification
ME 1-4; East Barwon and West Barwon River upstream of Boundary Creek			
pH (pH units)	5.26 8.67	Minimum reported Maximum reported	The full range has been considered as it demonstrates the variability of pH in the system.
Aluminium (mg/L)	0.086	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Copper (mg/L)	N/A	Not considered further	No exceedances of Tier 1 screening value at this location, copper was only detected in one (1) of 29 surface water samples analysed at this location.
Iron (mg/L)	1.02	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Manganese (mg/L)	N/A	Not considered further	No exceedances of Tier 1 screening value at this location.
Zinc (mg/L)	0.0124	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Gauge 233275; Boundary Creek upstream of Big Swamp			
pH (pH units)	4.00 7.84	Minimum reported Maximum reported	The full range has been considered as it demonstrates the variability of pH in the system.
Aluminium (mg/L)	1.124	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Cobalt (mg/L)	N/A	Not considered further	No exceedances of Tier 1 screening value at this location.
Copper (mg/L)	N/A	Not considered further	No exceedances of Tier 1 screening value at this location, copper was only detected in two (2) of 35 surface water samples analysed at this location

Metal of interest	Selected EPC	Basis	Justification
Iron (mg/L)	3.48	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Manganese (mg/L)	N/A	Not considered further	No exceedances of Tier 1 screening value at this location.
Nickel (mg/L)	0.0119	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Zinc (mg/L)	0.0374	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Big Swamp			
pH (pH units)	5.48	Given the limited data set for Big Swamp, the detected concentrations for these key metals have been selected as the EPC for use in the ERA.	
Aluminium (mg/L)	0.26		
Copper (mg/L)	0.002		
Iron (mg/L)	48		
Manganese (mg/L)	0.024		
Zinc (mg/L)	**0.023**		
Gauge 233276; Boundary Creek downstream of Big Swamp			
pH (pH units)	2.9 7.0	Minimum reported Maximum reported	The full range has been considered as it demonstrates the variability of pH in the system.
Aluminium (mg/L)	5.86	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Cobalt (mg/L)	N/A	Not considered further	No exceedances of Tier 1 screening value at this location.
Copper (mg/L)	0.003	Maximum reported	Given the limited number of copper detections at this location, the maximum value has been selected.
Iron (mg/L)	33.55	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Manganese (mg/L)	N/A	Not considered further	No exceedances of Tier 1 screening value at this location.

Metal of interest	Selected EPC	Basis	Justification
Nickel (mg/L)	0.05	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Zinc (mg/L)	0.17	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Gauge 233228; ME 5; Boundary Creek at Forrest Rd, Yeodene			
pH (pH units)	2.72 7.80	Minimum reported Maximum reported	The full range has been considered as it demonstrates the variability of pH in the system.
Aluminium (mg/L)	8.42	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Cobalt (mg/L)	0.024	Maximum reported	Given the limited number of cobalt detections at this location, the maximum value has been selected.
Copper (mg/L)	0.005	Maximum reported	Given the limited number of copper detections at this location, the maximum value has been selected.
Iron (mg/L)	37.29	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Manganese (mg/L)	N/A	Not considered further	No exceedances of Tier 1 screening value at this location.
Nickel (mg/L)	0.031	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Zinc (mg/L)	0.15	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Gauge 233233; ME 6; Barwon River 100 m downstream Boundary Creek Confluence			
pH (pH units)	6.88 7.48	Minimum reported Maximum reported	The full range has been considered as it demonstrates the variability of pH in the system.
Aluminium (mg/L)	0.073	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Copper (mg/L)	N/A	Not considered further	No exceedances of Tier 1 screening value at this location, copper was only detected in one (1) of 6 surface water samples analysed at this location.
Iron (mg/L)	**1.37**	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.

Metal of interest	Selected EPC	Basis	Justification
Manganese (mg/L)	N/A	Not considered further	No exceedances of Tier 1 screening value at this location.
Zinc (mg/L)	0.035	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
ME 7-12; Baron River downstream of Boundary Creek Confluence			
pH (pH units)	4.3 8.1	Minimum reported Maximum reported	The full range has been considered as it demonstrates the variability of pH in the system.
Aluminium (mg/L)	0.36	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Copper (mg/L)	0.01	Maximum reported	Given the limited number of detected concentrations, the maximum value has been selected.
Iron (mg/L)	1.74	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Manganese (mg/L)	0.15	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.
Zinc (mg/L)	0.018	95% UCL	The number of results for this compound is such that use of the 95% UCL value is considered likely to represent the reasonable maximum exposure for aquatic receptors.