



# Ayr Creek Lagoon Investigation and Options Analysis



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*Front cover image: An aerial image of Ayr Creek lagoon, June 2018, following a natural opening.*

# Project introduction

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## Background

Ayr Creek flows through a modified catchment of farmland and housing in Inverloch, Victoria before draining into a lagoon where the creek meets the beach at the edge of Anderson Inlet. The Ayr Creek lagoon formed in late 2014 following a natural build-up of sand at the southern end of the creek. Since formation, the lagoon has been predominantly closed, with only occasional breaches to the inlet.

The lagoon supports fish and crustaceans and a diverse assemblage of wading and shore birds. However, there has been excessive algal growth due to catchment and marine inputs and climatic conditions; the decomposition of this vegetation has created strong odours, particularly in summer. Local residents are concerned about the odours and have asked for a solution to the issue.

## Objective

The objective of this project was to work with community and agency stakeholders to investigate the causes of the Ayr Creek lagoon odour issue and to provide an options analysis for management.

This report summarises community concerns about the lagoon and its management, the aspects of the lagoon that the community values as well as community management goals for the lagoon. It describes the coastal processes involved in the formation of the lagoon, the underlying causes of the odour and other concerns and assesses a broad range of management options according to a consistent set of criteria.

This project will support the Bass Coast Shire Council (BCSC), West Gippsland Catchment Management Authority (WGCMA) and the community to responsibly care for the lagoon and minimise the odour issues for the next 5 years and beyond.

## Method

Project steps included:

- Meeting with representatives from the BCSC and the West Gippsland Catchment Management Authority (WGCMA) to discuss the history of the issue.
- Reviewing previous investigations and plans regarding Ayr Creek and the lagoon, its water quality, catchment impacts and nearby coastal processes.
- Undertaking a site visit to investigate lagoon and catchment characteristics and develop a deeper understanding of the factors that may be contributing to the odour.
- Hosting a community workshop (May 11<sup>th</sup>, 2018) to discuss lagoon concerns, values, goals, factors contributing to the issues and potential management actions.
- Summarising findings in a draft report along with an options analysis of potential management actions.
- Hosting a workshop in Inverloch with community members (June 22nd, 2018) to:

- summarise findings to-date regarding the issue and causes
- confirm community goals for the lagoon
- present the preliminary options analysis
- outline site constraints and opportunities and how these affect available options
- identify community preferences regarding management and monitoring actions, to help support council decision-making.
- Updating the draft report in response to community and council comments and finalising the options analysis.
- Submitting this final report to BCSC and WGCMA.

# Ayr Creek lagoon

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The formation of the Ayr Creek lagoon is a relatively recent phenomenon, arising from large shifts in sand along the coastline. This section steps through the formation of the lagoon, subsequent changes and associated events.

## Formation

The Ayr Creek lagoon is a relatively recent geomorphological feature inside Anderson Inlet. Coastal process studies that reconstructed the Inverloch foreshore from navigation charts and aerial photos from 1858 to 1998 make no mention of it (Vantree, 2000). A satellite image of the inlet from 2010 shows no lagoon present (see Figure 1 below).



*Figure 1 – Satellite image of Ayr Creek in 2010, showing no lagoon. The red arrow identifies the mouth of Ayr Creek (Source: Google Earth).*

Since December 2012 there has been gradual change in the alignment of the main entrance channel of Anderson Inlet, with it moving south and east away from the shoreline at Inverloch, together with the growth of a spit at Point Norman (Water Technology, 2016). It is thought that the spit and subsequent lagoon formed due to the eastern longshore drift of large amounts of sand from Main Beach (Water Technology, 2016).

Aerial photos from November 2013 show a large sand lobe forming a spit at Point Norman that had not been apparent in January 2012 (Water Technology, 2016). A year later, in November 2014, the spit had increased in size, curving in from Point Norman towards the shore near Abbott Street, cutting off the previous deep entrance channel (Water Technology, 2016) (see Figure 2 below).



*Figure 2 - Satellite image of Ayr Creek in January 2014, showing the spit curving in at Point Norman (identified by the blue arrow), but no lagoon. Note how the sand spit has blocked off the deep entrance channel (Source: Google Earth).*

The storm events during 2014 and 2015 resulted in major erosion of Main Beach and the undermining of adjacent dunes and this sand is thought to have contributed to the creation of the lagoon (Water Technology, 2016).

### Connection to Anderson's Inlet

Prior to lagoon formation, Ayr Creek ran out across the beach between Point Norman and Point Hughes into Anderson Inlet (Vantree, 2000; Oldfield, 2011; Water Technology, 2016). Now Ayr Creek runs into the lagoon.

Google Earth satellite images in June 2015 show that the lagoon had a small partial connection to Anderson Inlet over the sand bar formed by the spit in the south east, with the lagoon hard up against the dunes along the foreshore. The amount of sand in the sand bar continued to increase and in December 2015 there was a small partial connection to Anderson Inlet in the north east of the lagoon (see Figure 3 and Figure 4 below). There have been reports of the lagoon connecting to Anderson Inlet on large tides.



*Figure 3 - Satellite image of Ayr Creek lagoon in December 2015, showing the lagoon formed with a small connection to the inlet. Note the remnant of the former deep entrance channel as the dark area in the centre of the lagoon (Source: Google Earth).*



*Figure 4 - Satellite image of Ayr Creek lagoon in May 2016, showing shallow areas and the lagoon having a partial connection to the inlet (Source: Google Earth).*

The latest Google Earth satellite image in April 2017 shows no channel or shallow areas across the sand bar connecting it to Anderson Inlet (see Figure 5 below).



*Figure 5 - Satellite image of Ayr Creek in April 2017, showing no channel or connections to Anderson Inlet (Source: Google Earth).*

No obvious channel across the sand bar was observed during a site visit in May 2018, though there was evidence of one in June 2018 (see Figure 6 below). With the dynamic nature of the sand movement in Anderson Inlet, connections to the channel can be quickly filled in.



*Figure 6 – Connection channel to Anderson Inlet (June 2018). Photo courtesy of BCSC.*

The marine algae wrack along the lagoon shore, visible during a May 2018 site visit, provides evidence that marine water is also pushed into the lagoon over the sand bar (see Figure 7 below). This probably occurs during storm surge or high tides.



*Figure 7 – Marine algae wrack has been washed into the lagoon over the sand bar, likely during high tides or storm surge.*

The lagoon had a large opening to the inlet in late June 2018, due to the combined impacts of large swells of around 4.5 m, a high tide of 2.7 m, 66 km per hour gusts of wind and 43 mm of rain. The lagoon subsequently reduced in size by around 50% within a few days (see Figure 8 and Figure 9 below).



*Figure 8 - Looking east along the lagoon, areas of algae and wet sand show the waterline prior to the opening.*



*Figure 9 - Aerial image of the lagoon following opening in June 2018. Darker patches of sand show the extent of previous inundation. Photo courtesy BCSC.*

Increasing sand deposition on the sand bar has formed low hummocky dunes with encroaching vegetation (Water Technology, 2016) (see Figure 10 below). The vegetation acts to stabilise the dunes further. As the lagoon has formed, sand has continued to move north along the Inverloch shore, forming a wide sandy beach to Point Hughes, with the main entrance channel coming into the foreshore north of Point Hughes.



*Figure 10 – Low hummocky dunes with encroaching vegetation to the south of the lagoon (June 2018). Photo courtesy of BCSC.*

## Historical sand movement

Historical studies have shown that the eastern end of Main Beach extending around Point Norman is highly variable with large sand lobes at various locations at various times, and beach widths varying in places by over 100 m (Water Technology, 2016). The intertidal/subtidal platform of coffee rock at Point Norman partially anchors the coastline position and alignment.

The formation of a spit at Point Norman is highly variable, changing in form and extent over periods of weeks to years (Water Technology, 2016). Within Anderson Inlet, sand is moved along the northern Inverloch shore from the mouth. This is a long-term ongoing geomorphic process with Holocene (<15,000 years ago) aged sand ridges forming part of the terrestrial landscape north of the caravan park (Bird, 1993).

In the mouth of the inlet, the extensive sand bars and tidal channels meander through time between Point Norman and Point Smythe depending on wave conditions, tides, and river flows (Vantree, 2000; Water Technology, 2016). A very large amount of sand is moved around on the sandbars and in the channels during each tidal cycle (Vantree, 2000).

Another lagoon, "Toys Backwater", was present in a period roughly from the early 1960s to the early 1970s (see Figure 11 below), and was the venue for swimming lessons for local children.

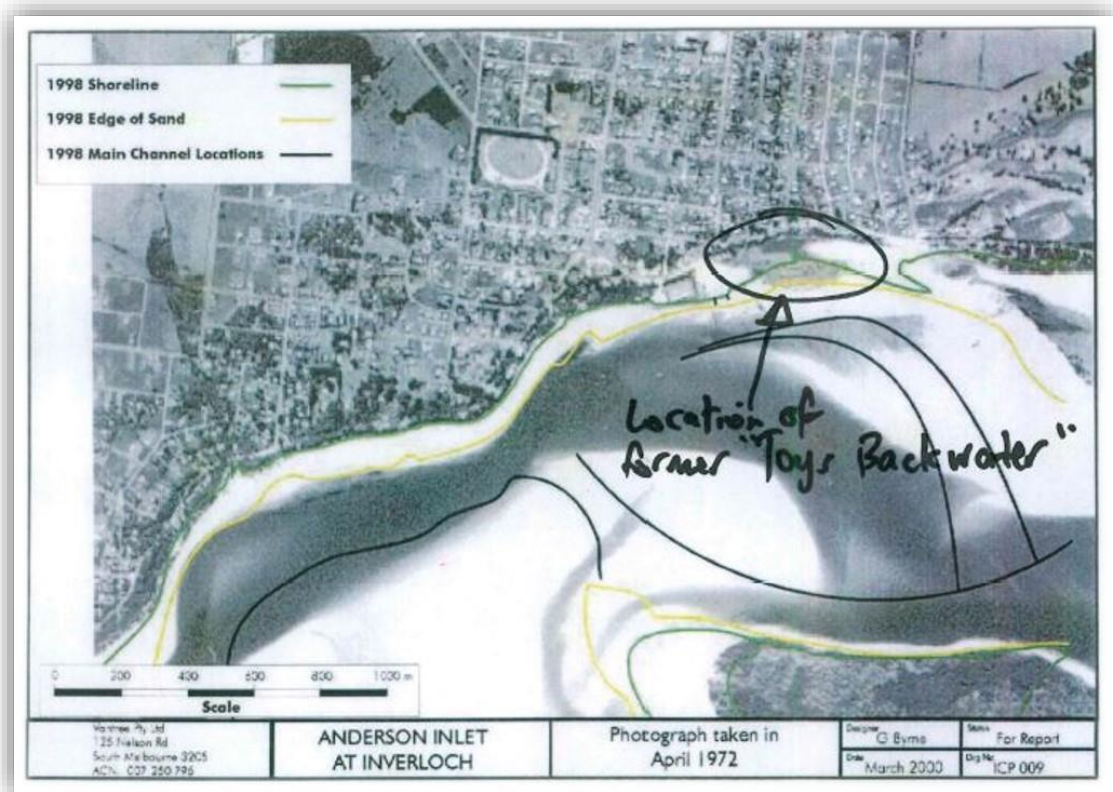


Figure 11 - Location of former Toys Backwater marked on an aerial image taken in April 1972. Photo courtesy BCSC.

## Coastal infrastructure

Building static infrastructure along the foreshore does not necessarily work well with the very dynamic nature of sand movement in Anderson Inlet (Vantree, 2000; Oldfield, 2011). Sand can cover the boat ramp and make it unusable in one or two tidal cycles (Vantree, 2000). It can move off beaches, uncover rock platforms and threaten beach stairs or other infrastructure as has happened at Abbott Street access point (Oldfield, 2011), Main Beach (Water Technology, 2016) and the Surf Beach (see Figure 12 below).



*Figure 12 - The Inverloch Surf Beach main access track following closure (July 2016). Photo courtesy BCSC.*

Various forms of erosion protection measures have been undertaken to stabilise the Inverloch foreshore over the years, including blue stone rocks and old tractor tyres (Oldfield, 2011; Water Technology, 2016) (see Figure 13 below). It is not known how long the Ayr Creek lagoon will exist, nor the role that climate change has played in its establishment.



*Figure 13 - Rock and tyres used for erosion protection.*

## Timeline: associated events

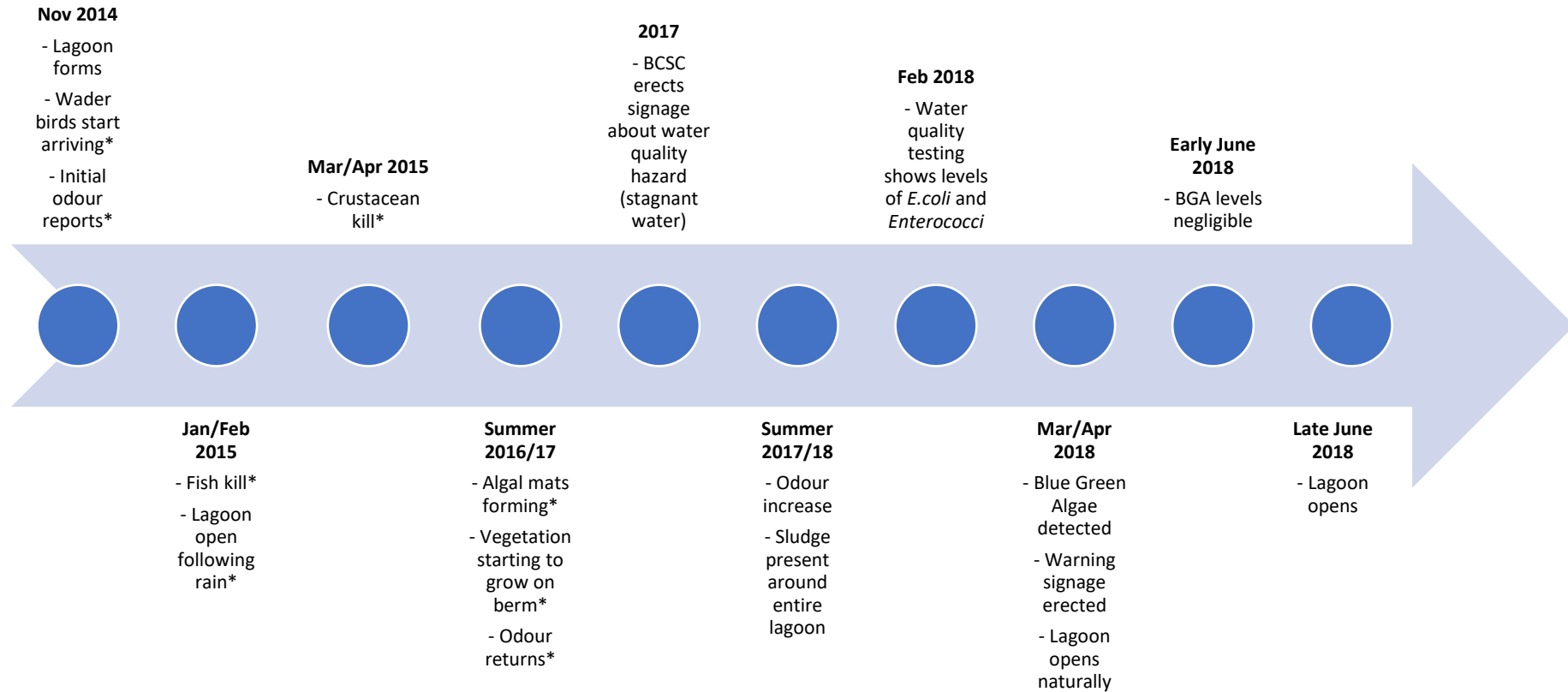


Figure 14 - The timeline above displays events associated with the lagoon. Community observations are marked with an asterisk (\*). Gradually over this period, the lagoon has been spreading and getting shallower (in response to king tides and rain events),

# Community perspectives

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Community perspectives regarding lagoon values, concerns and management goals for the lagoon were captured at a community workshop in May 2018. The workshop was attended by more than 50 community members, as well as representatives from the BCSC and the WGCMA.

## Values

The lagoon is appreciated by locals and tourist alike for a range of environmental and amenity values. The diverse range of birdlife the lagoon supports and the dynamic nature of the lagoon and associated coastal processes are particularly highly valued.

### Habitat for a diverse range of species

The lagoon provides feeding, nesting and/or breeding habitat for a range of birds, including internationally significant migratory waders and threatened beach-nesting bird species such as the Hooded Plover. The lagoon provides resources for these birds including: fish, plant material, mud and sand dwelling crustaceans; it is also likely to support other benthic macrophytes such as polychaetes and snails. The lagoon provides the community with an opportunity to view large numbers of international waders up close and to watch the changes in bird assemblage over time.



*Figure 15 - Oystercatchers in the lagoon, April 2018. Photo courtesy of Peter Hudson.*

Fish have also been sighted in the lagoon, these may be marine vagrants entering the lagoon on high tides or storm surges when there were connections to Anderson Inlet.

### Dynamic coastal change

The area is one of dynamic geomorphological change and locals value the opportunity to watch and experience the coastal processes associated with the formation and growth of the lagoon, an unusual coastal event.

## Ecosystem services

The community value the ecosystem services provided by the lagoon, particularly water filtration and erosion control (the build-up of sand between Point Norman to Point Hughes offers protection to public infrastructure from wave erosion).

## Amenity

The unusual and scenic nature of the lagoon is valued by photographers and walkers and provides opportunities for creative expression, such as the driftwood teepees that have appeared along the edge of the lagoon and foreshore.

## Concerns

Many locals, particularly those who live adjacent to the lagoon, are concerned the strong odours released during the summer months, Blue-Green algae (BGA) and poor water quality. Some other community members acknowledge these issues but are comfortable tolerating them.

### Odour

Residents report that the strong 'rotten egg' odours released during the hotter summer months are unpleasant and make it hard to enjoy the outdoor environment nearby, whether on the beach or on adjacent properties. This may also have an impact on tourism businesses – with some tourists perceiving that Inverloch is polluted due to the smell (see Figure 16 below).

### Blue-Green Algae

Water in the lagoon tested positive for the presence of BGA in March/April 2018. Locals are concerned about potential health impacts from human and animal contact (skin contact, ingestion and particulate/aerosol) with this and other potential pollutants in the water. Reduced water clarity is associated with the presence of BGA.

### Poor water quality

Nutrient and contaminant inputs in surface water run-off from farms, roads and domestic gardens combined with the lack of rainfall to flush the creek and lagoon can lead to poor water quality, making the water unsuitable for swimming.



Figure 16 - Strong odours and poor water quality are of particular community concern.

## Unknown nature of threats

The unknown nature of the potential threats was listed as a concern, with some community members uneasy about the lack of information provided regarding potential contaminants and associated impacts.

There were concerns that authorities were not undertaking enough monitoring of creek and lagoon water or follow up action to manage the issues listed above. The lack of knowledge about the permanence of the lagoon was also listed as a concern.

## Other

Other issues identified by the community are listed below:

- The introduced species Marram Grass, used to stabilise dunes due to its extensive rhizomes and dense clumps of grass, is present along the border of the lagoon. There is a concern that it is acting to stabilise the southern border of the lagoon, preventing further sand movement and therefore making the lagoon a more permanent feature. Some Melaleuca wood is also present on the foreshore, raising concerns that it could also be acting as a structure for sand build-up.
- Fish and crustacean kills have occurred in the lagoon.
- Mats of filamentous algae are present around the lagoon and are considered unsightly.
- Concerns were also raised about the potential for management interventions to threaten natural processes in the creek and lagoon.
- The current (May 2018) large extent of the lagoon has reduced the size of the available beach for recreation.
- Safety concerns have also been raised about unsafe access points – such as beach access stairs leading directly to water and the slimy edges being a slip hazard.

## Management goals

Preliminary goals were developed for the management of the lagoon at the May 2018 community workshop, based on the identified lagoon concerns and values. These goals are presented below.

Ayr Creek lagoon should be managed to protect:

- natural values such as birds and fish
- water quality
- amenity values
- public health and safety
- opportunities for natural processes to occur.

Responsible agencies should:

- Consistently collect and share information regarding risk (including water quality, potential health impacts)
- Clarify agency responsibility and jurisdiction
- Keep management costs reasonable.

Potential management actions were developed with these goals in mind.

## Responsibilities

Multiple agencies are involved in the management of the lagoon, depending on the area of responsibility.

### Bass Coast Shire Council

BCSC are the Crown Land Reserve Manager under the *Crown Land (Reserves) Act 1978* (Vic).

The BCSC Emergency Management Coordinator is the Local Water Manager under the South Gippsland Basin BGA Regional Coordination Plan 2016/17 (DELWP 2016). They are the Control Agency for minor to moderate blooms.

They are also the responsible authority for stormwater management and flood mitigation, including planning, installing and maintaining stormwater infrastructure and incorporating flood modelling results into the municipal planning scheme.

### West Gippsland Catchment Management Authority

WGCMA licences actions that impact the coastline or the bed and banks of waterways through the Works on Waterways (WoW) permit process, as an authority under section 67 of the *Water Act 1989* (Vic).

### Environmental Protection Agency

The EPA has responsibility under the *Environment Protection Act 1970* (Vic) to respond and investigate non-natural pollution events that impact water quality.

## Victorian Department of Environment, Land, Water and Planning

DELWP are the Crown Land landholder and must be consulted before any major works are undertaken.

# Main concerns: underlying causes

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This section outlines the processes underlying the lagoon issues, with a focus on the main community concerns of odour, Blue Green Algae and poor water quality.

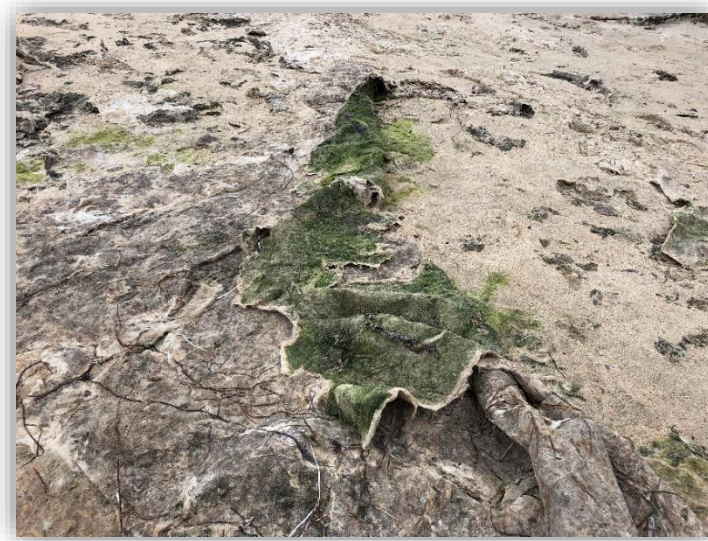
## Odour

Odours associated with the lagoon started soon after its formation, with the Clean Ocean Foundation taking water samples in response to concerns in December 2014. In April 2017, the local newspaper, the South Gippsland Sentinel Times, reported that smell had been an issue over the summer months for four years and had been gradually getting worse. This was confirmed by community members, noting that the odour was getting worse, and staying around for longer periods year on year.

The key cause of the odour is likely to be hydrogen sulfide (or 'rotten egg') gas, which was found to bubble up from disturbed sediments in the lagoon during a May 2018 site visit. Hydrogen sulfide is formed when organic matter decomposes in anoxic (low oxygen) conditions where sulfates are also present. Sulfates are found in sea water. At Ayr Creek lagoon, the presence of marine algae provides evidence of sea water overtopping the berm and entering the lagoon. Black sludge (metal sulphides) and white precipitate (sulphate) were also observed during the May 2018 site visit.

Anoxic conditions and odours are not unusual in estuaries and their terminal lagoons and are a natural part of the cycle of where these fresh and marine waters mix (Barton et al. 2008; Pope et al. 2015; Alluvium, 2015). A wedge of saltwater builds up below the freshwater, leading to stratification of the lagoon and low dissolved oxygen levels, limiting the survival of most aquatic species.

Organic matter is present both from catchment and marine inputs (vegetation) and from algae deposited during previous summer months. Mats of green, filamentous algae are accumulating each year, particularly along the north east shoreline, most likely pushed there by the wind (Figure 17). The increase in the duration of the odours may be due to the legacy of the previous summer's algal production, particularly the large mats of filamentous algae observed, providing increased organic matter for breakdown.



*Figure 17 - Mats of filamentous green algae are accumulating in the lagoon each season.*

The wide, mostly shallow lagoon provides a warm environment, accelerating the decomposition of organics and production of hydrogen sulfide, which is exacerbated during the warm summer months, leading to observable levels of the gas. In summer, with warm water temperatures and low winds the lagoon is likely to stratify with warm water on top of cooler, denser brackish or marine waters. This stratification and lack of wind generated mixing can lead to the bottom waters becoming anoxic. Stratified waters are also associated with increased growth or dominance of BGA.

### **Health risk**

Hydrogen sulfide can be detected at levels well below those that cause health impacts. Hydrogen sulfide can be harmful to human health, with risks ranging from mild irritation to death at extreme levels). It is denser than air and can pool in low areas during stagnant conditions.

## Blue-green algae

Though commonly called algae, BGA are actually a type of native cyanobacteria that photosynthesises. Under appropriate conditions (the presence of nutrients in a low nitrogen:phosphorus ratio, stratification, warm still water), they can multiply to high levels, forming “blooms”, usually a dark green to yellowish colour, sometimes turning bluish when dying.

At Ayr Creek lagoon, the shallow water allows high penetration of sunlight. The nutrients are likely to be entering the creek from the surrounding catchment (e.g. fertiliser application to lawns, animal faeces from farms) and the washing in of marine vegetation. The lagoon has become a relatively large, shallow body of water within Anderson Inlet with limited water exchange creating a long residence time. Rainfall in early 2018 was low, with very low flows from the creek that had little capacity to dilute or flush the lagoon. Warm, still conditions during summer exacerbate the issue.

BCSC water samples taken on the 24<sup>th</sup> April 2018 showed that the lagoon water at Abbott Street had three species of BGA (*Geitlerinema*, *Planktolyngbya* and *Phormidium*), with the latter present in noteworthy levels. Some species of *Phormidium* are known or suspected to be potentially toxic. The laboratory noted that the BGA levels were sufficient to influence water quality but should not pose a health concern. The water sample taken near the stairs adjacent to Norman Street contained only low counts of *Phormidium*. The laboratory noted that those levels are insufficient to have any impact on water quality.

### Health risk

BGA blooms can persist for weeks to months, depending on the weather conditions. As the bloom dies, it releases toxins into the water. These can persist for up to three months before degrading. Contact with the blooms can cause health problems for people and animals and should be avoided. Issues have included skin and eye irritation, and nausea, vomiting, and muscle weakness when swum in or swallowed (CSIRO, 2018). They can also form resting cells that allow the BGA to survive on the bottom of the lagoon in unfavourable conditions.

When BGA is detected, BCSC erects signs around the area warning beach users to avoid contact and notifies the relevant authorities (Figure 18 below). Management of BGA blooms is managed under the South Gippsland Basin Blue-Green Algae Regional Coordination Plan.



Figure 18 - Signage at a beach access point, warning beach users about the presence of Blue-green algae (April 2018)

## Poor water quality

In 2014, the bacteria *Enterococci* were found to be present in the lagoon, but at concentrations well below EPA standard trigger thresholds for action. *Enterococci* is a bacteria group found in the intestines of warm-blooded animals. It is used as an indicator of possible faecal pollution, usually from native birds and domestic dogs. Community members also undertook water quality testing of lagoon water near the Surf Parade bridge in February 2018, with the samples showing elevated levels of *E.coli* and *Enterococci*.

If levels are very high, or moderately high for two consecutive samples at public beaches within Port Phillip Bay, the EPA recommends that signs are erected warning users not to swim, additional monitoring is undertaken, and a field investigation may be undertaken to look into potential causes such as stormwater discharge and other potential sources of contamination such as public toilets (e.g. blocked toilets), the presence of bird roosting areas, the accumulation of seaweed, and the number of bathers and dogs using the site (EPA, 2011).

### Ayr Creek lagoon catchment

Ayr Creek is a small freshwater system primarily fed by overland flow and storm water drainage from an increasingly urbanised catchment in the township of Inverloch (HEC, 2002; BES, 2009; ASM, 2016). The Ayr Creek catchment is 255 Ha, with ~ 140 Ha in agricultural land upstream of the Bass Highway, with no natural channel evident above Nesci Court (ASM, 2016). Little Screw Creek catchment has been diverted into Ayr Creek (BES, 2009).

The lower part of Ayr Creek flows within a council-owned and managed drainage reserve. Over the last 20 years there have been significant community projects, led predominantly by the South Gippsland Conservation Society in partnership with the BCSC and the WGCMA, to construct a stormwater treatment wetland and revegetate the riparian zone within the creek reserve. These act to slow and filter flows down the creek and support denitrification (wetland) and filter overland flows (riparian vegetation). Macrophytes that grow in the wetlands take up nutrients from the water and are actively harvested to remove those nutrients from the system.

Water, nutrients, sediment and contaminants can enter Ayr Creek lagoon from the creek through stormwater connections (particularly between Surf Pde and Royal Pde, below the wetland connection, or from higher in the creek during high flows which bypass the wetlands). These accumulate in the lagoon, which acts as a settling pond, catching the stormwater.

Nutrient sources may include:

- Inputs from properties, such as fertiliser, herbicide, paint and detergents.
- Sediment from road works, building sites, erosion.
- Nutrients from abundant birdlife.
- Effluent from dairy farms upstream

## Other

### Fish and crustacean kills

At least one fish kill and crustacean kill were noted by the community, both in early 2015, not long after formation of the lagoon. The fish were noted as being juvenile Silver Trevally, a species that inhabits estuarine and coastal waters.

Potential causes include low dissolved oxygen (which is associated with algal blooms and increased water temperatures as well as the oxidation of hydrogen sulfide) or variable dissolved oxygen due to algal photosynthesis during the day producing high oxygen levels which are then used up by algal respiration at night; salinity stress due to freshwater inputs; clogging of the gills by algal blooms; or a combination of these factors.

# Management options analysis

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## Site constraints

The Ayr Creek lagoon is a dynamic and complex site and there is not an easy 'silver bullet' solution to the issues of lagoon odour and the other main concerns outlined by the community. Management constraints include:

- The dynamic, unpredictable nature of the lagoon (fluctuating size, water quality, the impact of storms, difficult to predict longevity).
- The lagoon's large size (lots of sand and water to move/treat).
- The combination of both catchment and marine influences (inputs from both, variable salinity both spatially and temporally).
- The need to protect ecological values (such as significant bird species).
- Works on waterways (WoW) permits are required from the West Gippsland CMA for many of the options.
- Many options are expensive and will need to be repeated.
- There is minimal historical water quality data available.

## Management options

There are a range of options that can be undertaken to manage the odours, poor water quality and presence of BGA, but it is likely that a combined approach, underpinned by monitoring will have the most success. A sound understanding of the physical size and volume of the lagoon and changing water quality conditions due to weather and catchment and coastal impacts would allow management actions to be targeted for optimum success as well as provide a clearer picture of the level of resourcing required.

A multitude of management options were assessed, under the themes of:

- physical manipulation of the lagoon site
- water quality treatment in the lagoon
- addressing catchment impacts
- improving knowledge and
- communicating.

Options were assessed by which issue it addresses, the potential for success, the likely longevity of any success, the potential for secondary benefits, resourcing implications, associated risk and the potential for community involvement.

All options assessed are provided in Appendix A and are presented alongside supporting actions that could be used to develop understanding of lagoon physical and water quality characteristics. An abbreviated list of options to be considered further is provided below. These options have a focus on addressing the lagoon odour but are likely to improve other interlinked BGA and water quality issues as well. Short-term, intensive options (remove algal mats, aerate, treat with activated clay or carbon) are presented to address the issue quickly, alongside an ongoing communication action and

a longer-term, less-intensive option (manage catchment impacts). 'No intervention' is also presented as an option.

### Community preference

As the catalyst for this investigation and options analysis was the community's concern about the lagoon's odour, the community was presented with the short-list of management options at a second project workshop (held in June 2018) and asked to rate their preferences.

Removal of algal mats and addressing catchment impacts were the two equally preferred options. Monitoring and communicating risk was also well rated. The community's non-preferred options were aeration and treatment with activated clay (Phoslock)/carbon (The Water Cleanser).

Community preferences for management options are presented as one more piece of information to help BCSC determine which course of action to undertake, along with cost, protection of values, feasibility etc.

### Recent weather events

Large ocean swells and high tide over winter 2018 have resulted in major changes to shape, depth and bathymetry of the lagoon. In June 2018, there was a large storm surge which resulted in the lagoon opening naturally to the ocean. This led to a flushing off the lagoon, which allowed the ocean to enter the lagoon and remove the build-up of nutrients.

In July, there were several storm surges which again flushed the lagoon and kept a constant connection with the ocean. During August, the lagoon has been permanently connected to the ocean due to large tides and high rainfall.

## Short list of management options

The top 3 management options are presented in order of community preference. It should be noted that a comprehensive approach would include the implementation of a package of options together as they address different aspects of the issue. For example, the removal of algal mats takes out a store of existing nutrient in the lagoon, while the application of activated carbon kickstarts microbial activity that process nutrients, addressing catchment impacts reduces future delivery of more nutrients and monitoring and communicating risk enhances community piece of mind about the issue.

### Remove algal mats

**Description:** When the lagoon water level is low, physically remove the build-up of algal mats from previous summers (see Figure 19 below).

**Rationale:** The build-up of organic matter is acting as a reservoir of nutrients – leading to worsening odour and longevity each year.

#### Pros:

- Opportunity to access the mats now that water level is reduced (winter 2018).
- Reduce organic load, a key source of hydrogen sulphide generation.
- Reduce slip around lagoon.
- Allow oxygen exchange between sediment and the water column.

#### Cons:

- Expensive (approximately \$30 000)
- Will need to be timed outside of beach-nesting bird breeding periods, or otherwise carefully managed.
- Requires a works on waterways permit.
- Will need to be repeated after excessive algal growth.
- Disruption of the natural ecosystem.



*Figure 19 - Algal mats along the north eastern shoreline of the lagoon, June 2018.*

## Address catchment impacts

**Description:** Undertake a proactive communication program regarding the protection of stormwater (e.g. proper management of animal faeces and disposal of wastes, reduction in private fertiliser and herbicide use in gardens). Undertake riparian management actions (such as planting buffer strips to filter overland flows of water to the creek, and water sensitive urban design solutions such as rain gardens) (see Figure 20 below).

**Rationale:** The catchment (urban and rural) is a source of nutrients and pollutants to the creek, which accumulate in the lagoon and drive the processes that result in odour, BGA and poor water quality.

### Pros:

- Improves the water quality, habitat values and amenity of Ayr Creek, as well as the lagoon.
- Empowers community members to help provide a solution.
- Existing or in development plans (such as the Ayr Creek Management Plan and the BCSC integrated water management plan) provide direction and actions that can assist this goal.
- Relatively inexpensive.

### Cons:

- Behaviour change can be a difficult, long-term process.
- Much of the stormwater is piped directly to the creek, bypassing the possibility of filtration by buffer strips.
- There is already a significant store of nutrients in the lagoon (algal mats) that will also need to be addressed.



*Figure 20 - Existing water treatment in the catchment (stormwater wetland (left), riparian vegetation (right)).*

## Monitor and communicate risk

**Description:** Proactively monitor water quality of creek and lagoon during higher risk times (particularly summer). Communicate water quality issues and any associated risk to beach goers as required (signage at access points, with symbols, map of affected area, present in multiple languages) (see Figure 21).

**Rationale:** Community members expressed concern that health risks were not adequately known or communicated, leading to tourists and locals swimming in the water during unsafe periods.

**Pros:**

- Reduced risk of adverse health outcomes.
- Peace of mind.

**Cons:**

- Ongoing testing is costly and requires staff resources.
- Raises community expectations and assumption of consistently 'good' water quality within a naturally variable system.



Figure 21 – 'No swimming' icon for beach warning signs. Icon courtesy EPA.

## No intervention

**Description:** Continue to monitor, but don't intervene unless major risk to other values/assets.

**Rationale:** The lagoon and coastline are dynamic, and it is difficult to predict the lagoon's longevity and changes in volume and water quality. For example, it has appeared and grown in recent years, may disappear of its own accord, and has recently flushed and massively shrunk in response to weather.

**Pros:**

- No impact to natural values.
- Low cost.

**Cons:**

- There may be several more summers of odour and water quality issues.
- Does not meet the expectations of some community members.

# Conclusion

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The Ayr Creek lagoon formed in late 2014 following the accumulation of sand at the mouth of Ayr Creek, a result of dynamic coastal processes. The lagoon shape and size has continued to grow, with seasonal fluctuations and occasional large and small openings to Anderson Inlet.

The lagoon supports ecological values such as significant wading and shore bird species and these, as well as the opportunity to watch the dynamic coastal processes at play, is highly valued by some community members.

The decomposition of organic matter and stratification of the water column in deeper areas of the lagoon has led to the formation of hydrogen sulfide (or 'rotten egg') gas. This is exacerbated in summer due to weather conditions and is of significant concern to sections of the community. This issue has seemed to increase over the past 3 years, likely due to the accumulation of algal mats acting as a reservoir of organic matter for decomposition. The lagoon has also had periods of poor water quality, with elevated levels of *E.coli*, *Enterococci* and BGA in the late summer and early autumn of 2018.

Management of the odour issue is complex, with no 'silver bullet' solution available. Site constraints include the unpredictable nature of the lagoon, its large size, the combination of marine and catchment influences, the need to protect ecological values, applicable regulations and the high cost of intervention.

There are a range of options that can be undertaken to manage the odour, poor water quality and presence of BGA, but it is likely that a combined approach, underpinned by a sound understanding of the lagoons size and water quality at the time of action will have the highest chance of success.

Options were assessed by which issue it addresses, the potential for success, the likely longevity of any success, the potential for secondary benefits, resourcing implications, associated risk and the potential for community involvement.

A short list of options to be considered further was presented to the community to capture community preference as an additional piece of information to help BCSC determine the most appropriate way forward. Preference was equally for removing the build-up of algal mats and addressing catchment impacts. Monitoring and communicating risk was also well rated. If implemented together, these options would compliment each other, each addressing different facets of the issue and each with additional benefits.

A 'watch and wait' approach (no intervention) is also a viable option. The June 2018 major opening event and subsequent lagoon shrinkage as well as the appearance and eventual disappearance of previous lagoons demonstrates the dynamic nature of this coastline and the potential for the issue to resolve itself.

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# Appendix A: full list of considered management options

Table 1 - Management options analysis for Ayr Creek lagoon.

Option	Description	Which issue it addresses	Potential for success	Longevity	Secondary benefits	Resourcing (per occurrence) <i>Low &lt;\$1000</i> <i>Med (\$1000 - \$10,000)</i> <i>High \$10,000 - \$50,000</i> <i>Very high &gt;\$50,000</i>	Risks/off-target impacts	Should it be considered further as a management option?	Potential for community involvement
Do nothing	no intervention in lagoon functioning.	none	low	years	Allow opportunities for natural processes to occur	Low	Risk of continued water quality, odour and BGA issues	Yes	n/a
<b>Water quality treatment in the lagoon</b>									
Physical active aeration of the lagoon water	Increase oxygen & disrupt stratification in the lagoon with physical aerator (bubbler or fountain) in the lagoon.	Odour Water quality BGA	Medium. Possibility the infrastructure could be compromised or covered with sand	Weeks. Have to be activated during spring & summer when lagoon starts to stratify or low mixing	Does not interfere with natural geomorphic processes	Medium to high, need quote based on current volume of the lagoon.	Disturbance of wading & shorebirds when active.	Yes	No
Treat with activated clays	CSIRO developed product Phoslock, which is added to the lagoon to capture & lock up phosphate permanently removing it as potential food for algae. Treatment should occur in late autumn or winter. Developed for freshwaters <a href="http://www.phoslock.com.au">http://www.phoslock.com.au</a>	Odour Water quality BGA	Medium to high. Currently have an enquiry to the company to see if it can work in marine or brackish waters. Could undertake proof of concept monitoring at a small scale quite cheaply.	Years. Phosphate captured permanently would probably need to be done for a couple of years while Ayr Creek water quality improves	Does not interfere with natural geomorphic processes	Medium to high, need quote based on current volume of the lagoon.	Settlement of the Phoslock onto the bottom of the lagoon makes it less attractive to wading or shorebirds for feeding.	Yes	No
Treat with carbon	Treat with Marine Easy Clean's "The Water Cleanser - Industrial". This is a relative passive treatment were wax blocks containing carbon & other trace mineral are put in Ayr Creek & lagoon to promote the growth of <i>Bacillus</i> bacteria which then reduce nitrogen. Has been used successfully in waste water treatment ponds.	Odour Water quality BGA	Medium to high. Could undertake proof of concept monitoring at a small scale quite cheaply.	Years. Would probably need to be done for a couple of years while Ayr Creek water quality improves	Does not interfere with natural geomorphic processes	Medium to high, need quote based on current volume of the lagoon.	None known	Yes	No
<b>Physical manipulation of the lagoon site</b>									
Clean up algal mats	When lagoon water level is low, physically remove the build-up of algal mats from previous summers	Odour Water quality BGA	Medium Will reduce organic matter load, a key source of hydrogen sulphide generation	Will need to be repeated every year after there has been excessive algal growth	Will reduce slip risk around the lagoon Will improve the appearance of the lagoon Allow oxygen exchange between surface and sand, supporting macroinvertebrates	High (previous quote for \$27,000)	Potential impacts to beach nesting birds. Avoid Hooded Plover nesting period – August to March.	Yes	n/a
Dredge a connection between the lagoon and Anderson Inlet	Dredging a connecting channel between the lagoon and Anderson Inlet to allow the lagoon water to mix & exchange	Odour Poor water quality BGA	Low would depend on gravity rather than creek flow	Days to weeks (channel would not be permanent). Needs to be done on a falling tide & calm sea state. Flows in the creek would increase	If done at the right time could allow for fish migration & could allow for the filamentous algae to be removed from the shoreline.	High	Fish kills, no water mixing, drainage to muddy anoxic puddle	No A WoW permit would not be issued by the WGCMA for an opening	No

Option	Description	Which issue it addresses	Potential for success	Longevity	Secondary benefits	Resourcing (per occurrence) <i>Low &lt;\$1000</i> <i>Med (\$1000 - \$10,000)</i> <i>High \$10,000 - \$50,000</i> <i>Very high &gt;\$50,00</i>	Risks/off-target impacts	Should it be considered further as a management option?	Potential for community involvement
				chances of success.					
Pump out lagoon	Pump out the water in the lagoon over the sand bar into the entrance channel of Anderson Inlet	Odour Water quality BGA	Low	Weeks to months	Would allow removal of filamentous algal mats. Would allow assessment of the bathymetry of the lagoon.	High, large volume of water to remove.	Large volumes of nutrient rich water pumped into Anderson Inlet, would want to do it on a falling tide to maximise it going out to sea & not up into the inlet.	No	
Fill in the lagoon	Filling lagoon in with sand	Odour Poor water quality BGA	Medium to low. It would require vast amounts of sand	weeks	Create a wide beach (at least initially) & protect the dunes	Very high	Danger of sand moving & impacting some other Anderson Inlet natural value	No A WoW permit would not be issued by the WGCMA for this action.	No
Pipe Ayr Creek to Anderson Inlet	Create a channel or install a large pipe to take the water from Ayr Creek directly to Anderson Inlet	Odour Poor water quality BGA	Low, pipe or channel could sand up. Difficult to deal with potential flood volumes	years	could allow for fish migration if designed for fish passage	Very high	Still leave lagoon as is	No A WoW permit would not be issued by the WGCMA for this action.	No
Remove weeds on sand bar	Manage weeds and vegetation on the sand bar to facilitate natural sand movement	Indirectly odour, poor water quality, and BGA by facilitating the eventual disappearance of the lagoon	Low to medium	Months to years	Help maintain habitat (bare sand) for hooded plovers	Medium to high, would probably need hand weeding	Disturbance of Hooded Plovers; need to be done outside of breeding season	Maybe	Yes
<b>Address catchment impacts</b>									
Riparian management	Plant increased riparian vegetation along creek and drainage lines to filter overland flows	Poor water quality BGA	Low – will contribute to improved WQ	years	Habitat values	Low – medium	n/a	Yes	Yes
Improve stormwater planning controls	Stormwater management (e.g. council housing development practices – not providing sufficient setbacks to creek)	Poor water quality Odour BGA	Low. Will not address current lagoon water quality	years	Improve lagoon & creek water quality in the long term.	High	Still leave lagoon as is	Maybe. Will not address current impacts (legacy of previous planning controls), could assist with further development in the catchment.	
Address sewage blockages	Make sure there is no sewage entering Ayr Creek	Poor water quality Odour BGA	Low – will contribute to improved WQ	Months – years	no	Medium – high	n/a	No. Nearby sewer mains have been relined relatively recently.	no
Divert stormwater to sewage treatment works	Separate stormwater system (e.g. like sewerage)	Odour Poor water quality BGA	Low. Difficult to deal with potential flood volumes	years	no	Very high (hundreds of thousands of dollars)	Still leave lagoon as is	No	No
<b>Communicate</b>									
Community education re the catchment	Proactive information about protection of stormwater by reduced application of garden fertiliser etc.	Poor water quality Odour BGA	Low – will contribute to improved WQ	Months – years	Improved health and amenity of Ayr Creek	Medium	n/a	Yes	yes
Raise awareness of lagoon values	Raise awareness & celebrate the lagoon, appropriate to risk level (e.g. brochures from BirdLife Australia., signage that is dynamic & digital	Unknown nature of threats	Low	Ongoing	Increased community and BCSC knowledge of lagoon values and processes	Medium to high	n/a	Yes	Yes

Option	Description	Which issue it addresses	Potential for success	Longevity	Secondary benefits	Resourcing (per occurrence) <i>Low &lt;\$1000</i> <i>Med (\$1000 - \$10,000)</i> <i>High \$10,000 - \$50,000</i> <i>Very high &gt;\$50,00</i>	Risks/off-target impacts	Should it be considered further as a management option?	Potential for community involvement
	communication as well); tourism opportunity – need for coastal interpretation, bird interpretive display on bridge, explaining the significance								
Communicate risk	Communicate WQ & risk – signage with symbols, multiple languages, map of area of concern/to avoid – at the times required	Unknown nature of threats	Medium	Needs BGA monitoring to be undertaken	Increased community trust, increased safety	Low to medium	n/a	Yes	no

Table 2 - Supporting actions to develop understanding of lagoon physical and water quality characteristics.

Supporting Actions								
Supporting action	Description	Which issue it addresses	Timeframe	Secondary benefits	Resourcing (per occurrence) <i>Low &lt;\$1000</i> <i>Med (\$1000 - \$10,000)</i> <i>High \$10,000 - \$50,000</i> <i>Very high &gt;\$50,00</i>	Risks	Should it be considered further?	Potential for community involvement
<b>Improve knowledge of the size, volume and changes in time of the lagoon</b>								
Photo points	Undertake monitoring of the size of the lagoon, either permanent (on bridge, navigation aid) or transient (opportunistic from post on access stairs). The transient method could be done by volunteers & uploaded to a website.	Unknown nature of threats. Will improve knowledge of the changes in size of the lagoon	On-going. Would allow photos at high & low tides daily. Volunteers would be less frequent.	Will support other management interventions, e.g. providing data to guide opening of the lagoon	Medium, interpret photos & co-ordinate volunteers	For best use, there would need to be a survey of the lagoon so that the photos can be interpreted. Volunteer safety must be addressed	Yes	Yes
Detailed geomorphic investigation of the lagoon	Investigate/model local coastal processes to understand how long the lagoon is likely to be present.	Unknown nature of threats	Once off	Will support other management interventions, e.g. to actively manage or not	High, needs to be done with high level of expertise	n/a	Maybe	No
Regular mapping of lagoon edge	The waterline of the lagoon would be mapped by walking around with a handheld GPS.	Unknown nature of threats. Will improve knowledge of the changes in size & position of the lagoon	On-going. Allow comparison of surface area over time. Help interpretation of photo points	Will support other management interventions, e.g. providing data to guide opening of the lagoon	Medium, needs purchase of the GPS & either volunteers or staff. Also need someone to interpret the data.	Need work safety plan	Not required, aerial imagery already owned by BCSC	Yes
Sand bar height & width survey	Survey of the size, width & position of the sand bar.	Unknown nature of threats. Will help understand the possible longevity of the lagoon	Allow assessment of the current sand bar & could allow future comparison	Will support other management interventions, e.g. providing data to guide opening of the lagoon	Medium, needs to be done with high level of expertise	n/a	No, only required if lagoon was to be opened, and/or if the lagoon was causing flooding	No
Bathymetric survey of the lagoon	Sounder survey of the lagoon to determine bathymetry & therefore volume.	Unknown nature of threats. Will help understand the possible longevity of the lagoon	Allow interpretation of photo points & GPS mapping.	Will support other management interventions, e.g. providing data to guide opening of the lagoon, or for Phoslock treatment.	High, needs to be done with high level of expertise	n/a	No, this level of detail not required	No
<b>Improve knowledge of Ayr Creek and lagoon water quality</b>								
Water physio-chemical monitoring	Regular monitoring of the salinity, dissolved oxygen, pH & temperature of both creek & lagoon.	Unknown nature of threats. Will improve knowledge about the issue and risk level	Will need to be repeated at weekly intervals during high risk times (spring & summer)	Will support other management interventions, e.g. providing data to guide opening of the lagoon, proactively communicating risk levels to community, increasing knowledge of the dynamics of the lagoon, determine if the lagoon thermally or salinity stratifies could inform turning on the aerator	Medium, needs water quality meter & boat access onto the lagoon	Workplace safety plan needed. Two people needed for lagoon sampling by boat	Yes	Yes Waterwatch EstuaryWatch
Continual dissolved oxygen monitoring of Ayr Lagoon	Continual monitoring of DO (telemetry feed for easy data download) of Ayr Lagoon. Also add temperature, salinity & water height for improved data interpretation.	Unknown nature of threats	On-going	Will support other management interventions, e.g. providing data to guide opening of the lagoon, communicating risk levels to community, increasing knowledge of the dynamics of the lagoon	High, a logger must be purchased & installed. Data needs to be interpreted. Possible risk of loss of logger by being buried in the sand	n/a	Yes	No
Water nutrient monitoring Ayr Creek and lagoon	Regular monitoring of the nutrients nitrogen & phosphorus in the water of the creek and lagoon & regular sharing of this information with the community.	Unknown nature of threats	On-going	Will support other management interventions, e.g. communicating risk levels to community, increasing knowledge of the dynamics of the lagoon	High, the lagoon would need to be sampled by boat, analytical costs.	n/a	Yes	No
Blue-green algae sampling of Ayr Creek & lagoon	Regular monitoring during spring and summer of the creek & lagoon & regular sharing of this information with the community.	Unknown nature of threats. BGA health risks.	Annual, spring & summer in high risk time	Will support other management interventions, e.g. communicating risk levels to community	High, the lagoon would need to be sampled, analytical costs.	n/a	Yes	No

Supporting Actions								
Supporting action	Description	Which issue it addresses	Timeframe	Secondary benefits	Resourcing (per occurrence) <i>Low &lt;\$1000</i> <i>Med (\$1000 - \$10,000)</i> <i>High \$10,000 - \$50,000</i> <i>Very high &gt;\$50,00</i>	Risks	Should it be considered further?	Potential for community involvement
<i>E. coli</i> & <i>enterococci</i> sampling of Ayr Creek & lagoon	Regular monitoring of bacterial levels <i>E. coli</i> & <i>enterococci</i> in the water of the creek and lagoon & regular sharing of this information with the community.	Unknown nature of threats	Annual, spring & summer in high risk time	Will support other management interventions, e.g. communicating risk levels to community	High, the lagoon would need to be sampled by. (e.g. frequent sampling over 6 months, courier, analytical tests, staff time, potential boat access for middle of lagoon)	n/a	Yes	No
BGA algal toxin BMAA sampling in Ayr lagoon	BMAA testing as part of Blue-green algae health risk assessment. There is a link to Motor Neuron Disease	BGA health risk	Once annually during high risk period to establish if present	Will support other management interventions, determining public health risk	High, analytical costs. Test relatively new to Australia	n/a	Maybe	No
Other monitoring	Community monitoring of the amount of filamentous algae, odour, birdlife. Clean Ocean Foundation monitoring, potential for coast watch to sponsor sites	Unknown nature of threats	Ongoing	Increased community and BCSC knowledge of lagoon values and processes - could identify peak odour times if tracked and compared to wind strength and direction, temperature, and Water Quality (i.e. detect trends and patterns to help with future communications).	Low	n/a	Yes	Yes