Aire Valley estuary floodplain project

FINAL REPORT

October 2020

alluvium

Alluvium and the Corangamite Catchment Management Authority acknowledge Traditional Owners of Country and recognise their continuing connection to lands, waters and communities. We pay our respects to Eastern Maar as the Traditional Owners of the lands on which the project is based and to Elders past, present and emerging. We look forward to continuing to work collaboratively with the Eastern Maar Aboriginal Corporation on achieving water for Traditional Owner cultural values and uses.

This draft report has been prepared by Alluvium Consulting Australia Pty Ltd for the Corangamite Catchment Management Authority under the contract titled 'Aire Valley estuary floodplain project'.

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Executive summary

The Aire River estuary is a naturally intermittently open/ closed estuary (IOCE) and supports the EPBC listed *Assemblages of species associated with open-coast salt-wedge estuaries of western and central Victoria ecological community*. Prior to development of the lands surrounding the Aire River estuary, sand would have been deposited at the estuary mouth, building up to create long periods of estuary mouth closure. Under these pre-development conditions estuarine water level would gradually increase over months, inundating the floodplain, in turn providing conditions for the specialised vegetation communities, estuarine dependent fish, and birds requiring open waters and shoreline habitats. Conversely there would also be periods where the estuary would open naturally, allowing for saline intrusion into the estuary, and movement of fish both into the ocean and back into the estuary.

There is a long history of management intervention in the Aire Valley. This has included agricultural development of floodplains, networks of drainage channels across the floodplain and artificial estuary openings. In the future, climate change will affect the Aire estuary, due to factors including sea level rise, decreasing river flows, increases in wave height and period, and increased temperature. This will have a range of impacts on the hydrodynamics and water quality of the Aire estuary, and the exact conditions will depend on a range of factors, including management arrangements. While there is uncertainty concerning the exact nature of the conditions that may occur over time, these predicted changes will have an impact on the environmental values and other values of the Aire estuary.

This project is **specifically focused on the environmental values** of the Aire River estuary and its floodplain. The Corangamite CMA commissioned this study to improve understanding of the critical needs of the environmental values and will use the findings and advice to inform future entrance management activities from an environmental perspective. Future management activities will need to consider the economic, social and cultural values of the Aire Valley, in conjunction with the environmental values described in this study.

The study, conducted by Alluvium Consulting and a Technical Panel of experts, considered the:

- Impacts of the current estuary management on the environmental values of the Aire River estuary
- Critical environmental needs of the estuary in terms of depth, timing and duration of floodplain inundation
- Estuary opening processes that may adversely impact on environmental values, including protected species
- Impacts of a closed estuary – drawing on existing inundation information.

The outcomes of this project should be used, along with other sources of information, as the basis for a review of options for land and entrance management to provide multiple and complementary benefits for the environment and floodplain landholders.

This project builds on existing work on the Aire estuary including mapping of vegetation communities, bird surveys, water quality information, inundation assessment, the Estuary Entrance Management Support System (EEMSS) and the Estuary Management Plan. In addition to the review and interpretation of existing information, new analyses for this project included:

- Review of water quality sampling from opening events
- Consolidation of a database of estuary openings over the last 11 years, and analysis of water levels, and closed / open entrance durations
- A water balance model to inform rates of water level increase in a closed estuary
- Inundation analysis using 30 years of satellite data to understand current duration and timing of floodplain inundation.

The additional analyses combined with existing information about the Aire River and stakeholder insights has allowed the Technical Panel to summarise the processes and environment requirements over different months of year. The associated risks of artificially opening the estuary to the current and potential environmental values of the Aire River estuary and floodplain have also been assessed by the Technical Panel using expert judgment (Table 1).

Table 1. Summary by month of estuary processes, environmental requirements and risk of artificial openings
(! = some risk, !!! significant risk)

<table>
<tr><th>Month</th><th>Summary of estuary processes</th><th>Summary of environmental value requirements</th><th>Risk of artificial opening to meeting environmental requirements during this period</th></tr>
<tr><td>December</td><td rowspan="6">The entrance is greatly restricted/closed. Gradual rise in water level behind sand berm at entrance.
Deep saline water progressively loses dissolved oxygen and eventually may become anoxic, particularly in the upper estuary.</td><td rowspan="4">Vegetation: Slow filling period advantages macrophytes and fresh/brackish-water herbs.
Fish: Supports migration, breeding, and more importantly growth of juvenile fish bred in previous spring. Rapid dropping water level can impact Blue Spot Goby eggs, a species important for the estuary food chain.
Birds: Facilitates waterbird foraging for many waterbird species from all guilds. This is particularly important when other areas in south-east Australia are in drought, and the Aire estuary can play an important role as a drought refuge for these species.</td><td rowspan="4">! !</td></tr>
<tr><td>January</td></tr>
<tr><td>February</td></tr>
<tr><td>March</td></tr>
<tr><td>April</td><td rowspan="3">Vegetation: Inundation of Swamp scrub and higher levels of floodplain is important to avoid changes to EVCs.
Fish: The connectivity created by higher flows and floodplain inundation is important for life history stages of many fish species. Galaxiids breeding.
Birds: This is an important time for migratory birds to be fuelling up prior to migration north – this requires large shallow areas of water.</td><td rowspan="3">! ! !</td></tr>
<tr><td>May</td></tr>
<tr><td>June</td><td rowspan="4">Entrance predominantly open but can shift between open/closed in response to storms/variable river flows.
This period resets the estuary. Increased inflows can reduce salinity within the estuary and transport sediment through the estuary.
Winter storm surge can occur when high waves push up the channel when entrance is open. This influx of well oxygenated seawater triggers breeding in many estuarine organisms.</td></tr>
<tr><td>July</td><td rowspan="2">Vegetation: An open estuary during this time enables germination in late winter (before more inundation in Spring).
Fish: Galaxiids recruit and grow in estuary (or sea). Mudfish breed late winter in freshwater, larvae move into estuary. Estuary Perch breeding in estuary influenced by freshwater flows.</td><td rowspan="2">!</td></tr>
<tr><td>August</td></tr>
<tr><td>September</td><td rowspan="3">Vegetation: An important period for recruitment of Swamp Scrub and aquatic herbs.
Fish: Spring is a period for Black Bream breeding, and estuary openings can reduce spawning success if eggs are washed from the estuary or from the impacts of low dissolved oxygen conditions.
Migration back into the estuary for many fish species (Tupong, Mudfish, Galaxiids, Eels).
Birds: This is an important period for migratory birds returning to the estuary, requiring, freshwater inputs for drinking water, and high productivity resulting from floodplain inundation. This is also a period of waterbird nesting when water levels should not be rapidly altered.
This period is also part of the Hooded Plover breeding season, where mechanical and human activity on the beach could impact breeding success.</td><td rowspan="3">! ! !</td></tr>
<tr><td>October</td><td rowspan="2">Reduction of river flow and ebb-tidal velocities results in restriction of the entrance channel. Seawater inflow is progressively reduced.</td></tr>
<tr><td>November</td></tr>
</table>

Findings and advice

The advice provided was developed by the Technical Panel and builds on that provided through EEMSS. The advice relates **only to the environmental values** of the Aire River estuary and floodplain, their requirements and the current management context of the estuary.

In addition to this advice, throughout the report a number of activities have been identified by the Technical Panel to improve the ongoing management of the Aire estuary and provide the conditions to support the environmental values. Improved knowledge will help build a better understanding of the condition and trajectory of these systems and support adaptive management practices in the future.

1. Resilience of the system under climate change will be very important

Climate change will affect the Aire estuary as sea level and air temperatures rise and river hydrology alters. While there is uncertainty concerning how conditions may change over time, these changes will have an impact on the environmental values and other values of the Aire estuary. Whatever the future holds for the Aire, its truly estuarine community will adapt and survive. Some species will increase in abundance while others may decline. Overall, it will be important to enhance the resilience of the ecological community to the impacts of climate change by reducing other pressures.

Management of environmental values in the estuary needs to consider adaptation to climate change. Similarly, other values and uses of the estuary should consider the impacts of climate change and adaptation strategies. Stakeholders should work together to develop an Aire Estuary Adaptation Plan to prepare for local climate change; this is a key focus of Victoria's new Marine and Coastal Policy (see Recommendation 6.8, page 38; 2020).

2. Artificial estuary mouth openings are restricting the potential of the estuary environmental values and putting environmental values at risk.

The presence of diverse assemblages of vegetation, fish and bird species show the current management arrangements and climatic conditions of the Aire River estuary are somewhat able to support the environmental values and objectives as described in the Estuary Management Plan. However, the absence of some species (such as migratory birds) and the manipulated inundation regime which may be restricting some plant species (e.g. change in some EVCs such as Swamp Scrub which is not being sufficiently flooded) suggests that the current management regime is restricting the ecological potential of the estuary.

Artificial estuary openings **increase the frequency of openings** compared to what would have occurred without intervention (i.e. naturally) under comparable hydrology. Each additional estuary opening leads to greater disturbance of the ecosystem and increases the risk of adverse ecological effects.

3. There is no environmental requirement to artificially open the estuary

Periods of open mouth states are an important part of dynamic IOCE environments. Several fish species require the river mouth to be open at particular times to complete their life cycles (including breeding, recruitment, and growth). Species which live in estuaries have to be highly adaptable because of the dynamic nature of estuaries. Based on analysis of natural openings in the Aire estuary (2008-2019), the frequency and timing of these will be suitable to meet the requirements of fish species present in the system. Therefore, under the current hydrodynamic conditions, there is no environmental need to artificially open the Aire estuary for fish requirements.

As part of an IOCE system, the native vegetation in the Aire estuary is resilient to inundation for long periods. Based on these vegetation characteristics, there is no environmental need to artificially open the Aire estuary.

4. If artificial estuary entrance openings are required to protect other values (non-environmental), there are ways to minimise the environmental risks

If the estuary were managed solely to protect its environmental values, there would be no artificial openings. Development of the estuary, however, has meant that human assets such as farmland, campgrounds and roads are flooded during estuary entrance closure. Opening the entrance to protect these values has historically (including recent times) taken precedence over the environment. We suggest a more patient approach to opening: reducing the frequency of artificial estuary openings and allowing time for natural openings where possible.

Current management could be modified to provide greater recognition of environmental values by reducing the frequency of artificial estuary openings during selected periods:

- **Late Autumn – Early Winter (April – June).** The connectivity resulting from higher flows and floodplain inundation is important for life history stages of many fish species. Inundation of Swamp Scrub and higher levels of the floodplain is important to avoid changes to some EVCs. This is an important time for migratory and other shore birds to be fuelling up prior to migration north – this requires large shallow areas of water.
- **Spring (September to November).** This is an important period for all aquatic life as the high productivity resulting from floodplain inundation is very important for all aspects of the ecosystem such as fish, water birds and aquatic plants. In addition, these water rises contribute to the health of migratory birds returning to the estuary, and waterbirds requiring freshwater inputs for drinking water. This is also a period of waterbird nesting when water levels should not be rapidly altered. Spring is also a period for Black Bream breeding, and estuary openings can reduce spawning success if eggs are washed from the estuary or impacted by low DO conditions. It is also an important period for recruitment of Swamp Scrub and aquatic herbs. This period is also part of the Hooded Plover breeding season, where mechanical and human activity on the beach could impact breeding success.

To minimise the environmental risks, the Technical Panel advise avoiding artificially opening the estuary when it is possible the estuary will open naturally within an acceptable timeframe before assets are compromised. In making an assessment about opening, managers should continue to consider factors such as current river flow, berm height and width, forecast rainfall and sea state and estuary water level.

There are water quality risks associated with both natural and artificial estuary openings and from a water quality perspective; one type is not superior to the other. The Technical Panel advise that management should aim to reduce the number and frequency of openings to reduce water quality risks.

In addition to estuary entrance management, complementary management to improve the overall condition and trajectory of the estuary could include:

- Reducing pasture grass on the estuary floodplain. One of the dilemmas for management of the estuary is balancing the need for high water levels by the native plant community against the deleterious effects of flooding on pasture grass. Poor water quality from the decay of drowned pasture grass poses a risk to the estuary on opening as the floodplain drains. This factor places constraints on the extent and duration of flooding under present land use.
- Decommissioning and filling or blocking drainage channels on the estuary floodplain to reinstate a more natural hydrology to the lower elevation areas of the floodplain. More frequently flooded areas should be targeted first. This should be done in line with the Victorian Rural Drainage Strategy.
- Raising the level of roads and bridges presently inundated at low levels

5. A further study is required to assess management options in the context of economic, social, cultural, and environmental values of the Aire Valley.

The advice in this report relates only to the environmental values of the Aire River estuary and floodplain, their requirements and the current management context of the estuary. Future management activities will need to consider the economic, social and cultural values of the Aire Valley, in conjunction with the environmental values described in this study. Therefore, the Technical Panel advise undertaking a further study that assesses management options and balances the needs of different values of the Aire Valley.

Contents

1 Introduction

One of Victoria's 18 Heritage Rivers, and the only Heritage River in the Corangamite region, the Aire River originates in the Otway Ranges, and joins the Calder River and Ford River to form the Aire Valley (Figure 1, Figure 4). The Aire River estuary is classified as an Intermittently Open / Closed Estuary (IOCE), a type of wave-dominated estuary. Across the coast of Victoria there are over 120 rivers and streams that enter the sea either via riverine estuaries or large embayments, and over 85% of these have estuaries that naturally close to the sea.

The Aire River estuary regularly closes as part of a natural process of waves transporting sand along the coastline and across the mouth of an estuary, forming a sand berm at the entrance. The closed estuary period is a naturally occurring state and is important for supporting the occurrence of associated vegetation communities, fish recruitment and ecosystem processes.

Currently, the Aire River estuary mouth is artificially opened to protect human assets that may be inundated under prolonged estuary closure. The Corangamite Catchment Management Authority (Corangamite CMA) use the Estuary Entrance Management Support System (EEMSS) to determine the threats of opening (or not opening) an estuary, and to assist in deciding whether or not to do an artificial opening. However, the EEMSS approach has limitations for identifying some of the more specific trade-offs of artificial estuary openings, including the implications (benefits / impacts) for human assets and environmental values.

Figure 1. *Aire Valley [Photo: Corangamite CMA]*

1.1 Project objectives and approach

Objectives

The Corangamite CMA commissioned this study to improve understanding of the critical needs of the environmental values of the Aire River estuary. Information from this project may be used to inform future entrance management activities from an environmental perspective including:

- times of the year when opening, or not opening, the estuary mouth is important to protect ecological values
- scenarios/times when the estuary mouth should not be artificially opened, in order to avoid adverse impacts on the ecology of the estuary and floodplain.

While there are many aspects to estuary management, this project is **specifically focused on the environmental values**. The study considered the:

- impacts of the current estuary management on the environmental values of the Aire River estuary
- critical environmental needs of the estuary in terms of depth, timing and duration of floodplain inundation
- estuary opening processes that may adversely impact on environmental values, including protected species
- benefits of a closed estuary – drawing on existing inundation information.

The outcomes of this project will be used, along with other sources of information, as the basis for a future study which may change management options (currently not funded). In this future study, alternative land and entrance management approaches that provide dual benefits for environmental values and floodplain landholders will be considered. This study follows on from, and complements, the Aire River Estuary Management Plan 2015-2023, which is an eight year action plan aimed to improve the environmental condition of the Aire River estuary.

Figure 2 shows how this objective is unpacked to guide the project questions, including understanding key environmental values (vegetation, fish, birds), the conditions required to support these values, and the processes and drivers that influence the conditions in the estuary.

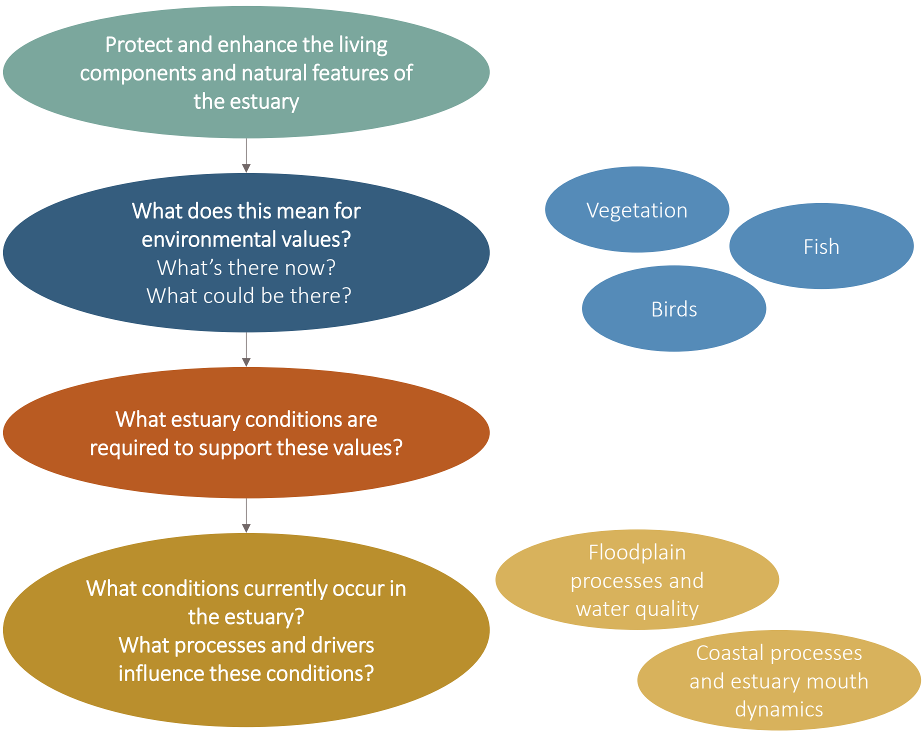


Figure 2. *Project questions to guide the investigation*

Project approach and engagement

The project tasks were guided by goal-setting with the Aire Valley Stakeholder Advisory Committee (AVSAC) and the establishment of key project questions/topics to be answered. Based on these questions (Figure 2), the Technical Panel reviewed and assessed the available data for the Aire estuary and other similar sites in terms of water quality, vegetation requirements, estuary mouth dynamics, and aquatic ecology.

This project builds on the existing work on the Aire estuary including mapping of vegetation communities, bird surveys, water quality information, inundation assessment, the Estuary Entrance Management Support System (EEMSS) and the Estuary Management Plan. In addition to the review and interpretation of existing information, new analyses for this project included:

- Review of water quality sampling from opening events
- Consolidation of a database of estuary openings over the last 11 years, and analysis of water levels, and closed / open durations
- A water balance model to predict rates of water level increase in a closed estuary
- Inundation analysis using 30 years of satellite data to understand current duration and timing of floodplain inundation.

This additional analysis, combined with existing information about the Aire and stakeholder information, has allowed the Technical Panel to summarise the processes and environment requirements over the different months of a year. Associated risks of artificial openings to the current and potential environmental values of the Aire estuary have been assessed.

The following groups have been engaged with this project.

Steering Committee. The purpose of the Steering Committee is to oversee project implementation, provide direction on the scope of work, and review and provide feedback for key milestones throughout the project. The Steering Committee is comprised of representatives from DELWP, Parks Victoria and Corangamite CMA.

Aire Valley Stakeholder Advisory Committee (AVSAC). The AVSAC is the community reference group for this project. Their role is to provide local input and insights and provide advice on values and concerns to be addressed through the project. This group includes landholders, a commercial eel licence holder, a tourist accommodation owner, VRFish, Field and Game, Landcare, Colac Otway Shire Council, Conservation Ecology Centre, DELWP, Parks Victoria and Corangamite CMA. A full list of AVSAC representatives is provided on page 71.

A project introduction meeting was held with the AVSAC, followed by a goal-setting meeting on 26 May 2020 and a discussion of environmental value requirements on 25 June 2020. The input provided in these meetings has been incorporated through this report.

The Technical Panel members contributing to this project are:

- Dr John Sherwood (estuary hydrodynamics and water quality), PhD, BSc
- Lance Lloyd (ecology, fish, birds), MSc, BSc
- David Carew (vegetation), BSc (Chemistry), BAppSc (Horticulture)
- Dr Sarah McSweeney (estuary opening and closing specialist), PhD (Coastal Geomorphology), BSc (Physical Geography)
- Dr Elisa Zavadil (coastal zone geomorphology), PhD (Geomorphology), BEng (Environmental), BSc (Earth Science).

1.2 This document

This draft report provides an overview of the project context (policy and estuary management), literature review, information provided by the AVSAC, findings of project analyses, and advice developed by the Technical Panel.

Context for the project	Background to the Aire Valley	Section 2
	Management of the Aire River estuary and floodplain	Section 3
Supporting technical information	Climate change	Section 4
	Estuary geomorphology & hydrodynamics	Section 5
	Estuary water quality	Section 6
	Estuarine and floodplain vegetation condition and requirements	Section 7
	Native fish condition and requirements	Section 8
	Bird species condition and requirements	Section 9
Findings and advice		Section 10

2 Background to the Aire Valley

Traditional Owners

Aboriginal people have occupied the Corangamite region for more than 30,000 years. Aboriginal people and their ancestors have cared for the environment for thousands of years and have always acknowledged their innate responsibility to care for the land. The Eastern Maar are Traditional Owners of Country within south-western Victoria, including the Aire Valley region. Eastern Maar Aboriginal Corporation (EMAC) is the professional organisation that represents the Eastern Maar People of South West Victoria and manages their Native Title rights and interests. The area around Cape Otway and the Aire Estuary is the land of the Gadubanud people (Eastern Maar Aboriginal Corporation, 2015). The Aire River and Estuary are designated Areas of Cultural Heritage Sensitivity.

Wetlands, such as those found near the Aire River estuary provided a variety of foods and the sheltered topography and close proximity to the ocean made this region a key settlement node for the Gadubanud people. Numerous archaeological sites have been recorded around the Aire Valley, mainly shell middens, lithic scatters, and rock shelters (Niewójt, 2009). The size of the population around the Aire Valley is uncertain, with few interactions documented between the Gadubanud people and early European settlers. A massacre of seven Gadubanud people at the mouth of the Aire River is documented in August 1846, sometimes known as the Aire River massacre. After this, there are few references to the Gadubanud people in press archives of the 1800s (Niewójt, 2009).

European settlement

The arrival of Europeans in the Otway region during the late 1840s led to disruption of Aboriginal society and ended a long-standing system of land management. Coastal and low-lying areas were taken up for grazing by the late 1840s, with several large runs established. The rich soils and high rainfall of the Otways led to most of the land being sold for farming by the 1880s and 1890s. In some of the more densely forested regions of the Otway Ranges, including the Aire Valley, land was released for sale, but was found to be unsuitable for agriculture and farms were therefore abandoned.

Forestry was also introduced to the region from the late 1840s and was the dominant industry. In the Aire River valley, Redwood (*Sequoia sempervirens*) plantations were established along the river, with extensive areas upstream from Hopetoun Falls. In recent years, environmental advocacy has seen the reduction of timber plantations and increased interest in eco-tourism and environmental conservation.

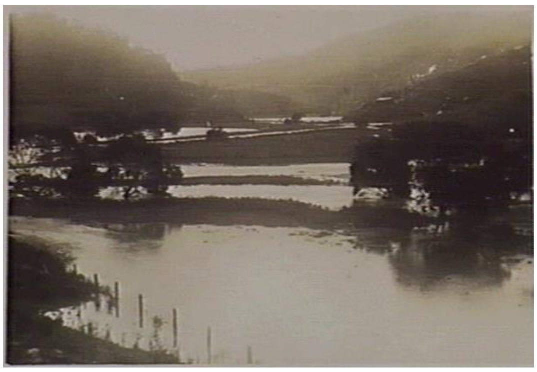



Figure 3. *Aire River at Glen Aire – Easter 1932 [Source: State Library of Victoria]*

Land use and management

The Aire River landscape zone, including the Ford River tributary catchment and the Parker and Elliot River catchments, is currently dominated by forestry (40%) and conservation (37%), with some non-dairy grazing (16%), dairy (5%) and other (2%) land uses (Corangamite CMA 2014). Interviews with landholders in 2015 found that most landholders were grazing beef, with some sheep, and that the floodplain and river flats are important to primary production in the summer months (RMCG 2015). Landholders of the Aire River valley have worked for many generations to make agricultural practices on the floodplain economically viable. In addition to agricultural production, tourism, hunting (waterfowl) and recreational fishing are important socio-economic values for the Aire Valley.

Figure 4. *Aire River valley and estuary. Source: ESRI World Imagery*

3 Management of the Aire River estuary and floodplain

3.1 Background

A sand bar often forms at the mouth of the Aire River closing the estuary mouth. Closure can lead to increased inundation of the Aire valley, including the privately owned agricultural land. These processes are further described in Section 5 (Estuary entrance conditions and hydrodynamics).

Impacts of inundation and management of the estuary opening have been documented for decades (Figure 5). Since the 1950s until 2000, the Aire River Drainage Committee, consisting of 17 Colac Otway Shire Council rate paying members, was responsible for the mechanical removal of the sandbar to reduce the threat of floodwaters inundating agricultural land. In recent decades, Parks Victoria have undertaken the artificial openings. The most recent event in May 2020 (Text Box 1) resulted in substantial inundation of agricultural land and flooding of Hordern Vale Road and Sand Road.

Panoramic view of mouth. River was flowing seawards at time of inspection along line shown. It was reported that the sand-bar had blocked the mouth during the previous weekend and a new channel through the bar had been excavated by the landowners affected.

Figure 5. *Parliamentary Public Works Committee inspecting the Aire River estuary in 1965 [Source: Department of Sustainability and Environment, 2009]*

Artificial estuary opening is regulated by waterway managers who are responsible for issuing approval under the *Water Act 1989*. In 2001 the responsibility for authorising works on waterways in the Aire Valley was vested with the Corangamite CMA. A permit to manage the opening of the Aire River mouth has since been issued to Parks Victoria. In 2003, a Memorandum of Cooperation was developed (Text Box 2), but this has since expired (as advised by Parks Victoria) and is now in need of review to reflect current changes to State policy.

Text box 2. Memorandum of Cooperation for estuary opening, 2003 [supplied by Parks Victoria]

All Parties agreed that when the water level reaches a pre trigger level of 1.09 m AHD the Neighbouring landowners may contact Parks Victoria officers to commence the process for opening the river. It is agreed that works to open the river will not commence until the water level reaches the official trigger level of 1.29 m and all legislative requirements have been met.

Parks Victoria agreed that once the water level reaches 1.29 m AHD, subject to weather, tide and sea conditions, it will follow the agreed opening procedure to ensure the river is opened as soon as practicable.

Water level is not the only factor to consider for mouth opening. The Victorian Waterway Management Strategy (2013) states that the decision process should commence when water level is considered to have a significant impact on the environmental, social, and or economic values of the estuary. Impacts associated with particular water levels may vary at different times of the year. Corangamite CMA do not currently artificially open estuaries for environmental reasons.

The Victorian Waterway Management Strategy also states that due to past management practices, there is an incorrect and widespread community belief that an artificial estuary opening is automatically initiated when the water reaches a particular level (DEPI, 2013). The reference to trigger levels in Text Box 2 from the expired Memorandum of Cooperation does not align with current State policy.

Note, there is a complex array of legislation, policy, plans, and strategies relating to management of the Aire River estuary. Relevant legislation, policies and strategies are outlined in further detail in Appendix A. Roles and responsibilities are also provided in Appendix A.

Text box 1. Case study - May 2020 inundation

The most recent inundation event was in May 2020. It was reported that the sand bar built to around 0.5 m deep and 50 m wide (Bell 2020) causing closure of the river mouth and inundation of the Aire valley. The impacts included inundation of Hordern Vale Road, restricting access to and from some properties. An estimated 1,500 acres was inundated (Bell 2020) and the water level reached at least 2.6 m at the Sand Road Bridge gauge board.


Left: track to Aire estuary mouth under water. Right: inundation of Aire River Valley (Supplied: Bruce Costin)

When the valley is inundated, stock must be moved to higher ground and inundation can cause access issues for some landholders. Prolonged inundation causes damage to pasture vegetation and can cause erosion of land including access tracks and walking tracks such as the Great Ocean Walk. Prolonged inundation can also damage private infrastructure such as pumps, sheds and machinery / vehicles. Aire Valley landholders have estimated their damages from the inundation in May 2020, this includes the cost of feed and hay, agistment of stock, reseeding pastures, drainage works, and refencing. There was also damage to vehicles, water supply, and public roads.

Given the timing of the request to artificially open the mouth, the water level elevation was too high for Parks Victoria to walk the excavator along the access track. A new access route, via the Great Ocean Walk, was utilised with a smaller excavator, following vegetation and cultural heritage approval processes.

Following large swells on the 21-22 May, the estuary was artificially opened on 23 May 2020 by Parks Victoria with the excavation of a channel through the sand bar. The flood levels receded over the following days, with a water level of 1.0 m AHD by 26 May 2020.

Photo: Excavation and artificial opening of the Aire River estuary on 23 May 2020. (Supplied: Parks Victoria)

3.2 Estuary Entrance Management Support System (EEMSS)

Currently, once an opening request is received by Parks Victoria, the Corangamite CMA will organise water quality testing and run an Estuary Entrance Management Support System (EEMSS) report. The EEMSS is a web-based decision support tool used by estuary managers when deciding whether to artificially open an estuary or not. The EEMSS was developed in 2006 in collaboration with the community and other stakeholders, including the Corangamite CMA and Parks Victoria. The use of the EEMSS ensures that a consistent approach to decision making is followed each time. An example report is provided in Figure 6.

The EEMSS report assists in determining the potential impacts of opening (or not opening) the estuary on the socioeconomic, environmental, and cultural assets for the estuary. In deciding whether an opening should occur the estuary manager must balance the often-competing threats posed by 'opening' or 'not opening' as listed in EEMSS. The EEMSS approach provides a way for estuary managers to transparently consider the range of potential impacts. However, users have noted that the tool has limitations for identifying some of the more specific trade-offs and implications (benefits / impacts) for human assets and environmental values. While EEMSS is a useful tool for considering these trade-offs, there can be challenges in the ultimate decisions regarding estuary openings and the point at which some risks or benefits may outweigh others is ultimately a matter for sound judgement and decision making.

Threats of Not Opening

Type	Name	Asset Score	Threat Score
Very High			
Birds	Margin Dwellers (non-vegetated habitat) (2)	5	4
Evc	Estuarine Reedbed	5	3
Evc	Estuarine Wetland	5	5
Evc	Swamp Scrub	5	5
Fish	Estuarine Seasonal Obligate (8)	5	4
Fishing	Short-finned Eel	5	4
Fishing	Mulloway	5	3
Land	Land manager 7	4	5
Land	Land manager 9	4	5
Camping	Camping - Aire River west camp ground	3	5
High			
Fish	Estuarine Seasonal Facultative (5)	4	3
Fishing	Greenback Flounder	4	3
Fishing	Long-nosed Flounder	4	3
Fishing	Yellow-eye Mullet	4	3

Threats of Opening

Type	Name	Asset Score	Threat Score
Very High			
Birds	Margin Dwellers (vegetated habitat) (3)	5	3
Birds	Waterbird- surface feeders (1)	5	3
Birds	Waterbird-diving (1)	5	3
Fish	Estuarine Seasonal Obligate (2)	5	3
Fishing	Mulloway	5	3
Fishing	Short-finned Eel	5	3
High			
Birds	Waterbird-diving (1)	4	3
Fish	Estuarine Seasonal Obligate (6)	4	3
Fish	Estuarine Seasonal Facultative (5)	4	3
Fishing	Greenback Flounder	4	3
Fishing	Long-nosed Flounder	4	3
Fishing	Yellow-eye Mullet	4	3
Fishing	Black Bream	5	2
Fishing	Estuary Perch	5	2

Figure 6. *Example EEMSS report (Corangamite CMA)*

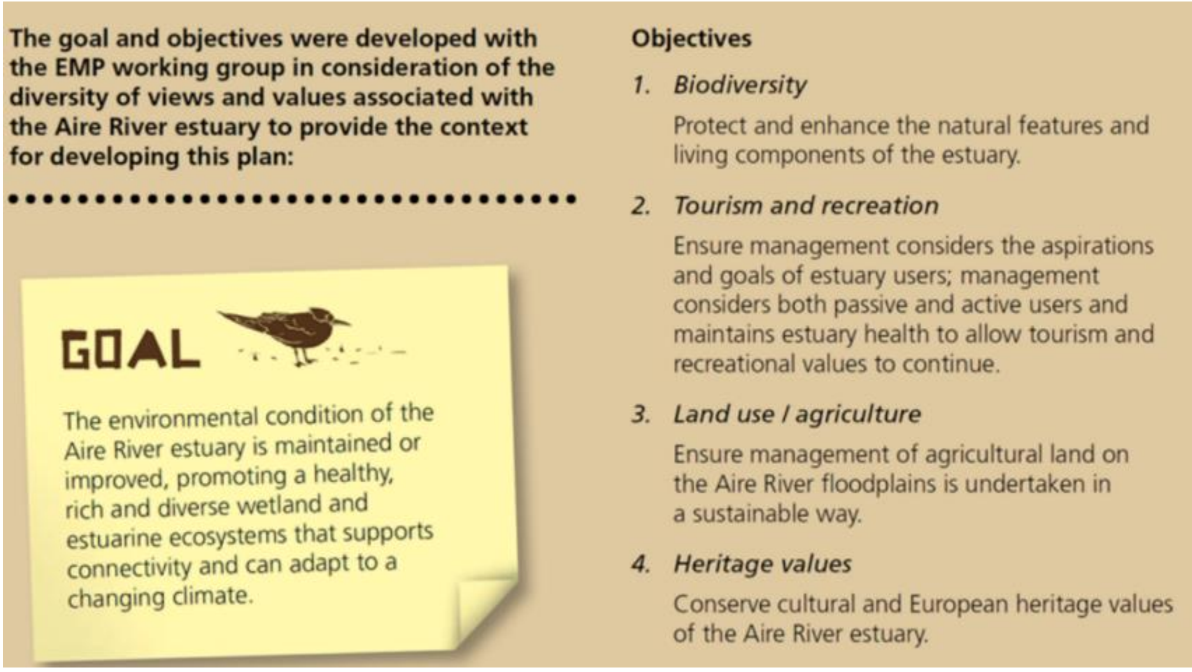
A bridge on Sand Road to a Parks Victoria campground crosses the estuary, and the gauge board on this bridge provides an important reference point for estuary entrance management. Observations of estuary conditions have been sporadic and only occur when landholders contact the Parks Victoria and officers physically inspect the site. Water level readings have been taken irregularly reducing their value for understanding the estuarine hydrology. There is now (from July 2020) a permanent water quality and water level monitoring station near Sand Road that provides live data on the estuary. [1]

Information on artificial estuary openings indicates that the estuary has been opened artificially over 60 times since October 2008 and has naturally opened around 20 times during this time period. Further information is available in Section 5.2 and Figure 21.

[1] Go to https://data.water.vic.gov.au/ and choose Surface Water Sites > Otway Coast Basin > 235283 Aire River @ Horden Vale

3.3 Goals and objectives for the Aire River estuary

Goals and objectives for the Aire River estuary were developed as part of the Aire River Estuary Management Plan 2015-2023 (EMP) (Figure 7). As part of the current study, a survey was provided to the AVSAC to assess if the goals and objectives were still relevant. A majority (64% of respondents) felt they were still relevant, 36% said 'somewhat' and 0% felt they were not relevant.



The goal and objectives were developed with the EMP working group in consideration of the diversity of views and values associated with the Aire River estuary to provide the context for developing this plan:

GOAL

The environmental condition of the Aire River estuary is maintained or improved, promoting a healthy, rich and diverse wetland and estuarine ecosystems that supports connectivity and can adapt to a changing climate.

Objectives

1. ***Biodiversity***

   Protect and enhance the natural features and living components of the estuary.

2. ***Tourism and recreation***

   Ensure management considers the aspirations and goals of estuary users; management considers both passive and active users and maintains estuary health to allow tourism and recreational values to continue.

3. ***Land use / agriculture***

   Ensure management of agricultural land on the Aire River floodplains is undertaken in a sustainable way.

4. ***Heritage values***

   Conserve cultural and European heritage values of the Aire River estuary.

Figure 7. *Goals and objectives from the Aire River Estuary Management Plan (Corangamite CMA 2015)*

Some challenges in achieving the objectives have been identified by the AVSAC, including the following.

- Balancing the objectives: environmental, land use/ agriculture, tourism and recreation, conserving heritage values, noting the need to consider:
  - Impacts upon farming and the community (perceived to have been neglected in the past)
  - Greater recognition of the productive capacity of the floodplain in agriculture especially in time of drought
  - Giving value to each stakeholder (across all objectives)
- Resources (including funding)
- Flexibility to adapt and respond more quickly
- Communication and consultation between government bodies and the community and land managers
- Lack of knowledge of the floodplain, including:
  - Getting the science right in a dynamic environment
  - Drawing on local knowledge
  - Understanding what a healthy floodplain is for the Aire.
- Climate change.

This project has been guided by the overarching goal for the estuary (Figure 7) and focuses specifically on the biodiversity objective while being cognisant of the need for a balance with the other objectives. The project focuses on improving the scientific understanding of estuary processes and draws on the valuable local knowledge that exists. In considering the biodiversity objective and supporting technical information, the technical assessments consider requirements for both maintaining, and improving, the current estuary condition over management timeframes (10-20 years), as well as implications for longer term management with a changing climate and sea level rise.

4 Climate change impacts on the Aire estuary

The Aire estuary will be impacted by climate change, along with other IOCEs in the region. It is important that the impacts of climate change are considered in the application of the environmental requirements and management of the estuary. This section discusses some of the possible impacts in terms of estuary entrance conditions, hydrodynamics and water quality.

Climate change is included as a threat to the ecological community associated with open-coast salt-wedge estuaries in the EPBC listing (DAWE 2018). The listing highlights climate change effects in the region that may impact estuaries, including a decrease in cool season rainfall, an increase in air and sea surface temperature, mean sea level rise, frequency of extreme weather events and ocean acidification, and a harsher fire weather climate (DAWE 2018; CSIRO & BoM 2015).

Projected sea level rise for the Aire estuary region under a high (RCP8.5) emissions scenario is around 0.12 m by 2030 and by 0.4 m by 2070 (CSIRO & BoM, 2015). Longer-term sea level rise projections indicate a potential 0.8m sea level rise by 2100 for the Victorian coastline.

Wave height and period are projected to increase in the Southern Ocean, with the largest increase in height (8.8 %) occurring during July-September (Hemer et al., 2013). This equates to an increase in wave power influencing the mouth. As river flow decreases, this means that the estuary may be closed longer. Winter storm surge may become more prevalent as a hazard if higher waves occur during an open entrance state. Estuary entrance conditions based on the current climate are discussed in Section 5.2. There is also uncertainty on how berms would respond to sea level rise, but this may include migration of the entrance sand berm upward and landward to adjust (Haines &Thom 2007).

The Otway Coast, including the Aire estuary, is projected to experience ongoing reductions in annual rainfall, with corresponding reductions in available runoff as a result of climate change (Table 2). Median projections from a range of climate scenarios and global circulation models predict a reduction of 5.8% (median) in annual rainfall from current conditions to 2065, with more conservative estimates (90th percentile) as high as 15.9%. The corresponding predicted runoff reductions are 15.8% (median) and 41.9% (90th percentile) (DELWP 2016). It should be noted that these estimates do not consider changing physical conditions within the catchment that would likely occur as a result of climate change, hence the actual reduction in runoff may be higher than the predictions provided. The role of catchment inflows are discussed in Section 5.3.

Table 2. Change in average annual runoff relative to the current climate baseline across all seasons (DELWP 2016).

	Average annual runoff (mm) (1975-2014)	Change relative to current climate baseline (%)					
		2040			2065		
		10th percentile	50th percentile	90th percentile	10th percentile	50th percentile	90th percentile
		Low	Medium	High	Low	Medium	High
Otway Coast	241	6.6%	-7.2%	-25.3%	-4.7%	-15.8%	-41.9%
Victoria	93	8.7%	-8.5%	-24.7%	1.5%	-15.9%	-43.8%

A recent study of 166 estuaries in NSW over the last 12 years showed an increase in water temperature of 0.2°C/year over the last 12 years, and with waters acidifying at a rate of 0.09 pH units and a slight freshening at 0.086 PSU/year (Scanes et al. 2020).

These changes will have a range of potential impacts on estuary extent, hydrology, water quality, and ecological processes; Appendix C outlines some of the potential impacts. The exact changes will vary at different estuaries based on location, morphology, and management and will also change over time. For example, Scanes et al. (2020) found that estuaries in NSW, in particular those that close periodically, have freshened over time, with lower streamflows (and energy to open the estuary) leading to longer periods of estuary closure and during these closure periods the freshwater inflows gradually reduce the salinity. However, it is also noted that over time this trend may change to salinisation if rainfall continues to decrease and flows become too small to compensate for evaporation, particularly during warmer months.

Saline coastal wetlands may have some capacity to adapt to accelerated sea level rise and hydrological alterations through sedimentation processes that maintain their elevation relative to water levels (Rogers *et al.* 2013). Estuarine and coastal habitats are also considered one of the most effective carbon sinks (Carnell *et al.* 2015). Understanding the dynamic impacts and managing the response to climate change and sea level rise will be an emerging challenge for estuary managers.

These varied changes will impact the environmental values of the estuary - some species will increase in abundance while others may decline. These changes are important when considering the condition and trajectory of environmental values in Sections 7 -9. Overall, it will be important to enhance the resilience of the ecological community to the impacts of climate change by reducing other pressures (DAWE 2018).

5 Estuary entrance conditions and hydrodynamics

This section describes the physical (i.e. water and sediment) processes of the Aire estuary. It includes the geomorphic context of the estuary, coastal processes of winds and waves, the opening and closing processes at the estuary mouth, and the role of river flows and floodplain inundation.

5.1 Geomorphic context and coastal processes

The Aire River estuary is a wave-dominated estuary type, also known as barrier estuaries, bar-built estuaries, ICOEs, or intermittently closed and open lakes and lagoons (ICOLLs).

A wave-dominated estuary occupies a coastal bedrock embayment that has been partially infilled by sediment derived from both the catchment and marine sources, and in which waves are the dominant force shaping the gross geomorphology (Ryan et al. 2003). Wave-dominated estuaries feature a supra-tidal (or sub-aerial) barrier at the mouth that encloses a broad central basin (Figure 8). The barrier creates a constricted entrance (which can be periodically closed) that allows the exchange of water between the central basin and the sea.

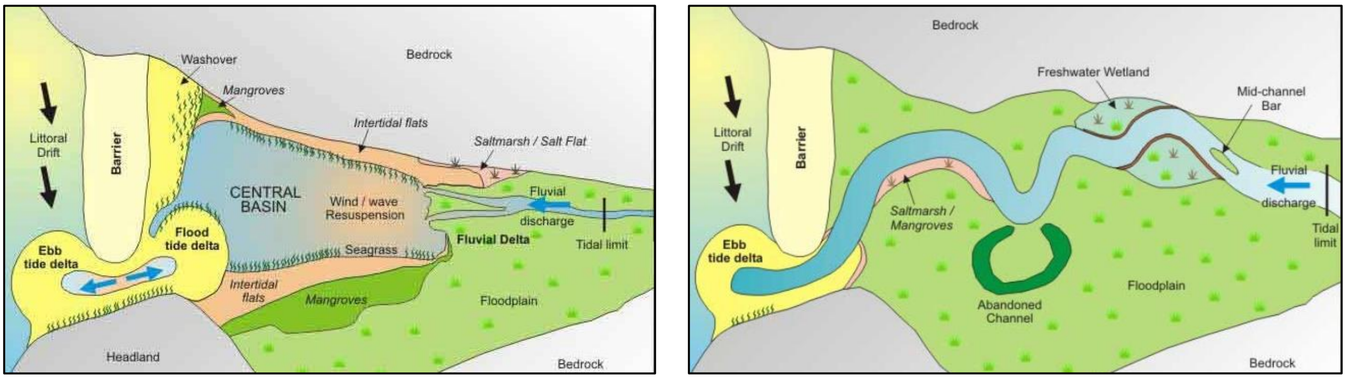


Figure 8. *Conceptual model of a wave dominated estuary (left) and wave dominated delta (right) (OzCoasts 2020, after Heap et al. 2001)*

Depending on the degree of sediment infilling, the central basin of wave-dominated estuaries may be irregularly-shaped, following the outline of the drowned bedrock valley. This is the case for the Aire River estuary, which now occupies an infilled embayment at the foot of the Otway Ranges (Figure 9). The development of present day estuary barrier features and marine sediment deposits towards the mouth of these estuary types typically date back to around 6,000 – 8,000 years ago, linked to the Holocene sea-level highstand in Australia (the period where relative sea level sustained the highest elevation above present mean seal level) (Dougherty et al. 2019).

The long-term evolution of wave-dominated estuaries is characterised by infilling of the valley, principally the central basin. Infilling of Australia's wave-dominated estuaries is dominated by the expansion of intertidal environments around the central basin and progradation of the fluvial delta and alluvial plain. Given sufficient time and constant sediment supply, wave-dominated estuaries have the potential to evolve into wave dominated deltas (Figure 8) when the central basin is completely infilled (or is bypassed by the river channel) (Ryan et al. 2003, after Roy et al. 2001, Heap et al. 2001).

The current geomorphic form and features of the Aire Valley estuary indicate the system is a relatively mature in-filled wave dominated estuary, progressing to a wave dominated delta (Figure 9).

The Aire River estuary enters the open southwest Victorian coast alongside a rocky calcarenite headland (Bird, 1993). The coast adjacent to the Aire River mouth is wave-dominated and microtidal (i.e. spring tidal range <2 m). The mean spring tidal range at the Aire River coast is approximately 1 m (Victorian Regional Channels Authority, 2019). The mean offshore significant wave height is 3.35 m and the mean wave direction is 233 °N (being from the South-West; McSweeney 2020a).

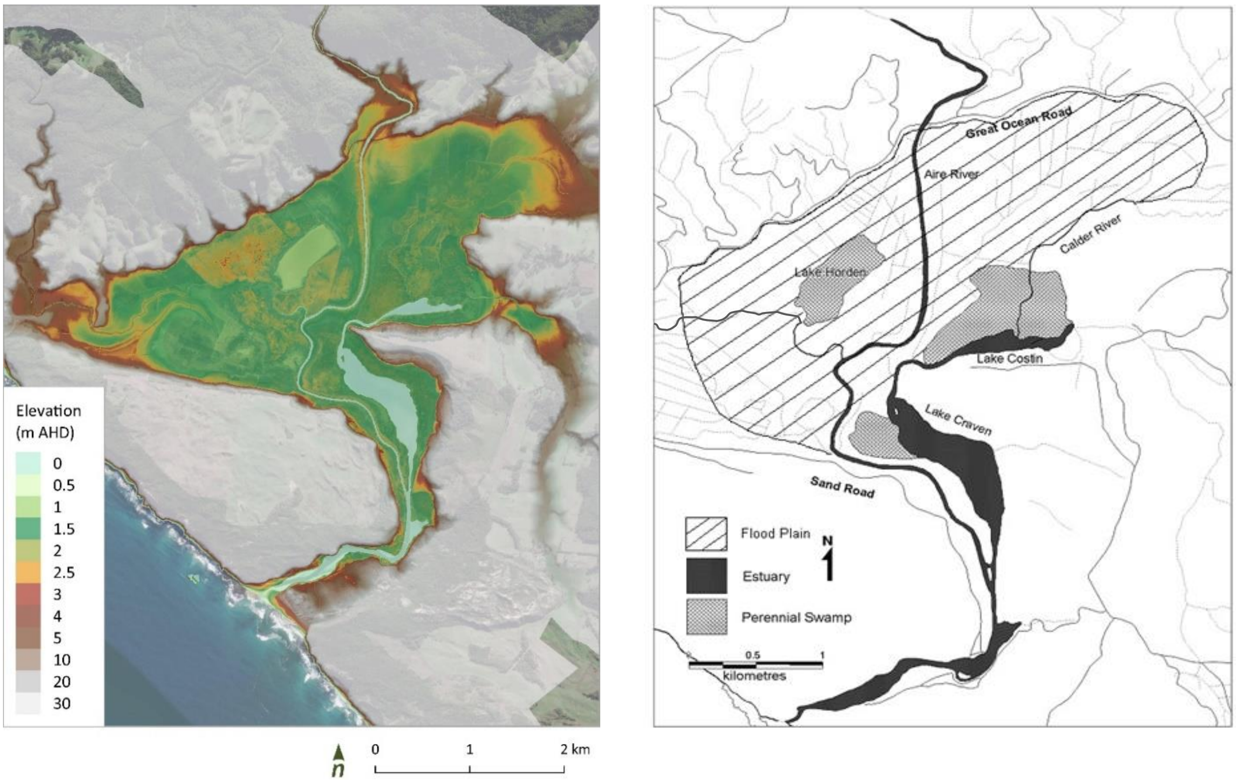


Figure 9. *Left: The Aire River estuary LiDAR elevation data (2010), indicating central estuary basin and floodplain features. Right: The Aire River estuary showing major geomorphic features (source: adapted from Barton and Sherwood, 2004).*

Waves propagate from the south-west all year round due to the influence of persistent south-west winds associated with low pressure systems in the Southern Ocean and the westerly wind belt. Water Technology (2011) report that local strong south-easterly winds also occur during summer and autumn along this section of coast. Coastal storms have an average significant wave height of 6 m and last for 4 days duration (McSweeney 2020a). Storms are also associated with waves from the south-west on average.

Wave height and period (Figure 10) are highest on average during June to September due to the increase in frontal activity offshore. Increased offshore wind speeds and storm occurrence results in more powerful waves influencing the coastline. Wave height and period are lowest during November to February due to decreased frontal activity during summer in Victoria. The seasonal reduction in offshore wave energy during summer is also attributed to the position of the subtropical ridge. During summer, the subtropical ridge is generally located to the south of the continent (just offshore of the Victorian coast). Stable high-pressure systems associated with the subtropical ridge act to block frontal systems and reduce the number of coastal storms influencing the coast (Hope et al., 2017). In winter, the subtropical ridge moves well north of the Victorian coast enabling frontal systems to directly influence the coast and bring larger ocean waves and more frequent storms.

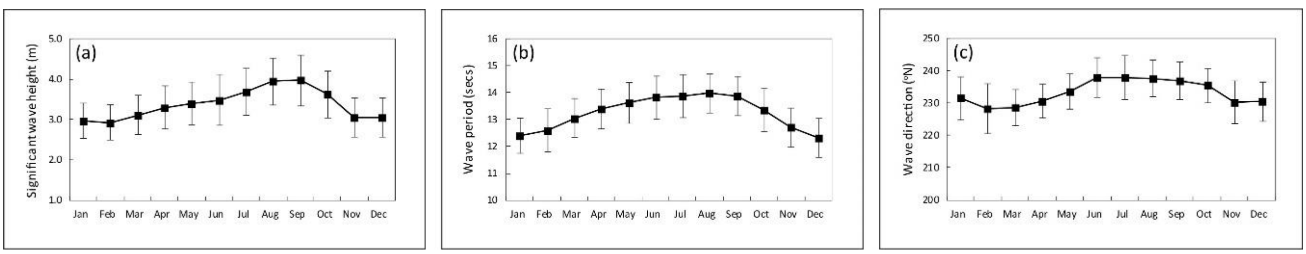


Figure 10. *Monthly variability in wave height, period, and direction calculated from 31 years of data (1979-2010) offshore of the Aire River estuary mouth (from McSweeney, 2020a). Error bars are monthly standard deviations.*

The high wave energy conditions mean that onshore sediment transport rates are considered high all year round in a global context (McSweeney et al. 2018). Sediment transport rates increase during storms when wave height and period are larger. At the Aire River coast, this generally occurs during winter. Estuary entrance closures always occur when onshore sediment transport rates are high and ebb-tidal velocities (as a function of fluvial discharge and the outgoing tidal prism) are low. Low ebb-tidal velocities result in insufficient energy to erode wave-deposited sand from the entrance channel.

Marram grass planting has occurred on the dune system at the Aire estuary (Figure 11). Geomorphically, marram would increase dune steepness, height and general stability (Hilton et al. 2006). The marram could also cause incipient foredune stability onto the beach, which may have forced the migration of the outlet channel to the west. While the marram may have contributed to dune stability and the location of the entrance area, it is unlikely to influence the entrance opening processes (frequency or duration). Entrance opening processes are discussed in the following section – openings are dependent on the local site hydraulics: the water level compared to the berm being crossed.


Figure 11. *Image of marram on dune to east of mouth May 2019 [Left], marram not impacting on entrance channel May 2014 [Right].*

5.2 Estuary entrance conditions

Entrance closures

Estuary entrance closures occur when relative wave energy is greater than fluvial energy at the mouth and the net direction of sediment transport is onshore (Figure 12).

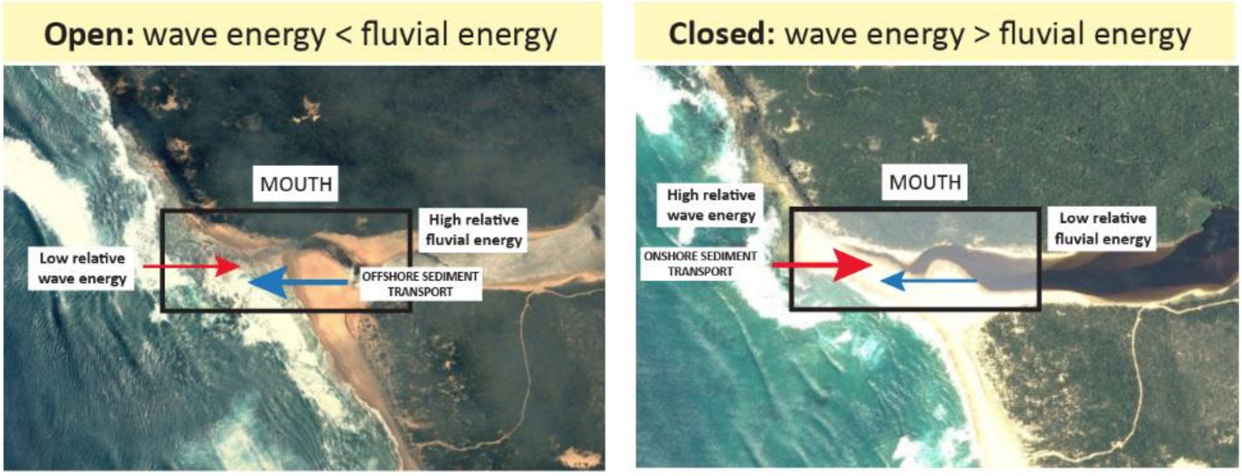


Figure 12. *Estuary entrance conditions are based on the balance of wave energy and fluvial energy*

Entrance closures can occur by two mechanisms which are controlled by variability in nearshore wave direction:

(a) Cross-shore transport; or
(b) Longshore transport and spit progradation.

Entrance closures by (a) cross-shore transport occur when the nearshore wave angle (i.e. relative to the shoreline) is near normal (Ranasinghe and Pattiaratchi, 2003). During near normal waves, swash processes transport sand onshore to infill the entrance channel without any spit growth at the mouth (McSweeney et al., 2018). Closures occurring by (b) longshore transport are related to the presence of oblique waves in the nearshore. Here the oblique angle of wave approach sets up an alongshore current and sediment is transported parallel to the coast via longshore drift.

Due to the persistent offshore South-West swell direction refracted nearshore waves tend to move sediment via longshore drift (Figure 13, Figure 20). Strong south-easterly winds may also contribute to eastward longshore drift and entrance closure via this mechanism during summer and autumn (Water Technology 2011). This means that (b) longshore transport and spit progradation is the most common mode of entrance closure at the Aire River (pers. Comm from landholder survey). At the estuary entrance, longshore drift results in the progradation of a sand bar and spit from the east which diverts the channel to the west. For both modes of entrance closure, sediment transport rates increase with corresponding increases in wave height and energy.

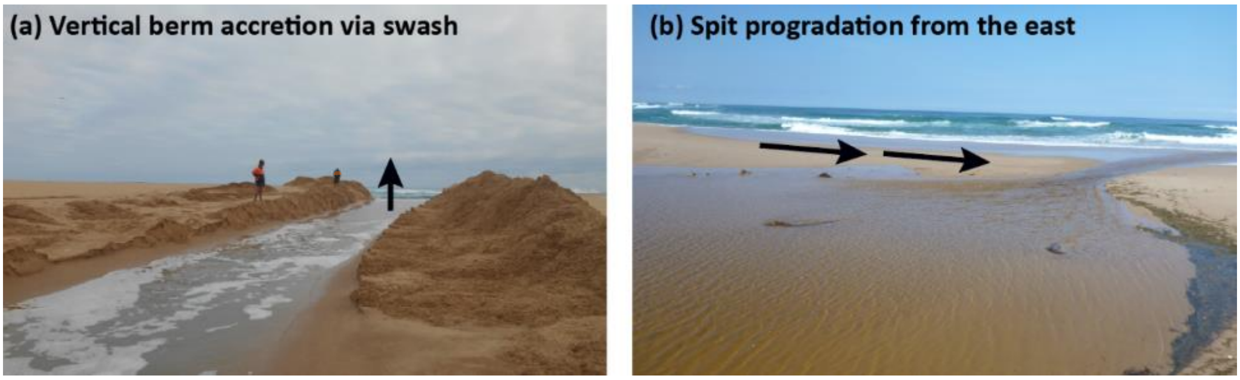


Figure 13. *Berm accretion and spit progradation*

The Aire estuary mouth has been managed in some way for over 50 years. Therefore, it is difficult to predict how frequently the estuary would naturally be open or closed.

To understand how estuary entrance conditions may change throughout the year, the relative balance between wave and stream (fluvial) power can be used to broadly predict estuary entrance condition (McSweeney, 2020). Wave power vs stream power represent the two opposing forces influencing the mouth. Stream power is a measure of fluvial processes that work to erode sand from the estuary mouth. Wave power (as a function of offshore wave height and period) is a measure of wave processes that work to transport sand onshore and build the berm.

This is considered below for the Aire estuary using a ratio of mean monthly stream power/wave power to compare these competing energies (Figure 13). This shows that during December-May relative wave power is higher than stream power, which means it is likely that the estuary will close. Conversely in June-November, there is higher stream power, meaning the estuary is more likely to remain open. Figure 13 uses monthly average values, but this ratio can also be used as a predictor of entrance condition over the event scale (e.g. storms).

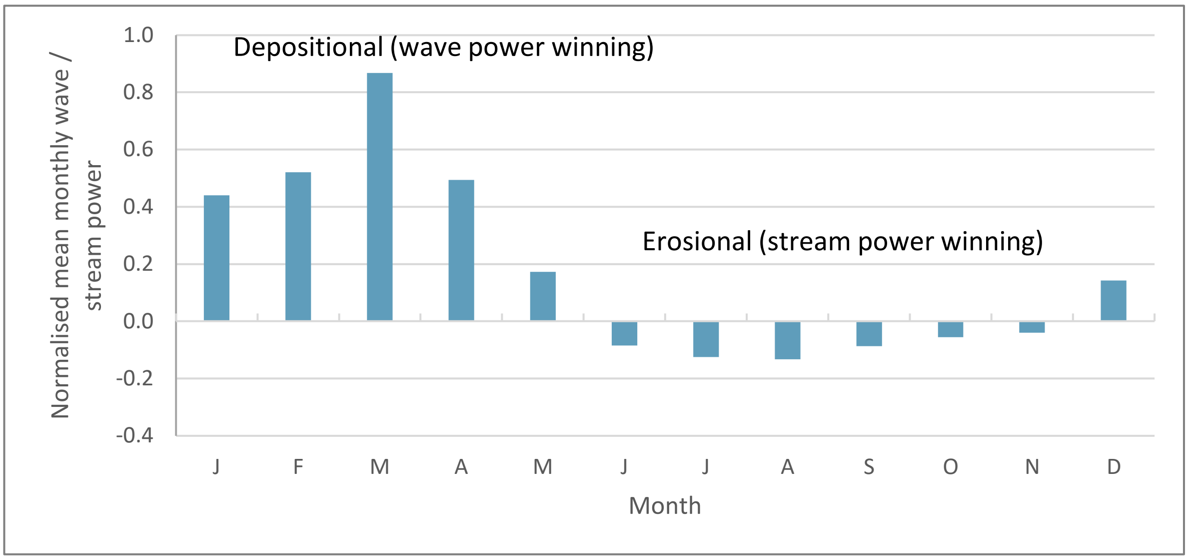


Figure 14. *Normalised ratio of monthly mean wave vs stream power/overall mean*

Natural openings

The Aire River estuary will open naturally when the water surface elevation of the lagoon is higher than the berm crest. This can occur via two main mechanisms: (1) overtopping from the catchment side; (2) overtopping from the ocean side.

(1) Overtopping from the catchment side: For this type of opening to occur, a period of high rainfall and/or increased fluvial inflow must occur. Fluvial inflow raises the basin water surface elevation to a height where it can overtop the berm. Overtopping creates a knickpoint at the seaward edge of the berm and lowers the berm elevation. Outflow velocities then increase, and the channel rapidly widens and incises. Once the estuary has drained, the opening duration is a function of on- vs off-shore sediment transport rates controlled by relative wave vs ebb-tidal energy.

(2) Overtopping from the ocean side: This mechanism of opening occurs via wave overtopping of the berm crest by ocean waves. As waves overtop the berm, they add water volume to the basin. This type of opening will only occur when the berm is narrow or when the lagoon very full and close to the ocean. This is because waves can only physically enter the lagoon once it is close to the sea and thus at a higher water level. This type of opening is less common at the Aire River. Opening via this mechanism would also occur when offshore waves are high and during spring tides. The estuary can be overtopped at high tide and seepage back through the berm at low tide may drive mechanical erosion and berm breaching via sapping and seepage.

A natural opening can sometimes arise from a combination of both processes – as observed in May 2014. This situation is most typical during winter storms when high fluvial discharge raises the estuary water level from inflow. As the lagoon is full and close the ocean at the berm position, overwash from waves at high tide gives it a final push. Waves contribute water into the lagoon at high tide and on the falling tide the estuary can open as hydraulic head increases. A scour channel will be eroded, and the channel will continue to widen and incise draining the basin of water.

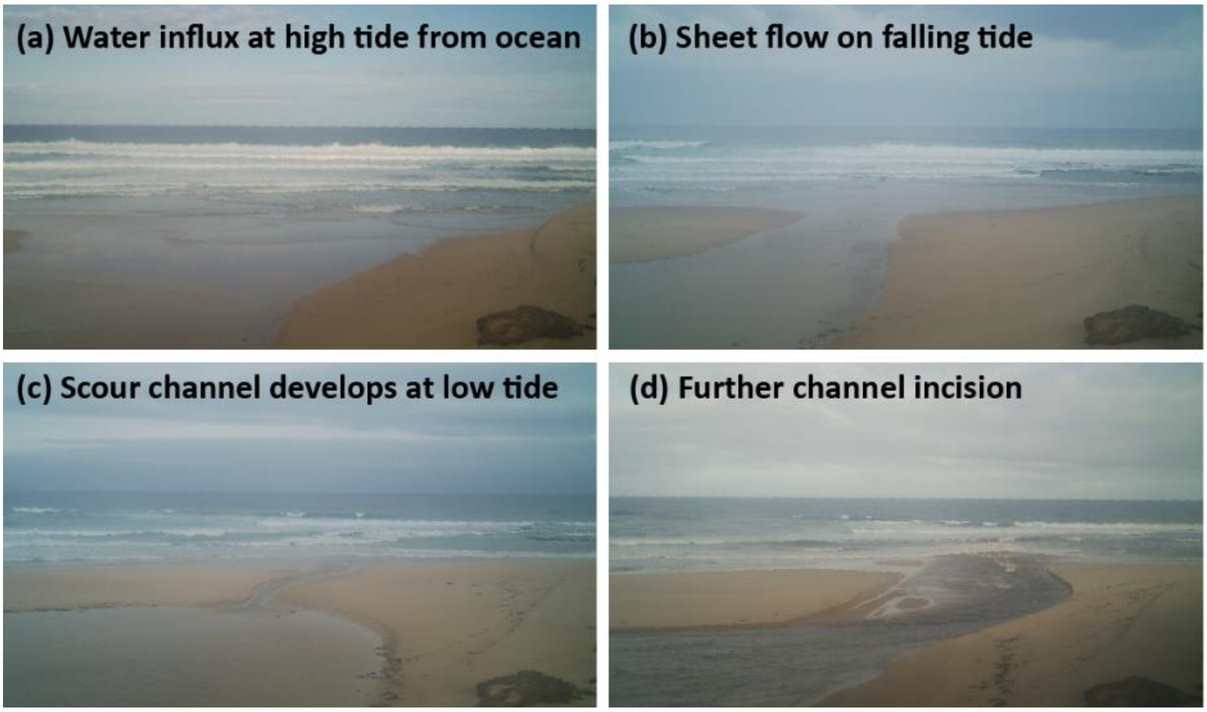


Figure 15. *Natural opening processes*

Current estuary entrance conditions

This section explores the occurrence of estuary openings (artificial and natural) in the Aire estuary for the period of 2008 – 2019. A dataset of estuary openings and closure periods has been prepared by combining both monitoring data from Parks Victoria (including notifications from landholders) and Corangamite CMA (including EEMSS reports), and also satellite imagery (PlanetLabs CubeSAT database - https://www.planet.com/) that helps to identify natural openings that occurred without Parks Victoria or Corangamite CMA being notified (McSweeney 2020b). A time series graph of this dataset is presented in Figure 21.

Requests to open the estuary are much more frequent in summer and autumn, with the highest total artificial openings in May, the end of the summer-autumn period (Figure 16). On average, there have been over 5 artificial openings a year over the last 11 years. The estuary is typically open for a greater percentage of the time in winter and spring when there are more natural openings.

The duration of estuary closures and openings for each season are shown in Figure 17 and Figure 18. For the 2008-2019 period , estuary closure periods ranged from 1 day to 83 days, with an average of 15 days. The longest closure periods were typically observed in summer and autumn.

The duration of estuary openings range from 1 day to 135 days, with an average of 22 days. Openings during winter are typically longer, with an average duration of 46 days, while the maximum duration over all seasons is 140 days. Natural openings were observed to have longer opening durations than artificial openings, with an average of 30 days compared to 19 days.

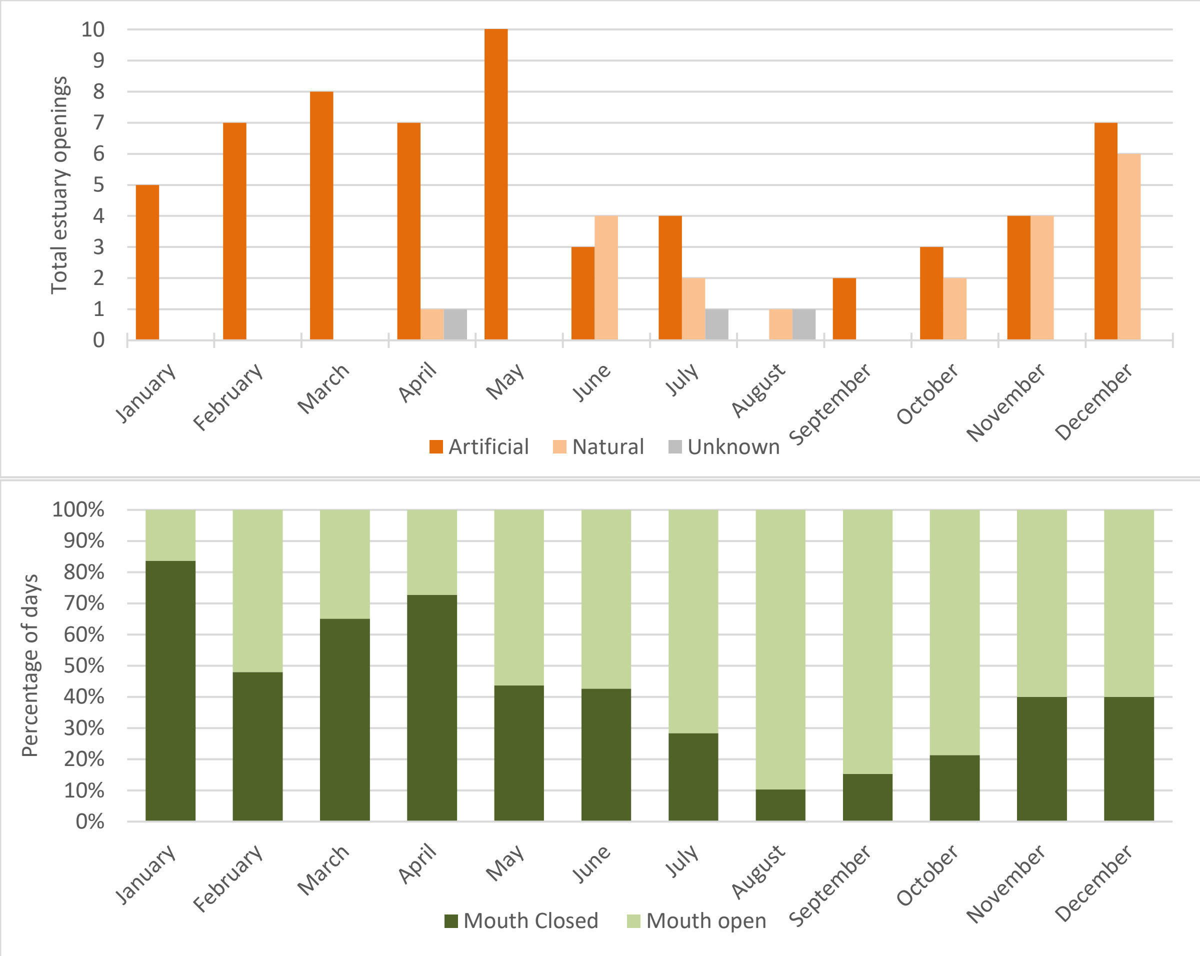


Figure 16. *Total number of Aire estuary artificial and natural openings for each month (2008-2019) [top] and percentage of days estuary mouth open / closed [bottom] (Data sources: Parks Victoria, Corangamite CMA).*

The range of historic natural opening heights for the Aire River are shown in Figure 19. Natural openings occur at a comparable water level on average (1.73 m AHD) to artificial openings (1.68 m AHD). The median water level at opening is also similar for natural openings (1.60 m AHD) and artificial openings (1.63 m AHD). Natural openings have occurred at a greater range of water levels compared to artificial openings. There have been two natural openings which occurred at a very high water level during winter (2.75 m AHD on 4/06/19 and 2.50 m AHD on 29/08/09; Figure 20).

The comparability of heights of natural and artificial openings suggests that management could adopt a more “wait and see” approach to artificial openings. The data shows the entrance commonly opens naturally at heights that may be desired by landowners.

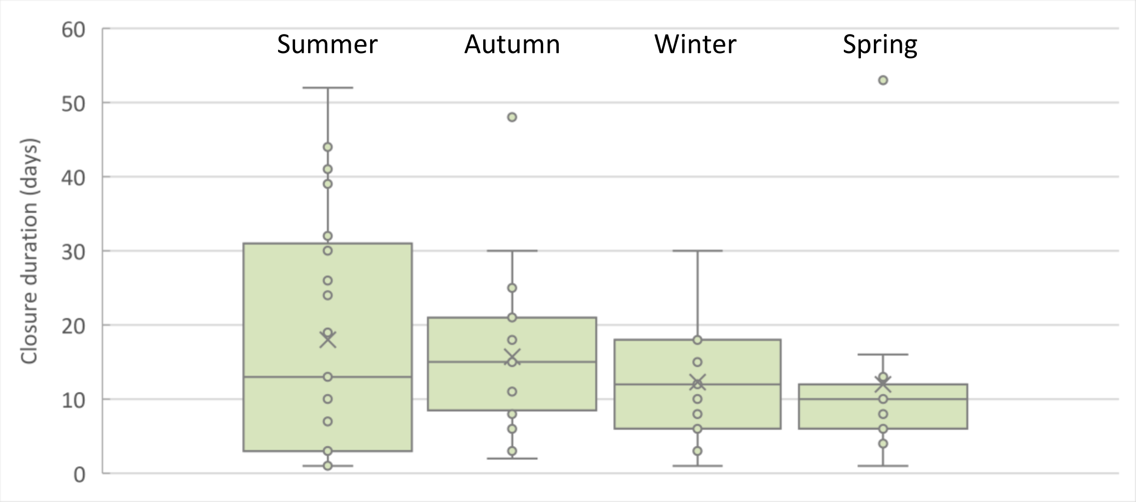


Figure 17. *Estuary closure durations for each season (2008 – 2019) (Data sources: Parks Victoria, Corangamite CMA).*

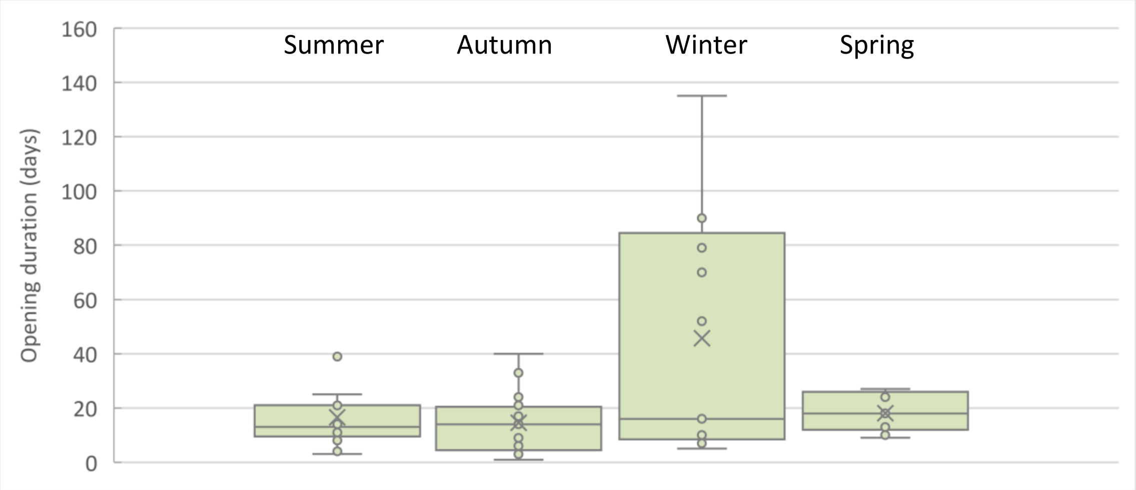


Figure 18. *Estuary opening durations for each season (2008 – 2019) (Data sources: Parks Victoria, Corangamite CMA).*

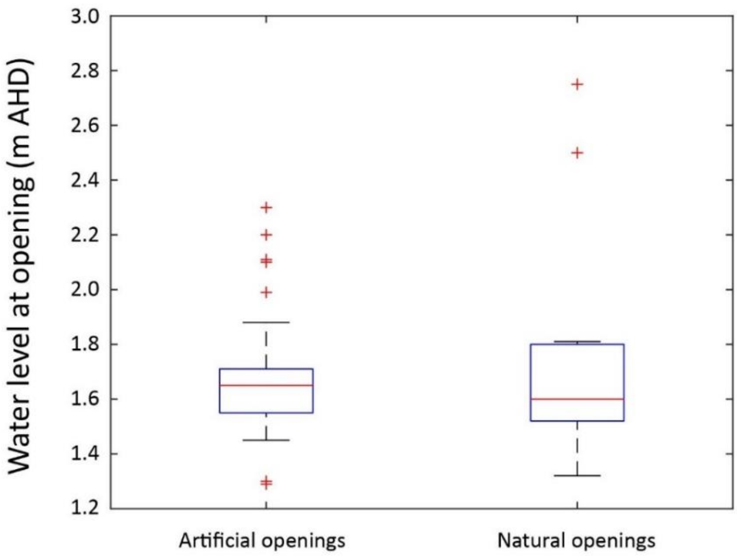


Figure 19. *Variation of water levels at artificial and natural openings (2008-2019) (Data sources: Parks Victoria, Corangamite CMA).*

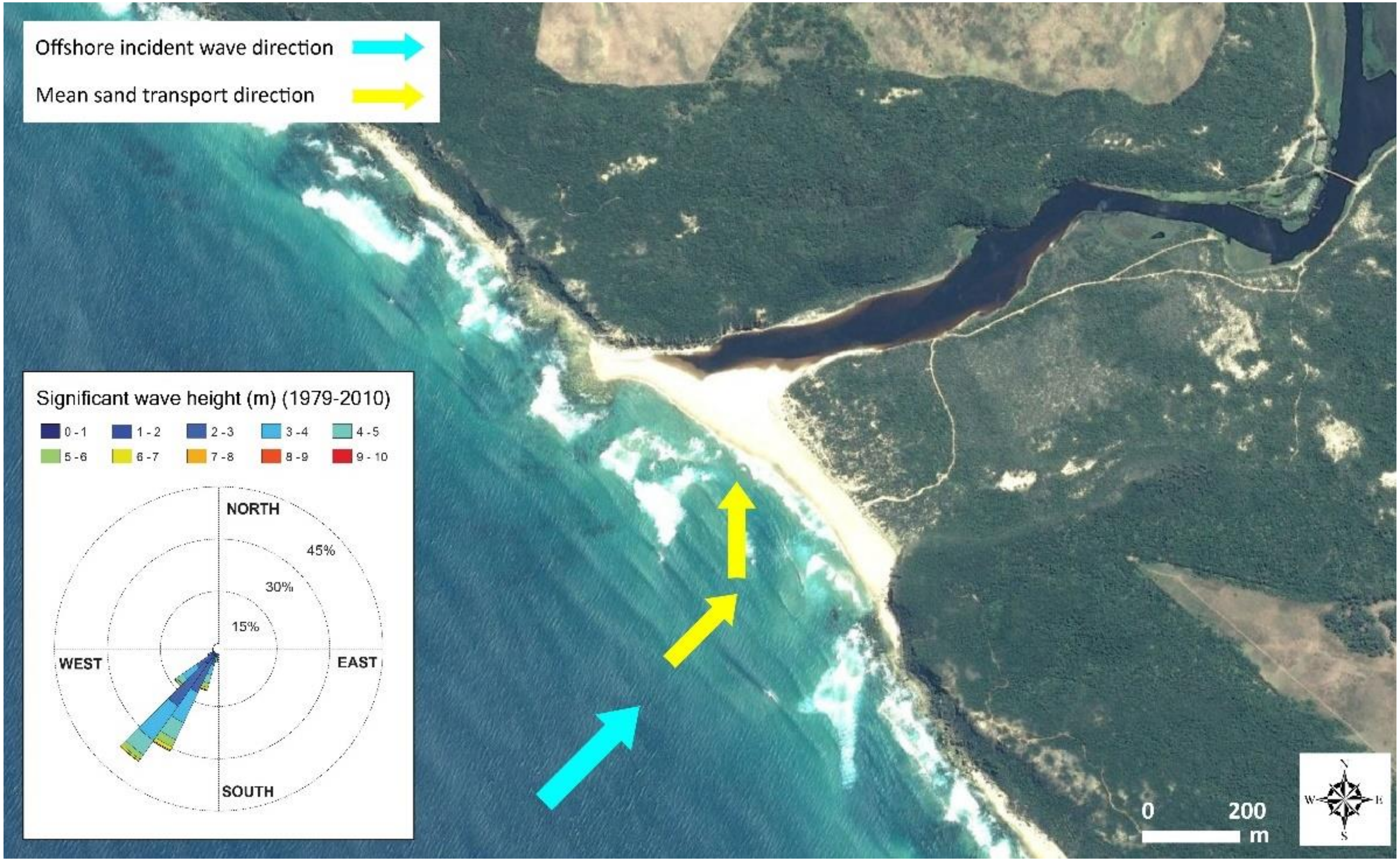


Figure 20. *Wave height and direction rose calculated from 31 years of data (1979-2010) offshore of the Aire River estuary mouth (from McSweeney, 2020a) and average direction of sediment transport in the nearshore.*

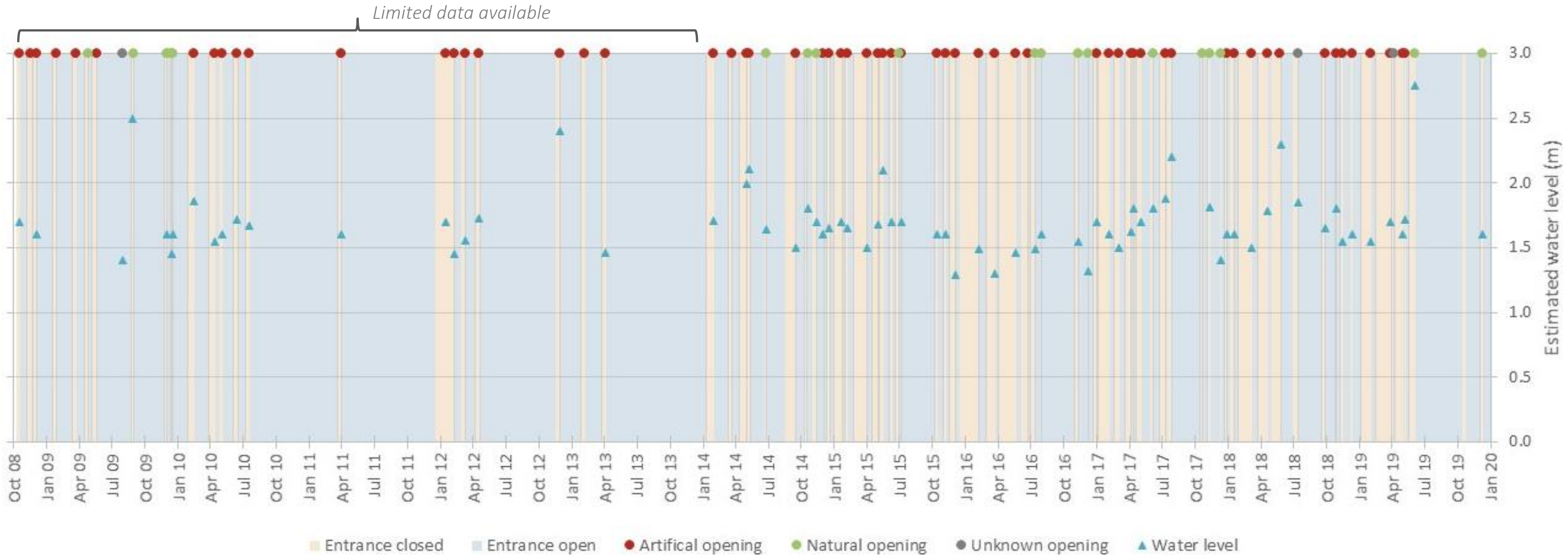


Figure 21. *Timeline of estuary opening from October 2008 to January 2020, including estimated water levels and method of opening (natural or artificial). (Sources: Parks Victoria, Corangamite CMA).*

5.3 Hydrodynamics

Above its narrow entrance section, the estuary channel crosses a wide floodplain of around 600 ha (1,500 acres) before reaching the base of the mountains at the site of the Great Ocean Road (Figure 4). A small tributary stream (Calder River) enters the Aire River main stem from the east, draining two interconnected shallow lakes – Craven and Costin. A larger tributary – the Ford River - enters on the west side. Lake Hordern is fed by a small channel off the Ford River. Further upstream within the floodplain is an ephemeral wetland, Lake Calder, which is crossed by an extensive system of shallow drains. Dimensions of the major components are given in Table 3.

Table 3. Dimensions of major components of the Aire estuary

Section of estuary	Surface Area (m2)	Ave Depth (m)*	Vol of water (ML)*
Floodplains	6×10^6	(1)	(6,000)
River	770	1.5	1155
Lake Craven**	550	0.3	165
Lake Costin**	230	0.23	53
Lake Hordern	423	0.3	127

**Water volumes and depths are based on a water level of 1.1m AHD at the Sand Road bridge gauge, except for the floodplains which are based on a depth of 1m over the floodplain. (source: Kelson 2003)*

***The channel connecting the lakes is over 1m deep*

River discharge in the Aire River is characterised by rapid flood peaks resulting from a combination of high rainfall, predominantly over winter and spring, and a steep catchment (Figure 22, Figure 23, Figure 28). Maximum flow can exceed 1,000 ML/day for short periods during winter and spring. Baseflows less than 100 ML/day are common through summer and autumn.

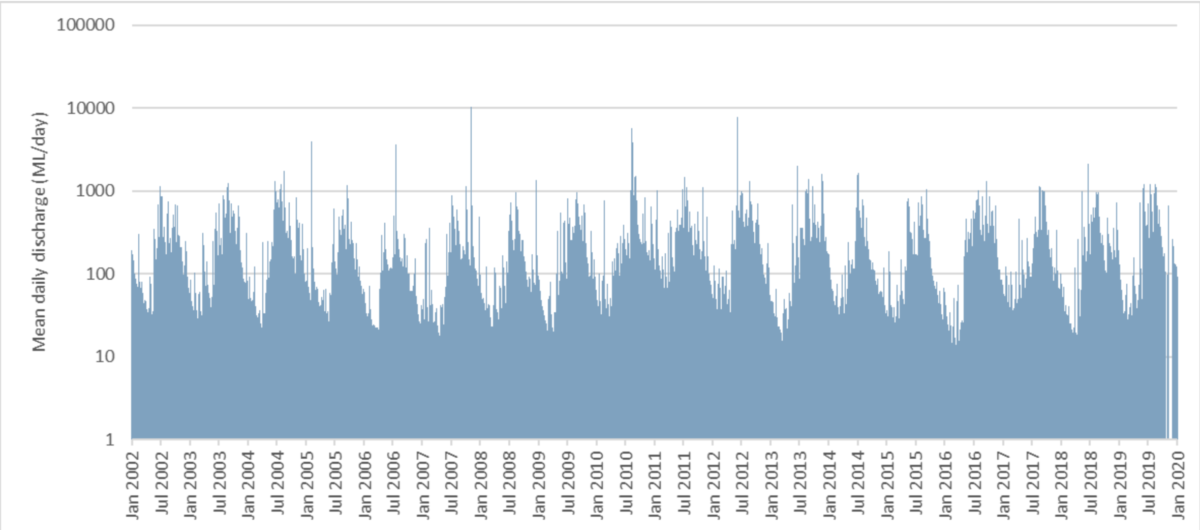


Figure 22. *Mean daily discharge of the Aire River at Wyelangta gauging station (No. 235219) 2002-2020. Note logarithmic scale. [Data Source: Water Measurement Information System]*

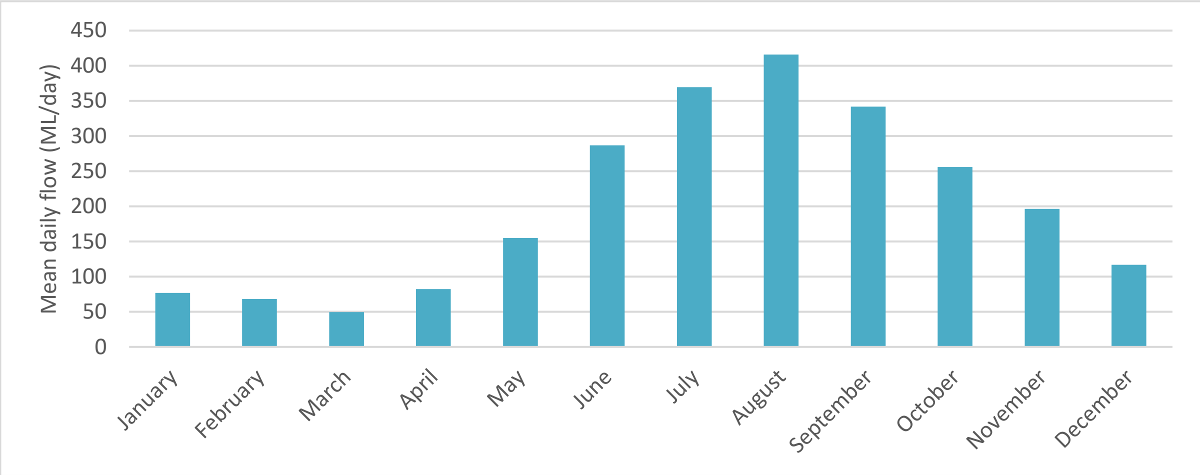


Figure 23. *Average daily flow for each month* at *Wyelangta gauging station (1954-2019) (Data source: Water Measurement Information System).*

The Aire River estuary intermittently closes, particularly during periods of low river flow. Estuary water becomes effectively dammed behind the sand berm as the entrance becomes increasingly restricted. When the estuary mouth is closed, the floodplain can be extensively covered by water 1 m or deeper. The extent of inundation at different elevations is provided in Figure 28. Levee banks have formed at the upper reaches of the Aire River estuary channel as a result of this flooding over many years.

When the estuary entrance is closed or greatly restricted, water levels in the estuary can rise in response to water inflows of four types:

1. River inflow – either gradual or rapid (floods)
2. Groundwater from the catchment
3. Seawater overtopping the entrance sandbar (via wave over-wash)
4. Seawater percolating through the sandbar into the estuary.

Mechanisms 2 and 4 are of much less significance than 1 and 3. The rise in water level depends on river inflows, rainfall and evaporation. A simple water balance model has been developed to represent this rise in water level during different times of the year, assuming a closed estuary. This model uses daily average flow rates, rainfall, and evapotranspiration for each month, and the volume and area to water level relationship for the estuary.

From a starting point of 0.8 m AHD, the time to reach 1.3 m AHD varies between 4 days (during wetter periods, such as July) and 16 days (during warmer, drier periods such as January; Figure 24). The increase in water level each day varies: from 0.01 – 0.06 m/day in summer – autumn, 0.04 – 0.16 m/day in winter, and 0.02 – 0.12 m/day in spring. The gradual wetting of the floodplain and increase in inundation extent is an important way of providing a mosaic of habitats for environmental values (discussed in Section 7).

These modelling results align with a recent event captured by the Corangamite CMA's newly installed monitoring gauge. The water level starts to rise on 18 July and increases from 0.8 m AHD on 19 July to 1.3 m AHD on 23 July, a rise of 0.13 m/day (Figure 25).

This water balance model could be used by estuary managers when considering artificial estuary openings to help inform how quickly water levels may rise at different times of the year.

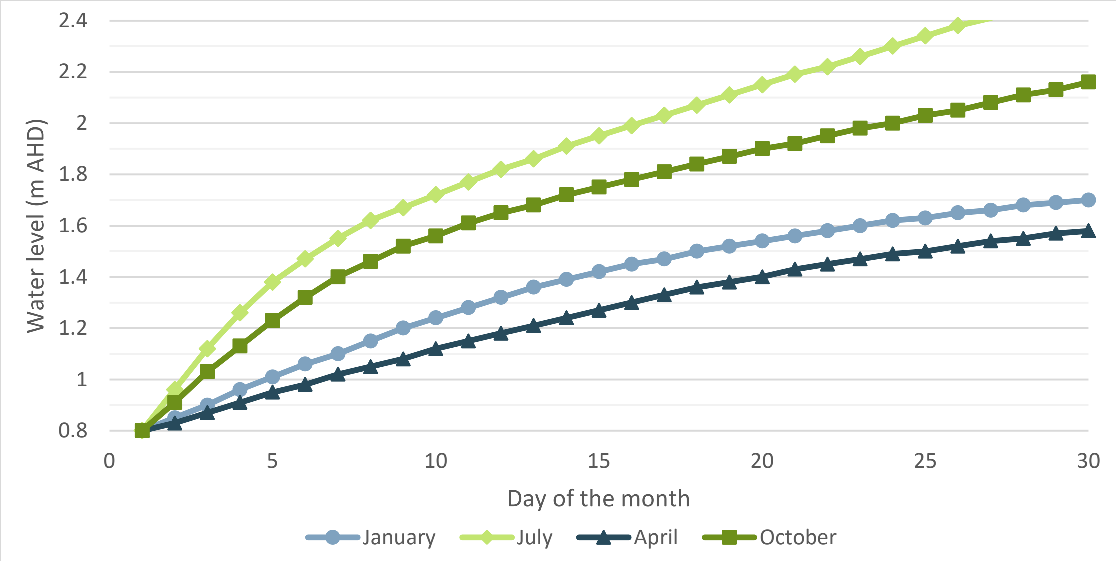


Figure 24. *Example rises in water level for different times of the year (based on water balance model)*

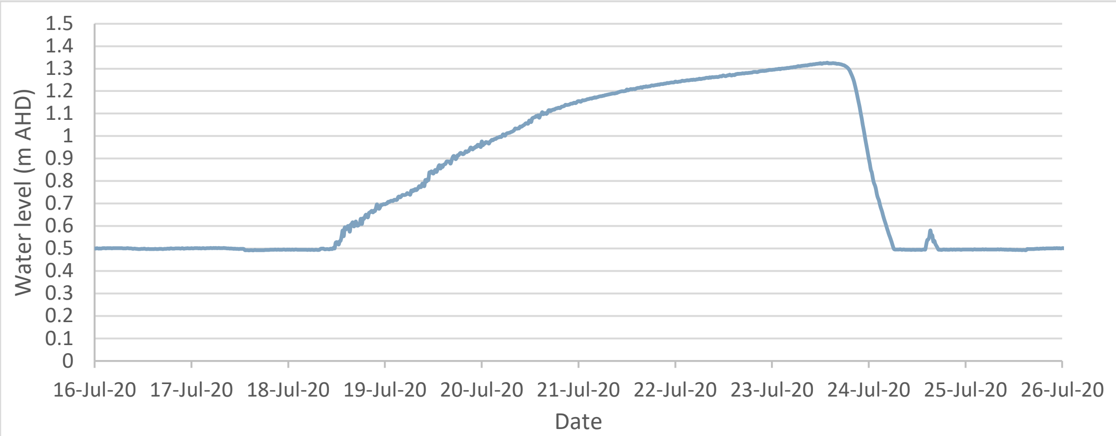


Figure 25. *July 2020 event, captured by new Hordern Vale gauge [Data Source: Water Measurement Information System]*

Once an estuary opening occurs, the estuary will drain, with the water level decreasing and the inundation reducing. The drop in water level is typically far more dramatic than the previous rise in water level, with drainage rates in the order of 0.02-0.04 m/hour (Figure 26). The drainage rate is influenced by the head difference, volume of stored water, and the entrance morphology (channel dimensions and discharge at the mouth).

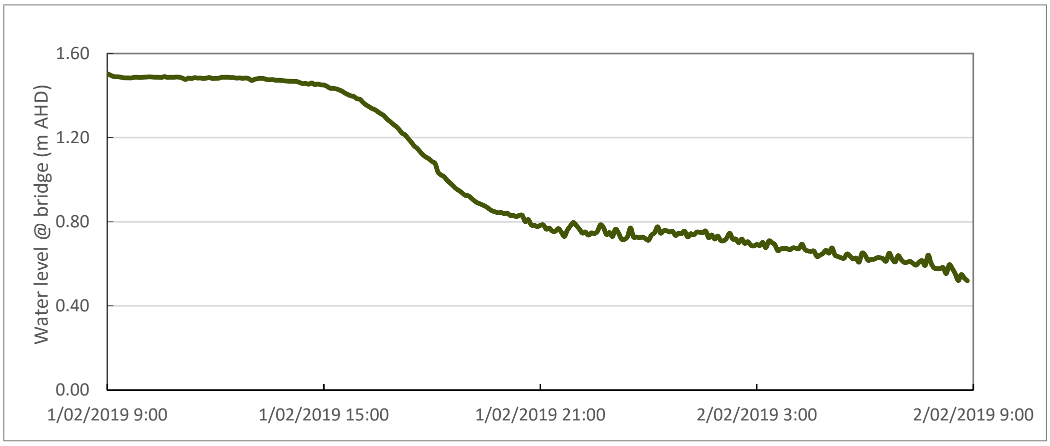


Figure 26. *February 2019 artificial opening, drainage rate of 0.04 m/hour (McSweeney 2020b)*

The current frequency and duration of floodplain inundation has been assessed using satellite imagery from 1986 to 2019. This imagery has been analysed for all wetland polygons in Victoria to determine the percentage time different areas (pixels) are wet at different times of the year. The results of this assessment are in Appendix C, including the timing (across the year), duration and extent of inundation.

A high- level summary of the inundation duration for different elevations (Table 4), shows the decrease in overall inundation duration as water level (and therefore floodplain inundation extent) increases. A monthly analysis of percent inundation has been completed for 3 representative water levels (1.5, 1.6 and 1.7m; Figure 27), demonstrating the variability across a year.

Table 4. Summary of floodplain inundation information for different elevations

Water level (m AHD)	% of time inundated (across whole year)
1.3	39%
1.5	25%
1.6	17%
1.7	11%
2.2	9%

This information on floodplain inundation extent, duration and timing has been used in conjunction with EVC mapping to assess any risks of the current regime to the vegetation communities.

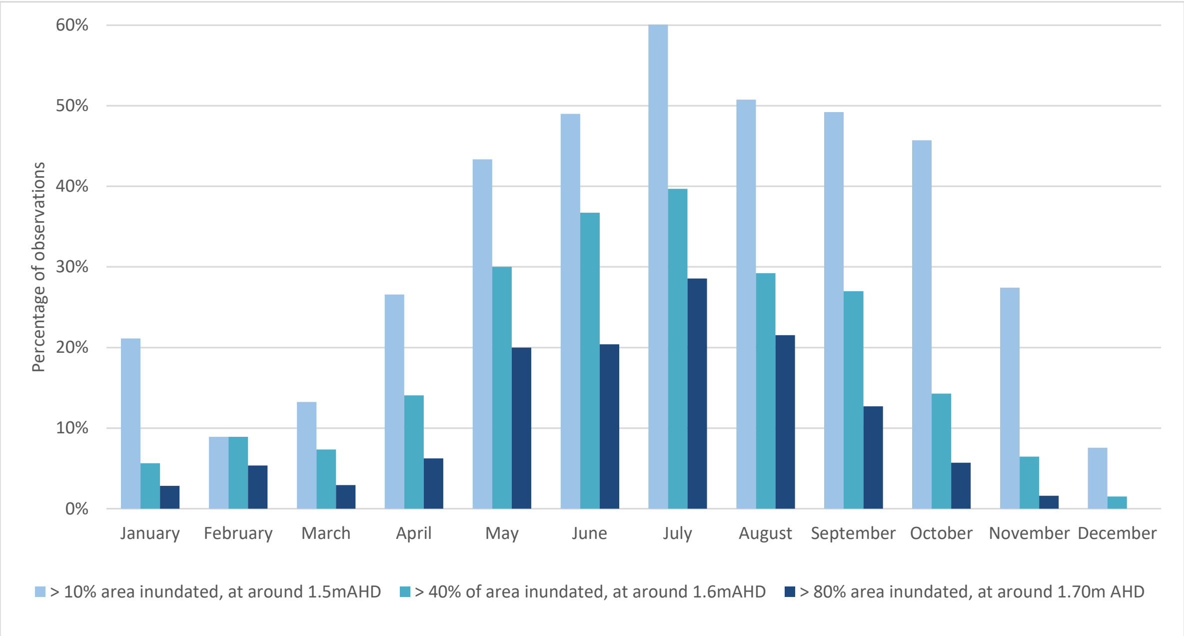


Figure 27. *Seasonal pattern of inundation based on satellite data for one example floodplain area*

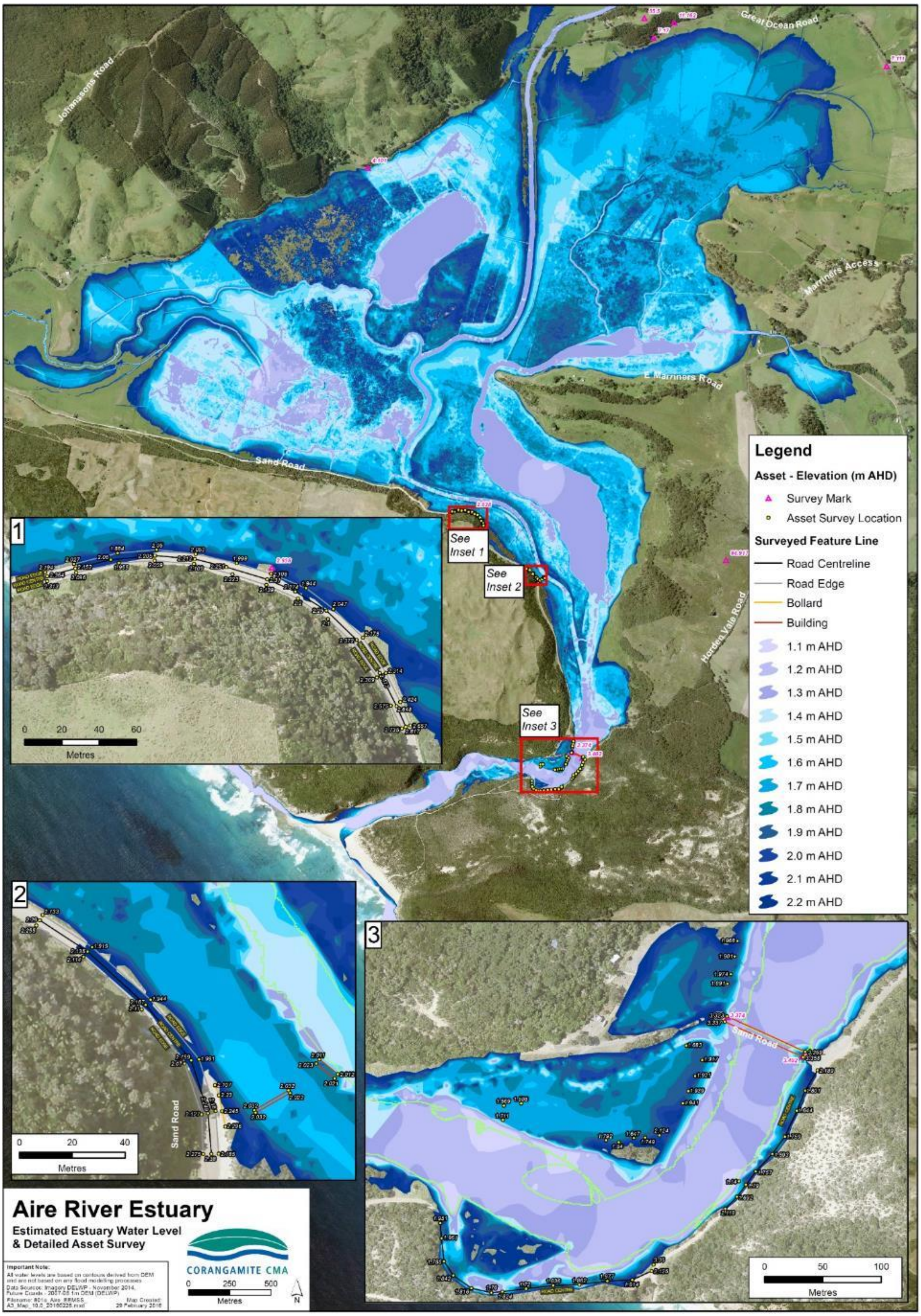


Figure 28. *Extent of flooding at different water levels. (Source: Corangamite CMA)*

5.4 Implications for the Aire River estuary floodplain

Prior to development of the Aire River valley, ocean derived sand would have been deposited at the estuary mouth. There would have been long periods of estuary mouth closure when the water level would gradually build up over months, inundating the floodplain and providing suitable conditions for the specialised ecological communities. Based on analysis of relative wave power and stream power, the estuary is more likely to close in December – May. Conversely there would also be periods where the estuary would open naturally, allowing for saline intrusion into the estuary. Based on analysis of relative wave power and stream power, the estuary is more likely to remain open in June - November.

There is a long history of artificial estuary openings. On average, there have been over five artificial openings a year over the last 11 years. These openings occur across the year, but more frequently in the summer/autumn period. The estuary is typically open for a greater percentage of the time in winter and spring and there are more natural openings. The water levels of artificial openings for the Aire estuary occur at comparable water levels to that of natural openings (see Figure 19).

The number of artificial openings, particularly in summer and autumn, will result in a more frequently open estuary than under natural conditions, and therefore reduced frequency, duration and extent of floodplain inundation. The increase in openings (and subsequent reduction in inundation) cannot be quantified with certainty based on the available information, but drawing on the analysis outlined in this chapter, the Technical Panel are confident that there has been an increase in the number of openings above the natural frequency.

In addition to the changes to the floodplain inundation regime, artificial estuary openings have specific geomorphic risks, including:

- Increased sand shoaling at the entrance (Haines 2008; Adams and Van Neikerk, 2020). During openings at natural water levels, large volumes of water flowing out to sea over an extended period in turn scours sediment from the lower and middle reaches of the estuary. However, when openings occur at lower water levels, flushing intensity is reduced, and sediment accumulates.
- If artificial openings occur at lower levels in summer – autumn periods or under future climate change conditions, then:
    - Reduced opening duration (Spurway et al. 2000) due to inefficient scour of entrances at low opening levels.
    - Openings at lower water levels can result in openings that do not drain the estuary as hydraulic head is lower (but also depends on berm height and length).

The following knowledge gap has been identified by the Technical panel to improve the ongoing management of the Aire estuary and provide the conditions to support the environmental values.

Knowledge gap: berm height and length

As described in this section, berm height and length provide a good indication of the likelihood that a natural opening will occur. Understanding the likelihood that a natural opening may occur is an important part of reducing artificial estuary openings and the associated risks. Berm height and location may also be impacted by climate change.

Monitoring of berm height (on the AHD scale) and length could be undertaken to better understand its dynamics and to provide a baseline for future changes. Record the time of opening in EEMSS so tidal elevations can be linked to berm length to compare energy slopes between openings.

This monitoring could be done by the Permit Holder and or through remote sensing and citizen science (e.g. a Fluker post).

A summary of the coastal processes and hydrodynamics over the year are summarised in Table 7.

Table 5. Summary of estuary processes, by time of year

Month	Hydrodynamics and coastal processes
January	Wave height low The entrance is greatly restricted/closed. Low river inflows (which exceed evaporative losses) result in a gradual rise in water level behind the sand berm at the entrance
February	
March	
April	
May	
June	Wave height high. Entrance predominantly open but can shift between open/closed in response to storms/variable river flows. Winter storm surge can occur when high waves push up the channel when entrance is open. This is more likely to occur on spring tides.
July	
August	
September	Wave height moderate – decreasing coming into summer. Reduction of river flow results in restriction of the entrance channel. Seawater inflow is progressively reduced
October	
November	
December	

6 Estuary water quality

This section outlines the water quality characteristics of the estuary, including salinity, dissolved oxygen, and nutrients. Drawing on available monitoring data, this section also explores conditions and management activities that can lead to poor water quality outcomes.

6.1 Salinity

An estuary is a mixing zone where freshwater from inland meets seawater. The salinity of river water is usually less than 1 part per thousand (ppt; 1g salt/kg water). Seawater is typically 35 – 37 ppt (35 – 37 g salt/kg water).

Salinity can vary continuously between that of river water and seawater within an estuary. Coping with such variable conditions is beyond many organisms but those that can survive do well in the highly productive estuarine ecosystems. The biota of estuaries are characterised by high abundance (large populations) and lower diversity (a smaller number of species) compared to freshwater and marine ecosystems (Turner et al. 2004; Hodgkin, 1994).

Mixing within the estuary requires turbulence and is primarily a function of the volumes and energy of incoming fresh and sea waters (wind energy can also mix surface layers of the estuary). Seawater can overtop the sand bar during heavy seas or on flood (incoming) tides. The flow has relatively low energy and seawater, being denser than river water, tends to spill over the entrance sand bar and travel upstream beneath the river water. The result is described as a highly stratified or "salt wedge" estuary. The latter term reflecting the shape of the saltwater layer (Figure 29). Such estuaries are the most common type across western Victoria (Sherwood *et al.* 2008; Barton and Sherwood, 2004).

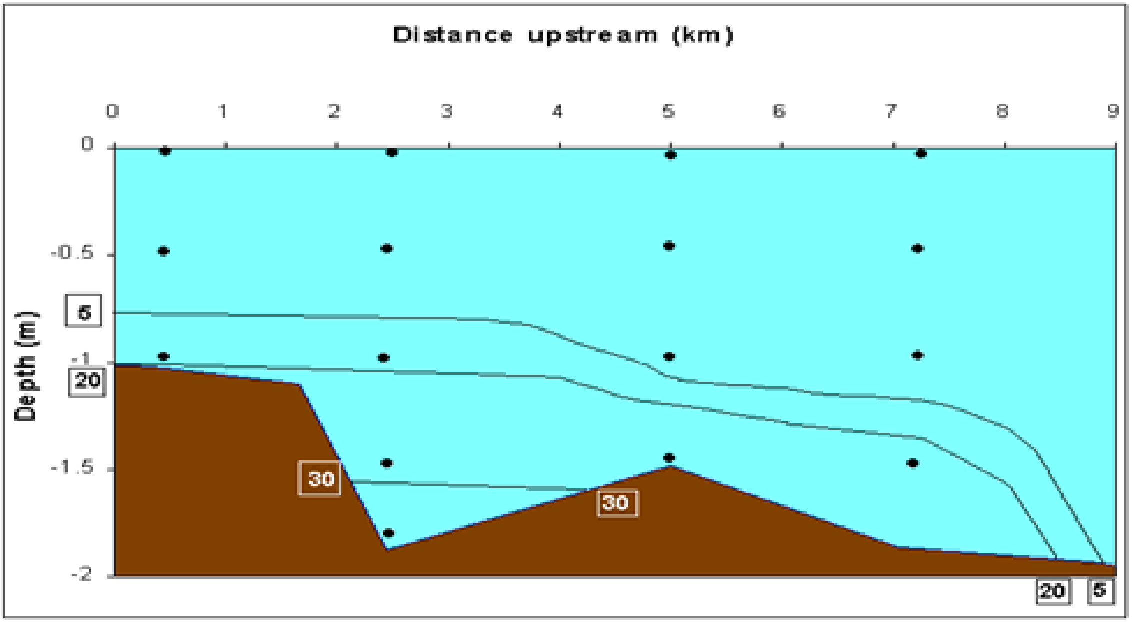


Figure 29. *A salt wedge in the Aire estuary. Black points are depths where salinity was measured. Lines (isohalines) connect points of equal salinity (source: Kelson 2003).*

The salt wedge (Figure 29) is typical of the Aire River estuary under low flow (< 200ML/day) conditions. The top 1m or so of the estuary is quite fresh (salinity < 5 ppt) and a deeper saltwater layer penetrates over 7.5km upstream from the mouth – to beyond the Great Ocean Road bridge (Kelson 2003; Water Technology 2011; Appendix A).

As river flow increases the salt wedge is progressively eroded by turbulence, retreating until the entire estuary is freshwater. Two studies have shown the estuary to be fresh when flows exceed 600ML/day (Kelson 2003; Water Technology 2011). As flow subsequently reduces saltwater re-enters the estuary and is progressively shunted upstream by each new flood tide. It may take from 5 to 8 days for the wedge to return to its maximum length (Water Technology 2011).

Incoming salt water also flows upstream in the Ford and Calder Rivers, at times reversing the flow direction of the former (Kelson, 2003). The shallow sill connecting Lake Hordern to the Ford River results in the lake remaining a freshwater system as only surface freshwater inflows are possible. Salt water does enter both Lakes Craven and Costin. Kelson (2003) found lake salinities commonly 3 – 7 ppt during 2002-3 with values over 20 ppt recorded in both lakes on one survey.

6.2 Dissolved Oxygen (DO)

The living things in the estuary can be divided into aerobic (oxygen loving) and anaerobic (oxygen fearing) organisms. The anaerobic organisms are those to whom oxygen is a poison – they typically are bacteria which occur in the bottom muds of estuaries where oxygen is not present.

Most of the organisms of human value in estuaries (fish, molluscs, plankton, algae) are aerobic. They require oxygen for respiration and excrete carbon dioxide as a waste product. Oxygen from the air dissolves in water directly or is added to it by plant photosynthesis. Direct dissolving from air is enhanced under turbulent conditions created by atmospheric winds or water flow. The maximum amount of oxygen that can dissolve (called the saturation limit) under Aire estuary temperature and salinity conditions is in the range 8-10 mg/L. As the DO concentration drops below about 5 mg/L aerobic organisms begin to be stressed and will move to more favourable conditions if they are able. Low DO conditions (< 5 mg/L) are referred to as 'hypoxic' and the absence of DO as 'anoxic'.

During low flow conditions when the estuary entrance is greatly restricted or closed the saltwater in the wedge can become gradually depleted in DO as aerobic organisms (including aerobic bacteria decomposing organic matter) consume it. Without an influx of new oxygenated seawater this deep water can become anoxic. The aerobic plants and animals in the estuary are then confined to the surface oxygenated layer. Once the water is anoxic anaerobic bacteria move from the bottom muds into the overlying water. Their respiration results in the build-up of ammonia and hydrogen sulphide ('rotten egg gas') in the salt wedge. These substances are highly toxic to fish (Text Box 3) and other creatures.

The Aire estuary typically has a surface layer (1-2 m deep) of well oxygenated water (i.e. DO > 5 mg/L; Kelson 2003; Water Technology 2011; Appendix B). Anoxic conditions do occur in the deeper salt water – more commonly in the upper estuary (see Figure 31).

Text Box 3 describes the risk of mass fish mortality. Over 50 mouth openings occurred between 2000 and 2010 (Water Technology, 2011) and 71 between 2008 and 2019 (Figure 20) without reports of mass mortality. However, a fish kill has been reported earlier and unsatisfactory water quality has been noted following mouth openings on several occasions as described in Appendix B. On this basis, the likelihood of such an event appears to be between "unlikely" and "likely" for the Aire estuary. The consequence of a mass mortality event is considered high, with the estuary ecosystem probably needing years to recover. Overall, considering both likelihood and consequence the risk of a fish mortality event is considered medium to high.

Text box 3. Mass fish mortality

Mass deaths of aerobic organisms ("fish kills") have been recorded in west Victorian estuaries when anaerobic conditions occurred throughout the water column following an opening.

Figure 30. *Mass mortalities SW Victorian estuaries resulting from estuary openings. Left. Black bream (Acanthopagrus butcheri) collected by volunteers after a Surrey River opening in June 1999. The ruler is 1 metre. (source: GHCMA). Right. Galaxias maculata observed after a Gellibrand River opening in 2000 (source: J. Sherwood).*

Mass mortality can occur for two reasons:

1. If opening of the estuary entrance (either naturally or artificially) drains off the surface oxygenated layer leaving only anoxic (no oxygen) or hypoxic (very low oxygen concentration) water in the estuary.
2. If the floodplain waters surrounding the main channel are anoxic and drain back into the main channel after the entrance opens.

In both 1 and 2, strong river inflows (which are usually well oxygenated) can act to flush the anoxic water downstream and provide a refuge for the aerobic community. Estuary openings present a greater risk under low river flow conditions as a result.

Fish kills involving mullet, salmon and bream have been reported for the Aire estuary (Barton and Sherwood 2004). One mass death (fish kill) incident reported to the EPA gave the cause as due to 'salinity', which is unlikely.

Type 1 openings provide one mechanism – in an extreme case all oxygenated water could be drained from the estuary. This has caused multiple fish kills in the Surrey estuary (in 1999 and 2005) and attracted considerable community attention (Becker 2007). For the 2005 event for the Surrey estuary, however, small estuarine resident species where found in large numbers six months afterwards, suggesting some individuals migrated to freshwater reaches during poor conditions, and then recolonised the estuary (Becker et al. 2009).

A second possibility is linked to poor water quality in the floodplain when it is inundated for long periods of time. Die-off of drowned pasture grass can contribute high oxygen demand as it decomposes. In the absence of adequate re-oxygenation from the atmosphere, flood water may become anoxic. Such waters have the unpleasant smell of hydrogen sulphide and are often dark in colour – so called 'black waters'. A fish kill due to this cause has been observed in the Gellibrand estuary (Kelly 2000). Outflowing waters having these characteristics have been described for one monitored Aire estuary opening (S. McSweeney, pers. comm). Aire estuary longitudinal surveys between 2003 and 2013 show that 7 of 26 openings resulted in low surface water DO post-opening. Poor floodplain water quality is a likely cause (Appendix B).

A third possibility is that fish simply became trapped on the floodplain as waters rapidly receded. This has also been observed in the Gellibrand and elsewhere (Whitfield and Cowley 2018).

6.3 Estuarine nutrients

Photosynthetic organisms including sea grasses, algae and phytoplankton require nutrients for growth just as land plants do. The important nutrients often in shortest supply are nitrogen (N) and phosphorous (P). One of these is often used up before the other and water bodies are described as 'nitrogen limited' or 'phosphorous limited'. Healthy estuary systems normally have low concentrations of N and P. Human activities can result in excessive concentrations of one or more of the nutrients in natural waters through agricultural runoff (fertilisers and animal waste) or urbanisation (sewage or storm water runoff) - a condition known as eutrophication. Excessive nutrient concentrations encourage the growth of reeds such as Typha and Phragmites (macrophytes) which can choke waterways. Phytoplankton and macroalgae can also benefit over other plant species from nutrient addition causing seasonal population increases (Woodland *et al.* 2015).

The Aire River is a Heritage River and its catchment is mostly included in forestry or national park reserves (Mondon et al. 2003). Mean nutrient concentrations measured in the Aire estuary reflect its relatively undisturbed catchment (Table 6). The Aire concentrations are similar to those of the Glenelg River but lower than those of the Curdies and Gellibrand estuaries. The latter two estuaries have similar wetland systems to the Aire but much more intensive agricultural activity in their catchments (Mondon et al. 2003). Unlike the Aire estuary, Curdies estuary has suffered multiple algal blooms consistent with its higher nutrient concentrations.

Victoria has recently revised its water quality guidelines for surface and groundwaters (SEPP 2018). Nutrient water quality objectives for Victorian estuaries are based on the 75th percentile of concentrations measured for a minimum of 11 samples collected over a year. The total phosphorous (TP) water quality objective is 0.09 mg/L and that for total nitrogen (TN) is 1.0 mg/L. For the Aire estuary 75th percentile concentrations based on 36 samples collected during 2002-3 are 0.057 mg/L for TP and 1.2 mg/L for TN (Kelson 2003). While TP meets its water quality objective, TN does not. The non-attainment of an environmental quality objective should trigger an investigation to assess the risk to beneficial uses and consideration of actions to address the risks (SEPP 2018).

Table 6. Mean total nutrient (TN and TP) concentrations measured for some west Victorian estuaries (Source: Kelson, 2003)

Estuary	Mean TP (mg/L)	Mean TN (mg/L)	Source
Aire River	0.04	0.87	Kelson 2003
Aire River	0.02	0.63	Mondon et al 2003
Curdies River	0.15	1.22	Maher 2001
Curdies River	0.23	1.80	Mondon et al 2003
Gellibrand River	0.07	1.0	Mondon et al 2003
Gellibrand River	0.05	0.85	Kelly 2001
Hopkins River	0.12	0.98	Mondon et al 2003
Glenelg	0.03	0.71	Mondon et al 2003
SEPP Objective*	0.09	1.0	SEPP (2018)
*The SEPP objective is based on a 75th percentile, not a mean (see text for more details)			

6.4 Photosynthetic activity in the estuary

About one-third of the 88 longitudinal surveys of the Aire estuary between 2005 and 2013 have shown the presence of 'super-saturation' of dissolved oxygen (>110%) for at least one site (Appendix B). Such conditions are most common in autumn and spring and are caused by enhanced photosynthetic activity by macrophytes (including sea grass), planktonic algae and or photosynthetic bacteria. A combination of warm waters, adequate nutrients, longer daylight hours and calm conditions favour the growth of plant and bacterial populations. The enhanced populations produce oxygen at a faster rate than it can be lost during the day. At night these same populations consume DO by respiration and can deplete DO concentrations (creating a diurnal 'sag' in DO). In extreme cases such overnight 'sags' may result in fish kills.

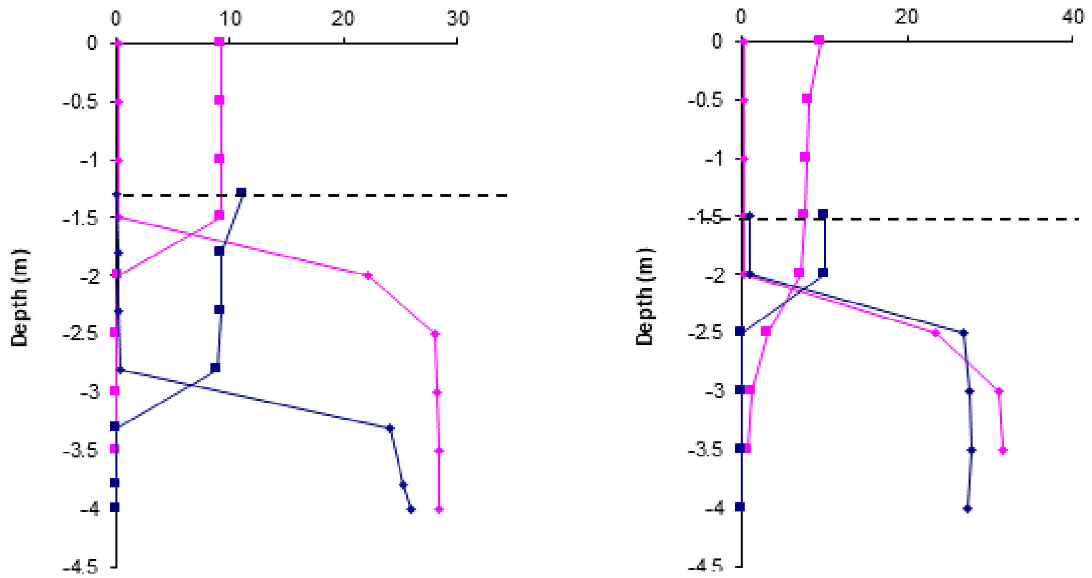
During calm conditions in the Aire estuary, algal and bacterial populations can become concentrated at the halocline, forming dense population "plates" at depths where they can optimise their access to sunlight (from above) and nutrients (from below). During early morning sharp drops in DO can be observed at the halocline because of the dominance of respiration activity overnight. Later in the day "spikes" in DO can occur as photosynthesis replaces the consumed DO (Appendix B).

Consistent with the estuary's nutrient status only one example of an algal 'bloom' was found in the study of 88 longitudinal surveys between 2005 and 2013 (Appendix B). On 7 May 2005 DO concentrations equal to 200 – 300 % of saturated values were detected in the upper 1.5m of the water column throughout the estuary. Such elevated conditions are caused by very high algal populations and can pose a threat to the estuarine community if they deplete DO overnight or generate toxins. Opening the estuary subsequently removed most of the algae and surface water DO concentrations had returned to values closer to 100% saturation during a post-opening survey on 17 May 2005.

6.5 During artificial estuary openings

Under current management processes, once a request to open the estuary is received, the estuary salt wedge is longitudinally surveyed for temperature, salinity, and dissolved oxygen. The latter parameter is especially significant. It is necessary to establish that a sufficient depth of oxygenated water – greater than 1.5m – is present throughout the estuary. Opening of the estuary mouth typically drains 1 - 1.5m of water from the estuary and the remaining water must have sufficient volume with greater than 5 mg O_2/L (about 50% of the saturation value).

There have been relatively few studies of the estuary water quality before and after an opening event. Kelson (2003) described two types of Aire estuary responses to artificial openings (Figure 31). During her study six openings were investigated. She focussed on the five where the 'after' studies were within three days of an opening. Surveys done later than this are subject to uncertainties due the influence of changes to river flow and/or sea state on conditions in the estuary.



a) Estuary artificially opened on 04/03/02 b) Estuary artificially opened on 06/03/03

Salinity (ppt) before opening — DO (mg/L) before opening — Estuary water level after opening

Salinity (ppt) after opening — DO (mg/L) before opening

Figure 31. *Vertical profiles of dissolved oxygen and salinity at the upstream limit of the estuary (Great Ocean Road Bridge) before and after artificial mouth openings. Water depth is given in relation to the Sand Road bridge gauge (source: Kelson 2003).*

In the first type of opening (Figure 31-a) about 1.2m of water drained from the estuary. Inflowing river water generated sufficient turbulence to erode the deeper anoxic water so that the 'before' and 'after' vertical profiles of salinity and DO are very similar. The depth of oxygenated water remained at 2m – presenting little risk to the estuarine community. Three openings showed this behaviour.

The situation was different for the second type (Figure 31- b). Here about 1.4m of water drained from the estuary but was not replaced by river inflow. Whereas there was over 2m of well oxygenated water before the opening only 0.5m remained afterwards. This sort of opening poses a much greater risk to estuarine organisms and was only observed once by Kelson.

The final opening was accompanied by sufficient river flow to completely erode the salt wedge and replace it with freshwater at the Great Ocean Road site.

Similar types of openings have been described by Water Technology in their review of Parks Victoria data collected for mouth openings (Water Technology 2011).

Within the Parks Victoria dataset there are 26 pairs of pre- and post- opening surveys (Appendix A). Of these 12 were separated by 5 days or less; 11 were separated by 6-8 days. The actual date of opening is not recorded in the file but dates for some were subsequently located. The majority of the post-opening surveys (19 out of 26) showed at least 0.5m of well oxygenated water (>5 mg/L) in surface waters. These estuary openings posed little risk to the estuarine community. In seven paired openings the post-opening profile showed at least one site along the estuary with low DO (<5mg/L) throughout the water column. All these openings would have created unfavourable conditions along sometimes extensive lengths of the estuary, in one case for at least 4 days (30 April 2009). All these openings with unfavourable conditions were in summer or autumn and poor quality water draining from the inundated floodplain appears the cause for some of them (Appendix A).

6.6 Implications for the Aire River estuary floodplain

Under natural conditions the Aire estuary floodplain would have been populated by plant communities adapted to immersion by fresh to brackish water for extended periods of time. Wetland plants have evolved to exist under such conditions without adverse effects on water quality. Remnants of these communities remain but large areas of the floodplain are now populated by grasses intolerant of immersion. The death of these plants creates a biochemical oxygen demand (BOD) which leads to poor water quality as DO drops. In extreme cases anoxia may develop and toxic gases such as hydrogen sulphide and ammonia build up in the water ("black water events").

Diurnal patterns in DO have been observed for the Aire estuary due to photosynthetic activity. Early morning sharp drops in DO can be observed at the halocline because of the dominance of respiration activity overnight and then "spikes" in DO as photosynthesis replaces the consumed DO later in the day. This process has also been observed in a long-term dataset for the Gellibrand estuary (Alluvium 2016). To reduce water quality risks, artificial estuary openings could be avoided during the earlier parts of the day.

There are water quality risks associated with artificial estuary openings. Based on available sampling data (Appendix B), many artificial estuary openings did not pose a water quality risk; however, 27% of events analysed had unfavourable water quality conditions after artificial openings, all in summer or autumn. In some cases, poor quality water draining from the inundated floodplain appears the cause; that is, the water quality in the channel prior to an event was suitable quality, and therefore the floodplain water is the primary source of poor quality water. To reduce water quality risks, avoid artificial estuary openings when there is low DO conditions (<5 mg/L)) in the surface waters (top 1.5m) of the main channel of the estuary or in waters covering the surrounding floodplain.

The following knowledge gap has been identified by the Technical panel to improve the ongoing management of the Aire estuary and provide the conditions to support the environmental values.

Knowledge gap: water quality

As described above, poor water quality is a risk associated with artificial estuary openings. There is currently some survey data available with limited analysis undertaken, and limited information about floodplain water quality. To reduce the frequency of artificial openings that lead to poor water quality conditions, there is a need to better understand the occurrence of poor water quality outcomes.

To improve the understanding of conditions that lead to poor water quality investigations, two projects with a defined life could be completed as follows:

- Pre and post opening surveys (post within 3-4 days) should be continued with the addition of monitoring of temperature, salinity and DO in the floodplain (including seasonal diurnal surveys). Floodplain monitoring would happen prior to an opening and could involve automatic data loggers taking hourly readings for a 24-hour period.
- If the automatic gauging station at Site 3 (campground Bridge) is to be a tool for estuary management, there is a need to assess how representative this is of conditions in the whole estuary (existing data sets could partly assist with this).

This knowledge gap could be addressed through research projects.

A summary of water quality over the year is given in Table 7.

Table 7. Summary of estuary water quality by time of year

Month	Water quality (based on typical hydrodynamics described in previous section, based on 2008-2019)
January	Surface water typically remains well oxygenated as a result of photosynthesis and direct dissolving from the atmosphere Deep saline water progressively loses DO. Respiration consumes it and rates of re-oxygenation are low due to reduced circulation and poor light conditions. Eventually deep water may become anoxic, particularly in the upper estuary
February	
March	
April	
May	
June	This period resets the estuary. Increased inflows can reduce salinity within the estuary and transport sediment through the estuary. Estuary may be fresh throughout for several days/weeks
July	
August	
September	While the estuary is open, seawater enters on flood tides and moves upstream beneath the surface fresher water. This influx of well oxygenated seawater triggers breeding in many estuarine organisms.
October	
November	
December	

7 Estuarine and floodplain vegetation condition and requirements

This section describes the ecological vegetation communities present in the Aire estuary, their location within the floodplain, and their condition. It then describes the environmental requirements for these communities and, drawing on the understanding of floodplain inundation and water quality (from Sections 5-6), discusses the implications of the current management for meeting these environmental requirements.

7.1 Description and condition

The native vegetation of the Aire River estuary floodplain is composed of aquatic and inundation tolerant species. The historic agricultural use of the floodplain has seen the higher and more reliably dry areas replaced with exotic pastures or crops.

Native vegetation quality is highest in the more undisturbed estuarine areas. A decline in vegetation condition is linked to increasing disturbance across the more elevated floodplain areas, and areas impacted by infrastructure development. In the past there has been more intensive agricultural activity on the floodplain with some areas of cropping and more active pasture management for dairy production. This initiated the establishment of a network of drains across floodplain areas to manage drainage and tidal ingress. In some areas (e.g. Lake Calder) these drains are not actively managed, and in these areas the reestablishment of native vegetation is observed - usually sedges and salt tolerant herbs.

The Ecological Vegetation Communities (EVCs) (see Figure 33, Table 8) have established in response to the hydrology and salinity of each area. There are three general vegetation zones (Australia Ecosystems 2010):

- Intact vegetation in reserves such as areas of Great Otway National Park, Lake Hordern and Lake Costin. The vegetation condition here is a result of the absence of grazing.
- Freehold land in the middle of the study area with large intact examples of a number of EVCs, particularly Estuarine Wetland, Brackish Wetland, Swamp Scrub and Tall Marsh. The vegetation here is of high quality due to the frequency of inundation and difficulty of access over drainage channels. Higher salinity has also reduced the exotic pasture vegetation from establishing.
- The upper third of the study area represents the poorest quality native vegetation. Vegetation has largely been cleared for agricultural purposes, and the freehold lands throughout this section of the study area have lower salinity levels that have supported the establishment of general pasture species.

The elevation range for each EVC on the Aire estuary floodplain is provided in Figure 32 along with the location of different EVCs within the profile of the estuary . Further information on EVC elevation can be found in Appendix C.

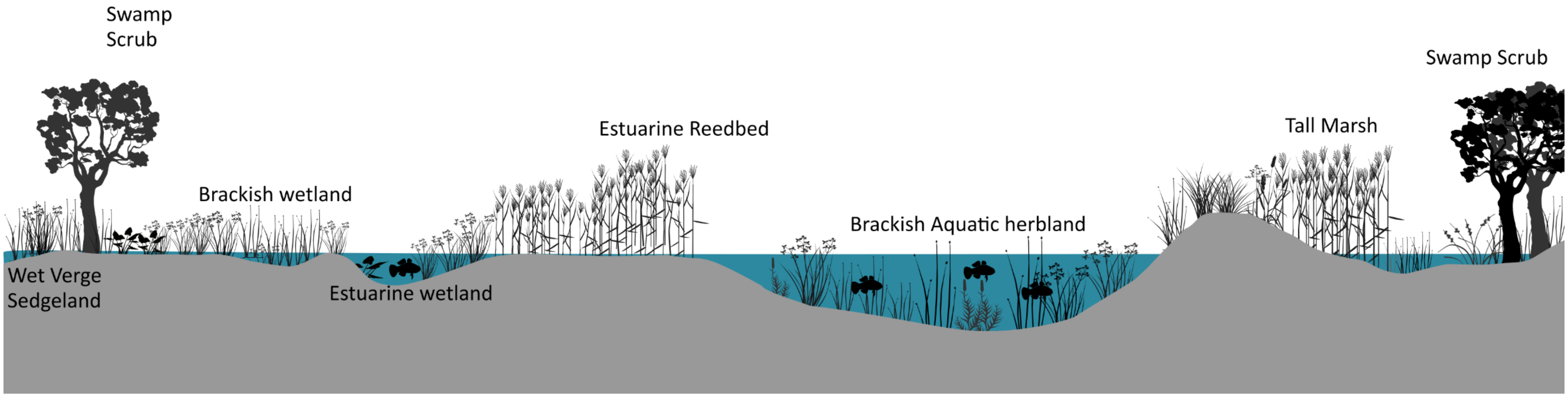


Figure 32. *Median elevation of floodplain EVCs in the Aire Estuary [top] and conceptual diagram of EVCs within Aire estuary [bottom]*

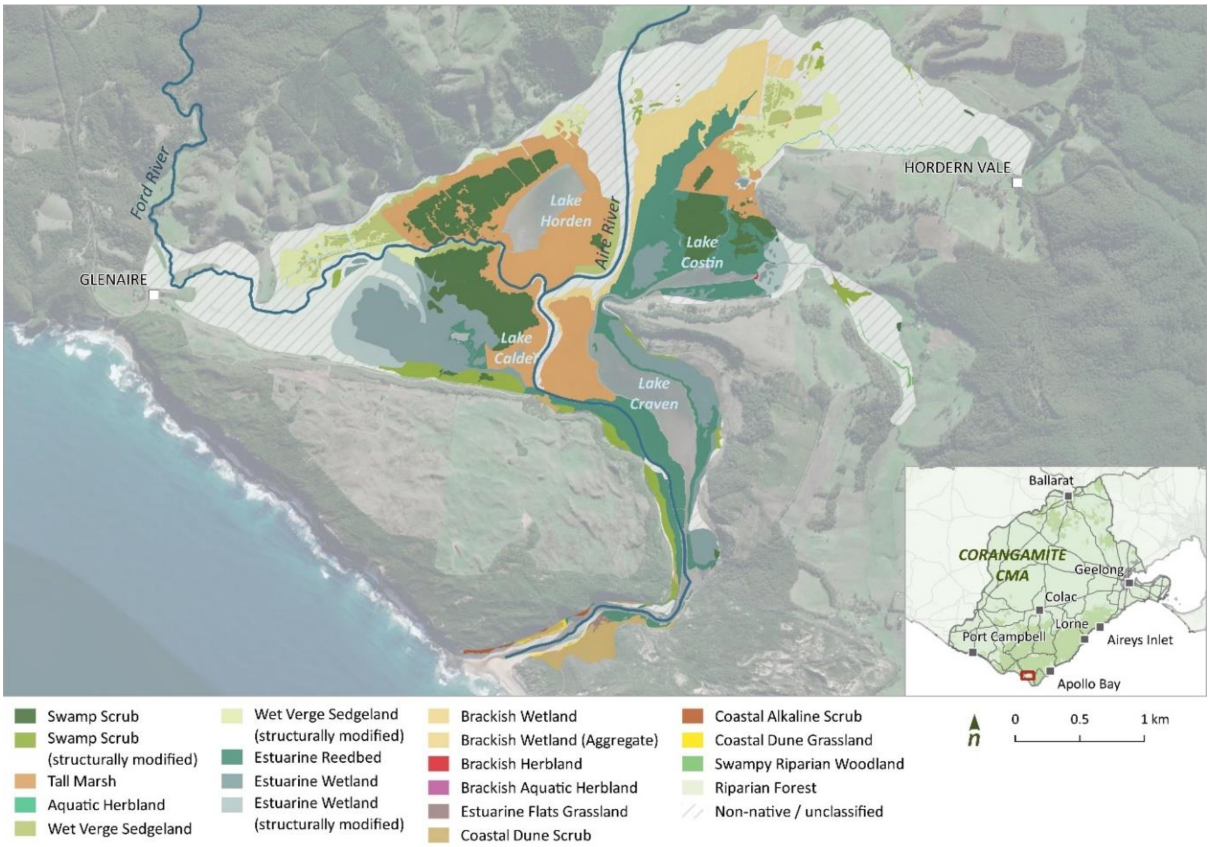


Figure 33. *Ecological Vegetation Classes of the Aire River floodplain [Data source: Australian Ecosystems, 2010]*

In addition to the EVCs, fringing and submerged vegetation was mapped as part of the Index of Estuary Condition (IEC) (Figure 34, Figure 35). The permanently inundated estuarine zones include unvegetated bare substrate, channel areas > 2m deep, macro-algae and seagrass.

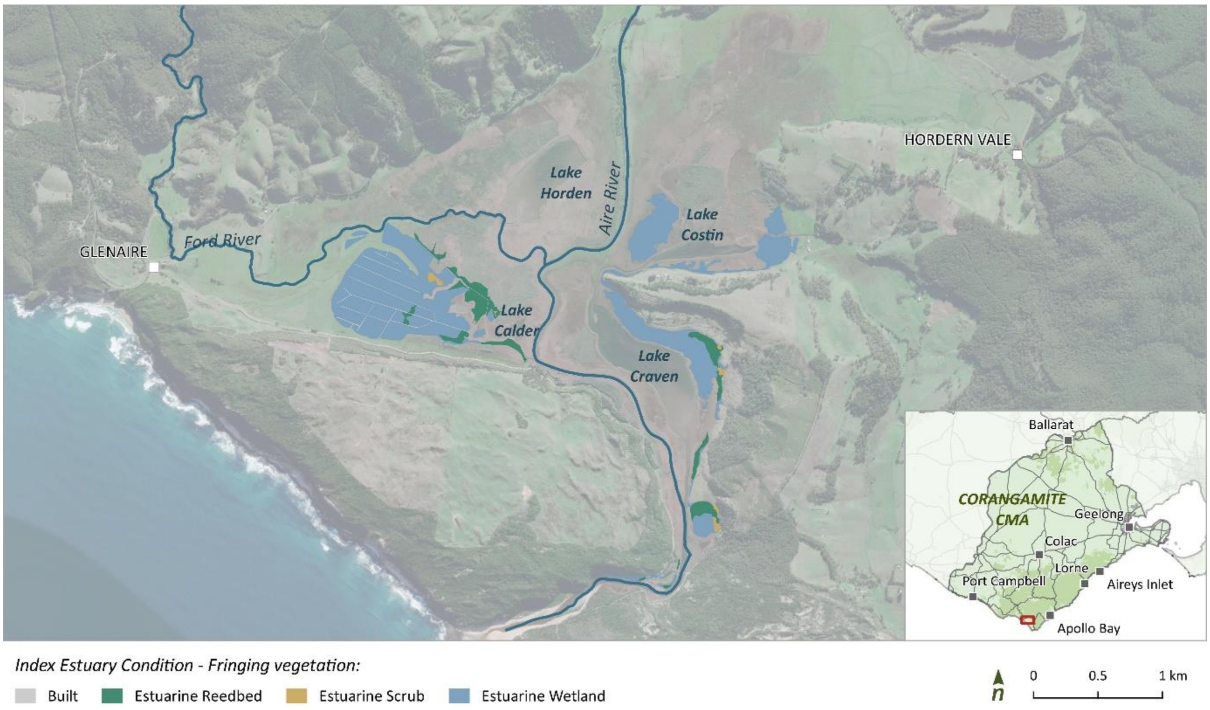


Figure 34. *Index of Wetland Condition - Fringing vegetation*

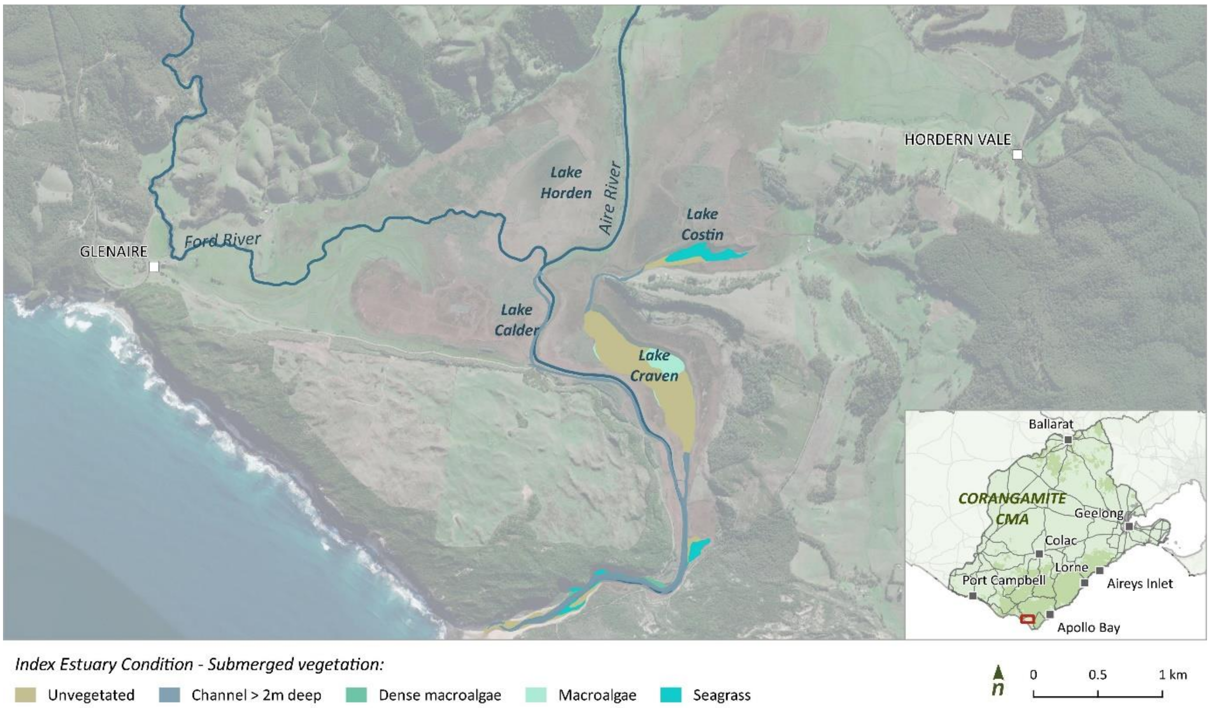


Figure 35. *Index of Wetland Condition - Submerged vegetation*

The Victorian Biodiversity Atlas holds 147 species records for the estuary and floodplain areas (106 native and 41 exotic species). *Cladium procerum* (Leafy Twig Sedge) is recorded and is recognised as Rare in the Victorian Biodiversity Advisory list. There are five Endangered EVCs and four Vulnerable EVCs present in the Aire River estuary (Table 8).

Table 8. Floodplain Ecological Vegetation Communities in the Aire River estuary

Vegetation community (EVC)	Area (ha)	Conservation status	Description
Aquatic Herbland (EVC 653)	1	Endangered	Fresh water semi-permanent to seasonal wetland vegetation, lacking woody species (or nearly so), dominated by herbaceous aquatic species (often with at least rootstocks tolerant of dry periods). Transitions to Brackish Aquatic Herbland with increasing salinity. This plant community was dominated by *Cycnogeton* spp. (Water Ribbons) with *Crassula helmsii* (Swamp Crassula), *Myriophyllum* spp (Water Milfoil) and *Ranunculus* spp (Buttercups). An invasive grass, *Paspalum distichum* (Water Couch), commonly degrades this plant community.
Brackish Aquatic Herbland (EVC 537)	<1	Vulnerable	Submerged (to weakly emergent) herbland, including more salt-tolerant aquatic species in semi-attached floating mats. Can exist during periods of inundation with the dry phase expressed as mudflats or a grassland/herbland. *Myriophyllum caput-medusae* (Coarse Water-milfoil) will be found in this zone in association with Lepilaena spp. (Water Mat) and Ruppia polycarpa (Many-fruit Tassel). Salt tolerant herbs such as Lobelia irrigua (Salt Pratia), Mimulus repens (Creeping Monkey Flower) and Selliera radicans (Shiny Swamp-mat) may occupy this wetland zone during dry phases.

Vegetation community (EVC)	Area (ha)	Conservation status	Description
Brackish Herbland (EVC 538)	<1	Vulnerable	Low herbland dominated by species tolerant of mildly saline conditions and intermittent inundation, generally species poor. This EVC occurs on heavy soils that are somewhat saline and only sometimes inundated. The soil salinity may be a result of salt spray or occasional inundation by large tides or floods of brackish water. *Lobelia irrigua* (Salt Pratia), *Ranunculus amphitrichus*, *Lachnagrostis* spp. (Common Blown Grass), *Isolepis cernua* (Nodding Club-sedge), *Selliera radicans* (Shiny Swamp-mat) and *Samolus repens* (Creeping Brookweed) occur in this community in the Aire Estuary.
Brackish Wetland (EVC 656)	51	Endangered	Brackish Wetland is the collective label for the various zones of sedgy-herbaceous vegetation associated with sub-saline wetlands. Includes wetter versions of Brackish Sedgeland (EVC13), Brackish Herbland (EVC 538) and Saline Aquatic Meadow (EVC 842). Within the Aire River study area this EVC was dominated by *Triglochin striata* (Streaked Arrowgrass), *Leptinella repens* (Creeping Cotula), *Selliera radicans* (Shiny Swamp mat), and *Rumex bidens* (Mud Dock), with a sparse cover of *Juncus kraussii subsp. australiensis* (Sea Rush).
Estuarine Reed Bed (EVC 952)	101	Endangered	Vegetation dominated by reeds (usually c. 1.5 - 3 m in height), in association with a sparse ground-layer of salt tolerant herbs. This EVC is dominated by *Phragmites australis* (Common Reed) at >50% cover in association with salt tolerant herbs such as *Selliera radicans* (Shiny Swamp mat) and *Samolus repens* (Creeping Brookweed). This vegetation has the potential to spread to un-grazed areas.
Estuarine Wetland (EVC 10)	112	Endangered	Rush-land / sedgeland vegetation, variously with a component of small halophytic herbs, occurring in regularly inundated wetlands of estuarine flats. Distinguished from Estuarine Reedbed (EVC 952) by the smaller stature and reduced dominance of *Phragmites australis*. Can be dominated by *Juncus kraussii subsp. australiensis* (Sea Rush) - although this was only sparse in the Aire Estuary. Areas of structurally modified Estuarine Wetland are present which are dominated by exotic species.
Swamp Scrub (EVC 53)	114	Vulnerable	Dense (and potentially up to 10-15 m) shrubby vegetation of relatively fertile swampy flats, dominated by Myrtaceous shrubs (to small trees), ground-layer often sparse, aquatic species conspicuous, Sphagnum and/or ferns tolerant of waterlogging sometimes present. The shrub component of this EVC in the Aire Estuary is comprised of *Leptospermum lanigerum* (Woolly Tea-tree) and *Melaleuca squarrosa* (Scented Paperbark). Areas of structurally modified Swamp Scrub are present which are dominated by exotic species.
Tall Marsh (EVC 821).	133	Vulnerable	Wetland dominated by tall emergent graminoids, typically in thick, species-poor swards of *Phragmites australis* (Common Reed)

Vegetation community (EVC)	Area (ha)	Conservation status	Description
Wet Verge Sedgeland (EVC 932)	74	Endangered	Wet Verge Sedgeland consists of dense stands of sedge species, with a range of herb and rush species which are tolerant of seasonal periods of inundation. Wet Verge Sedgeland consists of dense stands of sedge species, with a range of herb and rush species which are tolerant of seasonal periods of inundation. This EVC often occurs on fertile flats and is often replaced by agricultural pasture species. In the Aire Estuary this is made up of *Carex appressa* (Tall Sedge), *Carex gaudichaudiana* (Fen Sedge) and *Eleocharis acuta* (Common Spike-sedge). Associated plants include *Crassula helmsii* (Swamp Crassula), *Juncus* spp. (Rushes), *Cycnogeton procerum* (Water Ribbons), *Isolepsis inundata* (Swamp Club-sedge), *Persicaria decipiens* (Slender Knotweed) and *Ranunculus amphitrichus* (Small River Buttercup).
Unknown or undetermined (EVC 999)			Areas of highly modified vegetation. In this case these are predominately areas of pasture.

7.2 Estuary requirements

The vegetation communities in the study area occupy distinct zones. These are directed by depth and duration of inundation, salinity levels and the historic and current land use. Where the hydrology is highly consistent the vegetation is more stable. Where the hydrology is variable or there is induced change to the hydrology the vegetation is less stable and more prone to weed invasion. The hydrological requirements of the different EVCs are shown in Table 9.

Overall, the vegetation is generally stable in its current distribution, structural composition and quality. Some areas with the same hydrological regime have varying native vegetation quality due to grazing and stock damage but this is defined by a physical barrier (channel or fence). Other areas are seeing a transition from a modified state to a higher density of native species. This is common in frequently inundated areas where the agricultural activity is now less intensive (e.g. Lake Calder, Figure 36. ***Fringing vegetation % cover exotic vegetation***). Without intervention the vegetation will remain largely the same in the higher quality zones and continue to transition in the more hydrological variable areas.

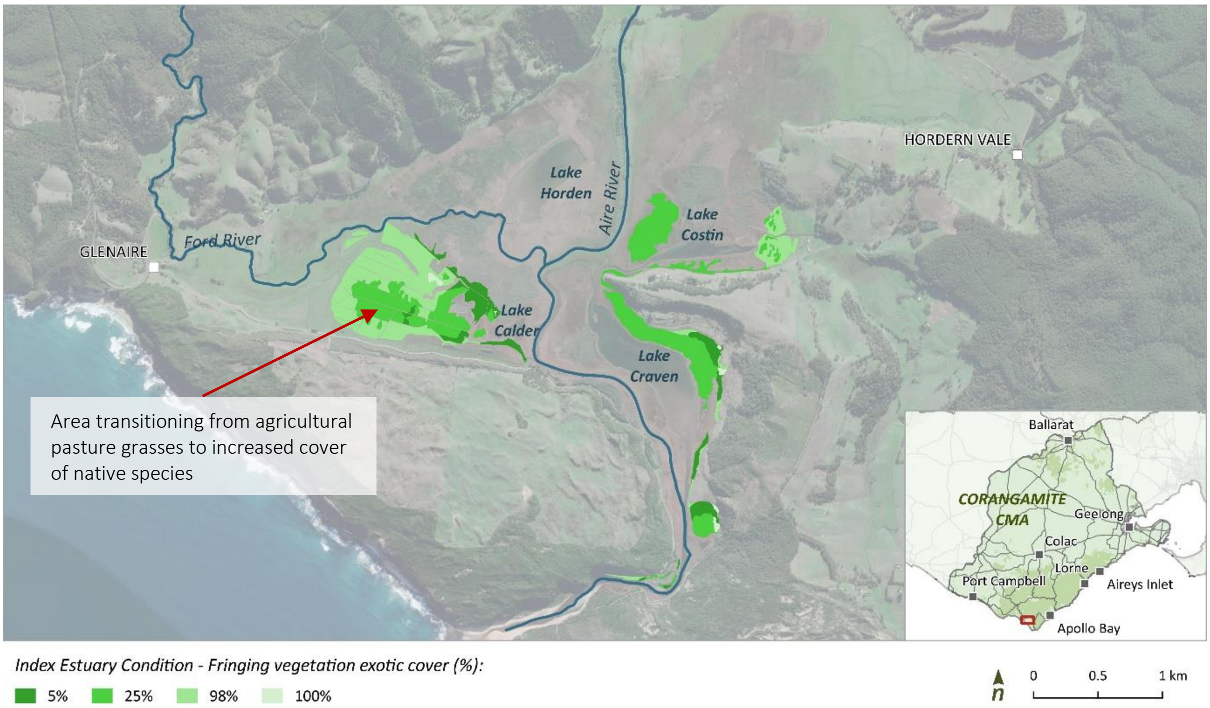


Figure 36. *Fringing vegetation % cover exotic vegetation*

Within Lake Calder, there is an area with an increasing level of native species (as indicated on Figure 36. ***Fringing vegetation % cover exotic vegetation***). Similar changes in vegetation can be seen between Lake Hordern and the Great Ocean Road. The response seen here is likely to be a response to the hydrology and salinity levels resulting from a change in management of these areas. With a reduction in intensity of the agricultural activity and maintenance of paddock drains water will be retained over these areas for longer and salinity will be gradually increasing.

Areas of non-wetland vegetation or non-native vegetation have also been mapped (see EVC 999 in Figure 33). These areas will also experience flooding in very high-water events and seasonal waterlogging. Drains have been established through most of this area to reduce waterlogging and increase utility of the land.

Table 9. Ecohydrological requirements for wetland EVCs. [Source: Frood and Papas (2016), Australian Ecosystems (2010)]

Vegetation community (EVC)	Ecological comments		Recommended water regime				
			Frequency	**Duration**	**Timing**	**Depth (cm)**	**Salinity (mg/L)**
Aquatic Herbland (EVC 653)	Transitions to Brackish Aquatic Herbland with increasing salinity.	High	Seasonal to permanent	1 to 12 months		30 - 100	<3,000
Brackish Aquatic Herbland (EVC 537)	Can exist during periods of inundation with the dry phase expressed as mudflats or a grassland/herbland.	Predictable from flooded to dry sate	Permanent to 8 in 10 years	>6 months to permanent		>100	>3,000 to 10,000
Brackish Herbland (EVC 538)	Variable hydrology with vegetation maintained by periodic inundation. In estuary situations the community can be expressed during water level drawdown.	High	Seasonal	1 to 6 months Not permanent		30 - 100	>3,000 to 10,000
Brackish Wetland (EVC 656)	Influenced by freshwater inflows and occurs adjacent to more saline vegetation such as Estuarine Wetland.	Moderate	Seasonal	1 to 6 months or brief inundation Not permanent		30 - 100	>3,000 to 10,000
Estuarine Reed Bed (EVC 952)	Generally < 30 cm depth with tolerance of 100cm in flood conditions	Low	Seasonal to Twice daily	1 to 6 months or brief inundation Not permanent	Can be twice daily	30	>3,000 to 10,000
Estuarine Wetland (EVC 10)	Generally < 30 cm depth with tolerance of 100cm in flood conditions	High	Seasonal to Twice daily	1 to 6 months or brief inundation Not permanent	Can be twice daily	30	>3,000 to 15,000
Swamp Scrub (EVC 53)	The degree of wetness varies within this EVC, but it is frequently waterlogged for extensive periods, occasionally to the extent of shallow inundation.	High	Seasonal or Bog	Constant waterlogging up to 9 months Not permanent		< 30	0 to 3,000 Occasional up to 10,000
Tall Marsh (EVC 821).	Depth is rarely greater than 1m for extended periods. Periodic drying assists with regeneration and species diversity.	Low	Seasonal to Permanent	> 6 months		30 - 100	0 to 10,000
Wet Verge Sedgeland (EVC 932)	This EVC is more often fresh but is tolerant of slightly brackish conditions.	High	Seasonal or Bog	1 to 6 months or brief inundation Not permanent	Winter Spring	< 30	0 to 3,000
Submerged Estuarine vegetation		Low	Permanent	Permanent		>50	3,000 to 30,000
Unknown or undetermined (EVC 999)	Drains have been established through most of this area to reduce waterlogging and increase utility of the land.	Moderate	Permanent	<1 month		< 10	0 to 3,000

*Permanent = Constant, annual or less frequently but before wetland dries; Seasonal = Annual or near annual inundation (e.g. 8-10 years in every 10); Bog = Constant waterlogging, inundation mostly superficial

7.3 Implications for the Aire River estuary floodplain

The key vegetation requirements are summarised in Table 10.

Table 10. Summary of vegetation requirements, by time of year

Month	Key requirements
January	Slow filling period from a wetland perspective. Advantage macrophytes and fresh/brackish-water herbs.
February	
March	
April	
May	
June	Inundation of Swamp scrub. Waterlogging & salt. Absence of this could lead to terrestrialisation / change to EVC
July	
August	Estuary open during this time enables germination in late winter (before more inundation in Spring).
September	
October	Recruitment period. Swamp scrub and aquatic herbs.
November	
December	

Risk of excessive inundation

The Aire river estuary vegetation has been assessed to be at a low risk of detrimental impacts (i.e. die-off) as a result of flooding or excessive inundation. A recent study (Sinclair et al 2020 – in prep.) set out to quantify the inundation risk to floodplain vegetation in estuaries across Victoria. The risk of detrimental impacts (i.e. plant death) on vegetation at the species level was determined by an expert panel. The likelihood of plant dieback or death was then used to assess the risk at the estuary scale for three water qualities (freshwater, brackish water and saltwater) over a range of 1 – 52 weeks of flooding and inundation.

Based on the vegetation communities present in the Aire River estuary the risk was calculated to be extremely low (compared to other estuaries in the State) for adverse impacts under all water quality regimes and periods of flooding up to 52 weeks. This assessment considered the fact that there is little intact vegetation on the Aire floodplain, but also that the vegetation that is present is generally at low risk from prolonged inundation.

While much of the floodplain has been cleared for agriculture, the EVC mapping presented in this report included an assessment of EVCs that would be present without intervention (Figure 33). Based on this EVC mapping and understanding of the natural patterns of flooding with fresh or brackish water, there is limited risk of prolonged inundation for the Aire estuary based on the current (and likely historical) vegetation communities present.

The findings from Sinclair et al (2020) and assessment by the Technical Panel supports the conclusion that based on the overall vegetation characteristics of the Aire estuary, there is no environmental requirement under the current climatic conditions to open the estuary to protect native vegetation values.

Risk of insufficient inundation extent and duration

The number of artificial openings (Figure 16, p19), particularly in summer and autumn, will result in a more frequently open estuary than under natural conditions, and therefore reduced frequency, duration and extent of floodplain inundation. An analysis of the water levels at the time of estuary openings, illustrates that the median water level at the time of artificial openings is 1.7 m AHD, and ranges from 1.3 to 2.3 m AHD (Figure 19, p20). Most of the artificial openings occur in summer and autumn (75% of recorded artificial openings 2008-2020); during these seasons, 75% of artificial openings occur at or below 1.7 m AHD.

The majority of the floodplain EVCs have large portions of their total area within the estuary located at an elevation below 1.7 m AHD (Figure 32). These EVCs will be inundated for some period of time under the current regime of estuary mouth management and will receive some of their hydrological requirements. The risk to these EVCs is that while they are situated lower in the landscape , they still may not be inundated for the period ecologically necessary.

The reduced inundation provides conditions for exotic grasses which compete with the native herbs and sedges reducing the native biodiversity especially in the Brackish Aquatic Herbland and Estuarine Wetland. A rapid drawdown in summer following an opening can expose the aquatic herbs and sedges to desiccation and heat reducing their health and viability.

The current practice of artificial opening of the Aire River has likely resulted in reduced frequency/duration of flooding of the higher elevation areas of the floodplain. The wetland EVCs at the higher elevations (i.e. Tall Marsh, Swamp Scrub, Aquatic Herbland, Wet Verge Sedgeland and Estuarine Reedbed) will be most impacted by the modified hydrology. Of the EVCs with a significant area situated above 1.7 m AHD, Swamp Scrub and Wet Verge Sedgeland are likely to be the most vulnerable under the current management conditions.

Wet Verge Sedgeland will be at risk due to the narrow elevation range that it occupies (Figure 32) and the water quality requirements of the EVC being primarily freshwater (Table 9). The hydrological requirements and distribution of this EVC requires extensive flooding of the estuary for adequate inundation of the EVC to occur. Swamp Scrub is also at risk of insufficient inundation across some of its mapped extents in the Aire estuary. This is demonstrated in the inundation analysis below (Figure 37, further details in Appendix C): the area of Swamp Scrub EVC to the north-west is partly inundated at 1.65 m AHD, which, based on satellite imagery, only occurs 10% of the time. Swamp Scrub may be at risk of terrestrialisation (i.e. the vegetation community may shift toward a less water tolerant community) with the drier hydrology occurring as part of current management.

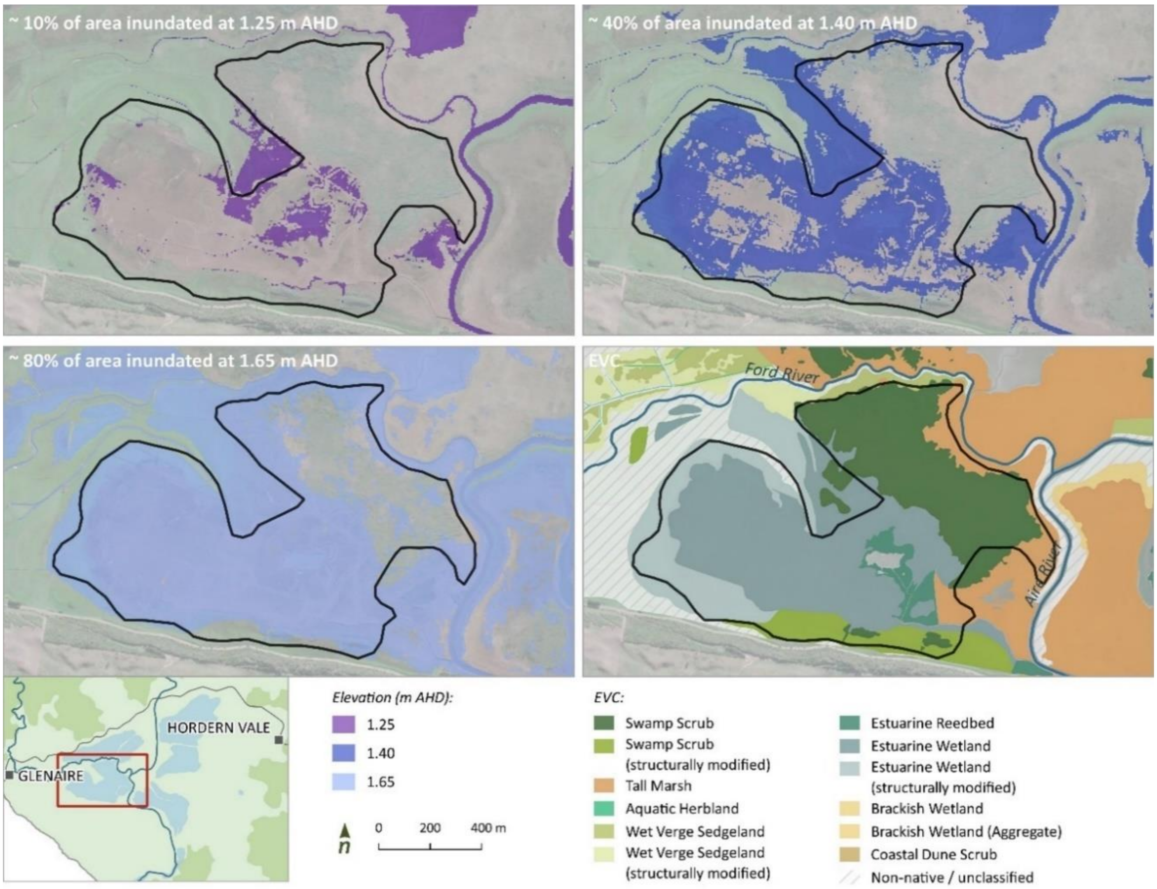


Figure 37. *Example inundation analysis for floodplain area with Swamp Scrub EVC*

Presence of pasture grass

As noted throughout this section, native vegetation in some areas has been cleared for agricultural purposes, and general pasture species have established. The presence of pasture grass on the estuary floodplain reduces native vegetation extent and introduces water quality risks from inundation and decay of the pasture. These grasses can be damaged or die during prolonged inundation causing resulting in impacts on agricultural production and water quality in the estuary aquatic habitat. Therefore, for the management of environmental values, reducing pasture grass on the estuary floodplain could be considered.

Knowledge gap: vegetation
If there is a desire to transition the floodplain vegetation from exotic pasture dominated species to native species, the time and resources required to do this is not known.

The plants currently occupying the floodplain, while not as tolerant of prolonged inundation as some native species, do have regeneration capacity from viable soil seed banks and root systems. Without intervention, to facilitate the transition from the current to a more natural vegetation community, the time for the transition is not clear. The succession process will evolve over time and require monitoring of the vegetation responses to the environmental conditions experienced during the transition period.

Management of vegetation on this scale in these environments is not common and will require specialist knowledge and input to be successful. The transition will take 3 to 10 years and vary spatially throughout the floodplain. A resourcing commitment will be required over that time to respond to changing conditions as they arise.

Impacts of climate change

While the impacts of climate change on the Aire estuary are difficult to predict (refer Section 4), some of the possible impacts on vegetation communities may include the expansion of species that can tolerate the changing water quality conditions – that is, if there are higher salinities in the estuary, species that can tolerate these higher salinities will expand their cover. If there is salinisation of the estuary, terrestrial and freshwater communities (including pasture grass) will become increasingly difficult to maintain on the floodplain.

8 Native fish condition and requirements

This section describes the native fish species present in the Aire estuary, and their requirements, including habitat, breeding and migration. This section also summarises the different requirements throughout the year for different species and what this means for the role of artificial estuary openings and the current management regime.

8.1 Description and condition

The Aire River estuary provides excellent habitat for native fish and it supports at least 26 species (as recorded in the Victorian Biodiversity Atlas 2020; Table 11). These fish can be divided into six categories based on their relationship with the estuary (Figure 38).

An assessment of the biology of these fish makes it clear that the majority of the fish supported by the Aire River estuary are either Estuary Resident (three species) or Estuary Dependent (12 species), moderate amounts of Estuary Opportunists (Marine) fish (eight species) but with fewer Estuary Opportunists (Freshwater) fish (two species) or freshwater (one species) fish (Table 11).

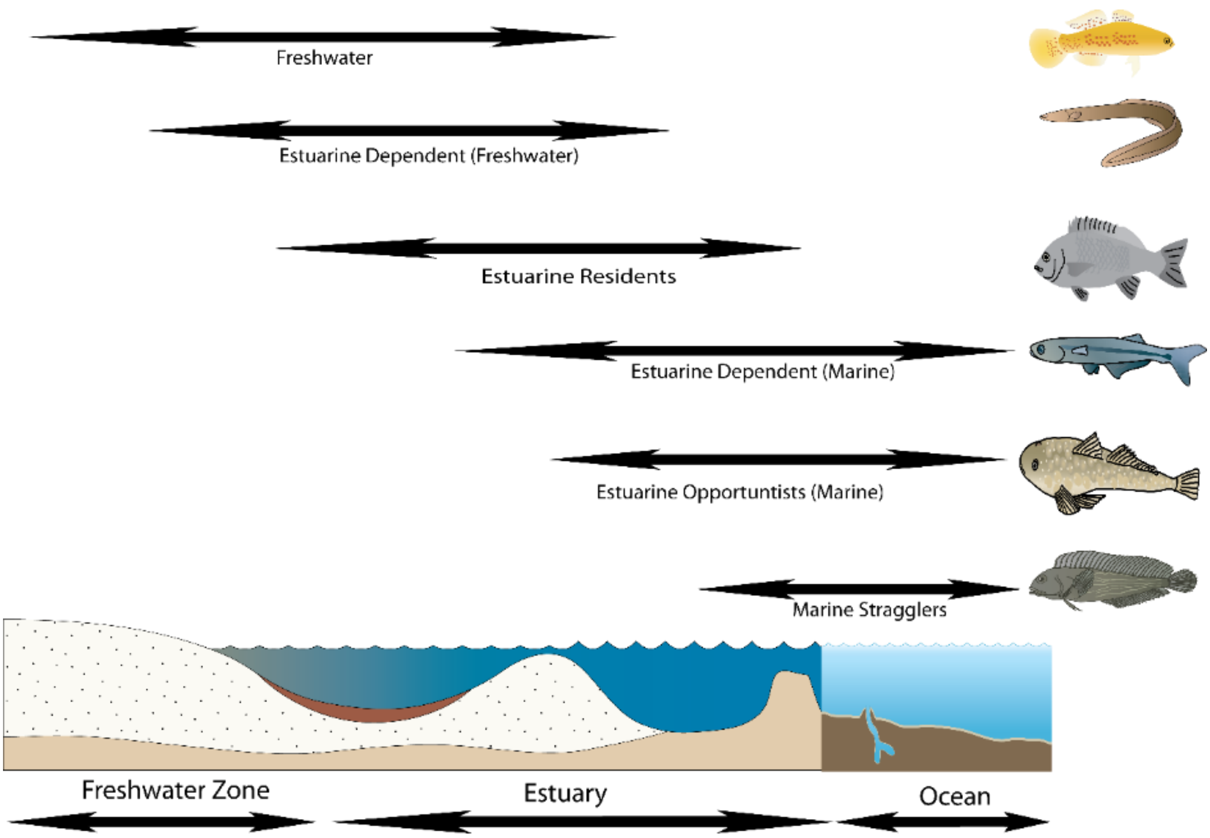


Figure 38. *Estuary Fish Classification (Lloyd et al. 2012)*

Table 11. Fish present within Aire River Valley (VBA search 2020)

Category	Scientific Name	Common Name
	Native Fish	
Estuary Resident	*Pseudogobius olorum*	Bluespot Goby
	Macquaria colonorum	Estuary Perch
	Acanthopagrus butcheri	Black Bream

Category	Scientific Name	Common Name
	Native Fish	
Estuary Dependent (Marine)	*Argyrosomus japonicus*	Mulloway
	Geotria australis	Pouched Lamprey
	Mordacia mordax	Shorthead Lamprey
	Mugil cephalus	Sea Mullet
	Aldrichetta forsteri	Yellow-eye Mullet
Estuary Dependent (Freshwater)	*Prototroctes maraena*	Australian Grayling#
	Anguilla australis	Southern Shortfin Eel
	Galaxias truttaceus	Spotted Galaxias
	Galaxias brevipinnis	Climbing Galaxias
	Galaxias maculatus	Common Galaxias
	Neochanna cleaveri	Australian Mudfish*
	Pseudaphritis urvillii	Tupong
Estuary Opportunist (Marine)	*Ammotretis rostratus*	Longsnouted Flounder
	Rhombosolea tapirina	Greenback Flounder
	Tetractenos glaber	Smooth Toadfish
	Afurcagobius tamarensis	Tamar Goby
	Pseudocaranx georgianus	Silver Trevally
	Arripis truttaceus	Western Australian Salmon
	Arripis georgianus	Australian Herring
	Arripis trutta	Eastern Australian Salmon
Estuary Opportunist (Freshwater)	*Retropinna semoni*	Australian Smelt
	Philypnodon grandiceps	Flatheaded Gudgeon
Freshwater	*Gadopsis marmoratus*	River Blackfish
	Exotic Fish	
Estuary Opportunist Freshwater	*Oncorhynchus mykiss*	Rainbow Trout
	Oncorhynchus tshawytscha	Chinook Salmon
	Salmo trutta	Brown Trout
	Gambusia holbrooki	Eastern Gambusia

Vulnerable under FFG and EPBC Acts; * Critically Endangered

Estuary resident and estuary dependent fish are the most important species in the system as these fish rely on the conditions within the estuary to enable them to complete their lifecycles. The Aire system supports 15 of these species, being almost 60% of the fish fauna. Another 10 species at least are benefiting from the Aire estuary with opportunistic visits to the estuary to exploit the food and habitat resources present.

Estuary Resident fish of the Aire River estuary include Black Bream, Estuary Perch and the Blue-Spot Goby. The first two fish are large-bodied fish which are important recreational fishing species. Blue-Spot Gobies are tiny fish but form large populations and will have an important role in ecosystem function. They are an important component in the food chain, eating micro and macroinvertebrates and then in turn being preyed on by larger fish and waterbirds.

Other recreationally important fish beside the Black Bream and Estuary Perch are Mullet, Salmon and Flounder which are either estuary dependent or opportunist species using the estuary's resources.

The two most conservation significant species are the Australian Grayling and the Australian Mudfish:

Australian Grayling (*Prototroctes maraena*) are regarded as vulnerable under the FFG Act and the EPBC Act having undergone very significant declines in population size and range (Commonwealth Environment Protection and Biodiversity Conservation Act 1999 [EPBC Act]). The Australian Grayling is known to occur in the Aire River estuary and is a small to medium-sized, slender, laterally compressed fish. The Australian Grayling migrates up from the estuary to mature and breeds in freshwater with larvae returning to the estuary by drifting with the flow downstream.

Australian Mudfish (*Neochanna cleaver*) is recognised as a Critically Endangered species in Victoria being listed under the Flora and Fauna Guarantee Act 1988 (FFG Act). The Australian Mudfish is a small tubular and scaleless fish. It grows to 140 mm in length. Features that distinguish this species from other galaxias are the presence of large, long tubular nostrils, a small head and eyes, large round pectoral fins and small pelvic fins, large flanges on the caudal peduncle, and a low, rounded to ovoid dorsal fin, elongated posterior.

Migratory species fall into two categories, Estuary Dependent (Freshwater) and Estuary Dependent (Marine). These species spend most of their lives in freshwater or marine environments but migrate to the estuary to complete their life-cycle by breeding (Lloyd et al. 2012b). In the Aire, this group includes the Australian Grayling, Tupong, Short-Finned Eel, Common Jollytail and Spotted Galaxias. These species mostly spend time as larvae or juveniles in the estuary while they mature, with the exception of Short-finned Eels. Short-finned Eel (*Anguila australis*) mature as they swim upstream in freshwater streams and lakes. Once reaching sexual maturity (14-24 years) they migrate to the sea where they travel to deep oceanic breeding sites in the Coral Sea to spawn. The larvae travel back on ocean currents to coastal waters before metamorphosing into glass eels and migrating back into estuaries.

8.2 Estuary requirements

The estuary requirements of each group of fish can be quite different with each species having specific requirements, but generally they are robust and tolerate a broad salinity range (DELWP 2013; Lloyd et al. 2012a, Koehn & O'Connor 1990, McDowall 1996). The requirements fall into four broad areas:

- water quality
- longitudinal access
- complex habitats
- flows.

Water quality is vital for native fish to survive within estuaries (see Section 6). Specific species have their own salinity requirements and tolerances, and most fish use the salinity gradients and salt wedge for navigating the estuary and in some cases, salt wedges become a location for spawning. Oxygen levels are important and can be variable and below certain critical minima most native fish will die. Flow and tidal movements are an important factor in improving water quality as is the presence of native vegetation and buffer zones between farmland and waterway to intercept nutrient run off around the estuary and upstream. High amounts of nutrients in the water can also create adverse water quality conditions for fish, as nutrients promote algal blooms, which can deplete dissolved oxygen in the water and nutrients also create nuisance plant growth (such as filamentous algae and reeds) which can trap young fish on the floodplain if sudden water level drops occur.

Most of the fish which are dependent upon the estuary, undertake local or long-distance migrations to complete their life cycles. The longitudinal connectivity and floodplain inundation from higher flows is critically important for life history of many fish. The Mountain Galaxias, for example, is able to survive in pools over the dry period, but they need to migrate between pools to thrive. Local movements are between habitats, looking for food and finding mates. Movements take place between the river and estuary and to nearby wetlands. The longer distance migrations are usually for breeding from freshwater or marine fish migrating to the estuary to spawn and for their larvae to grow and mature. Access is required between the sea and estuary (and estuary to sea), and between estuary and freshwater river reaches. As an example, the common jollytail requires access to move up and down the river to find food resources or to get to the estuary to breed. They need flows to get past natural and man-made barriers in the river. Many other fish species require the opportunity to migrate upstream and downstream to either complete their life-cycle or to find suitable habitats. Without movement, fish have a greater likelihood of local extinctions of species, if they are isolated in sections of the system.

There are diverse habitat types within the Aire River system which support native fish and these include open water, vegetation beds, pools, riffles, runs, woody debris, undercut banks, rocks and boulders, swamps, and estuarine and floodplains wetlands. These habitats are created and maintained by adequate flow regimes as well as adequate riparian vegetation. Increasing flows and flow variability and instream habitat complexity will allow native fish populations to build and potentially reduce the exotic fish numbers (gambusia and carp thrive in altered and low flows). Galaxias, the blue spot goby and the Mudfish all require heavily vegetated waters as they are susceptible to predation and good vegetation cover provides protection from predation. Aquatic vegetation beds are also essential as spawning locations and for larvae to recruit to after they hatch. Australian Grayling on the other hand, need open water and quite specific flow and salinity conditions for breeding. Complementary actions such as revegetation of instream and streamside species will increase habitat complexity and support more food resources which will also support native fish.

Flows and flow variability are critical to native fish. They trigger migrations and spawning behaviour as well as creating new or additional instream habitat which allow invertebrate populations to build and the fish larvae to feed upon micro and then macro-invertebrate species.

Table 12 lists the species within the estuary and provides a record of their flow and habitat requirements. Provision of these conditions will encourage recolonisation and restoration of their populations.

Table 12. Ecological requirements of key fish species in the Aire River Estuary[2]

Fish Species: Common Name	Fish Species: Scientific Name	Life Span	Spawning Season	Incubation Duration*	Migration	Other
Western Blue-spot Goby	*Psuedogobius olorum*	2-3 years	Oct-Jan	4 days	Local only	Need hollow in log or burrow under rock or wood as a substrate for laying eggs.
Australian Smelt	*Retropinna semoni*	1-2 years	Sept - Nov	9-10 days	Active movers between habitats and along anabranches	Aquatic vegetation required as a substrate for laying eggs
Australian Grayling	*Prototroctes maraena*^V, @V	Males 1-2 years Females 2-3 years	Feb - May	14-21 days in freshwater <2ppt	Larvae washed to estuary (& sea?) in May – July Juveniles migrate from sea upstream Oct - Dec	Demersal non-adhesive eggs Fry slender and buoyant. Spawning occurs after high flow in freshwater above saline reach – full moon to last quarter. Eggs develop in slow water to 5m deep. Juveniles spend May to Oct in estuary. The fish need high O_2, can swim up riffles at flow of 2-4m/s sustained swimming 0.6m/sec but prefer 0.2 to 0.35 m/sec
Tupong (Congolli)	*Pseudaphritis urvillii*	>5years	Sept - Dec	Unknown (likely to be short - 3 or so days)	Adults migrate downstream to estuary for breeding April to July. Juveniles migrate upstream Oct – Feb.	Congolli are susceptible to impacts from the presence of water flow barriers
Common Jollytail	*Galaxias maculatus*	2-3 years	April -June	Normally take 10-16 days between flow events or tides (in estuary	Downstream to estuary in autumn.	Aquatic/riparian/intertidal macrophytes required as a substrate for laying eggs
Broad-finned (or Climbing) galaxias	*Galaxias brevipinnis*	2-4 years (Uncertain)	May-June	Unknown – perhaps 5-7 days (same as *G. olidus*)	Larvae are washed downstream to the sea in winter. Juveniles return upstream in spring and early summer.	Prefer rocky streams with flowing water and good riparian vegetation however have are also found in habitats with silt substrates.

[2] Derived from Froese and Pauly (2018), Allen *et al.* (2002); Koehn & O'Connor (1990); Lloyd (1987); Merrick & Schmida (1984); McDowall (1996); Treadwell & Hardwick (2003); DELWP (2013); Lloyd *et al.* 2012a; Growns (2004); McKinnon (2007); Raadik (2014).
* Time that eggs take to develop into larvae (eggs require inundation at least for this period)
^V Listed as vulnerable species under FFG Act, ^CE Critically
@V Listed as vulnerable under EPBC Act

Fish Species		Life Span	Spawning Season	Incubation Duration*	Migration	Other
Common Name	Scientific Name					
Spotted galaxias	*Galaxias truttaceus*	2-4 years (Uncertain)	May-June	28 days at 12 degrees	Downstream to estuary in the wet period (winter/spring). Larvae swept to sea. Juveniles return from sea upstream in spring and early summer (Oct – Jan)	Large Woody Debris (LWD), undercut banks, boulders and good riparian vegetation however have are also found in habitats with silt substrates. Pools are also used extensively. Highly salt tolerant and occurs in turbid water – prob very tolerant of poor WQ. Can swim at 3.3m/sec for 1 hour – prefer 0.2m/sec
Australian Mudfish	*Neochanna cleaveri*	>1 year	Late Winter	unknown	The breeding is poorly known, with juveniles spending at least part of their early life at sea or estuary and return to freshwater at approximately two months of age in spring.	Occurring in coastal but freshwater wetlands, which are typically semi-permanent, shallow and often-muddy with dense vegetation. These fish are capable of at least partial aestivation (Koehn and Raadik 1991) and is therefore likely to survive some natural drying of its wetland habitat. The Aire River & Calder River Wetlands are considered as one of the stronghold areas on mainland Australia.
River Blackfish	*Gadopsis marmoratus*	4–7 years	Nov - Jan	7 - 10 days (plus 21 days 'tethered' larvae)	Local	Hard substrate required – hollow logs as a substrate for laying eggs
Flatheaded Gudgeon	*Philypnodon grandiceps*	4-7 years	Oct - Feb	4-6 days	Local only	Hard surfaces required as a substrate for laying eggs
Short-finned Eel	*Anguilla australis*	32 years	June - Mar	Unknown as it occurs in the marine environment	Flow freshes trigger downstream spawning migration of adult fish to the estuary (Jan-March) Adults migrate to the sea during autumn (April to May). Elvers return to the estuary after being spawned at sea in winter to spring (Jul-Nov) and undertake upstream migrations Nov – Feb (mainly)	Flow requirements really need to consider preservation of adult habitat – rivers and lakes. Breeding is cued by non-flow factors and occurs at sea.

Fish Species		Life Span	Spawning Season	Incubation Duration*	Migration	Other
Common Name	Scientific Name					
Black Bream	*Acanthopagrus butcheri*	29 years	Oct – Jan Backtracking otolith indicated spawning was in January and later into March dependent upon freshwater inflows, specific salinity and DO requirements being met (Jenkins et al 2018).	2 days	Estuary Resident – move around estuary seeking ideal salinities. Black bream are found to be highly mobile, travelling the entire length of estuary and into neighbouring estuaries (Williams et al 2017). Black ream resided in the upper estuary during winter and spring and the lower estuary during summer and autumn (Williams et al 2017). The eggs are planktonic and float on halocline generally around 15 g/L (Nicholson et al 2008).	Breeding in estuary at specific salinities, few found below 10g/l and viable eggs float on the halocline and suitable conditions for spawning and survival of eggs may be disrupted if the water column is disturbed by sudden artificial mouth openings (Nicholson et al 2008). Eggs fail to develop in waters below 5 g/L. They tend to inhabit areas where rocky river beds, snags or structures provide cover but can be found in open waters over sand or mud substrates. Larvae and small juveniles require seagrass beds and macroalgal habitats in shallow estuarine waters. Larvae remain in the water column for approximately one month before settling into shallow macrophyte beds at between 10 to 15 mm in length (Ramm 1986). Eggs require at least 50% oxygen to grow and hatch successfully (Hassell et al. 2008; Woodland et al 2019).
Estuary Perch	*Macquaria colorum*	>20 years	July to August	2-3 days	Estuary perch have particular home ranges and made occasional, upstream or downstream movements. Influenced by freshwater flows, estuary perch moved to the upper estuary during winter and spring and the lower estuary during summer and autumn. The adults move downstream prior to spawning. The species breeds in July to August in the estuary with fish recruiting in the estuary and then moving upstream to feed and exploit freshwater resources.	A large-bodied fish, usually less than 1.5 kg and relatively long-lived (over 20 years). They predominantly live in estuarine waters but make regularly and sustained forays into freshwater reaches of rivers provided access. (Koehn and O'Connor 1990; McDowall 1996; Merrick and Schmida 1984; Lintermans 2007).

8.3 Implications for the Aire River estuary floodplain

A summary of the estuary requirements for native fish species found in the Aire estuary are summarised in Table 13.

Risks of artificial estuary openings

There are several risks to native fish species from artificial estuary openings that have been identified:

- Increased incidences of poor water quality resulting from more frequent mouth openings. Low dissolved oxygen and shallower surface waters after openings present a general risk to the estuarine community. This can potentially lead to mass fish mortality (see Section 6).
- Low DO conditions after openings can also impact on fish egg development. For instance, Black Bream eggs won't develop with oxygen levels below 50% oxygen nor hatch successfully (Hassell et al. 2008; Nicholson et al 2008; Woodland et al 2019). (refer to Table 12). This is particularly relevant in Spring for Black Bream.
- Estuary openings can reduce spawning success by floating eggs being swept out to sea (e.g. Black Bream, during spring and early summer months)
- Reducing floodplain inundation from late Autumn to early winter can reduce the floodplain connectivity that is important for life history stages of many fish species, especially the critically endangered Australian Mudfish.
- Sudden water level drops could strand fish eggs, their larvae and adults on floodplains and in vegetation.

Open estuary periods

Periods of open estuary mouths are an important part of dynamic IOCE environments. Several fish species require the river mouth to be open at particular times to complete their life cycles. In the Aire estuary, a number of fish species rely upon mouth openings to enable them to either leave the estuary or re-enter after some time at sea for a critical ecological function (breeding, recruitment, and growth).

Eel are one such species. The adults need to leave the estuary in autumn to travel to the Coral Sea where they breed and die and then fingerlings return back to estuaries in winter/spring. Further, eels are flexible in terms of timing or indeed delaying their movement until the right conditions. There is not a need for precise periods for natural openings, as long as, over time some openings coincide with desired periods for the fish. Saline intrusion up the estuary is also important as a trigger for breeding in crustaceans such as copepods and fish species such as Black Bream.

Species which live in estuaries have to be highly adaptable because of the dynamic nature of estuaries. They have evolved so that their requirements for open estuary periods will be suitably met naturally. Species are flexible and long-lived species (e.g. eels) do not require even annual openings. Natural openings of the Aire have occurred at least 19 times over the period from 2008 – 2019 (Figure 16), or on average 1-2 times per year, with openings occurring in all seasons. Most of the recorded natural openings occurred in June to December, with one natural opening in April. It is also possible there would have been more openings which were not recorded or others which were replaced by artificial openings. Figure 21 (p22) shows that there are natural opening at least every couple of years (annual to every 3 years) at suitable times to meet the requirements of eels and other fish species present in the Aire system. Therefore, under the current hydrodynamic conditions, there is no environmental need to artificially open the Aire estuary for fish requirements.

Impacts of climate change

While the impacts of climate change on the Aire estuary are difficult to predict (refer Section 5), some of the possible impacts on fish species include:

- If there is salinisation, this may threaten the Aire's mudfish population if present freshwater strongholds cannot be replaced higher in the floodplain. This is a major issue given the species EPBC conservation status (a Matter of National Environmental Significance) and the Aire's importance to it in a regional and state-wide context.
- If there is salinisation and ongoing connectivity with the marine environment (i.e. through open estuary periods), this will likely result in increasing dominance of marine opportunists fish within the estuary

The following knowledge gap has been identified by the Technical panel to improve the ongoing management of the Aire estuary and provide the conditions to support the environmental values.

> *Knowledge gap: fish recruitment*
> Annual assessment of recruitment of fish – focusing on black bream, Australian Grayling and Australian Mudfish would allow a broader understanding of these species and the trajectory of their populations within the Aire estuary.
> This data, along with the other fish data (such as the species present) will allow the responses by fish to the antecedent water regime to be assessed and allow a more sympathetic estuary entrance management to be undertaken.
> This monitoring could be done by the researchers or a specialist fish survey crew.

Table 13. Summary of fish requirements, by time of year

Month	Key requirements (general)	Key requirements (species)			
January	Migration Breeding and more importantly growth of juvenile fish bred in previous spring	Rapid dropping water level can impact Blue Spot Goby eggs [important for whole food chain]. Links to recreational fishing.	Eels, Galaxiids, Tupong upstream migration		Estuary Perch move into lower estuary during summer and autumn influenced by flow events to exploit food resources.
February					
March					
April			Galaxiids breeding (April-June)		Estuary Perch move into freshwaters in Winter
May	Connectivity from higher flows and floodplain inundation – important for life history				
June				Freshwater inputs for Mudfish into Winter period Mudfish breed late winter in freshwater, larvae move into estuary Estuary perch breeding in estuary influenced by freshwater flows	
July			Galaxiids recruit and grow in estuary (or sea)		
August					
September	Migration back into the estuary for lots of species	Black Bream breeding (Oct to Jan). Threat if open too often. Loss of year classes impact on rec fishing.		Mudfish juveniles return from sea/estuary into freshwater in spring	
October			Tupong return Oct – Feb. Galaxiids Upstream migration into estuary and Sept – Jan		Juvenile Eels move up to freshwater
November					
December					

9 Bird species condition and requirements

This section describes the bird species present in the Aire estuary, and their requirements, in terms of habitat, nesting and (for some species) migration. This section also summarises the different requirements throughout the year and what this means for the role of artificial estuary openings and the current management regime.

9.1 Description and condition

Table 14 lists the bird species which depend on water for feeding by swimming, diving or wading, or for the provision of nesting sites. These species are a significant component of the Aire River estuary and floodplain ecosystem.

The avian diversity associated with the waterways of the Aire River estuary and floodplain is relatively high with 56 species recorded (Table 14; VBA 2020; Hansen 2010) with 17 of these species being listed as being of conservation significance (and the majority of these either vulnerable or endangered). Work by Hansen (2010), reported 61 species, but this included some species that are not considered water dependent (i.e. they do not rely on river, estuaries or wetlands for habitat). There were also differences in areas the Hansen (2010) survey covered (and the fact it was a single survey) and the VBA search (which covers multiple surveys), which explains that some species in Hansen were not in the VBA list and some birds present in the VBA search were not recorded by the Hansen (2010) survey.

The Aire River estuary held the second greatest number of waterbirds and the second highest species diversity (species number) during a survey of 11 estuaries in south west Victoria by Hansen (2010). The Aire was notable in the suite of estuaries in that it had a high number of waterbirds using open water due to the presence of three large water bodies (Lakes Craven, Costin and Hordern) and the estuary itself. It is also significant that it held high numbers and high species diversities of vegetation margin dwellers and large numbers of dabbling functional birds (but made up of only three species) compared to other regional estuaries. The Aire estuary would provide a valuable drought refuge to many species, given the relatively permanent and extent of open waterbodies present in the Aire estuary.

Notable listed species include the resident and nationally listed White-bellied Sea Eagle, Blue Billed Duck, terns, Australian Bittern, Lewin's Rail, Royal Spoonbill and Plumed Egret. The Ruddy Turnstone and Latham's Snipe are migratory and also depend upon habitats along the East Asian–Australasian Flyway.

The species present, and their abundance, respond to the variety of wetland types present, their condition and their watering regimes. In the long-term, abundant and diverse native bird populations are indicative of wetland health (Reid and Brooks 2000). Each species requires suitable foraging, refuge and breeding habitat to be maintained within the wetland complex. To understand the requirements of the bird species, it is necessary to understand when they use the wetlands, and how the birds access the required resources.

In these systems waterbirds can be split into four general groups (Lloyd et al. 2012) which are based on four key foraging microhabitats. Understanding which birds feed where helps understand how the water regime and vegetation responses will benefit species in the habitats that are created or supported. These foraging groups are:

- deep/open water (>300 mm)
- reed beds
- shallow water (<300 mm)
- shorelines/mudflats.

The open water species include the fish eaters, Darter, Cormorants, pelicans and gulls as well as the birds of prey. The latter include the White-Bellied Sea-eagle and the Black Falcon (listed as Vulnerable) while the former include the Pied Cormorant and Caspian Tern which are listed as Near Threatened (and under the EPBC Act as a Migratory Species).

The other significant bird group utilising open water habitats are ducks and teal such as the Grey Teal, Chestnut Teal, Pink-eared Duck, and Pacific Black Duck. This group also includes the listed species of Australasian Shoveler and Hardhead (listed as Vulnerable) and the Blue-billed Duck (listed as Endangered).

Reedbed species are those shy species which feed and nest amongst dense reedbeds of Typha, Lignum and Sedges. They are often cryptic and rarely seen by visitors to these habitats as they are generally very well camouflaged. The Australian Bittern is considered endangered and the Lewin's Rail is Vulnerable, but all the species are considered of high significance as this habitat is often disturbed or cleared for agriculture or access to rivers. Latham's Snipe is Near Threatened and is classified as Migratory meaning they leave to fly to the Northern Hemisphere in our winters along the East Asian–Australasian Flyway.

Shallow water feeding species need access to submerged vegetation in the shallows to forage for fish and invertebrates which are often prolific there. These habitats need inundation for much of the year, although occasional periods of drying are tolerable. This group of birds include the listed Plumed and Little Egrets (Endangered) and the Royal Spoonbill (Near Threatened).

The shoreline or mudflat species often do well in estuarine habitats where there is a strong tidal signal resulting in a regular drying and inundation of the mudflats and shoreline twice a day. They also prefer wetlands which slowly dry out allowing birds to access the invertebrates or plants on the mudflats. This group includes some of the most common birds such as Wood Duck, Eurasian Coot, Dusky Moorhen, Swamphens and Ibis which are generally resident. The less often sighted and listed species Ruddy Turnstone (Vulnerable) is also migratory - heading north in our winters along the East Asian–Australasian Flyway.

The Hooded Plover inhabits sandy ocean beaches along southern Australia (Birds Australia). They feed upon small invertebrates from the sand near the water's edge. They lay their eggs in shallow scrapes in the sand, usually on the upper beach above high tide mark (or in adjacent backing sand dunes) from August to March (sometimes April). Eggs take about a month to hatch and chicks just over a month to fledge. Artificial mouth openings may affect both feeding and breeding habitat from excavator use and human presence on the beach and beach collapse as the mouth opens.

Table 14. Birds of the Aire River estuary (VBA 2020 and Hansen 2010)

Feeding Guild	Scientific Name	Common Name	Conservation Status	
			FFG / Victoria	EPBC /Commonwealth
Open Water	*Anas castanea*	Chestnut Teal		
	Anas gracilis	Grey Teal		
	Anas superciliosa	Pacific Black Duck		
	Aythya australis	Hardhead	Vulnerable	
	Chroicocephalus novaehollandiae	Silver Gull		
	Circus approximans	Swamp Harrier		
	Cygnus atratus	Black Swan		
	Falco subniger	Black Falcon	Vulnerable	
	Haliaeetus leucogaster	White-bellied Sea-Eagle	Vulnerable	Migratory
	Haliastur sphenurus	Whistling Kite		
	Hydroprogne caspia	Caspian Tern	Near threatened	
	Malacorhynchus membranaceus	Pink-eared Duck		
	Microcarbo melanoleucos	Little Pied Cormorant		
	Morus serrator	Australasian Gannet		
	Ninox strenua	Powerful Owl	Vulnerable	
	Oxyura australis	Blue-billed Duck	Endangered	
	Pachyptila turtur	Fairy Prion	Vulnerable	Vulnerable
	Pelecanus conspicillatus	Australian Pelican		

Feeding Guild	Scientific Name	Common Name	Conservation Status	
			FFG / Victoria	EPBC /Commonwealth
	Phalacrocorax carbo	Great Cormorant		
	Phalacrocorax sulcirostris	Little Black Cormorant		
	Phalacrocorax varius	Pied Cormorant	Near threatened	
	Podiceps cristatus	Great Crested Grebe		
	Poliocephalus	Hoary-headed Grebe		
	Spatula rhynchotis	Australasian Shoveler	Vulnerable	
	Tachybaptus novaehollandiae	Australasian Grebe		
	Thalasseus bergii	Crested Tern		
Reed bed	*Acrocephalus australis*	Reed-Warbler		
	Botaurus poiciloptilus	Australasian Bittern	Endangered	Endangered
	Cisticola exilis	Golden-headed Cisticola		
	Hypotaenidia philippensis	Buff-banded Rail		
	Lewinia pectoralis	Lewin's Rail	Vulnerable	
	Poodytes gramineus	Little Grassbird		
	Gallinago hardwickii	Latham's Snipe	Near threatened	
	Zapornia tabuensis	Spotless Crake		
Shallow water	*Ardea intermedia plumifera*	Plumed Egret	Endangered	
	Ardea modesta	Eastern Great Egret	Vulnerable	
	Ardea pacifica	White-necked Heron		
	Dacelo novaeguineae	Laughing Kookaburra		
	Egretta garzetta	Little Egret	Endangered	
	Egretta novaehollandiae	White-faced Heron		
	Hirundo neoxena	Welcome Swallow		
	Petrochelidon nigricans	Tree Martin		
	Platalea flavipes	Yellow-billed Spoonbill		
	Platalea regia	Royal Spoonbill	Near threatened	
	Tadorna tadornoides	Australian Shelduck		
Shoreline/mud flat	*Arenaria interpres*	Ruddy Turnstone	Vulnerable	
	Cereopsis novaehollandiae	Cape Barren Goose		
	Chenonetta jubata	Australian Wood Duck		
	Erythrogonys cinctus	Red-kneed Dotterel		
	Fulica atra	Eurasian Coot		
	Gallinula tenebrosa	Dusky Moorhen		
	Porphyrio melanotus	Australasian Swamphen		
	Thinornis rubricollis	Hooded Plover	Vulnerable	Vulnerable
	Threskiornis molucca	Australian White Ibis		
	Threskiornis spinicollis	Straw-necked Ibis		
	Vanellus miles	Masked Lapwing		

9.2 Estuary requirements

The estuary requirements of the waterbirds in the Aire estuary are largely determined by the availability and complexity of habitat. Most Australian waterbirds are opportunistic in their patterns of movement, feeding ecology, habitat use, and patterns of reproduction and moulting (Kingsford and Norman 2002). They respond to water regime changes by migrating locally or regionally. The suitability of the habitat depends upon the vegetation present, the characteristics of the wetland (as determined by inflows creating cycles of inundation and drying), and the productivity of the wetlands. The permanent aspects of the fringing wetlands and estuary provide important summer and drought refuge for waterbird species either locally, regionally or from elsewhere in Australia and abroad (Lloyd et al 2012).

Foraging habitat is determined by water depth, vegetation communities and water properties. These requirements will also be influenced by the responses to water regime and habitat management of fish, macroinvertebrates, vegetation and water quality (outlined elsewhere in this report).

Breeding requirements are also complex and require a diversity of conditions for successful breeding in waterbirds. These include:

a. Inundation of the wetland needs to occur from late winter / early spring.
b. Inundation in late winter / early spring must persist for long periods, for example a minimum of four months (for rapid breeders e.g. ducks) to seven months for the successful breeding of most other waterbird species.
c. Many waterbird species will not breed in wetlands with highly regulated water regimes which don't mimic natural systems (Briggs et al. 1997).
d. The water regime needs to be predictable with wetting and drying occurring within seasonal context (within and between years). Rapid and/or erratic changes in water levels within a wetland can result in low numbers of aquatic invertebrates, the food of many waterbirds (Briggs et al. 1997).
e. Sudden drops in water level will also result in colonial nesting waterbirds abandoning their nests and young before they fledge (Kingsford 1998, Kingsford and Norman 2002).

Manipulation of, water regimes is not generally possible in the Aire system as its catchment is unregulated. An important exception is artificial mouth openings which can result in unpredictable water regimes (see d above) and sudden water level drops (e above) both of which can impact upon water birds.

Waters which become enriched in nutrients or are very saline or remain high for long periods (even with good water quality), can also have impacts on aquatic and emergent macrophytes. If water quality declines, then waterbird habitat (especially for shallow water and shoreline species) can be impacted leading to declines in these species. It has been noted that even in non-breeding seasons, if sudden drops occur or the water levels stay high for too long then water birds leave the estuary and utilise nearby wetlands and farm dams.

9.3 Implications for the Aire River estuary floodplain

The current management of the estuary may be restricting the ecological potential of the estuary for resident birds as well as for migratory birds in particular, as these have not been observed at the Aire estuary, but the habitat exists for these species. This may be due to the direct impacts of artificial openings and also the reduced inundation extent and duration at key periods.

Risks of artificial estuary openings

There are many specific risks associated with artificial estuary openings that are limiting the potential of bird species in the Aire estuary:

- Without a regularly inundated floodplain birds such as black swans are discouraged from nesting or risk having nests stranded after an opening mid breeding.
- Local residents report ducks and other waterbirds frequently have their breeding season interrupted or fail due to impacts from artificial mouth openings.
- Migratory birds require suitable shallow flooded areas to supply food on their arrival in spring and prior to their departure in autumn. Water levels which are gradually changing provide continual access to

new resources for waders and dabbler species. The Aire floodplain does not provide such conditions at present and migratory birds will seek other regional wetlands as a result.

- At times of drought in SE Australia estuarine wetlands can provide an important drought refuge for water birds. The Aire estuary offers reduced potential to provide such a resource under existing management.
- The Hooded Plover is a listed beach nesting bird (Vulnerable at State Level and under the EPBC Act). Its breeding success is negatively impacted by human activities on southwest Victorian beaches (and elsewhere). Trenching to open the entrance, with its associated human activity, will reduce the viability of the beach for this and other beach nesting species.

Insufficient inundation extent and duration during key periods

The overall estuary requirements for bird by time of year are provided in Table 15. Floodplain inundation provides habitat for birds in the following key periods:

- Summer – early Autumn (January – March).
  Facilitate waterbird foraging for many waterbird species from all guilds. This is particularly important when other areas in south-east Australia are in drought, and the Aire estuary can play an important role as a drought refuge for these species.
- Late Autumn – Early Winter (April – June).
  This is an important time for migratory birds to be fuelling up prior to migration north – this requires large shallow areas of water.
  Spring (September to November).
  This is an important period for all aquatic life as the high productivity resulting from floodplain inundation is very important for all aspects of the ecosystem such as fish, water birds and aquatic plants all of which support the waterbird community. In addition, these water rises contribute directly to the health of waterbirds requiring freshwater inputs for drinking water and to breeding success. This is also a period of waterbird nesting when water levels should not be rapidly altered. It would also support migratory birds returning to the estuary after their migrations from the northern hemisphere.

The following knowledge gap has been identified by the Technical panel to improve the ongoing management of the Aire estuary and provide the conditions to support the environmental values.

Knowledge gap: waterbirds

There is currently limited understanding of the seasonal use of the Aire floodplain by birds and their breeding success. In order to further understand the potential for the Aire estuary in a regional context and to inform management of the estuary to support environmental values, further surveys and information on birds is important.

This could be addressed through quarterly waterbird surveys to understand the Aire's seasonal use by birds, and their breeding success or otherwise which can be tied back to the antecedent period of water regimes, providing valuable information on management requirements as well as the trajectory of populations.

This monitoring could be done by the BirdLife Australia, Field Nats, Field and Game, Eco lodge, or Corangamite CMA

Table 15. Summary of bird requirements, by time of year

<table>
<tr><th>Month</th><th colspan="4">Key requirements</th></tr>
<tr><td>January</td><td colspan="3" rowspan="3">Drying out supports birds. Exploit mud areas, drawdown
Gradual water level changes expose different habitat / feeding areas - supports birds.
Facilitate waterbird foraging for a many shorebird species and other waterbird species from all guilds. Drying stimulate nutrient cycling
Expose wetland fringe and create shallows
(Invertebrates hatching if inundates- and this can be used by waterbirds)</td><td rowspan="3">Aire estuary can play an important role as a drought refuge when other areas on south-east Australia are in drought</td></tr>
<tr><td>February</td></tr>
<tr><td>March</td></tr>
<tr><td>April</td><td rowspan="5"></td><td rowspan="3"></td><td rowspan="4"></td><td rowspan="4">Migratory birds feeding and putting on weight to allow migration to northern hemisphere. Big shallow water areas important here. Gradual filling up of water levels. Role of Aire to provide water when other areas (in SE Aust) in drought</td></tr>
<tr><td>May</td></tr>
<tr><td>June</td></tr>
<tr><td>July</td><td rowspan="5">Gradually increasing water level / inundation over this period very important for waterbirds
Freshwater inflows allows drinking water available for waterbirds</td></tr>
<tr><td>August</td><td rowspan="5">Hooded plovers breeding on beach – risk of estuary openings directly impacting</td><td></td></tr>
<tr><td>September</td><td rowspan="4">Waterbird nesting. Risk of nest abandonment if open estuary during this period and water levels drop suddenly. Any rapid changes in water level can disrupt waterbird breeding.</td><td rowspan="3">Migrating birds returning
Productive conditions.
Invertebrates hatching with inundation</td></tr>
<tr><td>October</td></tr>
<tr><td>November</td></tr>
<tr><td>December</td><td></td><td></td></tr>
</table>

10 Findings and advice

The Aire River estuary is a naturally intermittently open/ closed estuary (IOCE) and supports the EPBC listed *Assemblages of species associated with open-coast salt-wedge estuaries of western and central Victoria ecological community*. Prior to development of the Aire River estuary, sand would be deposited and build up at the estuary mouth. There would have been long periods of estuary mouth closure where the water level would gradually build up over months, inundating the floodplain and providing conditions for the specialised vegetation communities, estuarine dependent fish, and birds requiring open waters and shoreline habitats. Conversely there would also be periods where the estuary would open naturally, allowing for saline intrusion into the estuary, and movement of fish both into the ocean and back into the estuary.

There is a long history of management intervention in the Aire Valley. This has included agricultural development of floodplains, networks of drainage channels across the floodplain and artificial estuary openings.

The advice provided below has been developed by the Technical Panel and builds on that provided through EEMSS. The advice relates only to the **environmental values** of the Aire River estuary, mouth entrance area, and floodplain, the requirements of these values and the current management context of the estuary. This advice is provided to inform short- and longer-term management decisions related to the Aire River that may be explored in future stages (beyond this project). No direct management changes will result *solely* from this advice; that is, other (non-environmental) values should also be considered if changing any management arrangements.

1. Resilience of the system under climate change will be very important

There will be a range of changes under climate change that will affect the Aire estuary, including sea level rise, decreasing river flows, increases in wave height and period (and thus wave power), and increases in temperature. These will have a range of impacts on the hydrodynamics and water quality of the Aire estuary, and the exact conditions will depend on a range of factors, including management arrangements. While there is uncertainty surrounding how these conditions may change over time, any changes will have an impact on the environmental values and other values of the Aire estuary.

Whatever the future holds for the Aire, its truly estuarine community will adapt and survive. Some species will increase in abundance while others may decline. Overall, it will be important to enhance the robustness of the ecological community to the impacts of climate change by reducing other pressures.

Management of environmental values in the estuary needs to consider adaptation to climate change. Similarly, other values and uses of the estuary should consider the impacts of climate change and adaptation strategies. Stakeholders should work together to develop an Aire Estuary Adaptation Plan to prepare for local climate change; this is a key focus of Victoria's new Marine and Coastal Policy (see Recommendation 6.8, page 38; 2020).

2. Artificial estuary mouth openings are restricting the potential of the estuary environmental values and putting environmental values at risk.

The presence of diverse assemblages of vegetation, fish and bird species show the current management arrangements and climatic conditions of the Aire River estuary are somewhat able to support the environmental values and objectives as described in the Estuary Management Plan. However, the absence of some species (such as migratory birds) and the manipulated inundation regime which may be restricting some plant species (e.g. terrestrialisation of some EVCs such as Swamp Scrub which is not being sufficiently flooded) suggests that the current management regime is restricting the ecological potential of the estuary.

Artificial estuary openings **increase the frequency** of openings compared to what would have occurred without intervention (i.e. naturally). This increase cannot be quantified with certainty based on the available information, but based on the analysis outlined in this report, the Technical Panel are confident that there has been an increase above the natural frequency. Each additional estuary opening leads to greater disturbance of the ecosystem and increases the risk of adverse **ecological** effects.

The impacts of the current estuary entrance management regime on the environmental values are:

- Increased incidences of poor water quality resulting from *more frequent* mouth openings. Low dissolved oxygen and shallower surface waters after openings (artificial or natural) present a general risk to the estuarine community. Surface water quality prior to an opening is almost always better than after.
- Increased sand shoaling at the entrance and reduced opening duration due to inefficient scour of entrances at low opening levels. This then can be a driver of reimplementation of the berm (i.e. estuary closure).
- Openings at lower water levels can result in openings that do not fully drain the estuary as hydraulic head is lower (but also depends on berm height and length).
- Poorly timed openings may result in floating fish eggs being swept out to sea (e.g. Black Bream, during spring and early summer months)
- Without a regularly inundated floodplain birds such as Black Swans are discouraged from nesting or risk having nests stranded after an opening mid breeding.
- Migratory birds require suitable shallow flooded areas to supply food on their arrival in spring and prior to their departure in autumn. Water levels which are gradually changing provide continual access to new resources for waders and dabbler species. The Aire floodplain does not provide such conditions at present and migratory birds will seek other regional wetlands as a result.
- Vegetation communities at higher elevations on the floodplain may shift toward a less water tolerant community without adequate inundation.
- Reduced inundation provides conditions for exotic grasses which compete with the native herbs and sedges reducing the native biodiversity especially in the Brackish Aquatic Herbland and Estuarine Wetland.
- Rapid drawdown in summer following an opening can expose the aquatic herbs and sedges to desiccation and heat reducing their health and viability.
- At times of drought in south-eastern Australia estuarine wetlands can provide an important drought refuge for water birds. The Aire estuary offers reduced potential to provide such a resource under current management.
- The Hooded Plover is a listed beach nesting bird (vulnerable at State Level and under the EPBC Act). Its breeding success is negatively impacted by human activities on Southwest Victorian beaches (and elsewhere). Trenching to open the entrance, with its associated human activity, will reduce the viability of the beach for this and other beach nesting species.

3. There is no environmental requirement to artificially open the estuary

Periods of open mouths are an important part of dynamic IOCE environments. Several fish species require the river mouth to be open at particular times to complete their life cycles (including breeding, recruitment, and growth). Species which live in estuaries have to be highly adaptable because of the dynamic nature of estuaries. They have evolved so that their requirements for open estuary periods will be suitably met naturally. Based on analysis , natural openings of the Aire estuary will be of suitable frequency and timing to meet the requirements of fish species present. Therefore, based on fish requirements there is no environmental need to artificially open the Aire estuary.

As part of an IOCE system, the native vegetation in the Aire estuary vegetation is resilient to inundation for significant depths and long periods and some EVCs require these inundation periods for their survival. Based on these vegetation characteristics, there is no environmental need to artificially open the Aire estuary.

4. If artificial estuary entrance openings are required to protect other values (non-environmental), there are ways to minimise the environmental risks

If the estuary were managed solely to protect its environmental values, there would be no artificial openings. Development of the estuary, however, has meant that human assets such as farmland, campgrounds and roads are flooded during estuary entrance closure. Opening the entrance to protect these values has historically taken precedence over the environment. The Technical Panel advise a more patient approach: reducing the frequency of artificial estuary openings.

Current management could be modified to support environmental values by **reducing the frequency of artificial estuary openings during the following periods.** Artificial openings during these periods have the greatest likelihood of reducing the potential of environmental values in the Aire estuary.

- **Late Autumn – Early Winter (April – June).** The connectivity resulting from higher flows and floodplain inundation is important for life history stages of many fish species. Inundation of Swamp Scrub and higher levels of the floodplain is important to avoid changes to some EVCs. This is an important time for migratory and other shore birds to be fuelling up prior to migration north – this requires large shallow areas of water.
- **Spring (September to November).** This is an important period for all aquatic life as the high productivity resulting from floodplain inundation is very important for all aspects of the ecosystem such as fish, water birds and aquatic plants. In addition, these water rises contribute to the health of migratory birds returning to the estuary, and waterbirds requiring freshwater inputs for drinking water. This is also a period of waterbird nesting when water levels should not be rapidly altered. Spring is also a period for Black Bream breeding, and estuary openings can reduce spawning success if eggs are washed from the estuary or impacted by low DO conditions. It is also an important period for recruitment of Swamp Scrub and aquatic herbs. This period is also part of the Hooded Plover breeding season, where mechanical and human activity on the beach could impact breeding success.

To minimise the environmental risks, the Technical Panel advise avoiding artificially opening the estuary when it is possible the estuary will open naturally within an acceptable timeframe before assets are compromised. By waiting for natural openings, this will reduce the frequency of artificial openings and the environmental and other risks associated with this management activity.

In making an assessment about opening managers should continue to consider factors such as current river flow, berm height and width, forecast rainfall and sea state and estuary water level. The water balance model developed for this project could be used to help inform how quickly water levels may rise at different times of the year. Monitoring of these parameters will continuously improve understanding of the likelihood that the estuary will open naturally.

There are water quality risks associated with both natural and artificial estuary openings and from a water quality perspective; one type is not superior to the other. The Technical Panel advise that management should aim to reduce the number and frequency of openings to reduce water quality risks, and avoid artificial estuary openings when there are increased water quality risks, including:

- Avoid openings when pre-opening surveys show lower DO (<5mg/L) in the surface waters (top 1.5m) of the main channel of the estuary or in waters covering the surrounding floodplain to reduce the likelihood of fish kills and impacts on egg development.
- Where feasible avoid openings during the earlier parts of the day (when DO is lower after respiration activity overnight). Openings later in the day allow time for DO to be increased by photosynthesis. It is recognised that other factors (e.g. tide times) must also be taken into account when planning openings.

In addition to estuary entrance management, complementary management activities to improve the overall condition and ecological trajectory of the estuary could include:

- Reducing pasture grass on the estuary floodplain. One of the dilemmas for management of the estuary is balancing the need for high water levels by the native plant community against the deleterious effects of flooding on pasture grass. Poor water quality from the decay of drowned pasture grass poses a risk to the estuary on opening as the floodplain drains. This factor places constraints on the extent and duration of flooding under present land use. The risk of DO reduction caused by death of pasture grasses will diminish over time as the more tolerant native plant species colonise the pasture areas.
- Decommissioning (blocking/infilling) of the drainage channels on the estuary floodplain and restoration of the natural hydrology. Landscape restoration opportunities are present on the floodplain. Engagement with landholders to amend the hydrological changes brought about by the installation of drains could result in restoration of some EVCs across the floodplain. Active intervention such as blocking/sand bagging channels to retain water on the floodplain and actively removing levee banks to

increase flooding when water levels rise could accelerate restoration outcomes. If such actions have not already been undertaken, they are examples of works that could be considered and small projects such as this could further reduce the pressure to actively manage the estuary mouth if a shift in land use could be achieved. Reinstating the hydrology to the lower elevation areas of the floodplain (more frequently flooded) should be targeted first. This should be done in line with the Victorian Rural Drainage Strategy.

- Raising the level of roads and bridges presently inundated at low levels

5. A further study is required to assess management options in the context of economic, social, cultural, and environmental values of the Aire Valley.

The advice in this report relates only to the environmental values of the Aire River estuary and floodplain, their requirements and the current management context of the estuary. Future management activities will need to consider the economic, social and cultural values of the Aire Valley, in conjunction with the environmental values described in this study. Therefore, the Technical Panel advise undertaking a further study that assesses management options and balances the needs of different values of the Aire Valley.

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List of project contributors: Aire Valley Stakeholder Advisory Committee

The following representative participated in the AVSAC meetings and or provided comments on the draft report. We thank everyone for their input and insights on this project.

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Robert Costin	Local land holder
Ros Denney	Local land holder
Brian Denney	Local land holder
Ian Marriner	Local land holder
Andrew & Hannah Marriner	Local land holder
Rich Blood	Local land holder
Lisa Deppeler	Local land holder
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Scott Hanger	VFA
Rod Amos	Fish and Game
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Jessica Reid	Parks Victoria , Steering Committee representative
Hayley Vinden	Corangamite Catchment Management Authority, project manager and Steering Committee representative

Appendix A: Legislation, policy and management responsibilities relevant to the Aire River valley

There is a complex array of legislation, policy, plans, and strategies relating to management of the Aire River estuary. Relevant legislation, policies and strategies are outlined in Figure 39 and further detail about each provided below.

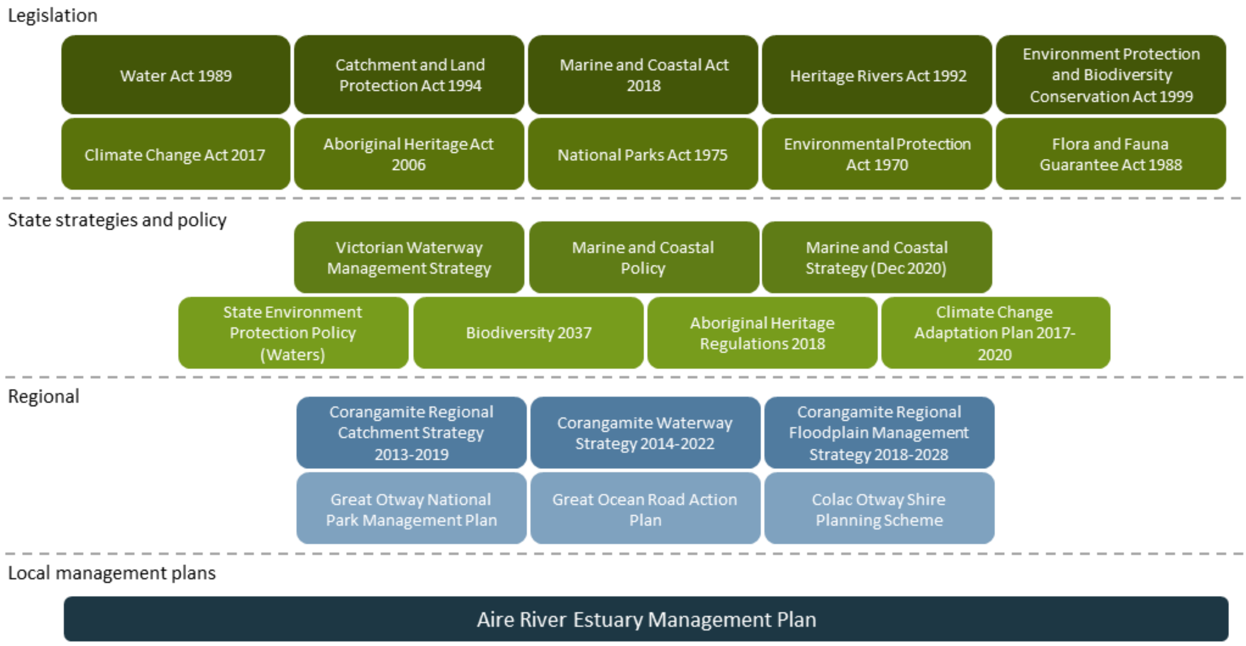


Figure 39. *Estuary management strategy and planning arrangements for the Aire River estuary.*

A1. Legislation

A number of key pieces of legislation govern land, river, coastal and estuary management in Victoria. The legislation relevant to management of the Aire River estuary is summarised below.

Water Act 1989

The *Water Act 1989* provides the framework for managing Victoria's water resources. The Act designates Catchment Management Authorities as having a lead role in developing and delivering regional programs for waterway management. The Act outlines their functions and powers in relation to waterway management, floodplain management and regional drainage. Under the Act, CMAs must prepare regional waterway strategies for the Minister and seasonal watering proposals for the Victorian Environmental Water Holder.

Catchment and Land Protection Act 1994

The *Catchment and Land Protection Act 1994* establishes a system of integrated management and protection for catchments. The Act also aims to encourage community participation in the management of land and water resources and sets out a system of controls on noxious weeds and pest animals. Catchment Management Authorities were established under the Act and it sets out their functions, powers, and duties.

Marine and Coastal Act 2018

The recently introduced *Marine and Coastal Act 2018* provides an integrated and coordinated approach to planning and managing the marine and coastal environment. This includes enabling protection of the coastline and the ability to address the long-term challenges of climate change, population growth and ageing coastal structures. The Act also aims to ensure all partners work together to achieve the best outcomes for Victoria's marine and coastal environment. Under the Marine and Coastal Act DELWP have prepared the Marine and Coastal Policy (March 2020) and are in the process of developing the Marine and Coastal Strategy (due for release in March 2021). At the local level, Coastal and Marine Management Plans will translate marine and coastal policy and strategy to on-ground action and will be prepared by Crown Land managers.

Heritage Rivers Act 1992

The *Heritage Rivers Act 1992* identifies 18 Heritage River Areas in Victoria. The Aire River is one of these rivers and the only Heritage-listed River in the Corangamite region. The Act protects public lands in heritage river or catchment areas which have significant recreation, nature conservation, scenic or cultural heritage attributes. The Act prohibits some land and water-related activities in these areas, including constructing artificial barriers and structures which may impact on water fauna or significantly impair the area’s recreation, nature conservation, scenic or cultural heritage attributes. The Act also restricts diversion of water, some clearing practices, plantation establishment and grazing in some areas.

Climate Change Act 2017

The *Climate Change Act 2017* provides a legislative foundation to manage climate change risks, maximise the opportunities that arise from decisive action, and drive transition to a climate resilient community and economy. The Act supports the development of system-based adaptation action plans for key systems that are either vulnerable to the inevitable impacts of climate change, or essential to ensure Victoria is better prepared. The Marine and Coastal Strategy (due for release in 2021) will be an adaptation action plan of the coastal and marine sectors under the Climate Change Act.

Aboriginal Heritage Act 2006

The *Aboriginal Heritage Act 2006* provides protection and management for Victoria's Aboriginal heritage and is linked to the Victorian planning system. The legislation provides protection for all Aboriginal places, objects and ancestral remains regardless of their inclusion on the Victorian Aboriginal Heritage Register or if they are located on public or private land. The Aboriginal Heritage Regulations 2018 give effect to the Aboriginal Heritage Act and specify requirements for cultural heritage management plans and activities in areas of cultural heritage sensitivity. The Aire River and Estuary are designated Areas of Cultural Heritage Sensitivity.

National Parks Act 1975

The Aire River Valley is included in the Great Otway National Park as designated in the *National Parks Act 1975*. The Great Otway National Park was created in December 2005 through the amalgamation of a number of National and State Parks, reserves, and other areas of public land. The Great Otway National Park and Otway Forest Park Management Plan (Parks Victoria and DSE 2009) identifies values, threats, and strategic direction for managing and enhancing the sustainable use of the park. For the Aire Heritage River, significant values provided for under the Act include natural values (including large stands of cool temperate rainforest), many significant flora and fauna species, geomorphological sites of significance, high diversity native fish species (including six threatened species) and scenic values between Hopetoun Falls and the Great Ocean Road and at the estuary.

Environment Protection and Biodiversity Conservation (EPBC) Act 1999

The EPBC Act focuses on the protection of matters of national environmental significance. In 2018, the Australian Department of the Environment and Energy listed the “Assemblages of species associated with open-coast salt-wedge estuaries of western and central Victoria ecological community” as Endangered. The Aire River is one of 25 river systems identified as having salt-wedge estuaries that are part of the ecological community. Salt-wedge estuaries are typically ecosystems of high ecological value which are increasingly under threat. They contribute high levels of productivity to coastal and nearshore marine environments, and provide important refuge, nursery or breeding habitat for a wide range of invertebrates, fish and birds. Many estuaries also support rare and threatened flora and fauna, in addition to internationally significant bird species.

A2. Regional plans and strategies

Victorian Waterway Management Strategy 2013-2021

The Victorian Waterway Management Strategy aims to maintain or improve the condition of waterways, including estuaries, across Victoria to support environmental, social, cultural and economic values that are important to communities. The Victorian Waterway Management Strategy provides direction for regional decision-making, investment and management issues for waterways, as well as the roles and responsibilities of management agencies.

Corangamite Regional Catchment Strategy (RCS) 2013–2019

The Corangamite RCS 2013–2019 provides a strategic, integrated framework for natural resource management in the Corangamite Catchment Management region. The RCS recognises the strong connection between the health of the catchment and the wellbeing of the community. It encourages greater participation and investment in the protection, enhancement and restoration of land, water, and biodiversity resources in the Corangamite region. The RCS identifies desired regional outcomes and priorities. It is an overarching strategic framework that guides the long-term direction for managing Corangamite's land, water resources, biodiversity, and coastal assets.

Corangamite Waterway Strategy (CWS) 2014-2022

The purpose of the CWS 2014-2022 is to provide a framework and regional work program for the Corangamite CMA, in partnership with other agencies, industry and community groups, to maintain or improve the condition of rivers, estuaries and wetlands. The CWS sets priorities and outlines a work program to guide investment over the medium term (eight years) to 2022. The CWS also guides the coordination of efforts by landholders, partner organisations and the wider community. The CWS was prepared under the Victorian Waterway Management Strategy framework and guidelines and aligns with the strategic directions outlined in the Corangamite Regional Catchment Strategy. A key Management Activity for the Aire River Estuary outlined in the CWS was to develop a management plan for the Aire estuary that incorporates the Estuary Entrance Management Support System and a risk-based approach for estuary openings. This was completed in 2015 (Corangamite CMA 2015).

Corangamite Regional Floodplain Management Strategy (RFMS) 2018-2028

The Corangamite RFMS 2018-2028 provides a single regional planning document for floodplain management and a regional work program to guide future investment priorities. It focuses on flooding associated with river systems (riverine flooding) and coastal storm surge inundation, including planning for projected sea level rise. The Strategy recognises that assets such as farmland or built infrastructure can be inundated when river mouths, such as the Air River's, are closed. However, the Aire estuary and surrounding land is not identified as a priority risk area, with a focus on flooding of residential and township areas elsewhere in the region.

A3. Roles and responsibilities

The diversity of habitats, land use and land tenures surrounding estuaries typically results in a number of agencies and groups having responsibility for managing particular aspects of the system. This is the case for the Aire River. Details of roles and responsibilities in estuary management at a state and local level can be found in Table 16. Figure 40 illustrates the complex land tenure divisions surrounding the estuary.

Table 16. Roles and responsibilities of key stakeholders, adapted from Aire River Estuary Management Plan 2015-2023 (Corangamite CMA 2015)

Group or agency	Regional responsibility
Corangamite Catchment Management Authority (CCMA)	Regional caretaker of waterway health, including the development of the Corangamite Waterway Strategy and Aire Estuary Management Plan; implementation of waterway work programs; authorisations of works on waterways, including estuary mouth openings, responding to natural disasters and incidents affecting waterways. CMA activities are governed by the *Catchment and Land Protection Act 1994* and part 10 of the *Water Act 1989*.
Local Government (Colac Otway Shire)	Council has responsibilities under the *Planning and Environment Act 1987* to administer the planning scheme, under the *Road Management Act 2004* to maintain local infrastructure and under the *Emergency Management Act 1986* to coordinate emergency management at a municipal scale. Council also has statutory responsibility under the *Environmental Protection Act 1970* to regulate septic systems on private land.
Department of Environment, Water, Land & Planning (DELWP)	Development of waterway policy, coordination of regional delivery and prioritisation of government investment in waterways; management of fisheries, including recreational fishing.
Department of Economic Development, Jobs, Transport & Resources (DEDJTR)	The purpose of DEDJTR is to create the conditions to sustainably develop the Victorian economy and grow employment.

Group or agency	Regional responsibility
Parks Victoria	Management of the Great Otway National Park and Reserves, including the reserves in the Aire River valley and estuary.
Environmental Protection Authority (EPA)	Responsible for the protection and improvement of Victoria's environment by establishing environmental standards, regulating, and working with organisations to meet these standards.
Traditional Owners (TOs) – Eastern Marr	Traditional Owners have rights and interests to lands and water within their recognised region, including participation in decision making on how land and/or waters are used.
Game Management Authority (GMA)	The Aire River floodplain wetlands are designated State Game Reserves, as such GMA as a state agency have wetland use responsibilities.

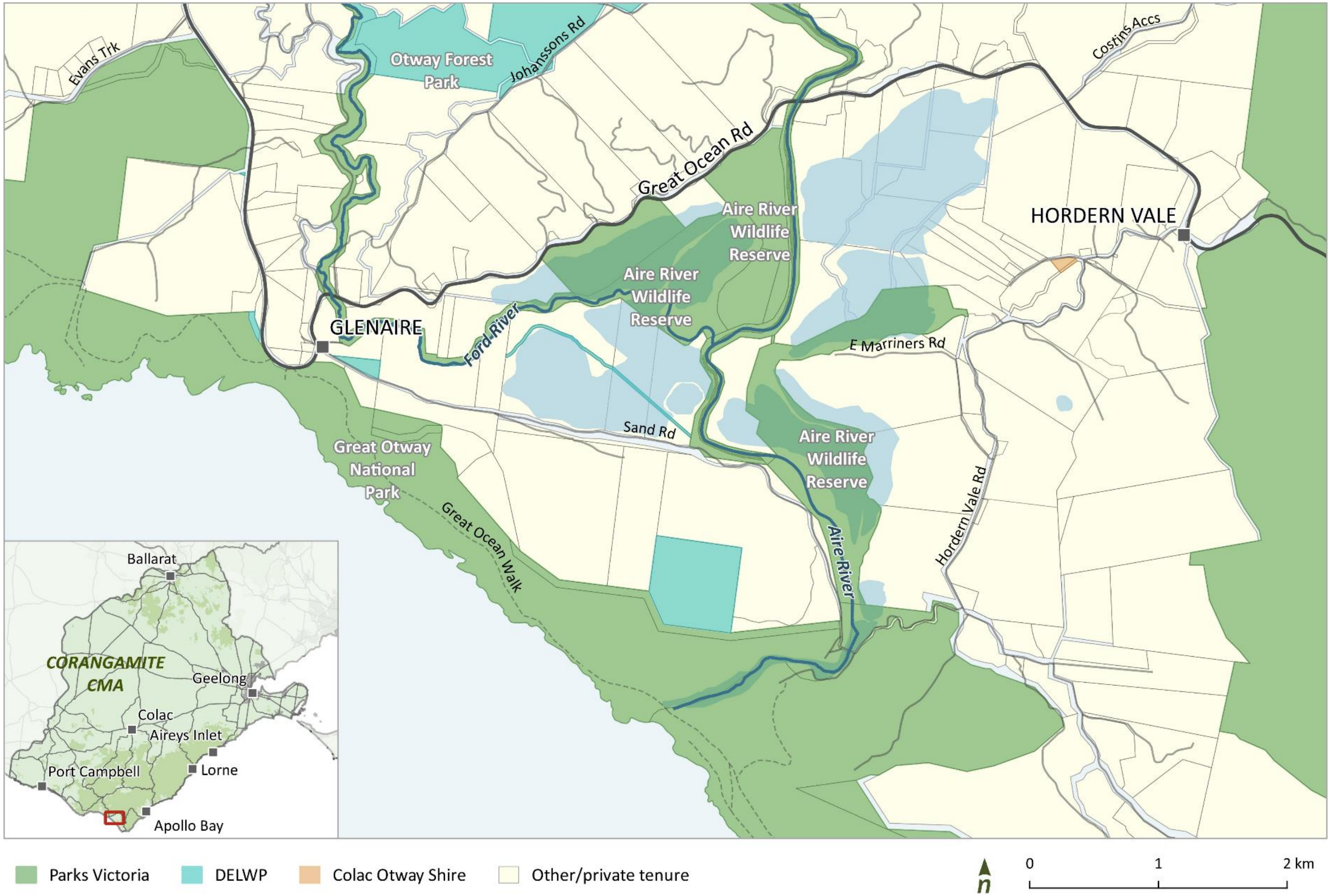


Figure 40. *Aire Estuary land management. Note light blue shading indicates estuary floodplain areas. Source: Data.Vic - Public Land Management (PLM25).*

Appendix B: Analysis of estuary monitoring data

B1. Methodology

Sample sites

The estuary is approximately 8km long. Sample sites were relatively unevenly spaced along the estuary until the limit of boat access at the Great Ocean Road Bridge (Table 17, Figure 41). Sites 1-4 and sites 7-9 are more closely spaced than sites 4-7.

Table 17. Description of sample sites used for the longitudinal surveys. See Figure 41 for map.

Site No.	Description	Distance upstream (km)	Latitude	Longitude
1	River mouth	0	-38.806173	143.463314
2	Halfway between mouth and bridge	0.79	-38.803464	143.469815
3	Campground bridge	1.66	-38.802226	143.478023
4	100m downstream of Lake Craven	2.10	-38.798196	143.478613
5	Opposite pump shed	3.86	-38.787802	143.466693
6	Downstream of Ford River	4.74	-38.78122	143.466017
7	Second revegetation site	6.47	-38.769292	143.473833
8	Large Cyprus tree below GOR	6.87	-38.765582	143.473549
9	GOR bridge	7.08	-38.763838	143.474472
Ford River	In Ford River (occasional sample)	Not measured		

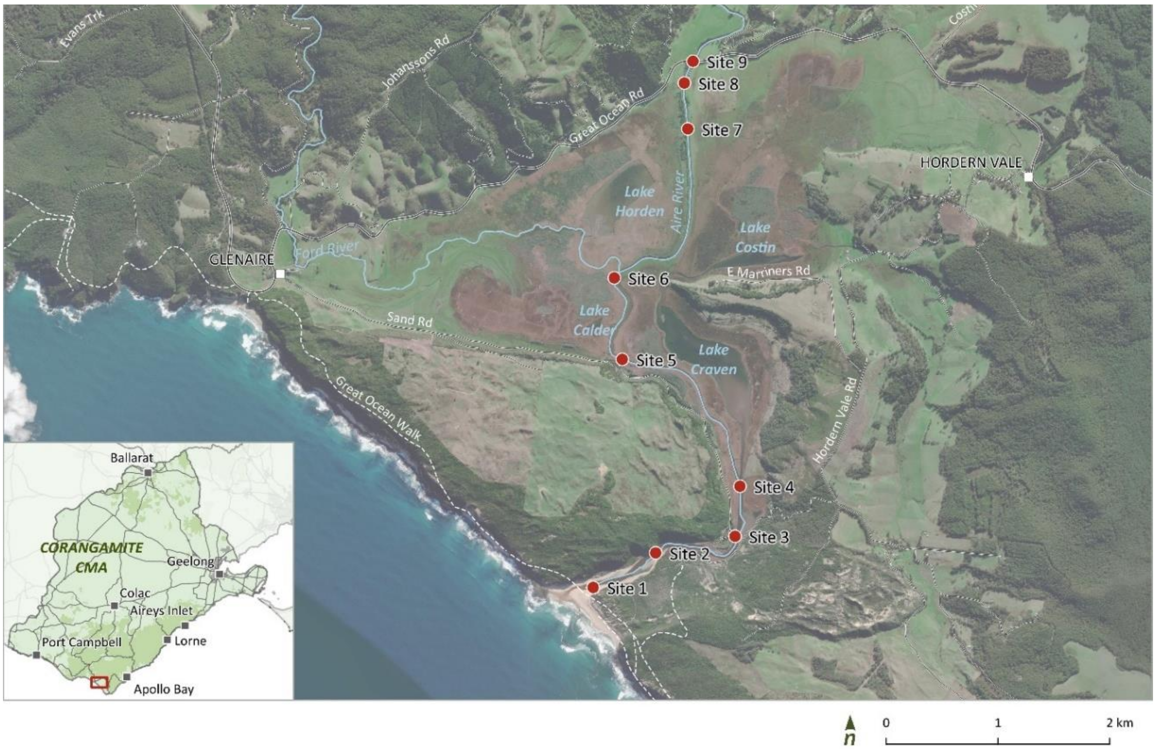


Figure 41. *Sample site locations of the Aire Estuary. See Table 17 for details.*

Survey technique
Longitudinal profiles of temperature, salinity, conductivity, DO (mg/L and % saturation), pH (for approximately half the surveys) were conducted by consultants prior to and often following a mouth opening. Readings were taken at 0.5m intervals from the surface to bottom at each site. Water level was recorded at the campground bridge on some surveys. Consultants have provided graphs of vertical profiles for most surveys – copies of some are reproduced here.

B2. Data set summary
The dataset comprises 88 surveys for 62 opening events between 7 March 2002 and 3 April 2013 (11 years). Water Level at the Campground Bridge (Site 3) gauge was recorded for 49 of the surveys.

There are 26 paired surveys (pre- and post- opening). Of these 12 were separated by 5 days or less; 11 were separated by 6-8 days. The actual date of opening is not recorded in the file. Dates for some openings were based on the estuary opening dataset developed for this project.

To summarise each survey two parameters were used:

- Minimum depth along the estuary at which DO dropped to 5mg/L (approximately 50% saturation under estuary conditions)
- Minimum depth along the estuary at which salinity was 15ppt (an approximate midpoint of the halocline).

These two parameters were used to provide a simple categorisation of each survey.

B3. Observations

Two mixing states of the estuary
In its low energy state vertical profiles of salinity along the estuary have very similar shapes (Figure 42 and Figure 43). The estuary halocline occurs at a constant depth throughout the estuary. There is little turbulent mixing, whether by wind, sea water or river flow at these times. Most pre-opening surveys (22/28) showed this state but only 6/27 post opening surveys demonstrated it.

Figure 42. *Uniform vertical salinity profiles prior to estuary opening on 17 October 2008.*

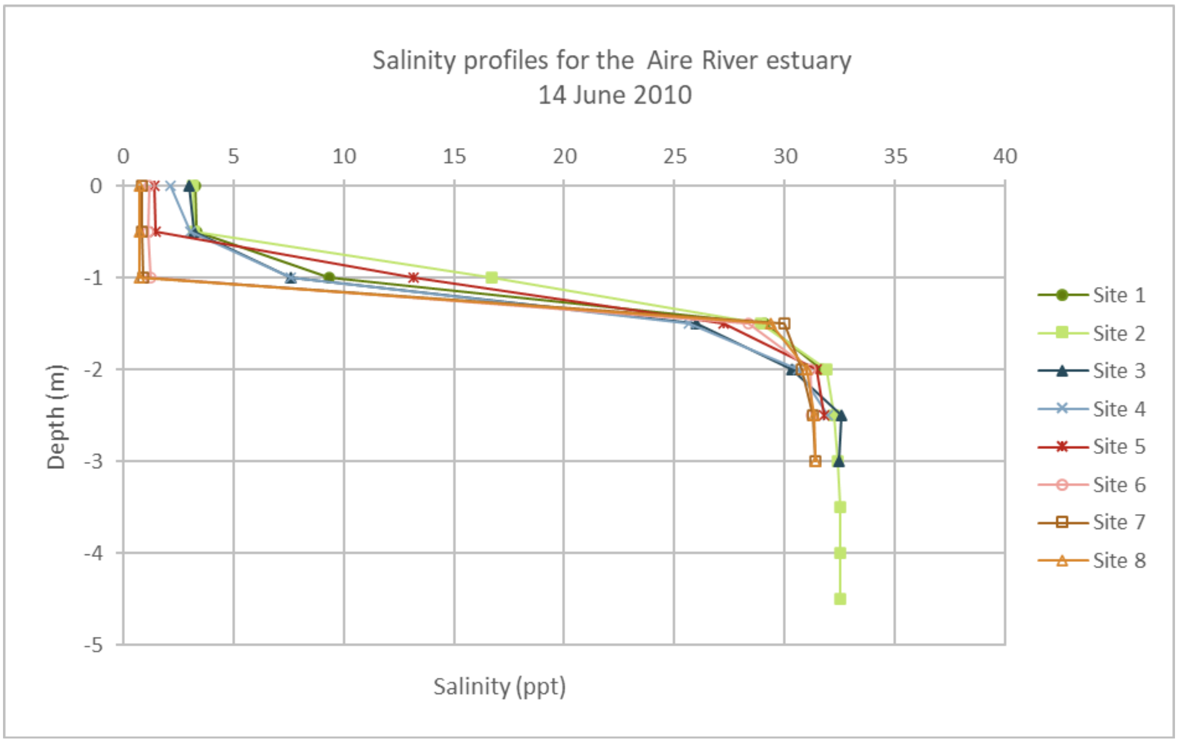


Figure 43. *Uniform vertical salinity profiles prior to estuary opening between 14 and 16 June 2010.*

An alternative estuary state (6/28 pre-opening surveys; 21/27 post-opening surveys) shows a change in vertical salinity profiles along the estuary (Figure 44 and Figure 45). Significant outflows from the estuary following opening can generate sufficient turbulence to mix water across the halocline. After opening inflowing sea water can also generate mixing as it moves upstream on the flood tide. Figure 44 and Figure 45 show the post-opening profiles of the surveys in Figure 42 and Figure 43.

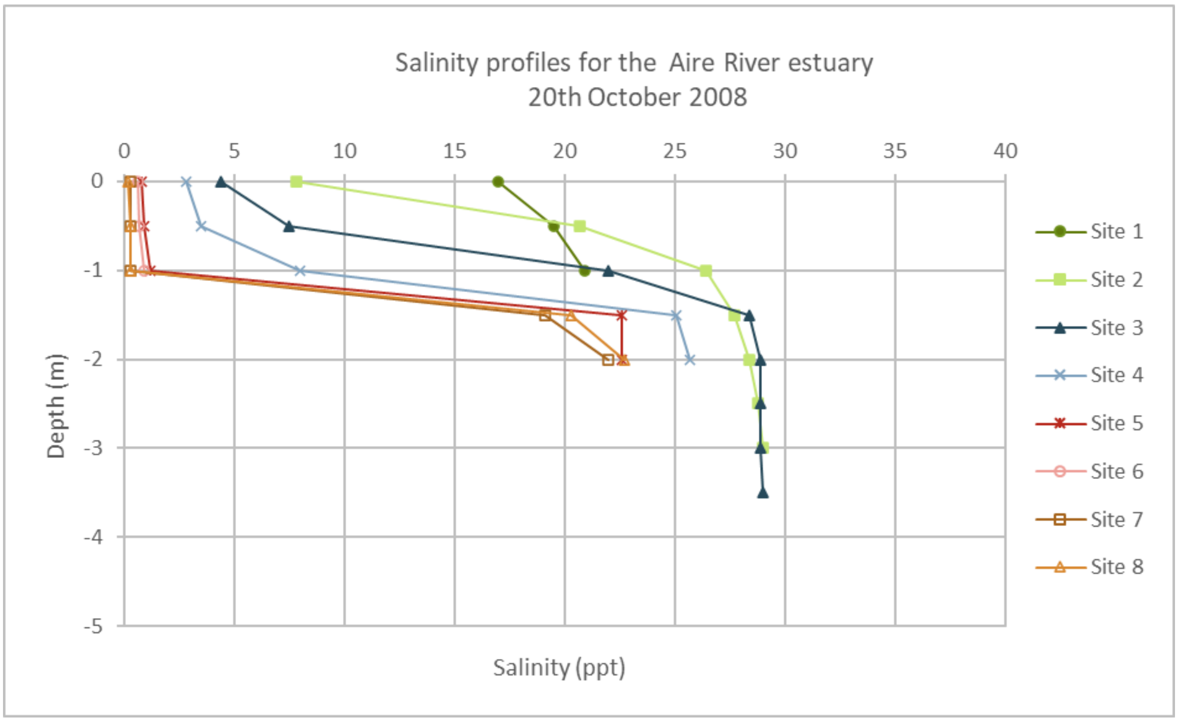


Figure 44. *Salinity profiles along the estuary following an opening on 17 October 2008. Compare these profiles to those pre-opening (Figure 42).*

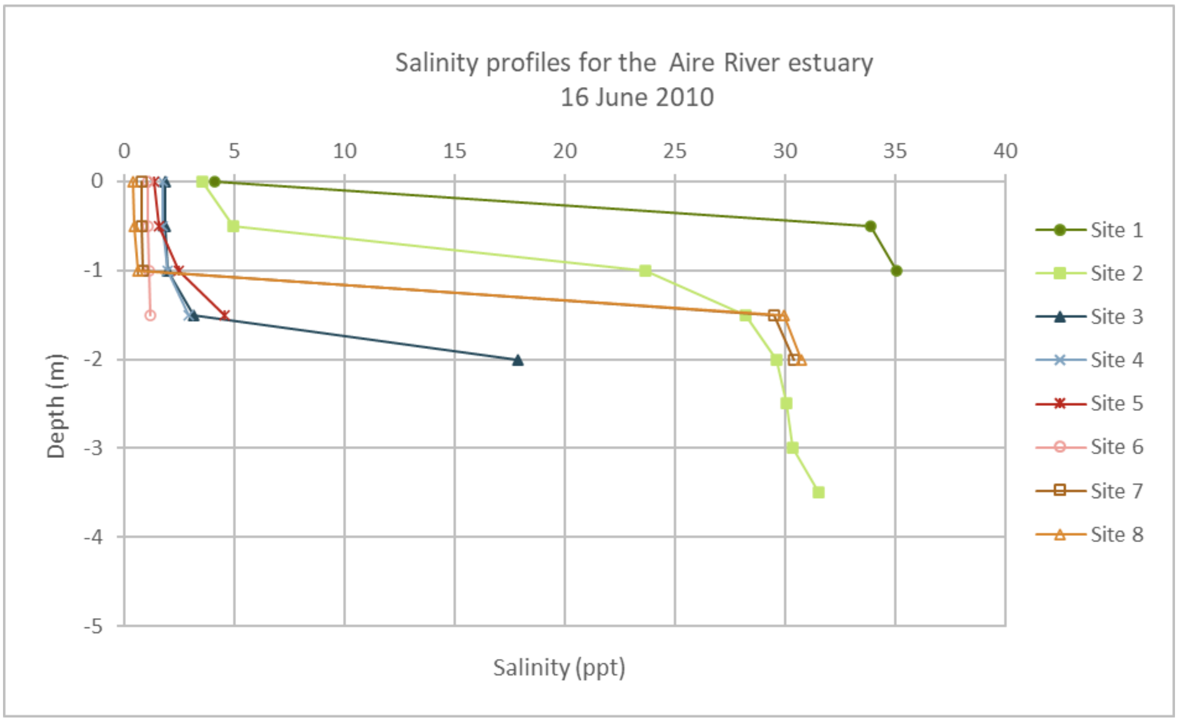


Figure 45. *Salinity profiles along the estuary following an opening between 14 and 16 June 2010. Compare these profiles to those pre-opening (Figure 43).*

Decrease in water level on opening

Changes in water level at the campground bridge are recorded for 18 opening events between 11/12/05 and 29/11/2012. The mean water level drop (± one standard deviation) was 1.1m (± 0.4m); the maximum decrease 1.67m and the minimum 0.24m (Figure 46).

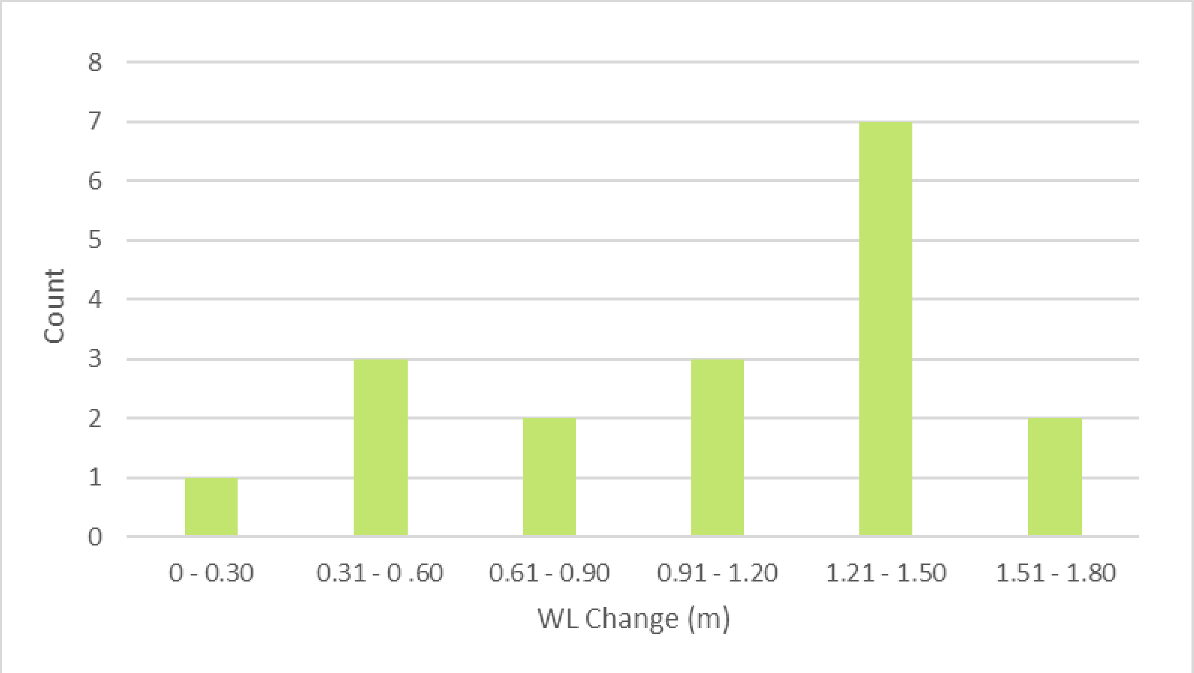


Figure 46. *Distribution pf water level decreases for 18 estuary openings between December 2005 and December 2012 (7 years).*

Effect of opening on the halocline

The minimum depth at which a salinity of 15 was found in the estuary pre-opening is shown in Figure 47. Saline water (Salinity>15) was commonly (20/30 surveys) at depths exceeding 1.5m.

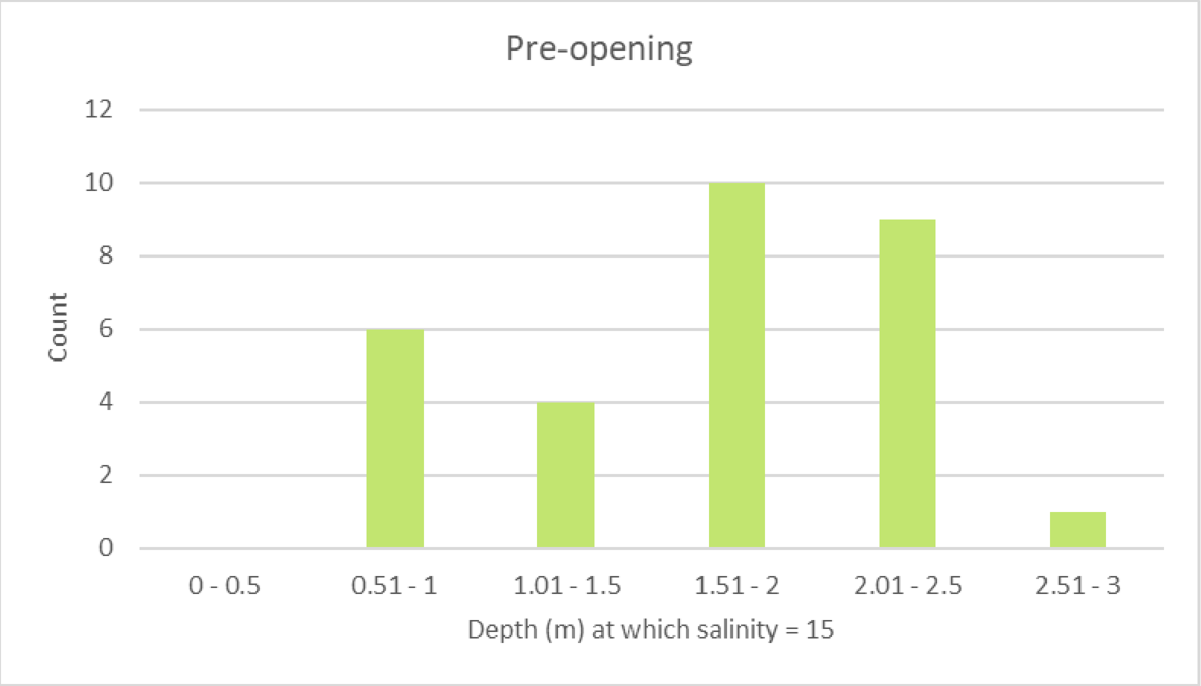


Figure 47. *Distribution of the minimum depth at which salinity =15 for surveys conducted pre-opening of the estuary.*

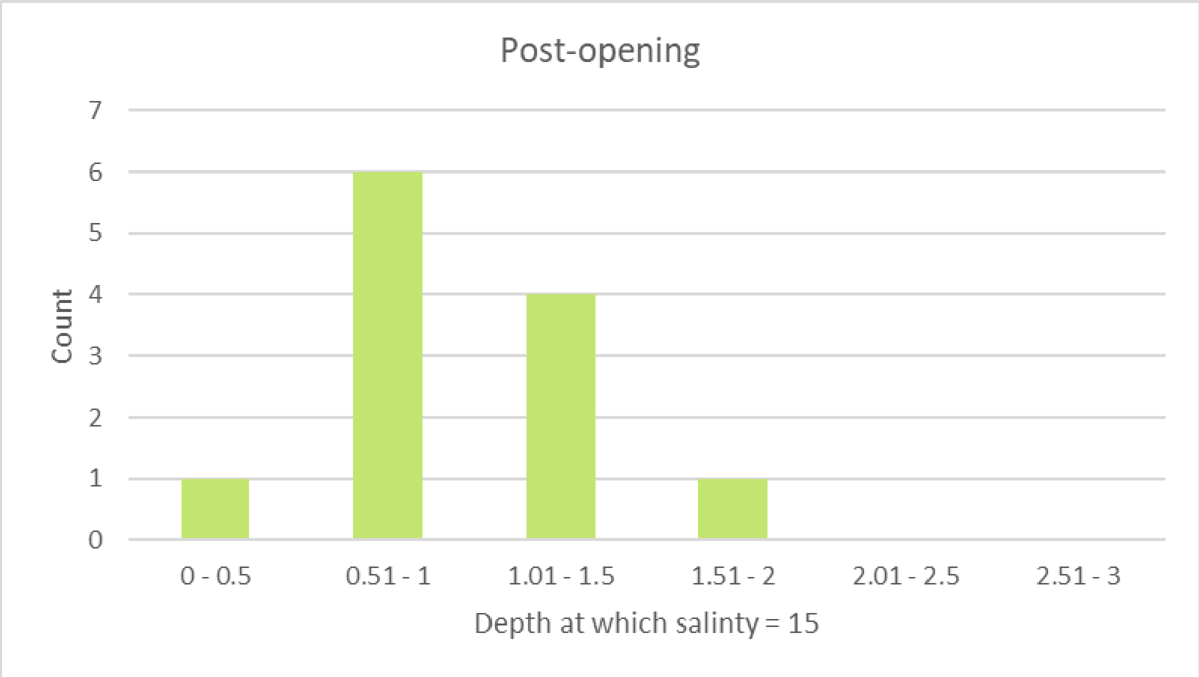


Figure 48. *Distribution of the minimum depth at which salinity exceeds 15 for post-opening surveys*

After opening the estuary saline water was found closer to the surface – in 11 of 12 surveys it was within 1.5m and for 7 surveys, within 1m (Figure 48).

Changes to DO profiles after estuary opening

Pre-opening surveys generally (29/33 surveys) showed DO greater than 5 mg/L to at least a depth of 1.5m or more along the estuary (Figure 49). Following opening the depth of oxygenated water was significantly reduced as surface water was drained to sea. About half the post-opening profiles (16/33) showed 1m or less of oxygenated water at one or more sites in the estuary; 10/33 showed 0.5m or less (Figure 50). The latter represents a potentially dangerous condition for the estuarine aerobic community.

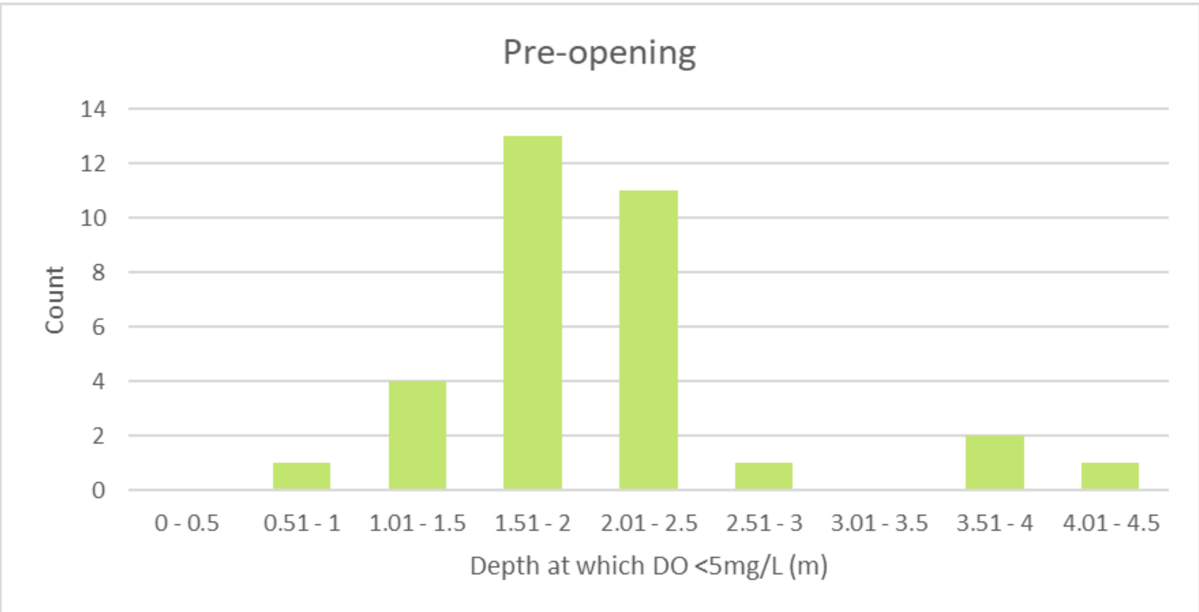


Figure 49. *Minimum depth at which DO <5mg/L for 33 individual surveys conducted prior to an opening.*

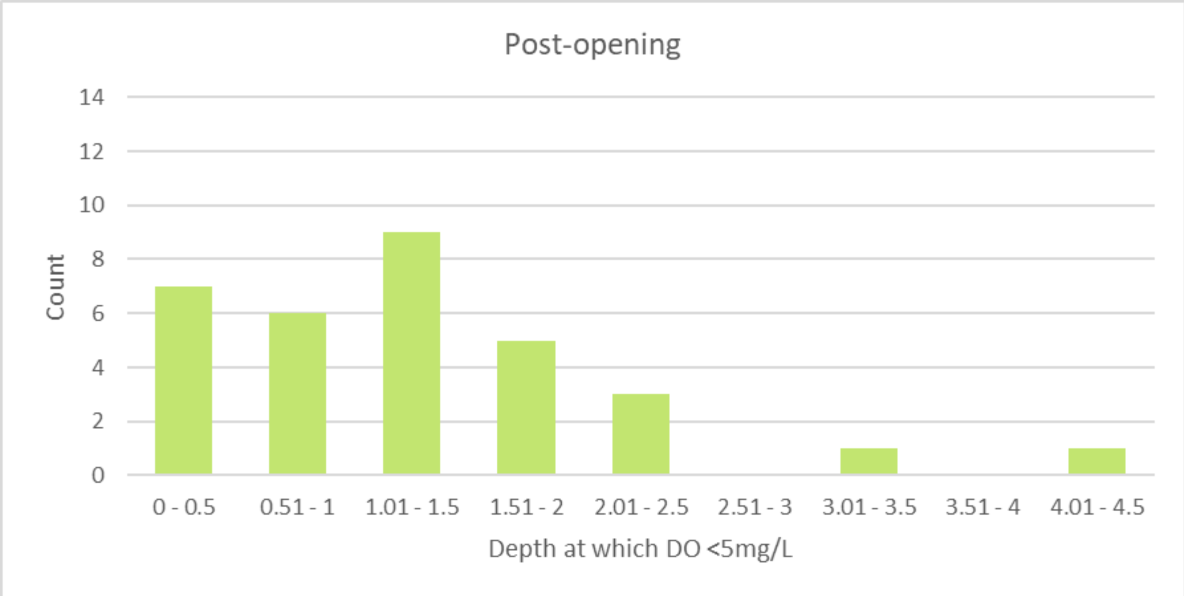


Figure 50. *Minimum depth at which DO <5mg/L for 33 individual surveys conducted after an opening.*

Anoxic deep water

During late summer and autumn surveys anoxic bottom water was commonly found at depths beyond 2 – 3m and more commonly in upper estuary sites 7 – 9 (Figure 51, see also later Table 18 and Table 19). This reflects the lack of bottom water exchange when flood tide inflows are reduced as sand progressively restricts the estuary entrance.

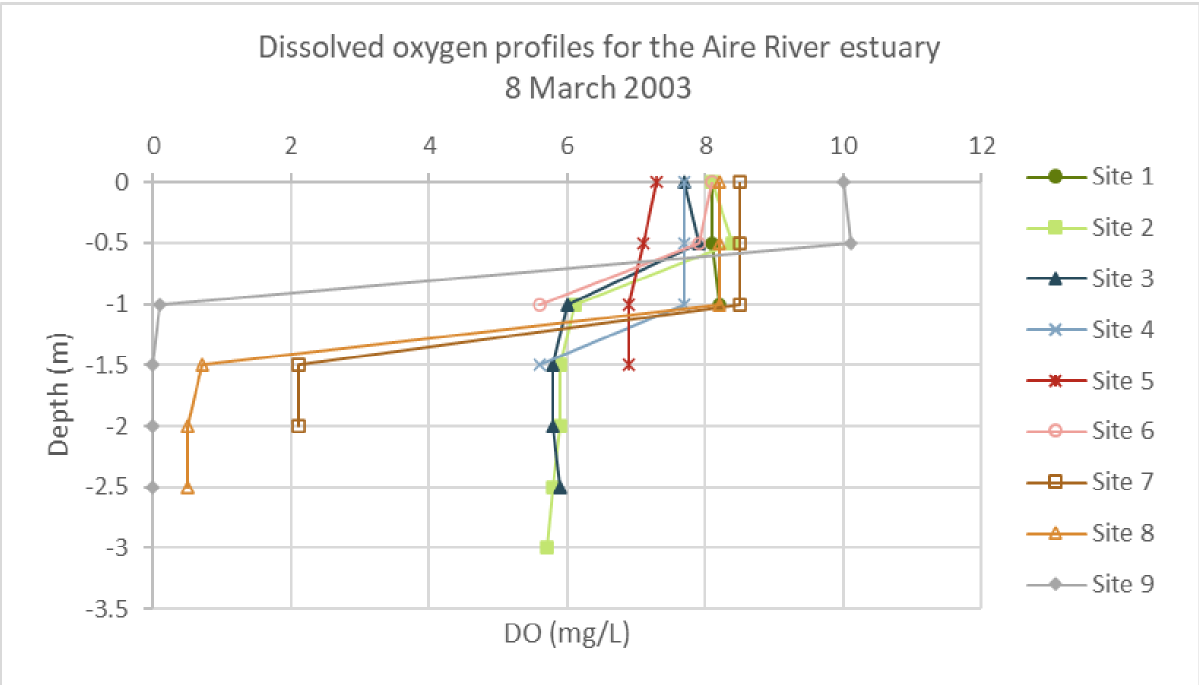


Figure 51. *Contrasting profiles of DO along the estuary. Well oxygenated "new" seawater below 1m depth at sites 2-3; Low DO /anoxic water below 1m at sites 7 – 9.*

Algal population effects on DO

During calm conditions dense populations of algae and/or photosynthetic bacteria occupy vertically restricted bands (or "plates") positioned near the halocline to optimise access to light (from above) and nutrients (from below). The populations produce high DO "spikes" by photosynthesis at the halocline as the day proceeds but overnight their respiration consumes DO creating low DO "sags" which can persist into early daylight hours. DO "spikes" at the halocline were observed for at least one site (n=10 surveys), distributed throughout the year:

summer (11/12/05, 25/1/08, 19/12/11) autumn (9/5/08, 3/5/10, 13/4/12) winter (14/6/10; Figure 52) and spring (12/11/02,7/9/07, 14/11/08). On eight surveys, an oxygen "sag" was detected at the halocline. Five of these surveys were in autumn (April and May; 21/4/03; 17/5/05; 15/4/06; 12/5/06; 23/4/12) and one in each of winter (28/6/08) spring (21/11/08; Figure 53) and summer (28/12/07).

The surveys indicate the conditions conducive to formation of these algal or bacterial plates can occur year-round.

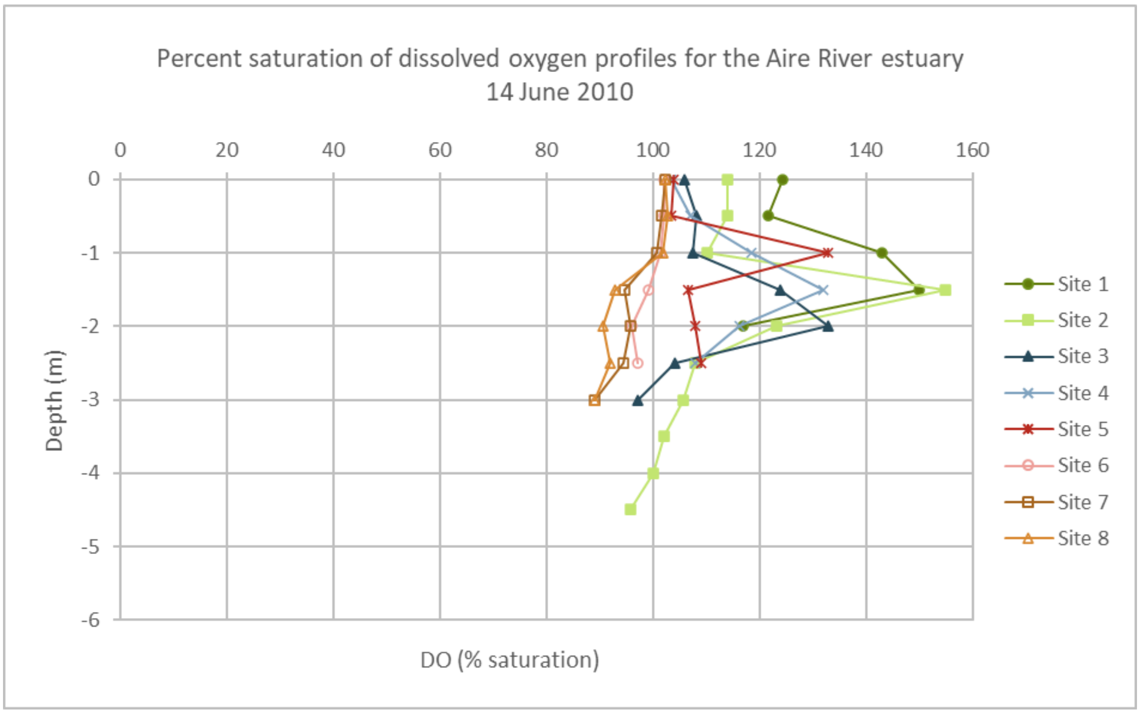


Figure 52. *Supersaturation in surface water of Sites 1 and 2. A "spike" in DO is also shown at the halocline of sites 1 to 5 (1-2m).*

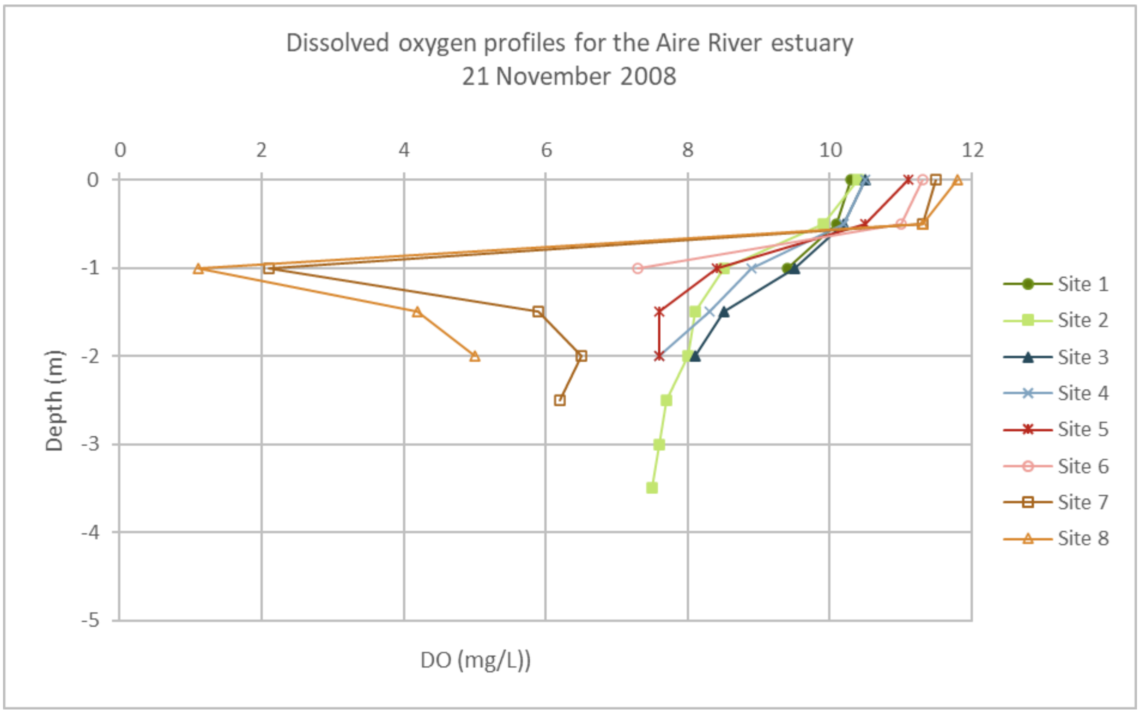


Figure 53. *Prominent decrease in DO at the halocline (1m) at sites 7 and 8 due to plates of algae and/or photosynthetic bacteria.*

Super saturation (defined as >110% saturation) indicates high photosynthetic activity by one or more of planktonic bacteria and algae, benthic algae or macrophytes (submerged or emergent). Thirty of 88 surveys (34%) showed one or more DO concentrations exceeding 110% saturation. Seasonally autumn had the highest number of such surveys (14 out 37surveys) followed by spring (7/15) winter (5/9) and summer (4/27). Supersaturation was most common in the lower estuary (sites 1 to 3; observed on 24 surveys) - over twice as many surveys showed high DO here compared to the upper estuary (sites 7 – 9; 10 surveys). On many of these surveys DO "spikes" were detected at the halocline (Figure 52).

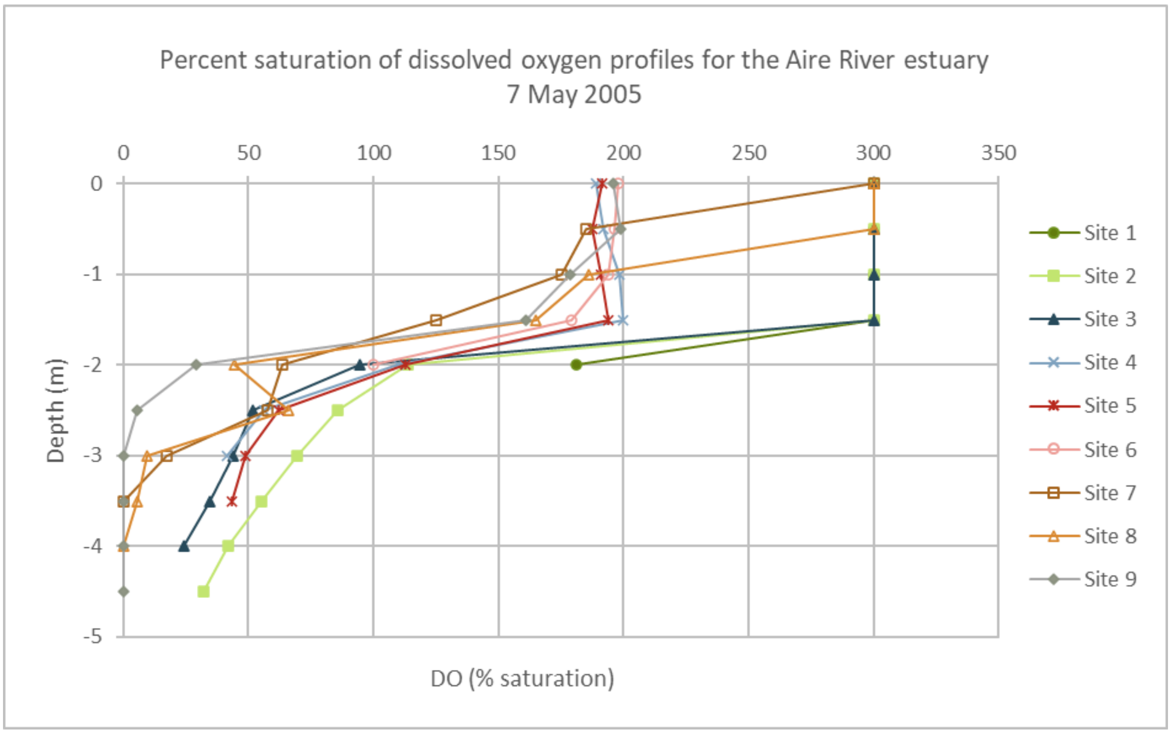


Figure 54. *Extensive super-saturation throughout upper waters of the estuary during a survey on 7 May 2005.*

One survey (7/5/05) showed extreme oxygen supersaturation in the surface 1.5m (up to 300%; Figure 54) indicating an extensive algal bloom throughout the surface waters of the estuary.

On six occasions opening of the estuary removed the surface water containing planktonic bacteria and/or algae and DO concentrations decreased (compare Figure 54 and Figure 55). In addition to the survey on 17/5/05 removal of super-saturated water was noted in surveys on 18/6/05, 21/11/05, 15/12/05, 13/5/08 and 11/5/10.

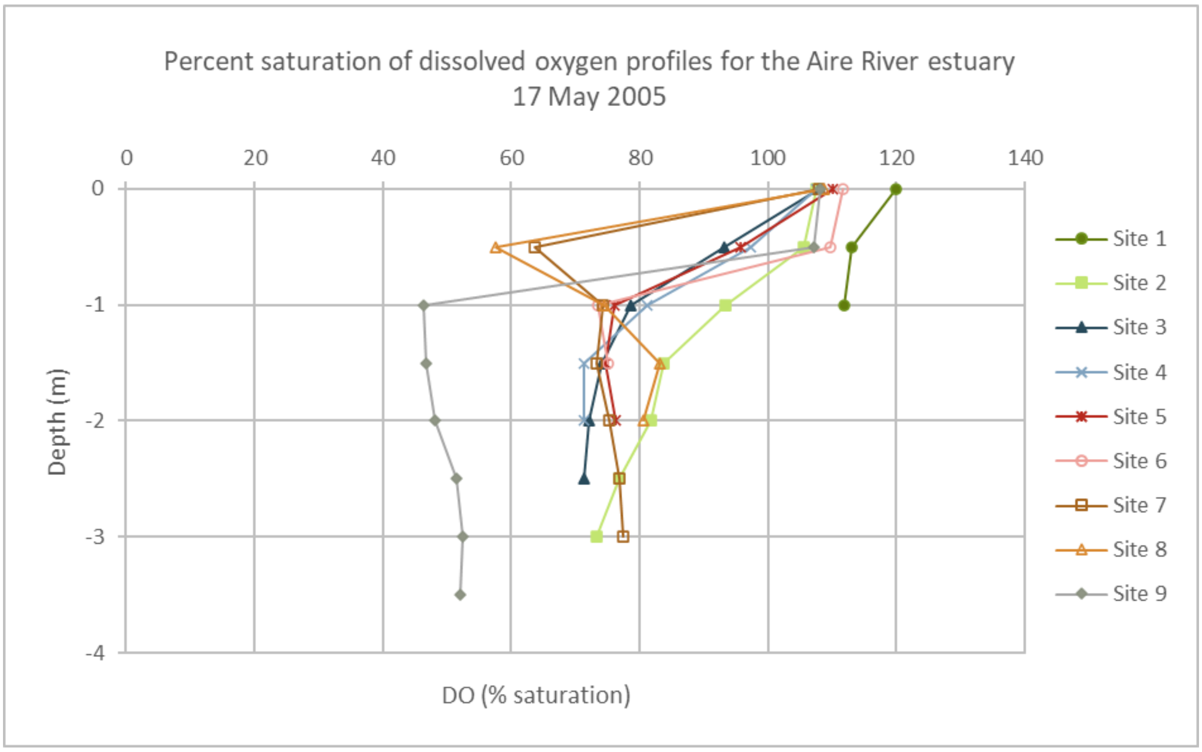


Figure 55. *Reduction in surface DO saturation (%) following an estuary opening after 7 May 2005. Note elevated concentrations (>110% saturation) remain at site 1.*

Good" and "bad" estuary openings.
Most estuary openings (19/26 paired surveys) resulted in adequate (>1m) surface oxygenated water remaining in the estuary. Examples of such "good" openings are shown in Table 18 and Table 19.

Table 18. DO concentrations exceeding 5mg/L in surface water of the estuary on 8 April 2004 following an opening between 1st and 8th April 2004.

8-Apr-04	Dissolved Oxygen (mg/L)								
Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
0	7.1	7.2	7.4	8.3	7.6	8.6	9	9.4	9.7
0.5	7	7.1	7.2	8.5	7.5	8.5	9	9.1	9.7
1	5.9	6.4	6.1	6.4	5.7	7.7	5.7	8.8	9.6
1.5	5.9	6.4	5.8	5.8	5.4		0.5	0	0.9
2		6.5	5.5		5.3		0	0	0
2.5		6.5	5.4					0	0
3		6.5	5.4						
3.5		6.4							

Table 19. DO concentrations >5mg/L in top 1m of water on 1 April 2011 after an estuary opening between 28 March and 1 April 2011

1-Apr-11	Dissolved Oxygen (mg/L)							
Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
0	8.7	8.5	8.4	7.9	8.5	9	8.9	8.8
0.5	8.1	8.6	8.5	7.8	8.4	9	8.9	8.9
1	6.7	7.3	8.4	7.7	8.2	8.9	9	9
1.5		6.2	5.5	5.2	4.1	4.9	3.2	2.7
2		5.5	5.1	3.7	4		1.1	1.1
2.5		5.3	4.3				0	0
3		5.2						
3.5		5.1						
4		3.7						

Table 20. Low DO throughout the estuary on 6 February 2006 following an opening between 3 and 6 February 2006.

6-Feb-06	Dissolved Oxygen (mg/L)								
Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
0	5.5	4.7	5.2	3.2	4.3	5.8	6	6.1	7.3
0.5	5.3	4.7	5.2	4.8	4.2	5.5	6	6	7.3
1		4.6	5.1	3.9	4.1		0.4	4.5	7.2
1.5		4.8	5.4					0	0
2								0	0
2.5								0	0

Table 21. Low DO throughout the estuary on 30 April 2009 following an opening on 26 April 2009.

30-Apr-09	Dissolved Oxygen (mg/L)							
Depth (m)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8
0	6.6	4.5	3.6	2.8	4.1	3.9	6.8	7
0.5	5.6	3.7	2.7	2.4	3	3.3	6.4	6.2
1	4.9	3.3	2.4	2.3	2.5	2.9	4.2	2.7
1.5	4.9	3.1	2.2	2.2	2.4		2.3	1.8
2		3	2.1		2.3			1.9
2.5		2.8	2		2.1			1.8
3		2.6	2					
3.5		2.5	1.9					
4		2.4	1.9					
4.5		2.1						
5		2						

Seven post opening surveys, all in summer and autumn, showed one or more sites where DO concentrations were less than 5 mg/L throughout the water column at one or more sites (e.g. Table 20 and Table 21; 22/1/05, 6/2/06, 30/4/06, 27/3/09, 30/4/09, 19/1/12, 7/2/13). In some instances, these conditions had persisted for several days after an opening (e.g. Table 21) and pose a risk to the estuary's aerobic community. They represent undesirable ("bad") outcomes of estuary opening.

Can "bad" openings be predicted?

The main tool managers can use to assess the environmental risk of opening the estuary is examination of the longitudinal survey conducted prior to a planned opening. The survey should show at least 1.5m of well oxygenated water (DO >5mg/L) throughout the estuary. Using this criterion, a drop of 1 – 1.5m in water level (chiefly from the surface layer) should leave an adequate volume of oxygenated water in the estuary. To test this the 7 openings which had poor DO status after opening were examined (see section 3.7).

- For three of the post-opening surveys no pre-opening survey was done (22/1/05, 27/3/09, 7/2/13) and so assessment against the criterion was not possible.
- In one case the pre-opening survey (3/2/06) showed low DO (<6mg/L) in the top 1m of sites 3-6; after opening (6/2/06) there was low DO in the top 1.5m of sites 1-6. This represents a situation where an opening could have been assessed as high risk
- For three pre-opening surveys (15/4/06, 24/4/09 and 12/1/12) surface water was well oxygenated to at least 1.5m throughout the estuary. Opening under these conditions could have been assessed as low risk.

Since the main estuary channel's surface water was well oxygenated for the three openings of the third dot point it is likely the source of low DO water is the inundated floodplain. Water level on opening was between 1.48m and 1.71m prior to opening on the pre-opening surveys of 3/2/06, 15/4/06, 24/4/09 and 12/1/12. As water levels rise above 1.3m the flood plain is submerged to an increased extent. As the entrance opens this water drains back into the main channel and becomes part of the surface layer. Poor water quality in the flood plain can result in poor water quality in the main channel post-opening.

B4. Summary

Prior to its opening the estuary has a fresher water layer (salinity <15) typically 1.5m thick over a more marine layer (salinity >15). The deeper water (>1.5m) often has a DO concentration below 5mg/L and particularly during autumn may be anoxic.

In autumn, the estuary is in a low energy state due to calmer days, a restricted estuary entrance and low river flow. Under these conditions the halocline shows a similar vertical profile throughout the estuary.

Dense populations of algae and/or photosynthetic bacteria (known as "plates") can develop in the halocline region producing DO "spikes" or "sags" in vertical DO profiles depending on whether photosynthesis or respiration is dominant. Plates can occur at any time during the year if calm conditions prevail.

Supersaturation (>110% saturation) also occurs in the estuary's surface waters, most commonly in spring and autumn indicating the presence of large algal populations. On one survey an algal bloom created supersaturation of 200 – 300%.

Opening of the estuary lowers the estuary water level by 1.1±0.4m on average. It is surface water that leaves the estuary resulting in shallower depths of water with salinity <15 and/or DO >5mg/L. Turbulence generated by the outflowing water erodes the deeper marine water giving a wider variation of salinity both vertically and horizontally in the estuary. Opening also sweeps out algal or bacterial populations in the surface waters lowering or removing DO supersaturation.

Most paired pre- and post- opening surveys (19/26) showed acceptable surface DO conditions after opening. On seven occasions in summer and autumn opening of the estuary resulted in DO concentrations <5mg/L at one or more sites throughout the estuary. These represent a significant proportion of the monitored openings (27%). Based on limited data (from 3 openings) it appears likely that a source of this water was the inundated floodplain. Low DO concentrations were observed to persist for up to 4 days after one opening (30/4/09 survey). Such conditions pose a threat to the estuary's aerobic organisms and justify caution in deciding whether to open the estuary.

Resources should be made available to allow more paired pre- and post-opening surveys, particularly in summer and autumn, to increase understanding of the estuary behaviour and associated risks of opening.

Diurnal monitoring of the inundated floodplain should be undertaken when the mouth is closed to better understand factors governing its water quality.

Appendix C: Analysis of wetland inundation

C1. Method

Input data

The wetland inundation database was utilised to assess wetland inundation history throughout the Aire estuary. This ESRI File Geodatabase documents the inundation statistics and water regime categories for each mapped wetland in the geospatial layer Victorian Wetland Inventory (Current). The wetland boundaries were derived primarily using aerial photograph interpretation (photos from 2007 to 2011) supplemented with existing geospatial datasets that provided context and informed the identification of wetland boundaries (e.g. vegetation mapping, topography). The core data used to produce the inundation statistics are Landsat multispectral imagery from 1986 to 2019. The database consists of a shapefile layer and three tables:

- *wetlands*: This shapefile layer presents polygons of mapped wetlands in the Victorian Wetland Inventory (Current).
- *individual_wetland_inundation*: This table documented the proportion of each wetland that was inundated for each processed Landsat image, which enables the user to track each wetland's inundation patterns over time.
- *percentage_wet_observations*: This table summarised the statistics from the individual inundation database within each 10-year rolling period and within the entire period.
- *wetland_regime_rolling*: This table documents the water regime categories within each 10-year rolling period and the entire record based on inundation duration and frequency.

A 5 m grid Digital Elevation Model (DEM) derived from LiDAR was also utilised to compare inundation extents to water levels in m AHD. The wetlands included in the analysis and the 5 m DEM are mapped in Figure 56.

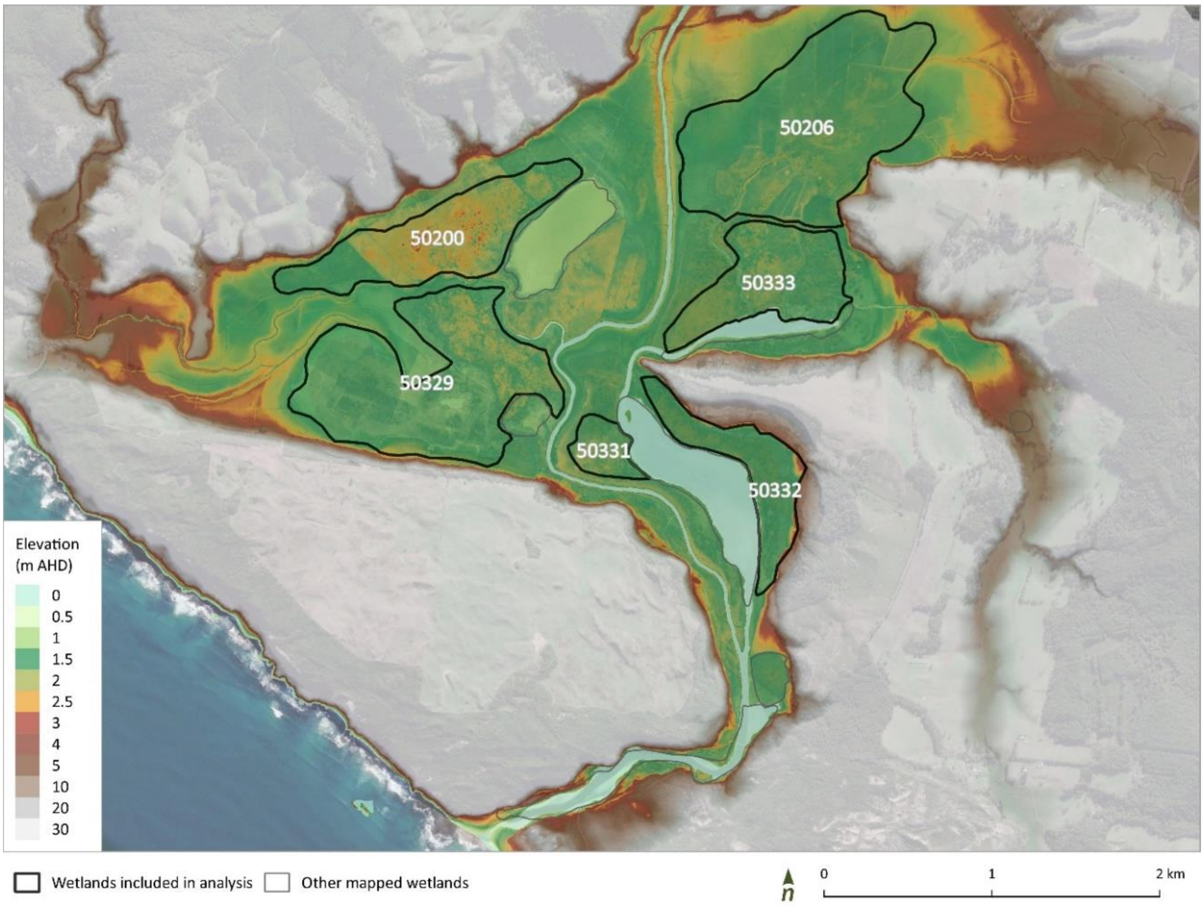


Figure 56. *5m DEM and wetland mapping for the Aire estuary.*

C2. Wetland inundation analysis

The individual wetland inundation data was summarised for each wetland and each month to determine the percentage of observations where the wetland was >10%, >40% and >80% wet compared to the total of clear observations for that wetland and month.

Utilising the QGIS 'zonal statistics' tool, an approximation for the area inundated at a certain level (m AHD) can be made. Through this method, an approximation of the level (m AHD) at which the wetland is 10%, 40% and 80% inundated can be made (Table 22). The inundation at these levels and the relevant EVCs in the wetland are mapped below. Summary statistics for the DEM can also be retrieved for each 'zone' (wetland), such as the minimum, maximum, and average height. These statistics are presented in Table 23 and Figure 57.

Table 22. Levels (m AHD) at which wetlands are 10%, 40% and 80% wet.

Wetland Number	Level (m AHD)		
	~10% of area inundated	*~40% of area inundated*	*~80% of area inundated*
50200	1.50	1.85	2.20
50206	1.50	1.60	1.70
50329	1.25	1.40	1.65
50331	1.50	1.65	1.80
50332	1.40	1.55	1.70
50333	1.45	1.60	1.80

Table 23. DEM statistics for six wetlands in the Aire estuary.

Wetland No.	DEM statistics (m AHD)				
	Mean	*Median*	*Standard deviation*	*Minimum*	*Maximum*
50200	1.92	1.94	0.32	1.12	3.52
50206	1.63	1.62	0.11	1.28	3.26
50329	1.49	1.42	0.22	1.06	2.38
50331	1.68	1.67	0.14	1.33	2.44
50332	1.65	1.58	0.49	-0.06	6.43
50333	1.65	1.66	0.20	-0.06	2.28

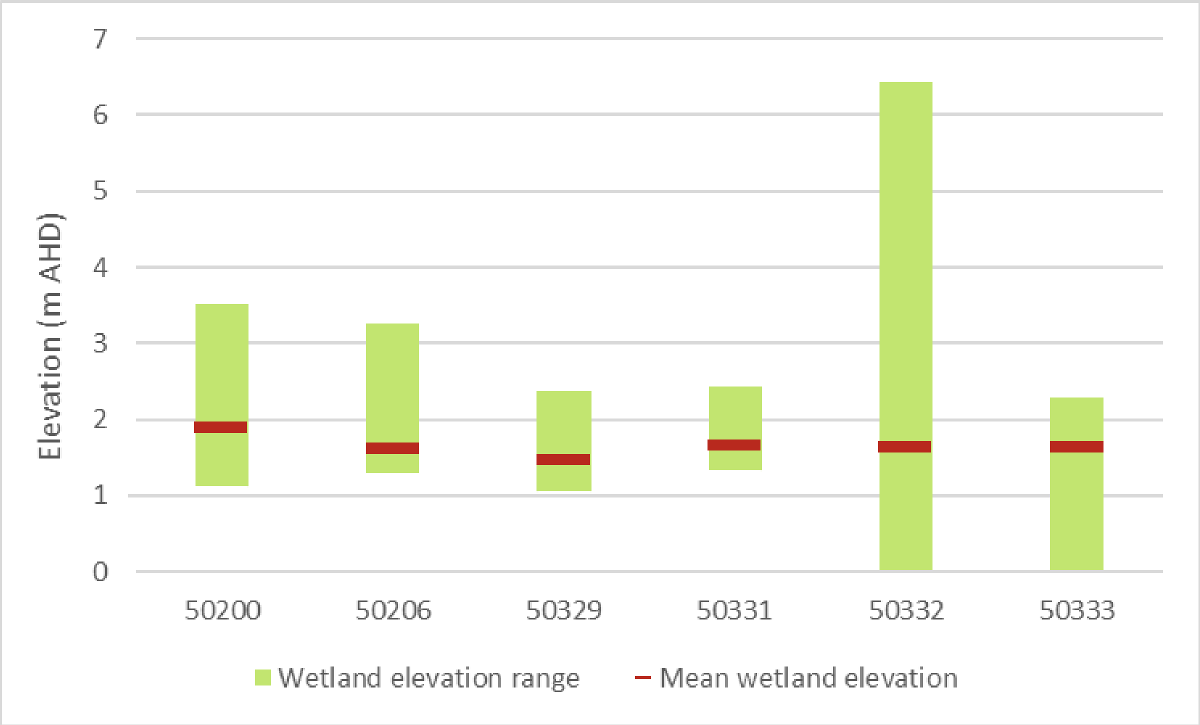
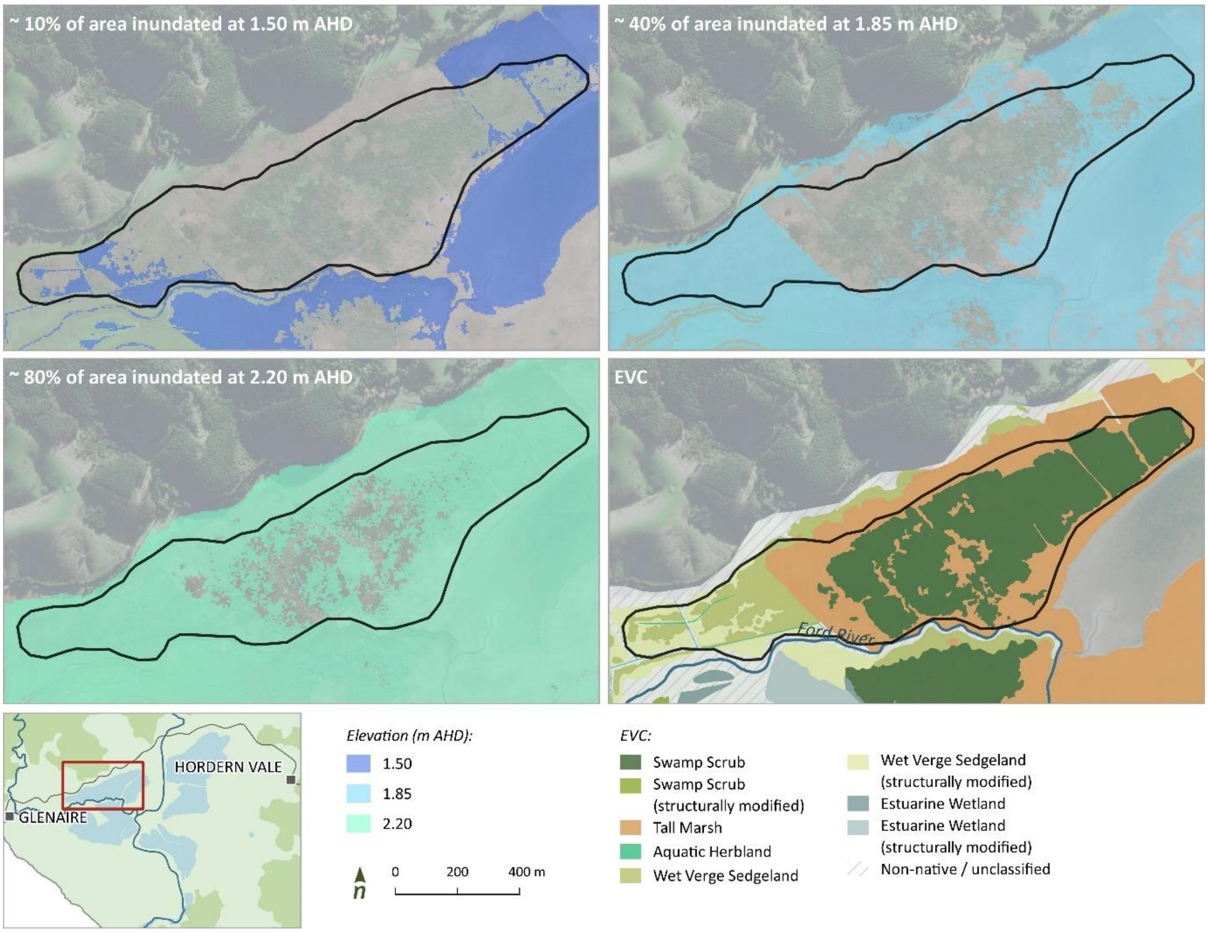
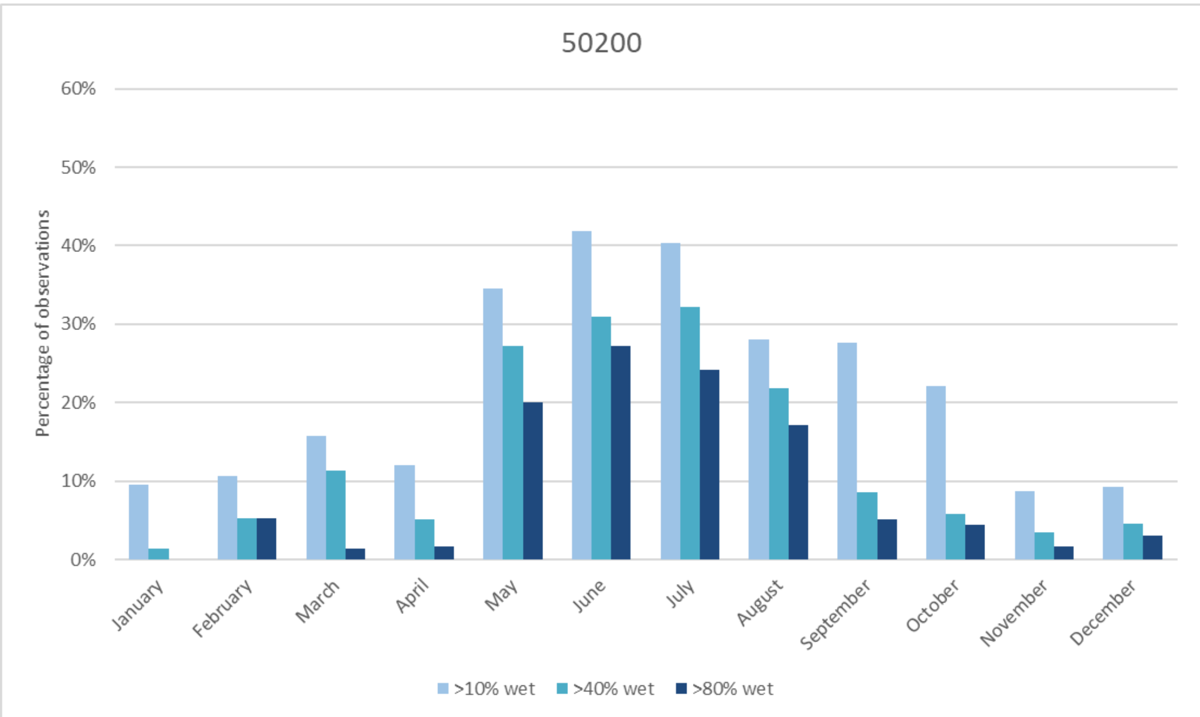


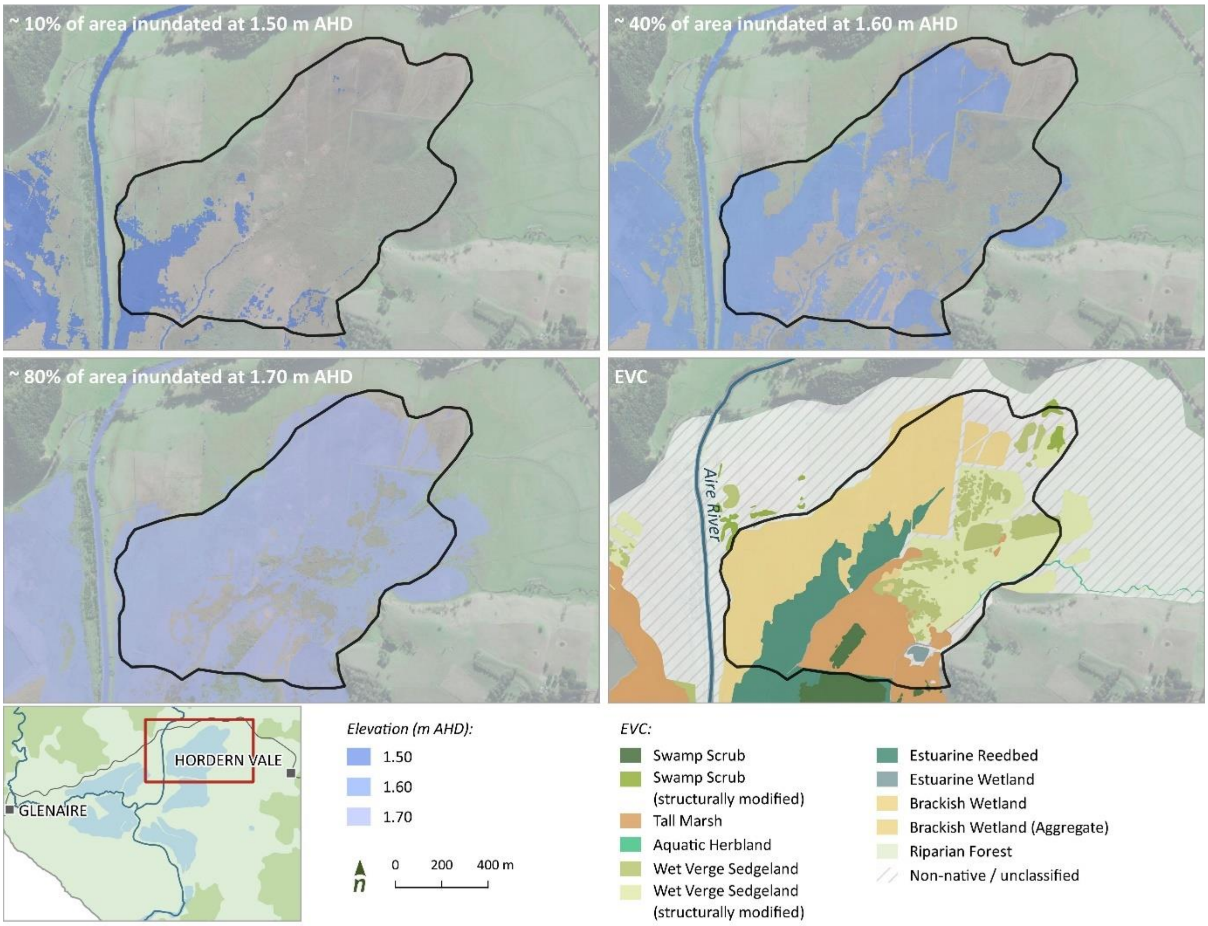
Figure 57. *Mean elevation (m AHD) and elevation range of six wetlands in the Aire estuary. Tabulated data available in Table 23*

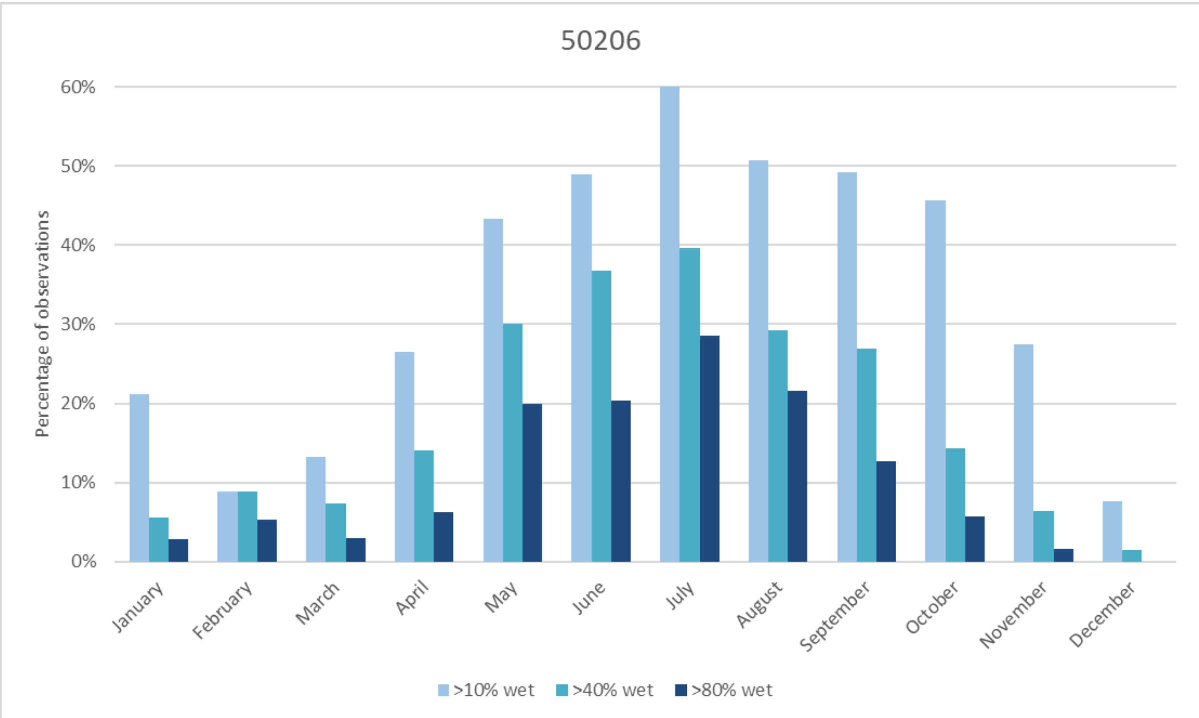
Wetland 50200



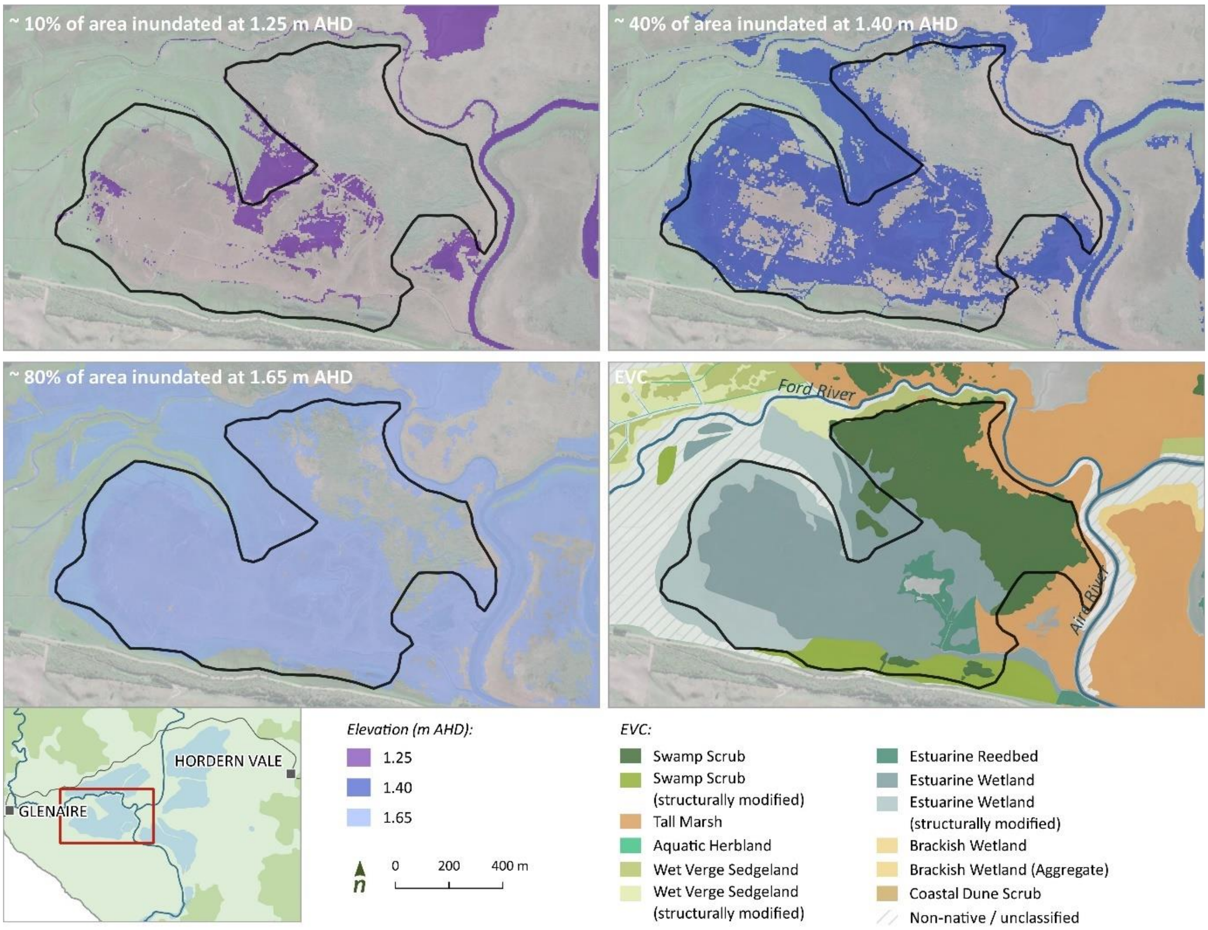


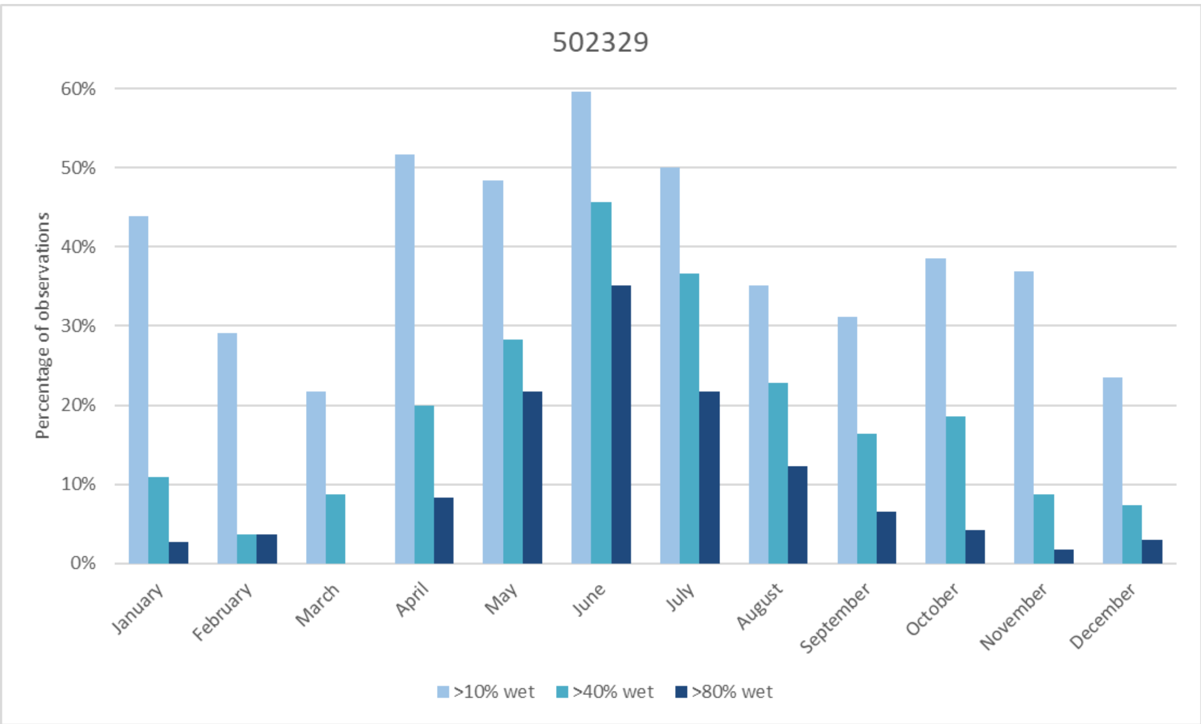
Wetland 50206



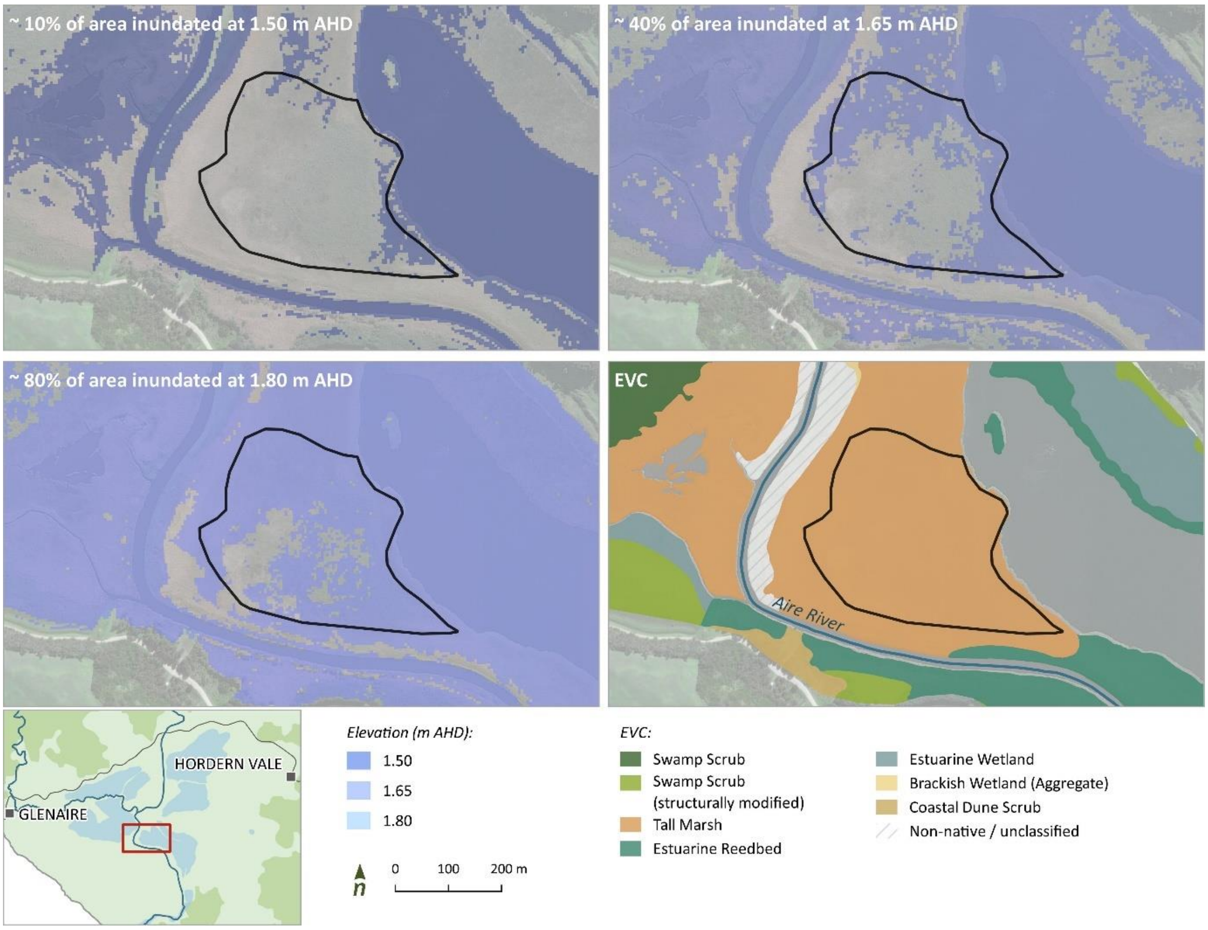


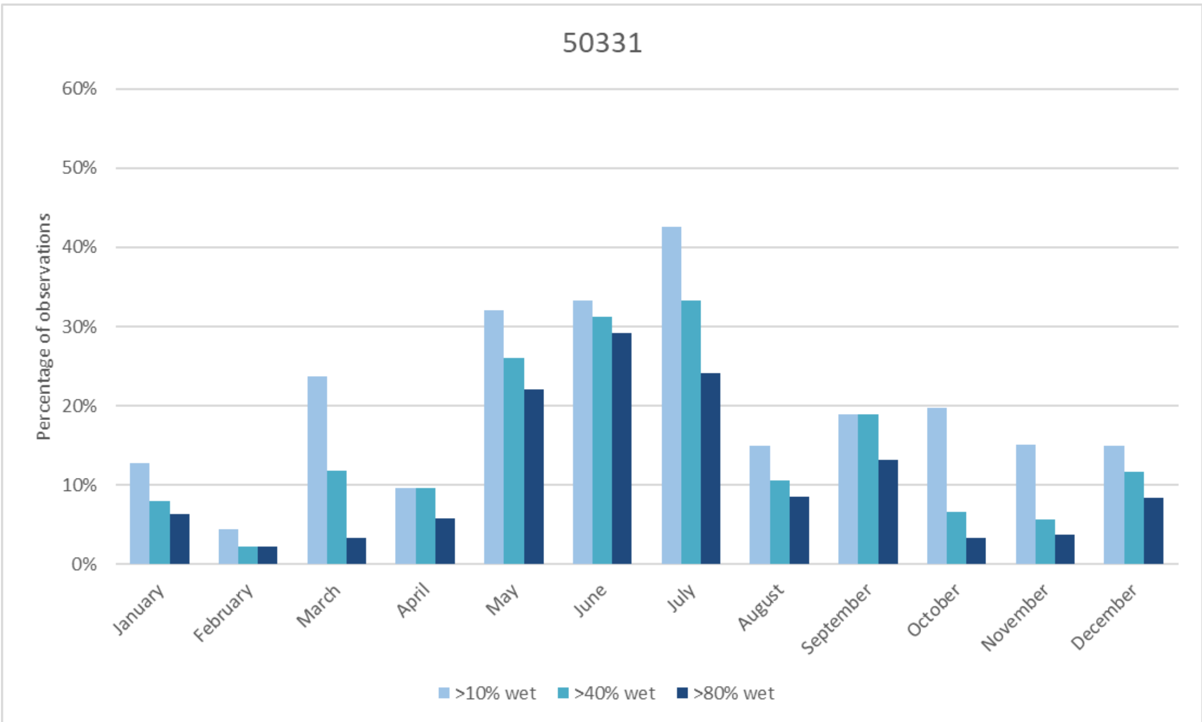
Wetland 50329



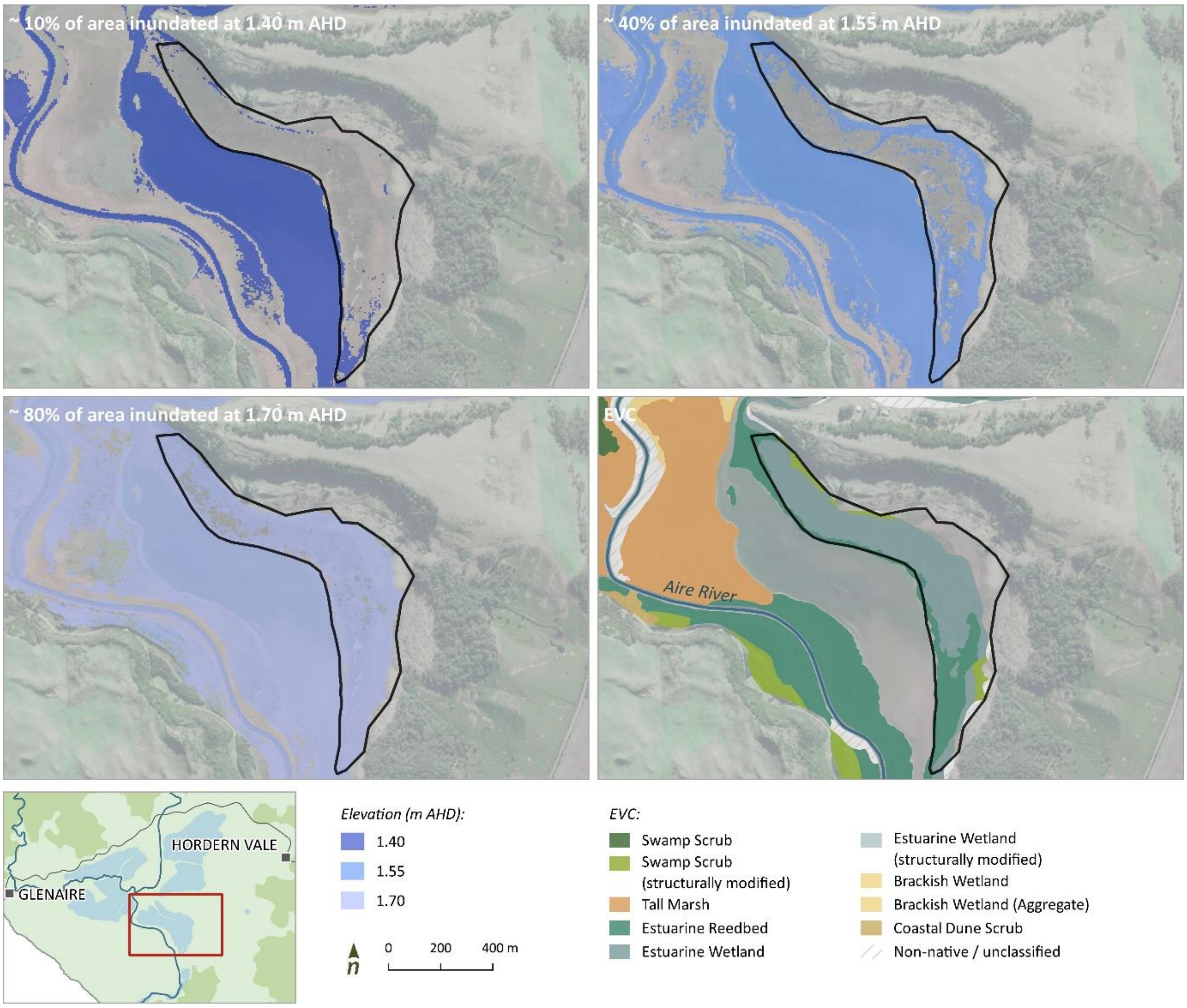


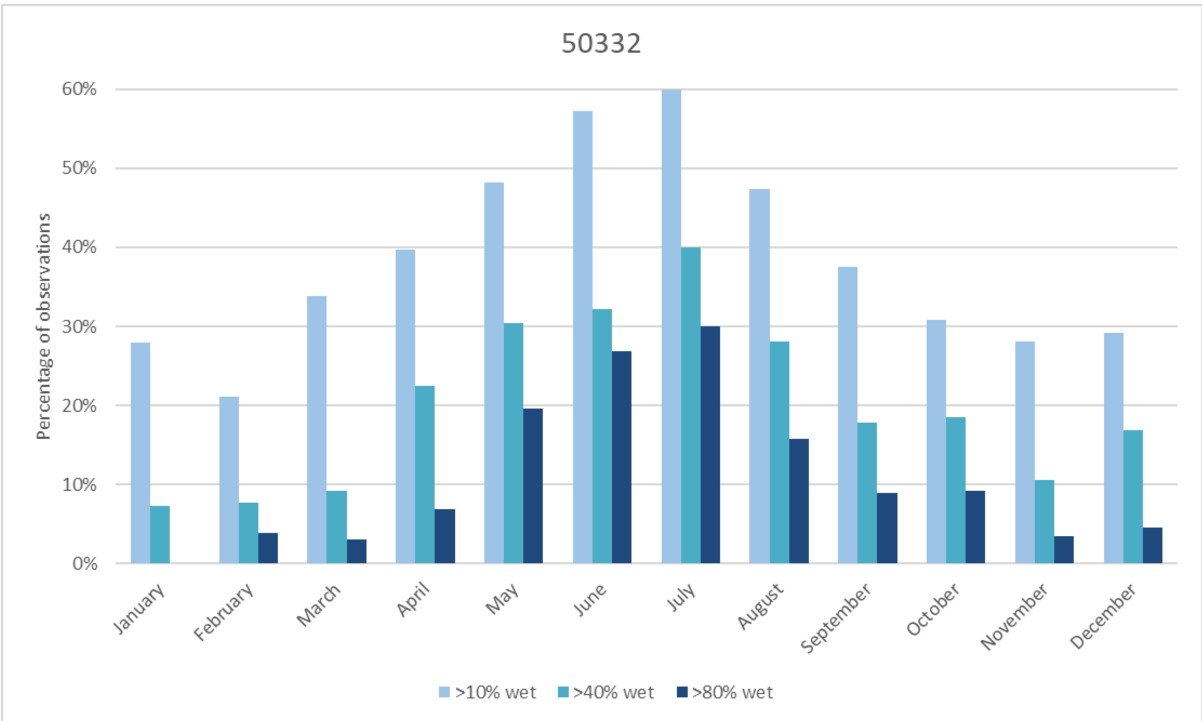
Wetland 50331



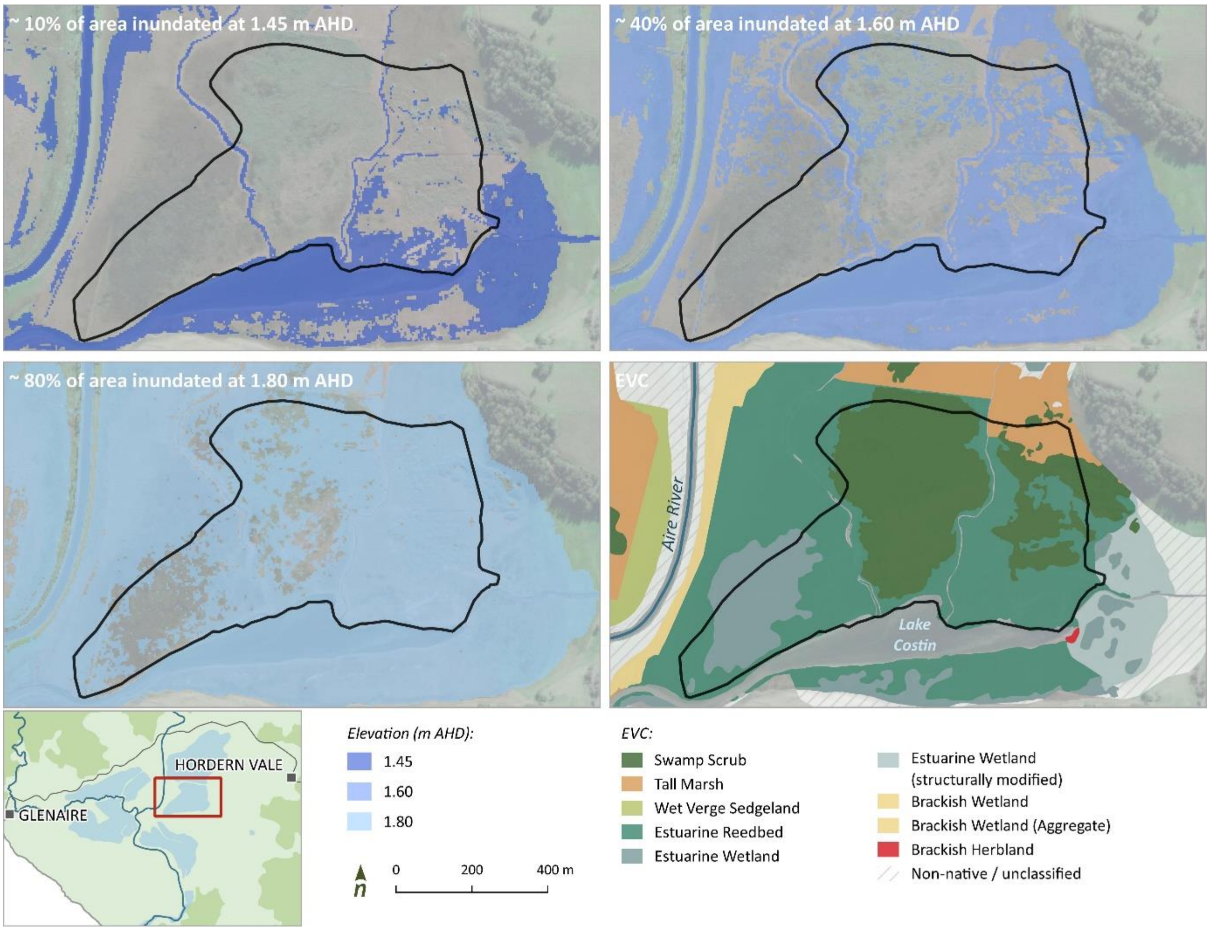


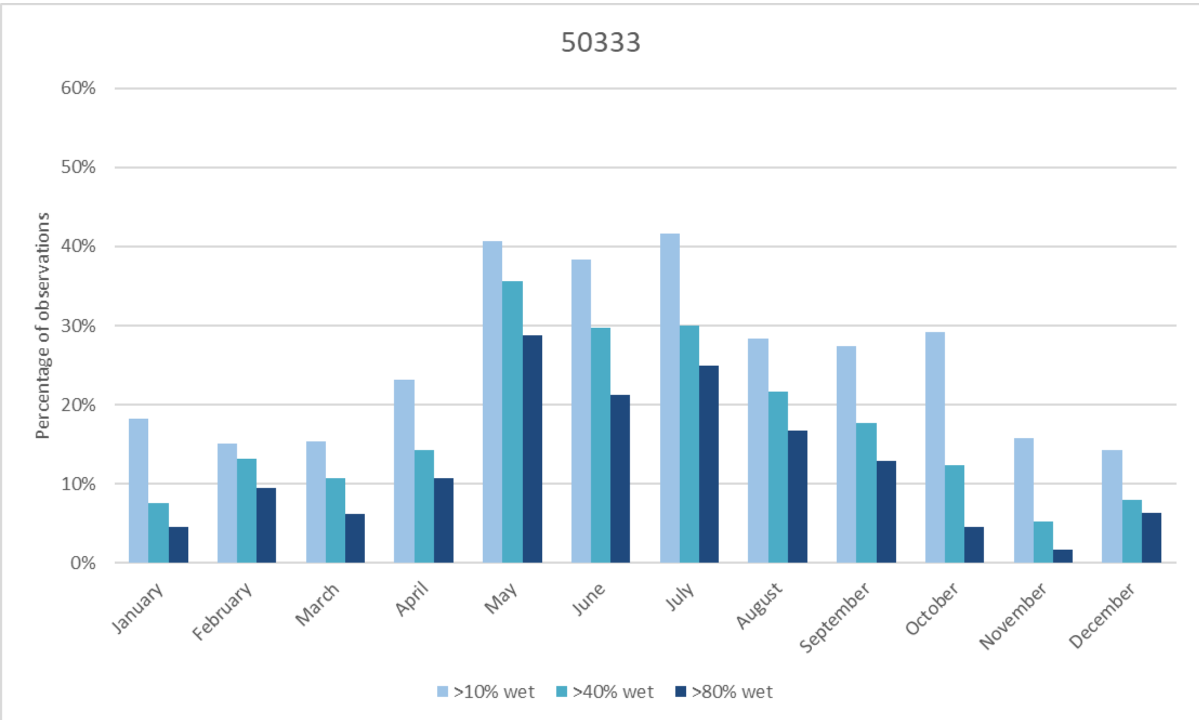
Wetland 50332





Wetland 50333





C3. EVC elevation analysis

To determine the elevation (m AHD) at which certain EVCs are inundated similar 'zonal statistics' analysis was undertaken on the EVC polygon layer for the Aire estuary. For each EVC zone the minimum, maximum and average elevation was derived, based on the 5m grid DEM.

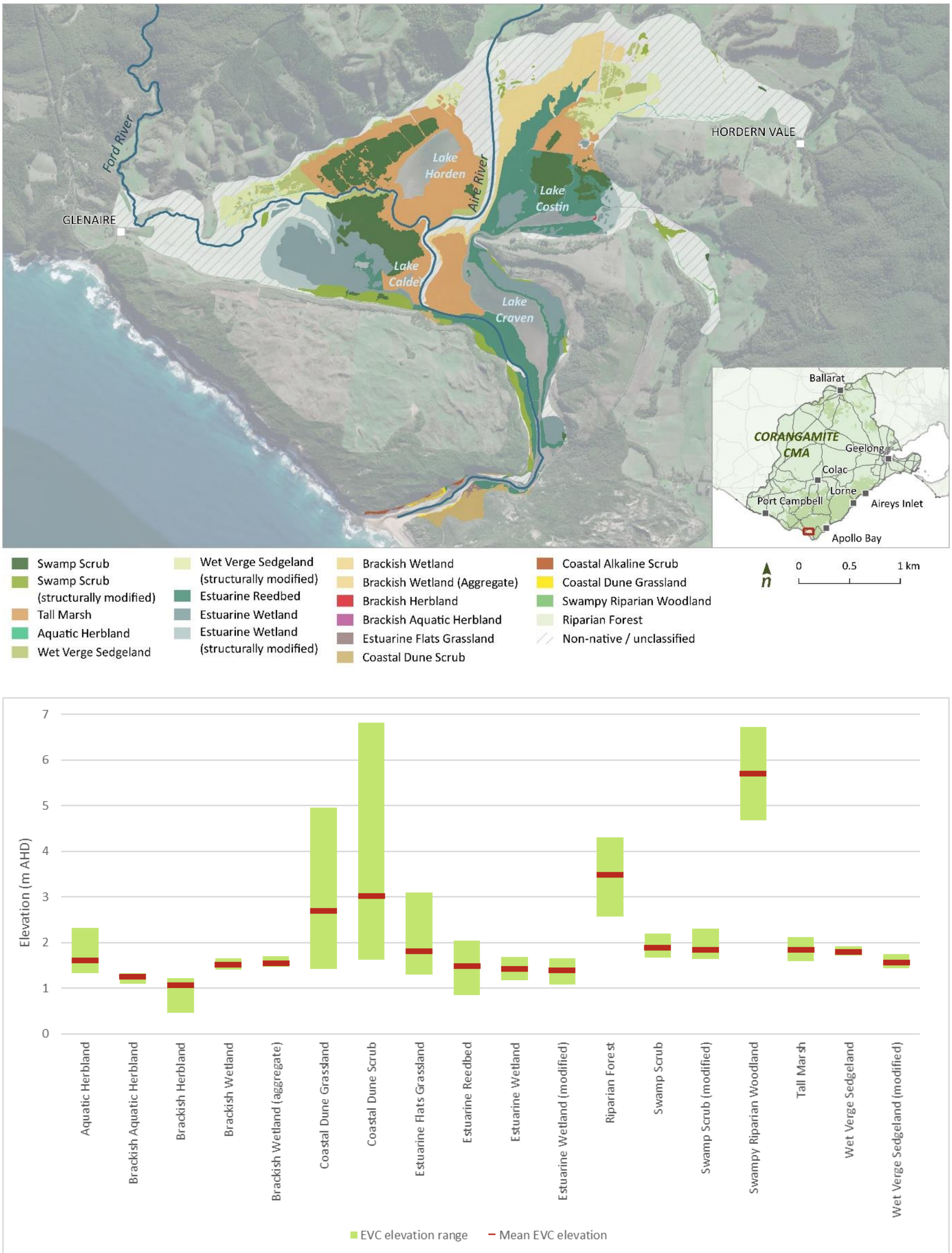


Figure 58. *Zonal elevation statistics for all mapped EVCs, with map of EVCs above*

Appendix D: Climate change and related impacts

The following table is an extract from the Approved Conservation Advice for Assemblages of species associated with open-coast salt-wedge estuaries of western and central Victoria ecological community and draws on the reference list provided below.

Table 24. Likely impacts of climate change on the salt-wedge ecological community (Department of Agriculture, Water and the Environment, 2018)

Climate Driver	Potential Impacts
Increased temperature	• Increased evaporation rates of shallow water bodies. • Decreased dissolved oxygen, with increased risk of hypoxia and fish kills. • Increased release of nutrients/toxicants from sediments into water column. • Altered rate of photosynthesis; productivity of estuary may be compromised. • Water temperature may exceed thermal tolerance of some species, which may lead to shift or decline in abundance and distribution of sensitive species. • Altered phenology, including reproduction, growth, metabolism, respiration, spawning, migration, dormancy, dispersal and community structure. • Loss of synchrony between fauna and food sources. For example, as temperature increases cues that fish respond to for spawning may not correspond with abundance of invertebrate hatching. • Changes to thermal stratification of water column may affect species distribution and movements. Increased stratification may result in lower abundance of zooplankton and increased incidence of jellyfish blooms. • Increased risk of invasive species (including algal blooms), pathogens and parasites.
Sea level rise	• Increased penetration of damaging waves to estuaries and low lying coastal ecosystems, causing erosion of protective dune barriers and sandbars at mouths, allowing greater marine influence. Existing wetlands may become lagoonal and new wetlands may develop in low lying areas. • Landward displacement of estuarine boundaries and riparian habitat, with increased saltwater intrusion upstream and altered estuarine tidal range. In some areas it may not be possible for the estuary to adjust range or position due to artificial barriers. • Altered periods of mouth closure; intermittently open estuaries may convert to more permanently open estuaries. • Nursery function of estuary (i.e. for fish, crustaceans) may be compromised.
Reduced rainfall	• Lower average runoff to rivers and estuaries resulting in reduced base inflows and altered frequency and reduced magnitude of outflows. • Altered entrance opening regimes with reduced erosion of sandbars at mouth. • Shallower freshwater layer in salt-wedge. • Increased marine component of estuaries, with marine zone moving further up into estuaries, when entrance is open to the sea. • Reduced flushing of estuaries resulting in increased retainment of poor quality water and increased risk of hypersalinity and anoxia and possible fish kills. • Reduced sediment inflows resulting in progressive erosion, saltwater inundation and reduced salinity stratification. • Reduced area of habitat for aquatic organisms. • Productivity and nursery function of estuary may be compromised. • Changes to dispersion and mixing of particulates, including pollution. • Altered phenology and species composition. • Loss of synchrony of species migration with entrance opening.
Extreme weather events	• Increased frequency of storm events, higher reach from storm surge and flash flooding may alter salinity distribution, affecting salt-wedge stability or lead to abrupt decreases in salinity.

Climate Driver	Potential Impacts
	• Increased periods of freshwater may affect sensitive estuarine species. • Extreme rainfall may result in increased runoff and sediment inflows to estuaries resulting in progressive infilling, enhanced estuary maturation, increased pollution, reduced water quality and eutrophication. • Stronger flushing influence of 'high flow' periods may result in increased loss of local communities and erosion, particularly at mouth. • Strong winds or cyclones may affect mixing, erosion, and wave climate.
Increased acidification	• Increased CO_2 concentration in seawater is resulting in more acidic oceans, affecting calcitic organisms, coastal food webs and productivity, with flow-on effects (physical and biological) to estuaries. • Heavy rain induced runoff from exposed acid sulphate soils may lead to acid flows into estuaries, affect plant and fish growth, and can lead to fish kills.
Increased fire and wind	• Increased frequency and/or intensity of aeolian dust and fire-born particulates can affect estuarine productivity and promote algal blooms. Similarly, more intense fires in catchments is likely to exacerbate runoff and sediment inflows. • Shifts in prevailing winds may influence surge frequency and wave climate.

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