



FINAL DRAFT REPORT:

Belongil Creek entrance opening strategy

September 2019



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1 Introduction

Byron Shire Council (Council) has engaged Alluvium Consulting and Salients to develop the Belongil Creek Entrance Opening Strategy (referred to herein as the Opening Strategy) and the associated Environmental Management Plan (EMP) in collaboration with Council, other government agencies and key stakeholders. The Belongil Creek catchment interacts with almost all facets of the Byron Bay community. Council seek to develop a long term sustainable Opening Strategy which minimises the impacts on natural littoral processes and the fragile ecosystems which exist within the Belongil Creek catchment, while also protecting the community and existing built assets from flooding.

The following document presents an overview of the study and a draft Opening Strategy and EMP.

1.1 Study overview and objectives

Belongil Creek is an intermittently closed and open lagoon/lake (ICOLL) system north-west of Byron Bay. The morphology of the estuary has evolved due to the wave dominated coastline and associated longshore drift processes which have formed the Belongil sand spit. Under natural littoral and runoff processes the beach berm forms a barrier to create a closed lake system. The beach berm is periodically eroded due to either coastal erosion, increased water levels associated with rainfall or overtopping in larger rainfall events.

In the last 50 years there has been significant urban and industrial development within the Belongil Creek catchment. This has resulted in increased runoff and pollution into Belongil Creek. To manage flood risk within the catchment the estuary mouth is currently mechanically opened when the water level at the Ewingsdale Road bridge gauge reaches 1 m AHD (Australian Height Datum). Prior to 2001, the entrance was mechanically opened when the water level reached 1.2 m AHD.

The Belongil Creek estuary entrance has been mechanically opened under a conditional interim licence since 2001. A condition of the licence requires Council to develop a sustainable long-term Opening Strategy. In order to develop this Opening Strategy, we must first develop a comprehensive understanding of the system, conditions and processes. The study aims to:

1. Outline existing conditions and processes within the Belongil Creek catchment
2. Outline the coastal processes that impact the estuary entrance under existing and predicted climate change scenarios
3. Assess existing flooding and flow dynamics within the Belongil Creek catchment and outline possible impacts of climate change
4. Assess the impact of the estuary opening condition on water quality
5. Assess existing aquatic and terrestrial ecology and determine the ecological communities most vulnerable to changes in the estuary entrance opening arrangements
6. Review historical management arrangements and ecological responses to entrance opening mechanisms
7. Engage with the community and stakeholders to determine management objectives for estuary opening
8. Assess different options for the management of the estuary and determine the optimal management arrangements.

1.2 Study area

Belongil Creek is situated approximately two kilometres to the northwest of the township of Byron Bay in northern New South Wales (Figure 1). The Belongil Creek estuary entrance is located on Belongil Beach and drains a catchment area of approximately 34 km². The creek flows from the discontinuous watercourses within the Cumbebin Swamp in a northerly direction for approximately 3 km before entering the South Pacific Ocean. A large portion of the remaining drainage network within the catchment is in the form constructed drains including the Union Drain from the west of the catchment. The Belongil Creek catchment supports a diverse range of land uses and industries including urban and industrial areas, agricultural areas and high value ecological areas including Cumbebin Swamp Nature Reserve and Tyagarah Nature Reserve. Mapping associated with the State Environmental Planning Policy (Coastal Management) highlights significant areas of Coastal Wetlands and remnant pockets of Littoral Rainforest near the estuary entrance.

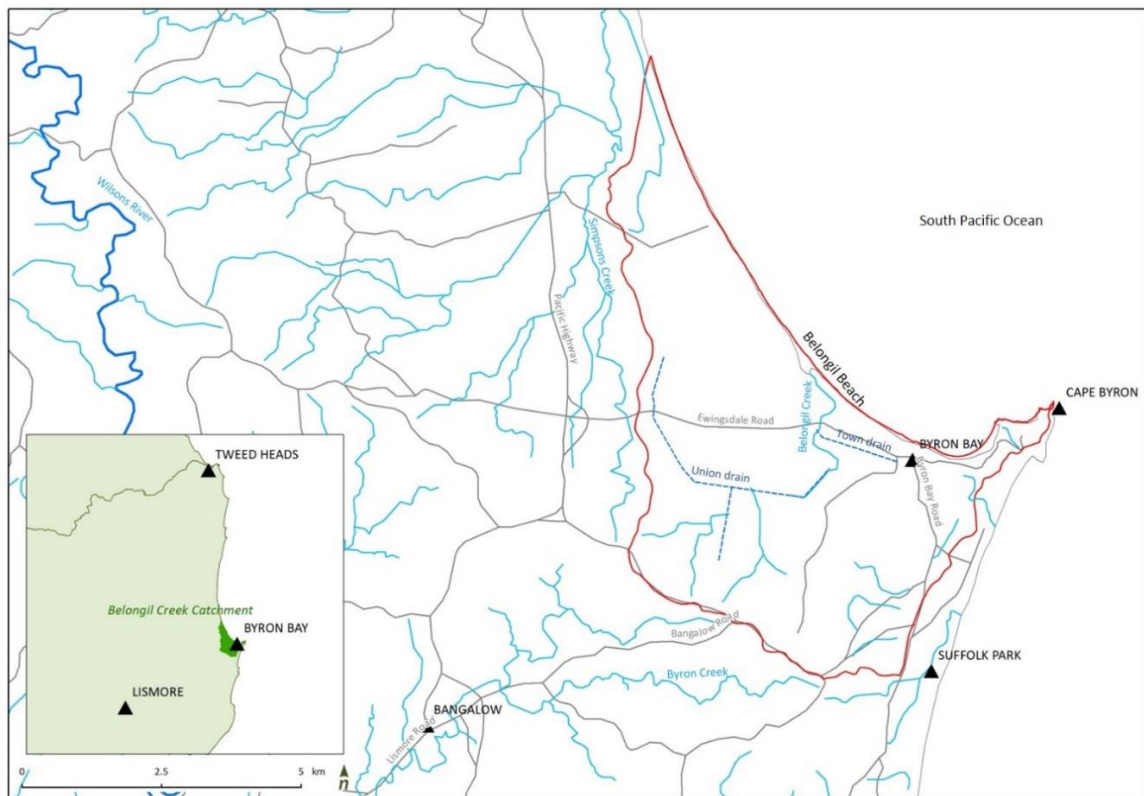


Figure 1. *Belongil Creek catchment study area*

1.3 Study structure

Development of the Opening Strategy and associated EMP involves seven key stages. These stages and associated outputs are shown below in Figure 2. This draft Opening Strategy and EMP report forms an output of Stage 5.

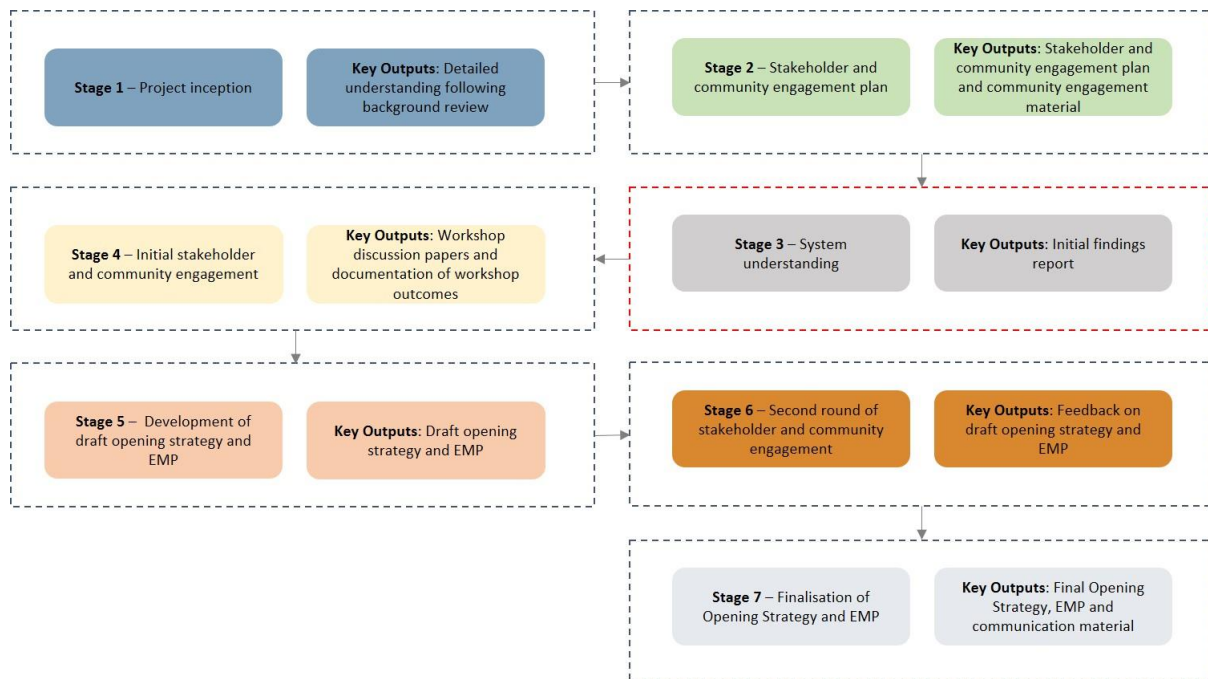


Figure 2. Project stages and key outputs flow chart

1.4 Report structure

This draft Opening Strategy and EMP report is presented in a number of sections including:

- **Section 1** - Provides an overview of the study, study area and report structure
- **Section 2** - Provides a brief summary of the Initial Findings report which is also contained within Attachment A of this report
- **Section 3** - Outlines the management objectives for estuary opening which were determined through stakeholder and community engagement
- **Section 4** – Assesses a range of options for estuary management against the management objectives
- **Section 5** – Outlines the proposed Opening Strategy.
- **Section 6** – Presents the Environmental Management Plan (EMP) for estuary opening

2 System understanding

The Belongil Creek estuary drains a catchment area of approximately 34 km² which supports a diverse range of land uses and industries including urban and industrial areas, agricultural areas and high value ecological areas including Cumbebin Swamp Nature Reserve and Tyagarah Nature Reserve. The catchment supports a range of vegetation communities of high conservation value, including mangroves, saltmarsh, broad-leaved paperbark swamps and swamp oak forest, with fringing rainforest patches providing habitat for threatened plant species including the white laceflower and stinking *Cryptocarya*. Mapping associated with the State Environmental Planning Policy (Coastal Management) highlights significant areas of Coastal Wetlands and remnant pockets of Littoral Rainforest near the estuary entrance. The Byron Bay township and Industrial estate are the two major urban and industrial centres within the catchment. Figure 3 provides an overview of the major features, assets and infrastructure in the Belongil Creek catchment.

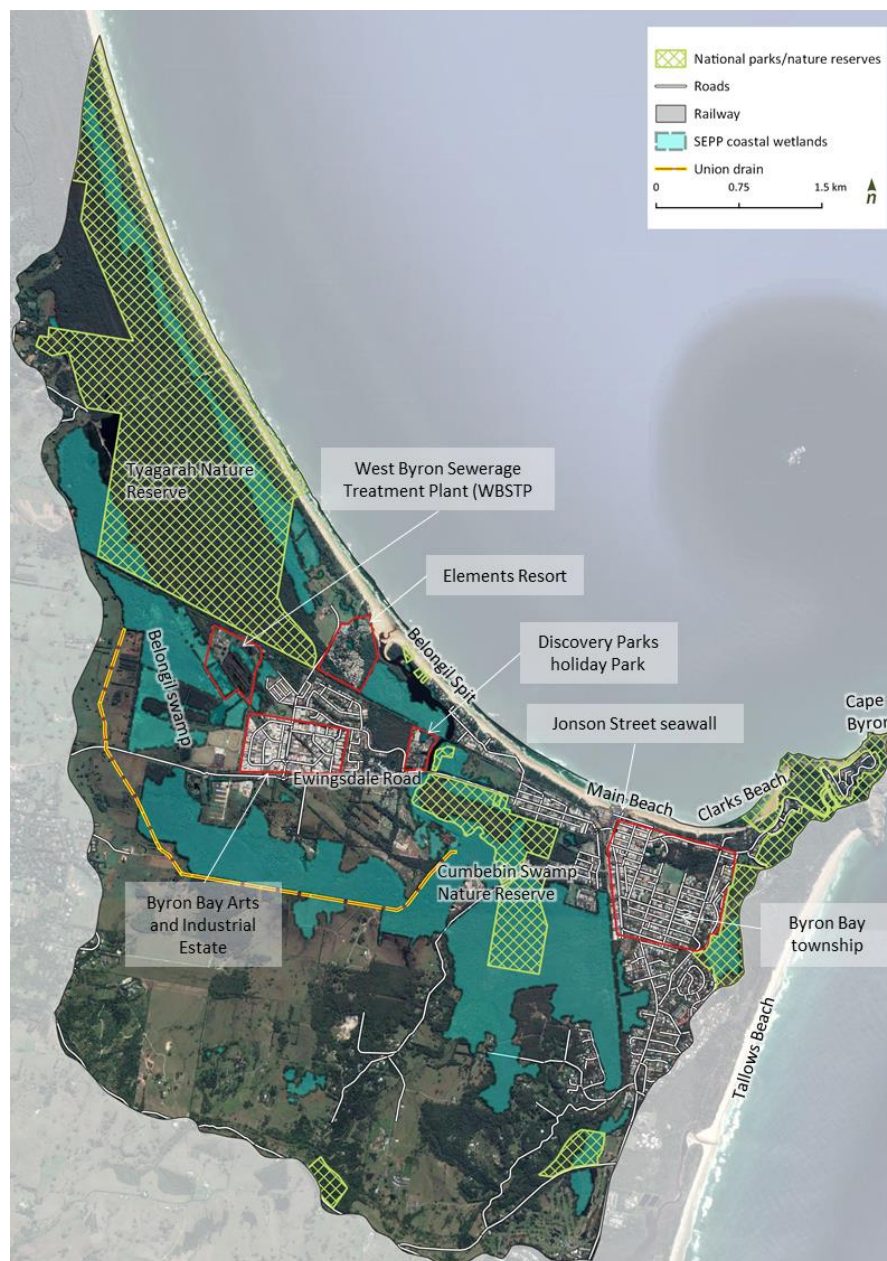


Figure 3. Major features and assets in the Belongil Creek catchment

A detailed assessment of the coastal, estuary and catchment conditions and processes is documented in *Belongil Creek entrance opening strategy – initial findings report* (Alluvium, 2018). This report is provided as Attachment A. Some of the key findings from the initial findings report are summarised below:

- 1. Catchment history** – European settlement of the catchment began in the 19th century and resulted in the clearing of vegetation and the drainage of wetlands to support agriculture. The catchment has been extensively modified since this time with extensive clearing, drainage works and urbanisation.
- 2. Coastal processes** – The Belongil Creek entrance and Belongil Spit are migrating to the north due to the northward transport of sand. The spit is also experiencing high rates of recession and has narrowed significantly in recent decades. As a result, the entrance and surrounding area are dynamic and are likely to continue to change.
- 3. Water quality** – Naturally water quality in ICOLL systems is highly variable and influenced by both freshwater and saline inflows. Other factors such as catchment runoff, groundwater inflows, wetland drainage and direct rainfall also have an impact. Major changes in the catchment in the last 100 years have significantly impacted water quality. These changes included disturbance of Acid Sulfate Soils (ASS), introduction of sewerage treatment plant and agricultural and urban runoff. Estuary opening can result in a short-term change in water quality, yet catchment inputs have much more control on water quality than tidal inputs. Further information regarding the potential impacts of the West Byron STP in the broader catchment are outlined in the Capacity Assessment of the Belongil Creek Drainage System report (AWC, 2016).
- 4. Ecology** - Vegetation communities within the catchment are highly fragmented however still retain high conservation values. Communities include mangroves, saltmarsh, broad-leaved paperbark swamps and swamp oak forest and littoral rainforests. The catchment and estuary provide important habitat for a diverse range of native fauna including migratory shorebird species and freshwater and estuarine aquatic species. The estuary supports a range of commercially and recreationally important fisheries (including crabs, prawns and fish) and fish habitat that is important as a nursery habitat for juvenile fish. After 100 years of artificial opening the ecology of the estuary and catchment has adjusted to reduced water levels and increased tidal inputs.
- 5. Flooding and flow dynamics** – Under naturally conditions the floodplain would have filled to approximately 2-2.4 m AHD as a result of berm development. The entrance barrier height is a critical control on catchment flood behaviour. The natural berm height of the estuary will rise with sea level. The entrance has been artificially opened for 100 years to reduce nuisance catchment flooding and allow agricultural and urban development. Much of the Byron Bay community has been developed based on an open estuary entrance. However, an open entrance can also increase flood levels during periods of high ocean levels (i.e. storm surges, high tides etc.).
- 6. Entrance management** – For nearly 100 years Council has actively managed the estuary entrance. Initially opening was undertaken to alleviate inundation of agricultural land however later flooding in Byron Bay CBD was a major driver. In 2001 the entrance opening level was reduced from 1.2 m AHD to 1.0 m AHD. The reduction was primarily aimed at reducing fish kills. Based on a bath tub analysis conducted in the initial findings report, Attachment A, lowering the opening level from 1.2 m AHD to 1.0 m AHD results in 10 times less water being drained from the drains and wetlands within the catchment into the estuary each opening. A fish kill event occurred in February 2019 following, prior to this event there were two recorded fish kill events following artificial opening since lowering the trigger level. The first was in April 2002 where approximately 400 fish were reportedly killed (Pont 2002), and the second was in March 2016 where six individual fish were recorded dead (Geolink, 2016). In each of these events the artificial opening was preceded by very high estuary water levels of 1.45 m AHD.

3 Management objectives

Defining clear objectives is an essential step to effective waterway management. Clear objectives that are reachable, and within the constraints and capabilities of the system, will lead to better management outcomes. The perceived success or failure of many waterway management projects can be as much a function of the selected objectives or criteria for success as the proposed intervention(s). Therefore, the importance of establishing achievable objectives for the estuary opening process is critical. Clear, measurable objectives will ensure the strategy is developed through evidence-based decision making. Generalities in objectives, such as 'fixing' the estuary, can lead to problems. Narrowing the objectives reduces ambiguity for stakeholders.

To assist in the development of management objectives for estuary opening the following engagement activities were undertaken in 2018:

1. A community drop in session held at the Byron Bay Community Centre on the 12th November
2. A stakeholder workshop held at Byron Shire Council's Chambers on the 13th of November.

The stakeholder workshop was attended by representatives from Byron Shire Council, NSW Office of Environment and Heritage, NSW Department of Industry – Fisheries (Cape Byron Marine Park), NSW Department of Industry – Crown Lands, Elements Resort, Belongil Catchment Drainage Board, Byron Bay Bird Buddies and Temple Byron. Key stakeholders who were apologies for the workshop included the Bundjalung of Byron Bay Aboriginal Corporation (Arakwal) and NSW National Parks and Wildlife.

During the workshop stakeholders were asked to identify the key values in the catchment and the outcomes sought for these values. In many instances the desired outcomes for the values were beyond what could be achieved through estuary opening management alone. As a result, management objectives were developed based on the outcomes discussed by stakeholders and placed into two categories:

Category 1: Management objectives which can be achieved by estuary opening management

Category 2: Management objectives which can only be achieved through a program of catchment management.

A summary of the key objectives identified from the workshop discussions are outlined below in Table 1. In developing an Opening Strategy and EMP it is only necessary to assess options against the Category 1 objectives in Table 1. Some of these management objectives are likely to be conflicting and a degree of compromise will be required.

The Opening Strategy and EMP will not be able to address the broader catchment management objectives outlined in Category 2. However, it was noted that Byron Shire Council have initiated a process to develop a broader Belongil Creek Catchment Management Plan. The list of Category 2 objectives provided in Table 1 are an initial set of objectives for the broader Belongil Creek catchment – it is envisaged a more extensive set of objectives will be identified as part of the broader catchment management plan.

Table 1. Overview of the key values and the objectives identified for both the estuary opening strategy and a broader catchment management plan

Value	Category 1 - Objective for estuary opening strategy and EMP	Category 2 - Broader objectives for the catchment management plan
<i>Ecological condition of the estuary and catchment</i>	<ol style="list-style-type: none"> 1. Protect the habitat and food sources for migratory shorebirds along the coastline and within the estuary 2. Limit erosion of the littoral rainforest area near the estuary entrance 3. Maintain as natural as possible entrance opening regime 4. Protect fish population and habitat including minimising the occurrence of fish kills in the estuary and nearshore surf zone 5. Limit the impact on benthic communities within the estuary and nearshore environment/surf zone 6. Limit negative impacts of estuary opening on water quality within the estuary and nearshore environment 7. Protect the existing native vegetation communities (i.e. post-artificial opening vegetation community not pre-European ICOLL community) 	<ol style="list-style-type: none"> 1. Maintain and enhance existing conservation areas including koala habitat 2. Protect the biodiversity and ecosystems services provided within the catchment 3. Improve the water quality entering the estuary from the catchment to support estuarine species 4. Protect the quality of groundwater and groundwater dependent ecosystems
<i>Flood mitigation</i>	<ol style="list-style-type: none"> 1. Do not increase flood levels and frequency in existing land uses 	<ol style="list-style-type: none"> 1. Minimise stormwater volumes draining from the urban/industrial areas 2. Improve drainage of urban/industrial areas to limit impacts on the community
<i>Water quality</i>	<ol style="list-style-type: none"> 1. Limit acidic runoff following artificial opening events 2. Limit deoxygenation following artificial opening events 	<ol style="list-style-type: none"> 1. Improve the water quality entering the estuary from the catchment
<i>Urban and industrial land use</i>	<ol style="list-style-type: none"> 1. Do not increase flood levels and frequency in existing urban/industrial areas 	<ol style="list-style-type: none"> 1. Ensure future land management decisions consider existing drainage constraints and limit the impact on the ecological, cultural and socio-economic values of the catchment
<i>Agricultural</i>	<ol style="list-style-type: none"> 1. Minimise any increases in flood levels and frequency in existing agricultural areas 2. Limit any increases in the duration of inundation events 	<ol style="list-style-type: none"> 1. Promote environmentally sustainable and diverse agricultural production within the catchment that maintains or enhances water quality in the receiving environment 2. Protect the post-European socio-economic values of the catchment 3. Improve soil health 4. Minimise impacts on groundwater levels and quality

Value	Category 1 - Objective for estuary opening strategy and EMP	Category 2 - Broader objectives for the catchment management plan
<i>Tourism and recreation</i>	<ol style="list-style-type: none"> 1. Limit the impacts of estuary opening on Elements Resort 2. Limit the erosion of the coastal area adjacent to Elements Resort 3. Limit the impacts on longshore pedestrian access 4. Maintain public safety at the estuary entrance 	<ol style="list-style-type: none"> 1. Limit the impacts of recreational use on the ecological values within the estuary and catchment 2. Promote sustainable eco-tourism within the catchment with a focus on education and supporting functional ecological systems 3. Promote community education on ecological values, services and the importance of catchment management 4. Limit drainage issues within Elements Resort 5. Limit the erosion of the coastal area adjacent to Elements Resort
<i>Cultural/Indigenous values</i>	<ol style="list-style-type: none"> 1. Protect culturally significant plant species/communities 2. Protect culturally significant areas 	<ol style="list-style-type: none"> 1. Enhance and protect the available traditional land uses and economies 2. Promote community awareness of the cultural significance of the estuary and catchment to the Arakwal people

4 Options assessment

A range of different estuary management options were developed in consultation with Council and assessed as part of this project. The proposed options have been categorized as follows:

1. **Breach levels within the estuary** – the water level that triggers an artificial opening of the estuary entrance
2. **Opening locations/methods** – the location at which the entrance is artificially opened
3. **Decoupling the catchment from the estuary** – using a flow control structure to isolate the catchment from the estuary under varied flow conditions.

The specific arrangements for each of the management options are outlined below.

4.1 Breach levels within the estuary

A total of five different breach level management options have been assessed. These include different water levels at the Ewingsdale Bridge gauge which would trigger mechanical opening of the estuary mouth. The different options assessed include:

- A. **No artificial opening** – The berm formed at the estuary entrance will not be mechanically opened.
- B. **1.0 m AHD trigger level** – The estuary entrance will be artificially opened when the water level at the Ewingsdale Bridge gauge reaches 1.0 m AHD. This is the trigger level currently used by Council under the existing conditional interim licence. Prior to this, the trigger level used was 1.2 m AHD. The lowering of the trigger level was initially based on recommendations made in the Estuary Management Plan (Peter Parker Environmental Consultants Pty Ltd, 2001) and subsequently in the Draft Belongil Creek Entrance Opening Strategy (BSC, 2005). The lowering was primarily to reduce fish kills by reducing turbidity and organic matter entering the estuary.
- C. **1.2 m AHD trigger level** – The estuary entrance will be artificially opened when the water level at the Ewingsdale Bridge gauge reaches 1.2 m AHD. This is the trigger level that was used by Council prior to the interim licence granted in 2001. The pre-2001 trigger level of 1.2m AHD appears to have evolved to avoid nuisance flooding of agricultural lands and to lower the risk of flooding in the Byron Bay CBD.
- D. **1.0 m AHD watch level and 1.2 m AHD trigger level** - When the water level at the Ewingsdale Bridge gauge reaches 1.0 m AHD this will trigger a “watch” alert. Predicted catchment rainfall should be considered and increased gauge monitoring should occur. If the berm appears to be near breaching at 1.05 m AHD and rainfall is predicted, then do nothing. If the berm is higher than this level and rain is predicted, then scrape in one location to 1.0 m AHD. If this does not result in natural opening, when the water level at the gauge is approaching and expected to reach 1.2 m AHD artificial opening of the estuary entrance is triggered.
- E. **1.4 m AHD trigger level** - The estuary entrance will be artificially opened when the water level at the Ewingsdale Bridge gauge reaches 1.4 m AHD.

The spatial distribution of areas inundated by the three trigger level elevations are shown in Figure 4. Importantly, the extent of inundation (Figure 4) and values in Table 2 assume a flat water surface (i.e. bath tub analysis), which is a reasonable approximation if the entrance is closed to the ocean (no tidal fluctuations) and there are limited inflows from the catchment. Inundation extents were estimated using the 1 m DEM. The primary level of land use is also displayed on the inundation map to indicate the major land uses impacted by the various breach levels.

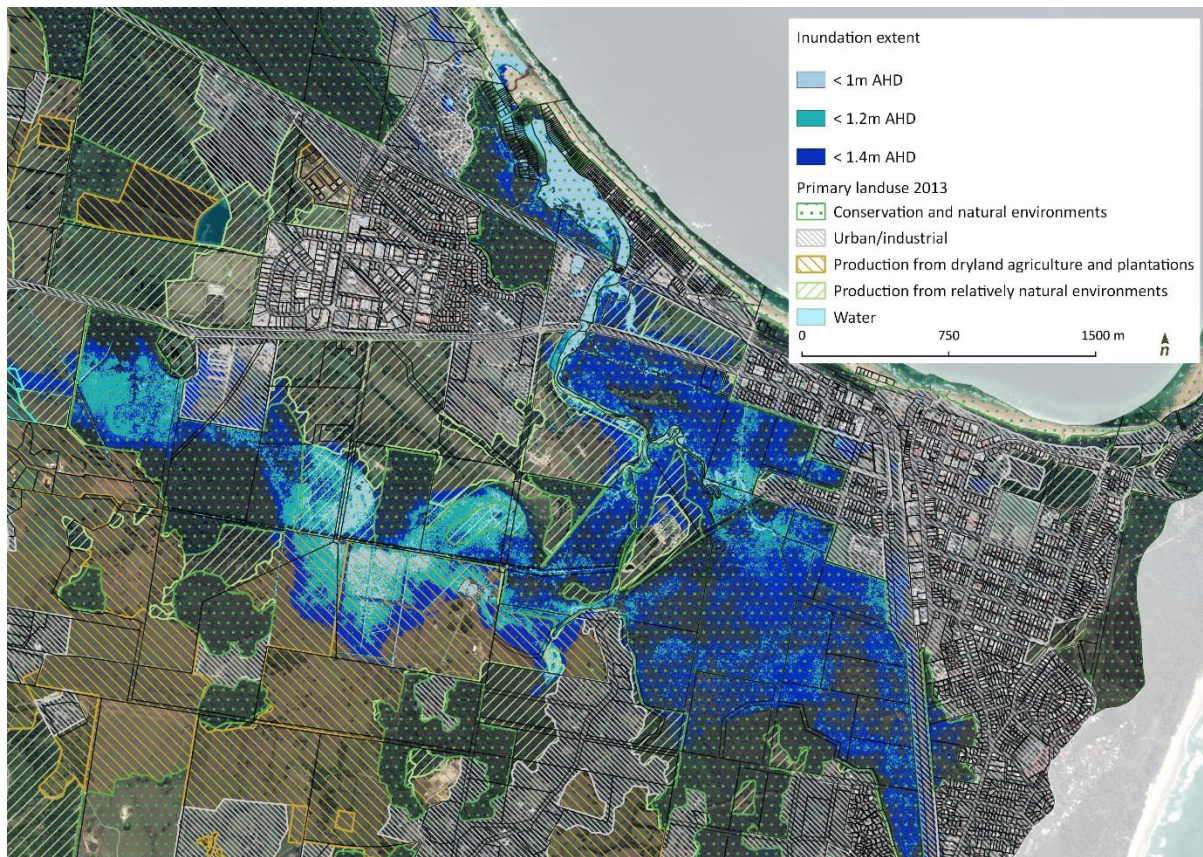


Figure 4. Inundation extents of proposed trigger levels derived from 1m DEM with primary land use overlaid

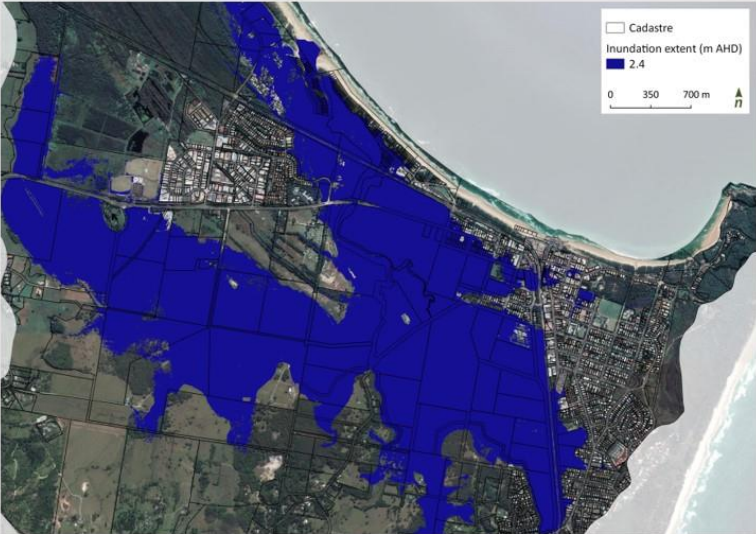
Table 2. Impacts of various artificial opening trigger levels on inundation and discharge volumes

Trigger level (m AHD)	Inundation extent - Area below (km ²)	% area inundation extent increase	Volume Below (m ³)	Volume increase from existing trigger level (m ³)	% volume increase	Volume discharged following opening (assuming drained to 0.8m AHD) (ML)	% volume discharge increase
1	0.41		330000			15	
1.2	1.35	224%	472000	142000	43%	157	947%
1.4	3.39	717%	903000	573000	174%	588	3820%

A qualitative scoring approach has been adopted based on how the potential outcomes will affect the management objectives. This scoring has been guided by relevant technical experts in a range of fields. While each objective may not necessarily have an equal weighting, this method readily allows for the comparison of options against each of the objectives. Given the complex nature of the processes and interactions involved there is a level of uncertainty in many of the outcomes. Given this uncertainty some of the objectives could not be scored and were assigned a question mark.

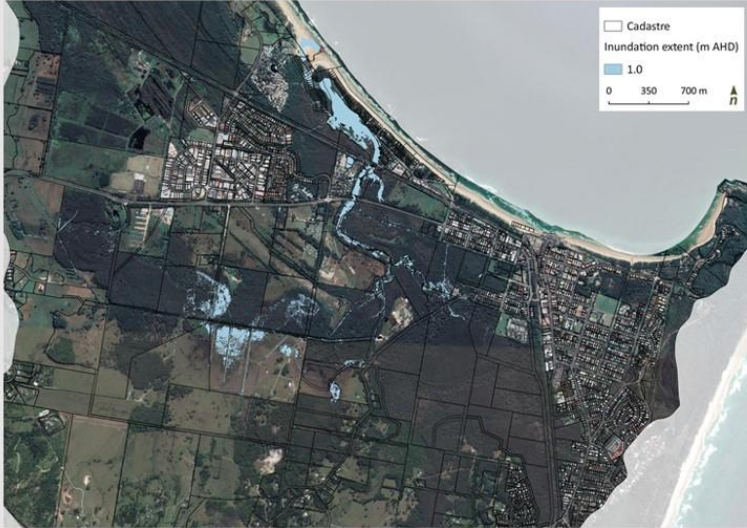
An assessment of each of the five management options is provided in Table 3 to Table 7. The assessment indicates Option 1B (i.e. 1.0 m AHD trigger level) scores highest against the range of objectives assessed. This option represents the current opening trigger level.

Table 3. Opening option 1A – No artificial opening assessment against management objectives

Opening option	Physical outcomes	Value	Management objective	Degree option achieves objective
<p>No artificial opening – The berm formed at the estuary entrance will not be mechanically altered to artificially open the estuary (note lowest point across the spit is \approx 2.0 - 2.4 m AHD according to 2013 LiDAR).</p> 	<ul style="list-style-type: none"> Natural range of water levels were much higher than existing (\approx 2.6 m AHD estimated natural breakout level prior to European settlement). Long term elongation of the Belongil Spit and northwards migration of entrance has led to one area separating the beach and estuary with an elevation of approximately 2.0 - 2.4 m AHD (as of latest LiDAR – 2013). If the beach berm across the entrance were to approach that height the estuary will likely cut a new entrance through the spit. In large breakout events a volume and velocity discharge increase would increase the volume of sand scoured from the entrance and increase the depth of the scoured channel and potentially from creek banks. A larger scoured entrance channel takes longer to infill because of coastal sediment transport and will tend to remain open for longer. Prolonged inundation of agricultural land, swamps and township. Prolonged inundation will reduce risk of peat fires. Long term inundation of mangrove pneumatophores potentially leading to mangrove loss as well as loss of estuary mudflats and saltmarsh, impacting shorebirds and estuarine invertebrates. Conversion of existing estuarine habitat to that potentially dominated by freshwater species. Potential change to the composition of estuarine invertebrates and fish which could influence nutrient dynamics, biodiversity and food sources for a variety of shorebirds. Critical impacts to extent and value of foraging/roost habitat for shorebirds, and structured habitat for fish. High flood risk to the township, industrial estate as well as low lying agricultural land. Reduced influence of high ocean levels and storm surges Increase in the tailwater elevation resulting in significant drainage issues from existing agricultural drains and stormwater drains from the township. Drainage gradient within these systems is already very low so increasing tailwater elevations will have significant impacts during rainfall events. Water in the catchment will have a greater residence time and increased opportunity for bio-chemical reactions before being drawn into the estuary, potentially leading to increase fish kills (potential for significant blackwater events and rapid flushing of acidic water). Paradoxically, less variability in the groundwater level (less discharge / recharge cycles in response to fortnightly tides) may actually reduce the potential for acid transport from groundwater. Potential shifts in existing native vegetation communities given the potential for prolonged periods of freshwater inundation in the estuary and the catchment. Long periods of reduced tidal exchange impacting on existing estuarine fauna communities. 	Ecological condition of the estuary and catchment	1. Protect the habitat and food sources for migratory shorebirds along the coastline and within the estuary	XXX
			2. Limit erosion of the littoral rainforest area near the estuary entrance	XX
			3. Maintain as natural as possible entrance opening regime	✓✓✓
			4. Protect fish population and habitat including minimising the occurrence of fish kills	XX
			5. Limit the impact on benthic communities within the estuary	XXX
			6. Limit negative impacts of estuary opening on water quality within the estuary	X
			7. Protect the existing native vegetation communities (i.e. post-artificial opening vegetation community not pre-European ICOLL community)	XX
		Drainage/Water quality	1. Do not increase flood levels in existing land uses	XXX
			High ocean levels/storm surge events	✓
			2. Limit acidic runoff following artificial opening events	N/A
		Urban and industrial land use	1. Do not increase flood levels in existing urban/industrial areas	XXX
			High ocean levels/storm surge events	✓✓✓
		Agricultural	1. Minimise any increases in flood levels in existing agricultural areas	XXX
			High ocean levels/storm surge events	✓
			2. Limit any increases in the duration of inundation events	XXX
		Tourism and recreation	1. Limit the impacts of estuary opening on Elements Resort	XX
			2. Limit the erosion of the coastal area adjacent to Elements Resort	X
			3. Limit the impacts on longshore pedestrian access	X
			4. Maintain public safety at estuary entrance	X
		Cultural/Indigenous values	1. Protect culturally significant plant species/communities	?
			2. Protect culturally significant areas	?

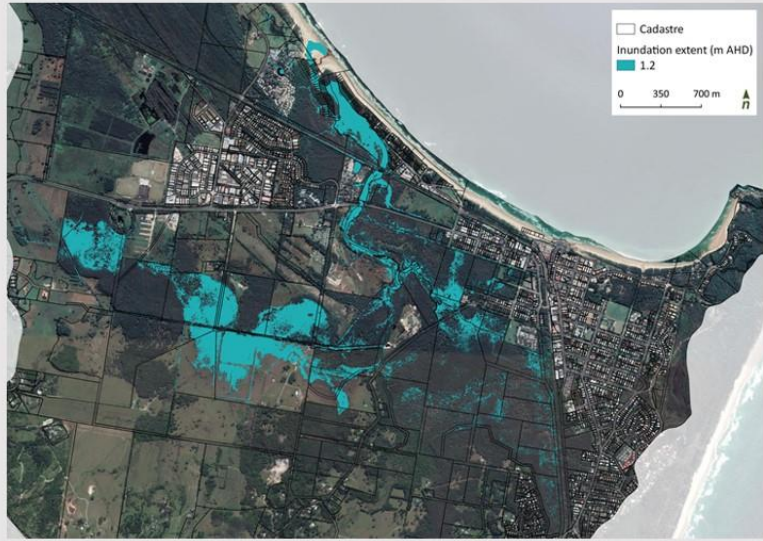
✓ = Slightly positive outcome
 ✓✓ = Moderately positive outcome
 ✓✓✓ = Significantly positive outcome
 ? = Some uncertainty
 X = Slightly negative outcome
 XX = Moderately negative outcome
 XXX = Significantly negative outcome

Table 4. Opening option 1B – 1.0 m AHD trigger level assessment against management objectives

Opening option	Physical outcomes	Value	Management objective	Degree option achieves objective
<p>1.0 m AHD trigger level – The estuary entrance will be artificially opened when the water level at the Ewingsdale Bridge gauge reaches 1.0 m AHD (i.e. the existing opening arrangement).</p> 	<ul style="list-style-type: none"> Effective entrance and persistent entrance channel may not necessarily form when breached at RL 1.0m AHD unless there is follow up rainfall. The stage of the tide when entrance is opened will also influence the level of scour and persistence of entrance channel. If there is no effective entrance channel, the entrance would close relatively quickly, and the frequency with which Council would need to artificially intervene in the entrance would increase. These types of problems will be exacerbated by sea level rise. Low discharge velocities will tend to reduce the amount of sand that is flushed out of the immediate entrance compartment during breach events. Frequent openings and low velocities tend to result in the net accumulation of sand (from washover by waves) in the entrance compartment and altered morphology (e.g. no clear tidal channel, variable flow patterns). Eventually, an equilibrium with a more shoaled entrance compartment results. This has flow on effects to patterns of extreme flooding. A more shoaled entrance takes longer to scour during large catchment flood events and is likely to exacerbate the extent of upstream flooding. However, it is likely that some of the accumulated sand will be flushed out in significant flood events. low discharge velocities may help limit bank scour and erosion of vegetation habitats. With frequent opening events, water in the catchment has less chance to accumulate and deteriorate before being drawn into the estuary. For example, stagnant water within the floodplain traps decaying organic material. When inundation is relieved rapid drainage of floodplains draws high BoD water into the estuary and causes a rapid drop in oxygen levels (a “blackwater” event). Frequent opening events mean high tidal exchange. High tidal exchange may result in salt penetration into freshwater swamps and drains. This can result in sulfate reduction (anaerobic breakdown of organic matter) and cause the accumulation of monosulfidic black ooze (MBO) which can cause significant deoxygenation of floodwaters. High tidal exchange may also lead to greater flushing of nutrients and constituents and greater water clarity. High ocean levels and storm surges increase water levels within the estuary and impact drainage of low lying areas Marine influence provides increased opportunities for estuarine organisms e.g. marine fish and yabbies. High potential flood storage of waters in swamps and wetlands. Low groundwater levels and increase in the variability of groundwater elevations over time, further enhancing oxidation of potential ASS and increasing transport of ASS products (influence may be mitigated via decoupling of estuary and catchment). Dry areas allow for tree establishment upstream of the estuary in former swampy areas. Dry areas may also improve conditions for weed establishment and fires (peat fires as well as additional fire load) 	Ecological condition of the estuary and catchment	1. Protect the habitat and food sources for migratory shorebirds along the coastline and within the estuary	✓ ✓
			2. Limit erosion of the littoral rainforest area near the estuary entrance	?
			3. Maintain as natural as possible entrance opening regime	✗ ✗
			4. Protect fish population and habitat including minimising the occurrence of fish kills	✓ ✓
			5. Limit the impact on benthic communities within the estuary	✓
			6. Limit negative impacts of estuary opening on water quality within the estuary	✓
			7. Protect the existing native vegetation communities (i.e. post-artificial opening vegetation community not pre-European ICOLL community)	✓ ✓
		Drainage/Water quality	1. Do not increase flood levels in existing land uses	Low ocean levels ✓ ✓ High ocean levels/storm surge events ✗ ✗ ✗
			2. Limit acidic runoff following artificial opening events	✗
		Urban and industrial land use	1. Do not increase flood levels in existing urban/industrial areas	Low ocean levels ✓ ✓ High ocean levels/storm surge events ✗ ✗ ✗
			2. Limit any increases in the duration of inundation events	✓ ✓ ✓
		Agricultural	1. Minimise any increases in flood levels in existing agricultural areas	Low ocean levels ✓ ✓ High ocean levels/storm surge events ✗ ✗ ✗
			2. Limit the impacts of estuary opening on Elements Resort	?
		Tourism and recreation	2. Limit the erosion of the coastal area adjacent to Elements Resort	?
			3. Limit the impacts on longshore pedestrian access	✓
		Cultural/Indigenous values	4. Maintain public safety at estuary entrance	✗
			1. Protect culturally significant plant species/communities	?
			2. Protect culturally significant areas	?

✓ = Slightly positive outcome ✓✓ = Moderately positive outcome ✓✓✓ = Significantly positive outcome ? = Some uncertainty ✗ = Slightly negative outcome ✗✗ = Moderately negative outcome ✗✗✗ = Significantly negative outcome

Table 5. Opening option 1C – 1.2 m AHD trigger level assessment against management objectives

Opening option	Physical outcomes	Value	Management objective	Degree option achieves objective
<p>1.2 m AHD trigger level – The estuary entrance will be artificially opened when the water level at the Ewingsdale Bridge gauge reaches 1.2 m AHD.</p> 	<ul style="list-style-type: none"> Significant increase (≈950 %) in the discharge volume would increase the volume of sand scoured from the entrance and increase the depth of the scoured channel. A larger scoured entrance channel takes longer to infill and will tend to remain open for longer. Increased discharge velocities associated with increased discharge volumes and potential associated increased scour potential adjacent to the littoral rainforest on the northern bank. Increased discharge velocities also may increase turbidity which is often due to flocculation of iron hydroxides associated with ocean water mixing with ASS runoff, which can lead to depleted dissolved oxygen. Increased re-entrainment of fine sediment and organic particulate due to increased discharge velocities when opened compared to a 1 m trigger level. Decreased salinity allowing for establishment of more competitive terrestrial and freshwater aquatic species. Including potentially invasive species. Mangrove and saltmarsh communities may decline, offset by an increase in freshwater swamp species. Reduced frequency of artificial openings. Prolonged inundation of subtidal biological communities such as mangroves (they may be able to adapt to a slight increase in water level), saltmarsh and estuarine macrophyte communities (they may shift in location to adapt to change). Decreased flood storage upstream of estuary as drains and wetlands will generally contain more water at the onset of a flood. This may result in increased wetland /swamp habitat as well as increased groundwater levels and a reduction in oxidation of PASS. High ocean levels and storm surges increase water levels within the estuary and impact drainage of low lying areas Increase in the tailwater elevation resulting in significant drainage issues from existing agricultural drains and stormwater drains from the township. Drainage gradient within these systems is already very low so increasing tailwater elevations will have significant impacts during rainfall events including increased flood durations. Reduced opening events will lead to reduction in tidal exchange which may influence water quality and mangrove health. Reduced tidal exchange may also reduce opportunity for flocculation of dissolved iron associated with drainage of ASS areas, which can lead to oxygen depletion. Water in the catchment will have a greater residence time and increased opportunity for chemical reactions before being drawn into the estuary, potentially leading to more frequent fish kills (potential for significant blackwater events and rapid flushing of acidic water). Paradoxically, less variability in the groundwater level (less discharge / recharge cycles in response to fortnightly tides) may actually reduce the potential for acid transport via groundwater. Increased nuisance flooding of agricultural land particularly adjacent to the Union Drain (See adjacent figure). Reduced dry areas potentially resulting in a transition from floodplain to wetland vegetation. Reduction in risk of peat fires. 	Ecological condition of the estuary and catchment	1. Protect the habitat and food sources for migratory shorebirds along the coastline and within the estuary	×
			2. Limit erosion of the littoral rainforest area near the estuary entrance	×
			3. Maintain as natural as possible entrance opening regime	×
			4. Protect fish population and habitat including minimising the occurrence of fish kills	×
			5. Limit the impact on benthic communities within the estuary	×
			6. Limit negative impacts of estuary opening on water quality within the estuary	×
			7. Protect the existing native vegetation communities (i.e. post-artificial opening vegetation community not pre-European ICOLL community)	×
		Drainage/Water quality	Low ocean levels	×
			1. Do not increase flood levels in existing land uses	×
		High ocean levels/storm surge events	2. Limit acidic runoff following artificial opening events	×
				×
		Urban and industrial land use	Low ocean levels	×
			1. Do not increase flood levels in existing urban/industrial areas	×
		High ocean levels/storm surge events	2. Limit any increases in the duration of inundation events	×
				×
		Agricultural	Low ocean levels	×
			1. Minimise any increases in flood levels in existing agricultural areas	×
		High ocean levels/storm surge events	2. Limit any increases in the duration of inundation events	×
				×
		Tourism and recreation	1. Limit the impacts of estuary opening on Elements Resort	✓
			2. Limit the erosion of the coastal area adjacent to Elements Resort	?
			3. Limit the impacts on longshore pedestrian access	✓
			4. Maintain public safety at estuary entrance	×
		Cultural/In digenous values	1. Protect culturally significant plant species/communities	?
			2. Protect culturally significant areas	?

✓ = Slightly positive outcome ✓✓ = Moderately positive outcome ✓✓✓ = Significantly positive outcome ? = Some uncertainty × = Slightly negative outcome ×× = Moderately negative outcome ××× = Significantly negative outcome

Table 6. Opening option 1D – 1.0 m AHD watch level and 1.2 m AHD trigger level assessment against management objectives


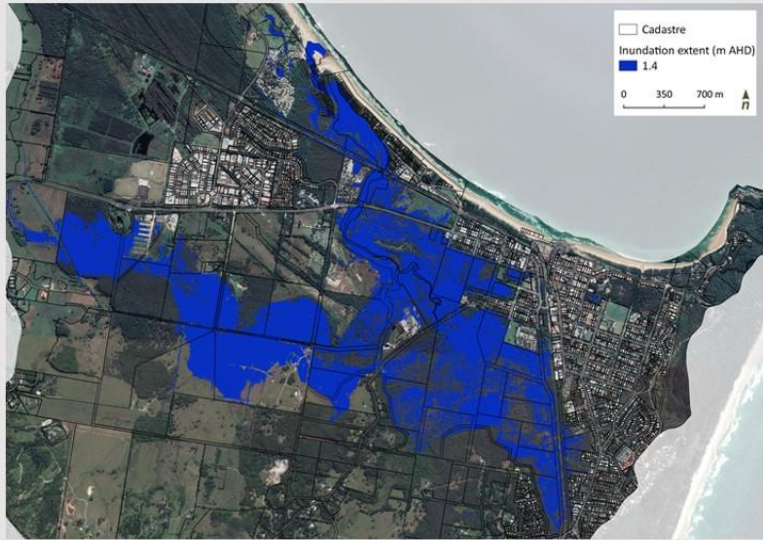
Opening option	Physical outcomes	Value	Management objective	Degree option achieves objective
<p>1.0 m AHD watch level and 1.2 m AHD trigger level - When the water level at the Ewingsdale Bridge gauge reaches 1.0 m AHD this will trigger a “watch” alert. Predicted catchment rainfall should be considered and increased gauge monitoring should occur. If the water level at the gauge reaches 1.2 m AHD this will trigger artificial opening of the estuary entrance</p> 	<ul style="list-style-type: none">• Similar physical outcomes as 1.2m AHD trigger level if 1.2m is adopted as an upper limit.• Allows for flexibility, including continued assessment of climatic conditions, water quality and flooding threats.• More closely approximates “natural” conditions with the ability to open the entrance at a range of heights (albeit a small range).	Ecological condition of the estuary and catchment	1. Protect the habitat and food sources for migratory shorebirds along the coastline and within the estuary	✗
			2. Limit erosion of the littoral rainforest area near the estuary entrance	✗
			3. Maintain as natural as possible entrance opening regime	✗
			4. Protect fish population and habitat including minimising the occurrence of fish kills	✗
			5. Limit the impact on benthic communities within the estuary	✗
			6. Limit negative impacts of estuary opening on water quality within the estuary	✓
			7. Protect the existing native vegetation communities (i.e. post-artificial opening vegetation community not pre-European ICOLL community)	✗
		Drainage/Water quality	Low ocean levels	✗
			1. Do not increase flood levels in existing land uses	✗ ✗
		Urban and industrial land use	High ocean levels/storm surge events	✗ ✗
			2. Limit acidic runoff following artificial opening events	✗
		Agricultural	Low ocean levels	✗
			1. Do not increase flood levels in existing urban/industrial areas	✗ ✗
			High ocean levels/storm surge events	✗ ✗
		Tourism and recreation	2. Limit any increases in the duration of inundation events	✗
			1. Limit the impacts of estuary opening on Elements Resort	✓
			2. Limit the erosion of the coastal area adjacent to Elements Resort	?
			3. Limit the impacts on longshore pedestrian access	✓
			4. Maintain public safety at estuary entrance	✗
		Cultural/In digenous values	1. Protect culturally significant plant species/communities	?
			2. Protect culturally significant areas	?
✓ = Slightly positive outcome ✓✓ = Moderately positive outcome ✓✓✓ = Significantly positive outcome ? = Some uncertainty ✗ = Slightly negative outcome ✗✗ = Moderately negative outcome ✗✗✗ = Significantly negative outcome				

Table 7. Opening option 1E – 1.4 m AHD trigger level assessment against management objectives

Opening option	Physical outcomes	Value	Management objective	Degree option achieves objective
<p>1.4 m AHD trigger level – The estuary entrance will be artificially opened when the water level at the Ewingsdale Bridge gauge reaches 1.4 m AHD.</p> 	<ul style="list-style-type: none"> Significant increase (≈3800 %) in the discharge volume and therefore velocity would increase the volume of sand scoured from the entrance and increase the depth of the scoured channel. A larger scoured entrance channel takes longer to infill and will tend to remain open for longer. Significant increase in discharge velocities and associated potential increased scour potential of the western bank adjacent to the pocket of littoral rainforest. Significant increase in the tailwater elevation resulting in significant drainage issues from existing agricultural drains and stormwater drains from the township. Drainage gradient within these systems is already very low so increasing tailwater elevations to this level would lead to limited drainage capacity and potentially increased flood levels and durations. Increased volumes of water and associated forces may cause significant operational difficulties during opening along with increased safety risks. Increased re-entrainment of fine sediment, MBO's and organic particulate due to increased discharge velocities. Significantly prolonged inundation of intertidal biological communities such as mangroves and saltmarsh that now inhabit the estuary possibly causing significant loss. Reduced frequency of artificial opening events. Reduced influence of high ocean levels and storm surges Reduction in tidal exchange given the longer periods when the entrance is closed but immediately after a breaching event tidal exchange may be enhanced given the increased size of the scoured channel and therefore reduction in tidal attenuation. Following a breaching event, an increase in tidal signal due to the wider entrance may increase opportunity for flocculation of dissolved iron associated with ASS products which can lead to oxygen depletion. Water in the catchment will have a greater residence time and increased opportunity for chemical reactions before being drawn into the estuary, potentially leading to more frequent fish kills, potential for significant blackwater events and rapid flushing of acidic water (although the acid may be more dilute given the additional volume of water). Increased nuisance flooding of agricultural land, particularly adjacent to the Union Drain (See adjacent figure). Reduced dry areas potentially resulting in a transition from floodplain to wetland vegetation, also reducing risk of peat fires. Decreased flood storage upstream of estuary as drains and wetlands will generally contain more water at the onset of a flood. This may result in increased wetland /swamp habitat as well as increase in groundwater levels. Potential increase in human health issues with increased still water and therefore mosquito/midge interactions – decreasing current buffer from urban development as swamps would likely increase in extent 	Ecological condition of the estuary and catchment	1. Protect the habitat and food sources for migratory shorebirds along the coastline and within the estuary	✗ ✗
			2. Limit erosion of the littoral rainforest area near the estuary entrance	✗ ✗
			3. Maintain as natural as possible entrance opening regime	✗
			4. Protect fish population and habitat including minimising the occurrence of fish kills	✗ ✗
			5. Limit the impact on benthic communities within the estuary	✗ ✗
			6. Limit negative impacts of estuary opening on water quality within the estuary	✗ ✗
			7. Protect the existing native vegetation communities (i.e. post-artificial opening vegetation community not pre-European ICOLL community)	✗ ✗
		Drainage/Water quality	Low ocean levels	✗ ✗
			1. Do not increase flood levels in existing land uses	✗
		High ocean levels/storm surge events	2. Limit acidic runoff following artificial opening events	✗
		Urban and industrial land use	Low ocean levels	✗ ✗
			1. Do not increase flood levels in existing urban/industrial areas	✗
		High ocean levels/storm surge events		
		Agricultural	Low ocean levels	✗ ✗
			1. Minimise any increases in flood levels in existing agricultural areas	✗
			High ocean levels/storm surge events	
		Tourism and recreation	2. Limit any increases in the duration of inundation events	✗ ✗
			1. Limit the impacts of estuary opening on Elements Resort	✓
			2. Limit the erosion of the coastal area adjacent to Elements Resort	?
			3. Limit the impacts on longshore pedestrian access	✓
		Cultural/In digenous values	4. Maintain public safety at estuary entrance	✗
			1. Protect culturally significant plant species/communities	?
			2. Protect culturally significant areas	?

✓ = Slightly positive outcome ✓✓ = Moderately positive outcome ✓✓✓ = Significantly positive outcome ? = Some uncertainty ✗ = Slightly negative outcome ✗✗ = Moderately negative outcome ✗✗✗ = Significantly negative outcome

There is significant uncertainty surrounding some of the outcomes associated with raising the breach level. Some of the likely issues include:

1. There may be reduced acidic runoff from groundwater ingress due to the reduction in tidal fluctuation overall. However immediately after opening a larger opening channel (due to increased scour) will result in greater tidal exchange and flocculation of dissolved iron from ASS which could result in a reduction in dissolved oxygen. Furthermore, following opening events there will be significantly higher volumes of stagnant water drawn from the catchment which could potentially result in blackwater events. As a result, there is significant uncertainty surrounding how the long term variations in water quality would impact on the estuary (and nearshore environment following release of water) if the level was raised.
2. The existing vegetation and instream biota communities have adapted to over a century of anthropogenic management of the opening regime. For the past two decades a relatively consistent opening regime has been maintained. Modifying the opening arrangement, which could result in longer periods of entrance closure, reduced long term tidal exchange and increased ponding of fresh and saline water in the catchment, will likely have impacts on the existing ecological communities including mangroves and saltmarsh as well as the benthic infauna that shorebirds forage on.
3. The drainage of the urban areas including Byron Bay CBD and the Arts and Industrial Estate will be impacted if the tailwater is increased. While this may not impact flood levels significantly it is likely to increase the duration of nuisance flooding and may increase exposure to mosquito and midge issues.

As a result, the assessment of the issues relative to the desired objectives, and significant issues outlined above, the current management arrangement is preferred. However, to allow more time to reach favourable opening conditions it is recommended that a 1 m AHD watch level and 1.1 m AHD trigger level be implemented. Furthermore, there is less uncertainty surrounding the outcomes associated with this opening regime due to the long term monitoring data available for the past 20 years of stable management.

However, as sea level rises occur, opening at a 1 m AHD level will become less practical, requiring increasingly frequent intervention. As a result, a process for raising the level incrementally should form part of the Opening Strategy. Raising of the trigger level could mimic Option 1D (i.e. 1.0 m AHD watch level and 1.2 m AHD trigger level). However, it is recommended the trigger level be raised incrementally once the opening frequency increases beyond what is practical. For example, if opening is required consistently every month then the trigger level could be raised by 0.1 m. The response in the estuary would then need to be monitored for several opening events before any further increase is adopted.

4.2 Opening locations/arrangements

Five different opening locations or arrangement were also assessed. The existing opening location is between Elements Resort and the environmentally sensitive Belongil Spit. The spit contains a known shorebird and seabird nesting area for species with significant conservation status. The opening locations/arrangements assessed include:

- A. **Maintaining the existing opening location** – Under the current interim license the entrance opening is to be excavated between the south east corner of Lot 10 DP 243218 and the northern extent of the 7(j) Scientific Zone, with the centreline of such excavation being located approximately 10 m north of any authorised bird protection fence subject to any significant site constraints. This results in excavation occurring further to the north during breeding season (Aug – Dec) and approximately halfway between the permissible opening points during non-breeding season (Jan – Jul). Access to the site is from the north for both locations.
- B. **Moving the opening location to the north** – Move the opening location north, this would involve redefining the two existing points in which the entrance is to be opened under the current interim license.

- C. **Moving the opening location to the south** – Move the opening location south, immediately adjacent to the bird protection area at the end of the Belongil Spit. Given the current location of the spit this would approximately align with the current excavation point during non-breeding season.
- D. **Creating a tripper wall** - A “tripper wall” is a moderate training structure, constructed using geotextile containers, which remain buried under sand for much of the time to reduce the northward migration of the entrance. Following entrance opening, coastal processes tend to drive the entrance channel northwards where tidal currents begin to act on the foreshore adjacent to Elements Resort. A tripper wall would aim to reduce the northward migration of the estuary opening essentially anchoring the location of the breakout. The location of the wall would be similar to the alignment point of the existing opening location during bird breeding season.
- E. **Creating shore normal buried groynes** – Construct a series of shore normal buried "groynes" that behave somewhat like spur walls in a river. As the channel migrates across to this part of the entrance compartment, the entrance is close to closing and hence tidal velocities tend to be small. The buried groynes would aim to provide protection at the toe of the northern bank.
- F. **Permanently opening the estuary** – Installing entrance training structures such as rock walls to inhibit berm formation and create a permanently opened estuary entrance. Ongoing maintenance such as dredging will likely be required particularly shortly after training.

An assessment of each of the five management options is provided in Table 8 to Table 13. The assessment indicates Option 2A (i.e. Maintaining the existing opening location) scores highest against the range of objectives assessed. However, due to the northward migration of the spit and sensitivity of the bird nesting area it is recommended that northern opening location (breeding season) be used year-round. Under prevailing north to north east wind and swell conditions the opening location should be moved to the north to minimise impacts on the bird nesting area. Furthermore, the locations need to be adaptive, monitoring of the bird nesting area should be undertaken and adjustments made to ensure the area is not impacted by the opening. This option seems to get the balance right between protecting the littoral rainforest and Elements Resort to the north and the bird nesting area to the south.

A tripper wall was assessed in Option 2D as a method to protect Elements Resort from the northward migration of the entrance opening. While a tripper wall may be effective at limiting erosion to the north there is still some uncertainty on how the wall would impact estuary opening dynamics.

There is only one known successful tripper wall in eastern Australia (i.e. in Dee Why). The design of a tripper wall in Dee Why was informed by extensive studies of estuary opening/closing processes. This same level of understanding is not currently available for Belongil Creek. There are several differences between Dee Why and Belongil Creek estuaries. The Dee Why entrance has an increased berm height (opened at 2.2m AHD), significantly larger discharge volumes (~5-10 times) and increased wave exposure.

At the Belongil Creek entrance the littoral zone is wide and there is a risk the wall will act as a partial blockage of northward littoral sand transport resulting in the entrance filling and closing more rapidly following opening. This could result in reduced tidal exchange and increased artificial opening frequency.

Given the uncertainty and lack of design guidelines surrounding a tripper wall and its impacts on estuary opening/closing dynamics there are two broader options:

1. A trial and adjustment approach, whereby a temporary tripper wall is installed and monitored carefully to evaluate the response of the beach. The wall could be shortened, lengthened and/or raised as required (there is, however, substantially more effort required to adjust the alignment).
2. Undertake more intensive field studies and monitoring of future entrance opening events to gain a better understanding of entrance opening to enable a more informed design which considers the physical variations at the entrance - even so, a trial and adjustment approach would still be required.

Alternative arrangements such as buried spur groynes adjacent to the Elements Resort foreshore could prove to be a more suitable solution to limit erosion to the north but reduce the impact on entrance and beach processes. Regardless it is likely that either a tripper wall or buried groynes will need to extend into the littoral

rainforest area which may complicate acquiring development consent. Investigations for these options should be undertaken under the recently released NSW Coastal Management Framework.

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Table 8. Opening location/arrangement option 2A – Maintain the existing opening location assessment against management objectives

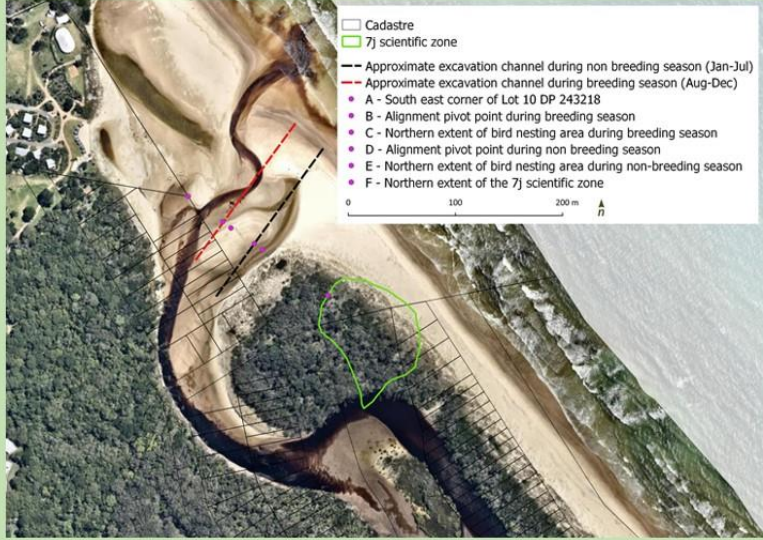
Opening option	Physical outcomes	Value	Management objective	Degree option achieves objective
<p>Maintain the existing opening location - Under the current interim license the entrance opening is to be excavated between the south east corner of Lot 10 DP 243218 and the northern extent of the 7(j) Scientific Zone (Bird protection area).</p> 	<ul style="list-style-type: none">Opening the entrance in this location is limiting the northward elongation of Belongil Spit and the resulting translation of the bird habitatEntrance will remain open longer than if located further north as entrance closure is driven by northward migration and infill	Ecological condition of the estuary and catchment	1. Protect the habitat and food sources for migratory shorebirds along the coastline and within the estuary	✓ ✓
			2. Limit erosion of the littoral rainforest area near the estuary entrance	✓
			3. Maintain as natural as possible entrance opening regime	✓
			4. Protect fish population and habitat including minimising the occurrence of fish kills	?
			5. Limit the impact on benthic communities within the estuary	✓
			6. Limit negative impacts of estuary opening on water quality within the estuary	N/A
			7. Protect the existing native vegetation communities (i.e. post-artificial opening vegetation community not pre-European ICOLL community)	N/A
		Drainage/Water quality	1. Do not increase flood levels in existing land uses	N/A
			2. Limit acidic runoff following artificial opening events	N/A
		Urban and industrial land use	1. Do not increase flood levels in existing urban/industrial areas	N/A
			2. Limit any increases in the duration of inundation events	N/A
		Agricultural	1. Minimise any increases in flood levels in existing agricultural areas	N/A
			2. Limit any increases in the duration of inundation events	N/A
		Tourism and recreation	1. Limit the impacts of estuary opening on Elements Resort	✓ ✓
			2. Limit the erosion of the coastal area adjacent to Elements Resort	✓
			3. Limit the impacts on longshore pedestrian access	✓ ✓
			4. Maintain public safety at estuary entrance	✗
		Cultural/Indigenous values	1. Protect culturally significant plant species/communities	?
			2. Protect culturally significant areas	?

Table 9. Opening location/arrangement option 2B – Moving the opening location to the north assessment against management objectives




Opening option	Physical outcomes	Value	Management objective	Degree option achieves objective		
<p>Moving the opening location to the north - Move the opening location north, this would involve redefining the two existing points in which the entrance is to be opened under the current interim license.</p> 	<ul style="list-style-type: none">Entrance closure is initiated by sand transported northwards along Belongil Spit and into the entrance. Belongil Spit elongates and pushes the entrance channel northwards. This may exacerbate erosion of the northern bank.As entrance closure typically results from northwards migration and infill, breaching in a more northerly location would tend to reduce the amount of time that the entrance stays open (less northwards distance to travel).Reduced duration of entrance opening will reduce tidal exchange, this may minimise opportunity for estuary to expel water which could lead to accumulation of MBO's and organic debris potentially leading to poor water quality and low dissolved oxygen. At the same time, reduced tidal exchange may provide less discharge/recharge cycles reducing the potential for acid transport via groundwater.	Ecological condition of the estuary and catchment	1. Protect the habitat and food sources for migratory shorebirds along the coastline and within the estuary	✓✓		
			2. Limit erosion of the littoral rainforest area near the estuary entrance	✗		
			3. Maintain as natural as possible entrance opening regime	✗		
			4. Protect fish population and habitat including minimising the occurrence of fish kills	?		
			5. Limit the impact on benthic communities within the estuary	✓		
			6. Limit negative impacts of estuary opening on water quality within the estuary	✗		
			7. Protect the existing native vegetation communities (i.e. post-artificial opening vegetation community not pre-European ICOLL community)	N/A		
		Drainage/Water quality	1. Do not increase flood levels in existing land uses	Low ocean levels	N/A	
				High ocean levels/storm surge events	N/A	
			2. Limit acidic runoff following artificial opening events		N/A	
		Urban and industrial land use	1. Do not increase flood levels in existing urban/industrial areas	Low ocean levels	N/A	
				High ocean levels/storm surge events	N/A	
		Agricultural	1. Minimise any increases in flood levels in existing agricultural areas	Low ocean levels	N/A	
				High ocean levels/storm surge events	N/A	
			2. Limit any increases in the duration of inundation events		N/A	
		Tourism and recreation	1. Limit the impacts of estuary opening on Elements Resort		✗	
			2. Limit the erosion of the coastal area adjacent to Elements Resort		✗	
			3. Limit the impacts on longshore pedestrian access		✓✓	
			4. Maintain public safety at estuary entrance		✗	
		Cultural/Indigenous values	1. Protect culturally significant plant species/communities		?	
			2. Protect culturally significant areas		?	
		✓ = Slightly positive outcome ✓✓ = Moderately positive outcome ✓✓✓ = Significantly positive outcome ? = Some uncertainty ✗ = Slightly negative outcome ✗✗ = Moderately negative outcome ✗✗✗ = Significantly negative outcome				

Table 10. Opening location/arrangement option 2C – *Moving the opening location to the south* assessment against management objectives

Opening option	Physical outcomes	Value	Management objective	Degree option achieves objective
<p><i>Moving the opening location to the south - Move the opening location south, immediately adjacent to the bird protection area at the end of the spit</i></p> 	<ul style="list-style-type: none">Increased threat to the designated bird nesting zone at the northern end of the spit.Excavation would go through bird nesting area during breeding season.May increase the opening duration as there is a greater distance in which the opening can migrate northward before eventually closingPotential increase in tidal exchange resulting in mixed impacts on water quality. Increased opportunity for estuary to expel water. Increased tidal exchange may provide more discharge/recharge cycles increasing the potential for acid transport via groundwater.May effectively create more of a backwater area adjacent to the eroding bank and littoral rainforest. This may provide some reduction in undercutting and erosion as there is less flow energy in this zone, although increased opening duration could lead to an increase in water movement and scour potential due to ebb and flow tidal influence .	Ecological condition of the estuary and catchment	1. Protect the habitat and food sources for migratory shorebirds along the coastline and within the estuary	✗
			2. Limit erosion of the littoral rainforest area near the estuary entrance	?
			3. Maintain as natural as possible entrance opening regime	✗
			4. Protect fish population and habitat including minimising the occurrence of fish kills	?
			5. Limit the impact on benthic communities within the estuary	✗
			6. Limit negative impacts of estuary opening on water quality within the estuary	
			7. Protect the existing native vegetation communities (i.e. post-artificial opening vegetation community not pre-European ICOLL community)	N/A
		Drainage/Water quality	1. Do not increase flood levels in existing land uses	N/A
			Low ocean levels	N/A
			High ocean levels/storm surge events	N/A
			2. Limit acidic runoff following artificial opening events	N/A
		Urban and industrial land use	1. Do not increase flood levels in existing urban/industrial areas	N/A
			Low ocean levels	N/A
			High ocean levels/storm surge events	N/A
		Agricultural	1. Minimise any increases in flood levels in existing agricultural areas	N/A
			Low ocean levels	N/A
			High ocean levels/storm surge events	N/A
			2. Limit any increases in the duration of inundation events	N/A
		Tourism and recreation	1. Limit the impacts of estuary opening on Elements Resort	✓ ✓
			2. Limit the erosion of the coastal area adjacent to Elements Resort	✓
			3. Limit the impacts on longshore pedestrian access	✓ ✓
			4. Maintain public safety at estuary entrance	✗
		Cultural/Indigenous values	1. Protect culturally significant plant species/communities	?
			2. Protect culturally significant areas	?


✓ = Slightly positive outcome ✓✓ = Moderately positive outcome ✓✓✓ = Significantly positive outcome ? = Some uncertainty ✗ = Slightly negative outcome ✗✗ = Moderately negative outcome ✗✗✗ = Significantly negative outcome

Table 11. Opening location/arrangement option 2D – *Creating a tripper wall* assessment against management objectives

Opening option	Physical outcomes	Value	Management objective	Degree option achieves objective
<p>Creating a tripper wall to the south - A “tripper wall” is a moderate training structure, constructed using geotextile containers, which remain buried under sand for much of the time to reduce the northward migration of the entrance. The location of the tripper wall would align approximately with the existing opening location during bird breeding season</p> 	<ul style="list-style-type: none"> Northward migration of entrance channel will be limited. Reduction in undercutting and erosion of northern bank adjacent to Elements Resort. If there is an increase in opening channel width there may be an increase in the duration of the tidal phase and therefore an impact on erosion of western bank upstream of the tripper wall. Speed with which the entrance closes will tend to be increased due to partial blockage of subtidal littoral transport (i.e. will act like a groyne). 	Ecological condition of the estuary and catchment	1. Protect the habitat and food sources for migratory shorebirds along the coastline and within the estuary	N/A
			2. Limit erosion of the littoral rainforest area near the estuary entrance	✓
			3. Maintain as natural as possible entrance opening regime	✗ ✗
			4. Protect fish population and habitat including minimising the occurrence of fish kills	N/A
			5. Limit the impact on benthic communities within the estuary	?
			6. Limit negative impacts of estuary opening on water quality within the estuary	?
			7. Protect the existing native vegetation communities (i.e. post-artificial opening vegetation community not pre-European ICOLL community)	N/A
		Drainage/Water quality	1. Do not increase flood levels in existing land uses	Low ocean levels N/A
				High ocean levels/storm surge events N/A
			2. Limit acidic runoff following artificial opening events	N/A
		Urban and industrial land use	1. Do not increase flood levels in existing urban/industrial areas	Low ocean levels N/A
				High ocean levels/storm surge events N/A
		Agricultural	1. Minimise any increases in flood levels in existing agricultural areas	Low ocean levels N/A
				High ocean levels/storm surge events N/A
			2. Limit any increases in the duration of inundation events	N/A
		Tourism and recreation	1. Limit the impacts of estuary opening on Elements Resort	✓ ✓ ✓
			2. Limit the erosion of the coastal area adjacent to Elements Resort	✓ ✓ ✓
			3. Limit the impacts on longshore pedestrian access	N/A
			4. Maintain public safety at estuary entrance	✗
		Cultural/Indigenous values	1. Protect culturally significant plant species/communities	?
			2. Protect culturally significant areas	?


✓ = Slightly positive outcome ✓✓ = Moderately positive outcome ✓✓✓ = Significantly positive outcome ? = Some uncertainty ✗ = Slightly negative outcome ✗✗ = Moderately negative outcome ✗✗✗ = Significantly negative outcome

Table 12. Opening location/arrangement option 2E – *Creating shore normal buried groynes* assessment against management objectives

Opening option	Physical outcomes	Value	Management objective	Degree option achieves objective
<p>Creating shore normal buried groynes - Construct a series of shore normal buried "groynes" that behave somewhat like spur walls in a river. As the channel migrates across to this part of the entrance compartment, the entrance is close to closing and hence tidal velocities tend to be small. The buried groynes would aim to provide protection at the toe of the northern bank.</p> 	<ul style="list-style-type: none"> Limited impact on northward migration of entrance channel. Reduction in undercutting and erosion of northern bank adjacent to Elements Resort. 	Ecological condition of the estuary and catchment	1. Protect the habitat and food sources for migratory shorebirds along the coastline and within the estuary	N/A
			2. Limit erosion of the littoral rainforest area near the estuary entrance	✓
			3. Maintain as natural as possible entrance opening regime	N/A
			4. Protect fish population and habitat including minimising the occurrence of fish kills	N/A
			5. Limit the impact on benthic communities within the estuary	?
			6. Limit negative impacts of estuary opening on water quality within the estuary	?
			7. Protect the existing native vegetation communities (i.e. post-artificial opening vegetation community not pre-European ICOLL community)	N/A
		Drainage/Water quality	1. Do not increase flood levels in existing land uses	Low ocean levels N/A
			High ocean levels/storm surge events	N/A
			2. Limit acidic runoff following artificial opening events	N/A
		Urban and industrial land use	1. Do not increase flood levels in existing urban/industrial areas	Low ocean levels N/A
			High ocean levels/storm surge events	N/A
		Agricultural	1. Minimise any increases in flood levels in existing agricultural areas	Low ocean levels N/A
			High ocean levels/storm surge events	N/A
			2. Limit any increases in the duration of inundation events	N/A
		Tourism and recreation	1. Limit the impacts of estuary opening on Elements Resort	✓ ✓ ✓
			2. Limit the erosion of the coastal area adjacent to Elements Resort	✓ ✓ ✓
			3. Limit the impacts on longshore pedestrian access	N/A
			4. Maintain public safety at estuary entrance	✗
		Cultural/Indigenous values	1. Protect culturally significant plant species/communities	?
			2. Protect culturally significant areas	?

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Table 13. Opening location/arrangement option 2F – *Permanently opening the estuary* assessment against management objectives

Opening option	Physical outcomes	Value	Management objective	Degree option achieves objective	
<p><i>Permanently opening the estuary - Installing entrance training structures such as rock walls to inhibit berm formation and create a permanently opened estuary entrance</i></p> 	<ul style="list-style-type: none">Consistently elevated tidal conditions within the drains, a situation which has the potential to cycle groundwater levels causing repeated recharge and discharge of ASS and enabling intermittent oxidation and transport of the resulting acid by the groundwater (could be limited by decoupling the estuary).Increased erosion of the western bank adjacent to littoral rainforest area as ebb and flood tide velocities increase.Increased salt water intrusion further up the estuary. This may also decrease the quality of agricultural landShift toward permanent estuarine ecological communities.The open entrance will result in storm tide events more easily penetrating the estuary and increasing the severity of flooding (Issue will be further exacerbated by sea level rise).Limited impact on peak flood levels within the CBD as this is largely controlled by the limited capacity of stormwater infrastructure but this will likely change with predicted sea level rise.Reduced incidence of nuisance flooding although this will change with predicted sea level rise.If water quality issues are not addressed in the catchment then pollutants will be flushed directly into ocean.High ocean levels and storm surges increase water levels within the estuary and impact drainage of low lying areasStructures required to keep the entrance open (such as rock walls) may reduce northward sand transport, reducing sand supply to the northern beaches and increasing the susceptibility to erosion. However, such structures will also tend to cause sand to accumulate to the south.Decreased public access along the beach and from Elements resort south towards Byron.Ongoing maintenance will likely be required (eg. dredging) . The need for dredging is likely to increase with time, as the beach needs to build up against the southern training wall until the alongshore drift is able to “bypass” the entrance.	Ecological condition of the estuary and catchment	1. Protect the habitat and food sources for migratory shorebirds along the coastline and within the estuary	XX	
			2. Limit erosion of the littoral rainforest area near the estuary entrance	XX	
			3. Maintain as natural as possible entrance opening regime	XX	
			4. Protect fish population and habitat including minimising the occurrence of fish kills	?	
			5. Limit the impact on benthic communities within the estuary	XX	
			6. Limit negative impacts of estuary opening on water quality within the estuary	?	
			7. Protect the existing native vegetation communities (i.e. post-artificial opening vegetation community not pre-European ICOLL community)	X	
		Drainage/Water quality	1. Do not increase flood levels in existing land uses	Low ocean levels High ocean levels/storm surge events	✓✓✓ XX
			2. Limit acidic runoff following artificial opening events		N/A
		Urban and industrial land use	1. Do not increase flood levels in existing urban/industrial areas	Low ocean levels High ocean levels/storm surge events	✓✓✓ XX
		Agricultural	1. Minimise any increases in flood levels in existing agricultural areas	Low ocean levels High ocean levels/storm surge events	✓✓✓ XX
			2. Limit any increases in the duration of inundation events		✓
		Tourism and recreation	1. Limit the impacts of estuary opening on Elements Resort		N/A
			2. Limit the erosion of the coastal area adjacent to Elements Resort		✓✓✓
			3. Limit the impacts on longshore pedestrian access		XX
			4. Maintain public safety at estuary entrance		X
		Cultural/Indigenous values	1. Protect culturally significant plant species/communities		?
			2. Protect culturally significant areas		?

✓ = Slightly positive outcome ✓✓ = Moderately positive outcome ✓✓✓ = Significantly positive outcome ? = Some uncertainty X = Slightly negative outcome XX = Moderately negative outcome XXX = Significantly negative outcome

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4.3 Decoupling of the catchment from the estuary

Two different options were assessed to decouple the catchment from the estuary. These include installation of water control structures at two different levels. The options assessed include:

- A. **Creating weirs at 1.2 m AHD** – Installation of control structures to limit the interaction of drain and swamp water with the estuary. These structures aim to control groundwater gradients thereby limiting groundwater discharge into drains. The increased inundation of Potential Acid Sulphate Soils (PASS) reduces oxidation potential of soils into Acid Sulphate Soils (ASS). Tidal conditions downstream of the weir will remain when the estuary entrance is open but not affect the drain upstream. Catchment flows will enter the estuary when levels exceed the weir height of 1.2 m AHD.
- B. **Creating weirs at 1.4 m AHD** – Similar to above however the weir height is installed 200 mm higher at 1.4 m AHD.

An assessment of each of the two management options is provided in Table 14 and Table 15. The most significant difference between the two options is the increased inundation extent upstream of the weirs which is likely to impact on agricultural productivity.


Decoupling of the catchment from the estuary aims to control the interaction of drain and swamp water with estuary water. This separation has been advocated for in several previous studies to assist in limiting the impacts of ASS and associated products on the estuary.

There is significant uncertainty surrounding some of the outcomes associated with decoupling the catchment from the estuary. Some of the likely issues include:

- 1. There may be a reduction in the oxidation of PASS and reduced runoff of ASS products flowing into the drains and estuary but there will also be prolonged inundation of land upstream of the weirs. This water has the potential build up with organic material and breakdown of this material could cause water quality to deteriorate. As a result, there is significant uncertainty surrounding how this water will affect downstream water quality during and following significant rainfall events where the respective weir levels are breached.
- 2. The extent of inundation of the land upstream of the weir and the duration that the land will be inundated will likely impact the agricultural productivity of the land surrounding the drain.
- 3. Weirs can modify environmental flows of freshwater needed for a fully ecologically functional estuary, decrease connectivity and create a barrier for fish movement between the estuary and freshwater habitats, which can further modify the ecology and biodiversity of the catchment.
- 4. Potentially modifying natural flow regimes (including allowing sediment to move into the estuary).


To further explore this option would require significant investigation into the appropriate locations and type of water control structures required. Any trial implementation of this type of strategy would also require a rigorous monitoring program. Any further investigations into decoupling the estuary should be undertaken under the recently released NSW Coastal Management Framework.

Table 14. Decoupling the catchment from the estuary option 3A – *Creating a weir at 1.2 m AHD* assessment against management objectives

Opening option	Physical outcomes	Value	Management objective	Degree option achieves objective	
<p>Creating weir at 1.2 m AHD - Installation of water control structures at 1.2m AHD to control the interaction of drain and swamp water with estuary water</p> 	<ul style="list-style-type: none">Control groundwater gradients within land adjacent to drains limiting ASS products flowing into drains.Limit tidal exchange within drains reducing opportunity for flocculation of dissolved iron associated with ASS products which can lead to oxygen depletion.Reducing the tidal influence of drain network may reduce the wetting and drying and associated oxidation of ASS and transportation of acidic drain water up and downstream (tidal pumping).Reduction in sulfate availability in drains may reduce sulfate reduction and reduce the accumulation of monosulfidic black ooze (MBO) which can cause significant deoxygenation of floodwaters.Increased runoff retention in upstream swamps and wetlands as well as farm land adjacent to Union Drain – increasing habitat for wetland/swamp flora and fauna, reducing productive agricultural land.	Ecological condition of the estuary and catchment	1. Protect the habitat and food sources for migratory shorebirds along the coastline and within the estuary	✓	
			2. Limit erosion of the littoral rainforest area near the estuary entrance	?	
			3. Maintain as natural as possible entrance opening regime	?	
			4. Protect fish population and habitat including minimising the occurrence of fish kills	✓	
			5. Limit the impact on benthic communities within the estuary	?	
			6. Limit negative impacts of estuary opening on water quality within the estuary	✓✓	
			7. Protect the existing native vegetation communities (i.e. post-artificial opening vegetation community not pre-European ICOLL community)	✓	
		Drainage/Water quality	1. Do not increase flood levels in existing land uses	Low ocean levels High ocean levels/storm surge events	✗ ✓
			2. Limit acidic runoff following artificial opening events		✓✓✓
		Urban and industrial land use	1. Do not increase flood levels in existing urban/industrial areas	Low ocean levels High ocean levels/storm surge events	✓✓ ✓
		Agricultural	1. Minimise any increases in flood levels in existing agricultural areas	Low ocean levels High ocean levels/storm surge events	✓ ✗
			2. Limit any increases in the duration of inundation events		✗
		Tourism and recreation	1. Limit the impacts of estuary opening on Elements Resort		N/A
			2. Limit the erosion of the coastal area adjacent to Elements Resort		N/A
			3. Limit the impacts on longshore pedestrian access		N/A
			4. Maintain public safety at estuary entrance		N/A
		Cultural/Indigenous values	1. Protect culturally significant plant species/communities		?
			2. Protect culturally significant areas		?

✓ = Slightly positive outcome ✓✓ = Moderately positive outcome ✓✓✓ = Significantly positive outcome ? = Some uncertainty ✗ = Slightly negative outcome ✗✗ = Moderately negative outcome ✗✗✗ = Significantly negative outcome

Table 15. Decoupling the catchment from the estuary option 3B – *Creating a weir at 1.4 m AHD* assessment against management objectives

Opening option	Physical outcomes	Value	Management objective	Degree option achieves objective	
<p>Creating weir at 1.4 m AHD - Installation of water control structures at 1.4m AHD to control the interaction of drain and swamp water with estuary water</p> 	<ul style="list-style-type: none">Control groundwater gradients within land adjacent to drains limiting ASS products flowing into drains.Limit tidal exchange within drains reducing opportunity for flocculation of dissolved iron associated with ASS products which can lead to oxygen depletion.Reducing the tidal influence of drain network may reduce the wetting and drying and associated oxidation of ASS and transportation of acidic drain water up and downstream (tidal pumping).Reduction in sulfate availability in drains may reduce sulfate reduction and reduce the accumulation of monosulfidic black ooze (MBO) which can cause significant deoxygenation of floodwaters.Increased runoff retention in upstream swamps and wetlands as well as farm land adjacent to Union Drain – increasing habitat for wetland/swamp flora and fauna, reducing productive agricultural land.Increased inundation extent upstream of weirs.Increased flood storage in swamps and wetlands upstream of weir could help give priority to release of urban runoff during rainfall events reducing risk of flooding of CBD and Arts and Industrial Estate.	Ecological condition of the estuary and catchment	1. Protect the habitat and food sources for migratory shorebirds along the coastline and within the estuary	✓	
			2. Limit erosion of the littoral rainforest area near the estuary entrance	?	
			3. Maintain as natural as possible entrance opening regime	?	
			4. Protect fish population and habitat including minimising the occurrence of fish kills	✓	
			5. Limit the impact on benthic communities within the estuary	?	
			6. Limit negative impacts of estuary opening on water quality within the estuary	✓ ✓	
			7. Protect the existing native vegetation communities (i.e. post-artificial opening vegetation community not pre-European ICOLL community)	✓	
		Drainage/Water quality	1. Do not increase flood levels in existing land uses	Low ocean levels High ocean levels/storm surge events	✗ ✗ ✓ ✓
			2. Limit acidic runoff following artificial opening events		✓ ✓ ✓
		Urban and industrial land use	1. Do not increase flood levels in existing urban/industrial areas	Low ocean levels High ocean levels/storm surge events	✓ ✓ ✓ ✓
		Agricultural	1. Minimise any increases in flood levels in existing agricultural areas	Low ocean levels High ocean levels/storm surge events	✗ ✗ ✓ ✓
			2. Limit any increases in the duration of inundation events		✗ ✗
		Tourism and recreation	1. Limit the impacts of estuary opening on Elements Resort		N/A
			2. Limit the erosion of the coastal area adjacent to Elements Resort		N/A
			3. Limit the impacts on longshore pedestrian access		N/A
			4. Maintain public safety at estuary entrance		N/A
		Cultural/Indigenous values	1. Protect culturally significant plant species/communities		?
			2. Protect culturally significant areas		?

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4.4 Summary and recommendations

A complex, interrelated suite of processes in the Belongil Creek ICOLL govern water quality, ecological condition and sediment movement. Natural ICOLLs like Belongil Creek have a high degree of dynamism. To allow for agricultural and urban development within the catchment the estuary has been artificially opened for over 100 years. The artificial opening has reduced some of the uncertainty surrounding estuary levels and allowed for an altered landscape to develop within the catchment. This includes the development of urban areas in the Byron Bay CBD and the Arts and Industrial Estate, the expansion of mangrove and saltmarsh communities, the transition to more marine fish assemblage and the gradual replacement of wetland vegetation communities by “drier” community types.

Many of the values that are important to stakeholder and the community are a function of this altered landscape. In the last 20 years a consistent opening regime has been maintained by Council. According to monitoring reports, there have been minimal fish kill events following an artificial opening during this period. There is a relatively high degree of certainty surrounding how the estuary responds to this regime given the long-term monitoring data available.

The options assessment indicated there is a high degree of uncertainty surrounding the outcomes that would result if the opening level of the estuary is raised. Many of the values identified by the stakeholders and the community would be threatened if the opening level was raised significantly. As a result, using the existing opening level as a watch level and introducing an immediate breach level at 1.1 m AHD provides the most positive outcomes for the important values identified within the catchment.

It is recommended that there is minimal change to the existing opening level to limit the impacts on the catchment. However, the strategy needs to clearly provide a framework to raise the opening level over time as sea level rise results in more frequent artificial opening events. To prepare for this change it is recommended that a watch level and immediate breach level be introduced as part of the Opening Strategy. These levels should be set at 1.0 m AHD and 1.1 m AHD respectively.

Over time both the watch level and immediate breach level will need to increase as sea levels rise. It is recommended the trigger for this increase in opening level be governed by council’s resources for artificial opening. For example, if opening is consistently required every month and this is beyond council’s resources then the watch level should be raised slightly (i.e. 1.0 m to 1.1 m). The response in the estuary would then need to be monitored for several opening events to inform any future management responses.

Where possible the Opening Strategy needs allow more adaptive management to allow for more natural opening events. If the berm appears to be near breaching and rainfall is predicted, then do nothing. If the berm is higher than this level and rain is predicted, then scrape in one location to 1.0 m AHD. If this does not result in natural opening and berm height or water level increases to 1.1 m AHD, then artificial opening should be undertaken.

The existing opening location during breeding season seems to get the balance right between protecting the littoral rainforest and Elements Resort to the north and the bird nesting area to the south. It is recommended that the northern opening location (breeding season) be used throughout the year. Additionally, under prevailing north to north east wind and swell conditions the opening location should be moved to the north to minimise impacts on the bird nesting area. Furthermore, this location needs to be adaptive, monitoring of the bird nesting area should be undertaken and adjustments made to ensure the area is not impacted by the opening. As the spit elongates more to the north and littoral rainforest is further eroded some management response in this area is warranted. A tripper wall or some shorter, shore normal buried groynes, beach scraping and protective works could help protect the littoral rainforest community and the Elements Resort foreshore. Planning and investigations for this option should begin now under the recently released NSW Coastal Management Framework. It is estimated that bank retreat in this area is currently occurring at a rate of 3-5 m/year.

5 Entrance opening strategy and Environmental Management Plan

5.1 Trigger levels

Overview

The watch level for the Belongil Creek estuary opening should be maintained at 1.0 m AHD. An Immediate Breach level of 1.1 m AHD should also be adopted. These water levels are measured at Council's [Ewingsdale Road gauge](#) and is available from the BoM's [website](#). This strategy provides an overview of the operational procedures and decision support framework to be used to inform entrance opening events.

Operational procedure

Rainfall monitoring

To inform estuary opening decision making the forecast for catchment rainfall is an important consideration. Rainfall forecasts should be taken from the Bureau of Meteorology (BoM) [Byron Bay forecasts](#). Reasonably reliable forecasts are provided at least a few days in advance. A typical forecast is shown in Figure 5. For this example, the key rainfall forecast metrics for this day are:

1. There is an 80% chance of any rainfall
2. There is a 50% change of 1 mm or more of rainfall
3. There is a 10% change of 5 mm or more of rainfall

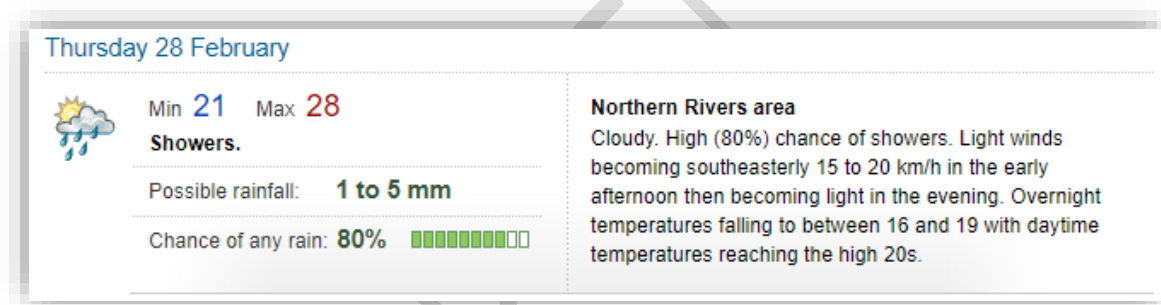


Figure 5. Typical BoM rainfall forecast

Estuary water level monitoring

Water levels in the estuary should be taken from the BoM's [Ewingsdale Road gauge](#). Recognising this data is real-time operational data from automated telemetry systems and has not been quality controlled. If in doubt water levels against the gauge board at the Ewingsdale Road bridge can also be inspected.

Ocean level monitoring

Ocean levels should also be monitored to inform estuary opening. At present the BoM executes hydrodynamic models, coupled with weather models to forecast "tidal anomalies", on a daily basis around the coast of Australia. The models are consistently improving as numerical methods and computational power increases. At the time of writing, the information to be accessed to consider ocean water levels over the following 3 days is as follows:

1. Access the forecast tidal anomalies from [BoM's OceanMaps model](#)
2. Examine the predicted [astronomical ocean tides](#)

If the two of these add to give a number in the range of the water level alert and immediate trigger levels, it becomes likely that there will be an impact on water levels in the estuary. Over time, the frequency of this impact will increase, as sea levels continue to rise offshore.

Waves can also have an impact on water levels in the estuary. If the entrance is closed, wave set-up and runup can introduce additional water to the estuary, superelevating the estuary water level above that in the ocean. At present, a qualitative assessment will need to be made using wave forecast information from the BoM and Manly Hydraulics Laboratory.

Rainfall, wave and water level rise relationship

A relationship between catchment rainfall, ocean levels/wave heights and estuary water level rise should be developed. This will help determine the potential rise in water level under different rainfall and ocean levels/wave height forecasts to inform decision making.

Berm height monitoring

The berm height is a critical factor in determining whether a natural opening event will occur. If the berm height is low there is a higher likelihood that a small rainfall event would trigger an opening event. If the berm height is high a larger rainfall event and larger rise in estuary level would be required to breach the berm.

It is recommended that the berm height be monitored fortnightly by either Real-time kinematic (RTK) GPS surveying or drone technology when the water level is between the watch level and the immediate breach level. Monitoring data will help inform the short-term planning for the opening procedure and will also be critical for the entrance morphodynamic monitoring discussed in Section 5.6.

Swell and wind direction monitoring

Typically following an opening event the entrance migrates in a northerly direction, but this is not always the case. Under prevailing north to north east wind and swell directions the entrance can migrate in a southerly direction toward the spit (and bird nesting area). Under these conditions it is recommended that the channel be excavated further to the north and the excess sand be placed on the southern side of the channel. Monitoring of the predicted prevailing wind direction and strength and swell direction should be undertaken to inform appropriate channel location.

Over time, information gathered in the entrance opening records will help determine the prevailing conditions that result in southward channel migration.

Decision support framework

A decision support framework which guides entrance management decision making based on the estuary water level, the rainfall forecast, ocean levels and berm heights is outlined in Figure 6. There is some flexibility within the framework when the estuary level is between 1.0 – 1.1 m AHD and ocean levels are not impacting on estuary levels. If the water level is within this range and no rainfall is forecast there is no urgent requirement to undertake artificial opening. If the berm height begins to exceed 1.1 m AHD and the water level remains below 1.1 m AHD, the berm can be scraped to help promote a more natural opening during the next rainfall event. However, if high intensity rainfall is forecast, artificial opening should be undertaken to reduce flood risk within urban areas.

There are circumstances where ocean levels result in estuary levels greater than 1.1 m AHD, but these levels can reduce over a period of days. In order to reduce instances of unnecessary opening, additional flexibility has been allowed between 1.1 – 1.2 m AHD. If the water level is within this range and no rainfall is forecast there is no urgent requirement to undertake artificial opening. If the berm height begins to exceed 1.2 m AHD and the water level remains below 1.2 m AHD, the berm can be scraped to help promote a more natural opening during the next rainfall event. However, if high intensity rainfall is forecast, artificial opening should be undertaken to reduce flood risk within urban areas. Additionally, if the water level has been above the immediate breach level of 1.1 m AHD for more than 14 days or exceeds 1.2 m AHD then artificial opening should be undertaken.

The framework requires regular monitoring of water levels, ocean level, rainfall forecasts and beach berm levels. In periods where there is low rainfall and low ocean levels predicted this monitoring can be once every three days. However, when there is significant rainfall and/or high ocean levels predicted monitoring needs to be almost continuously undertaken.

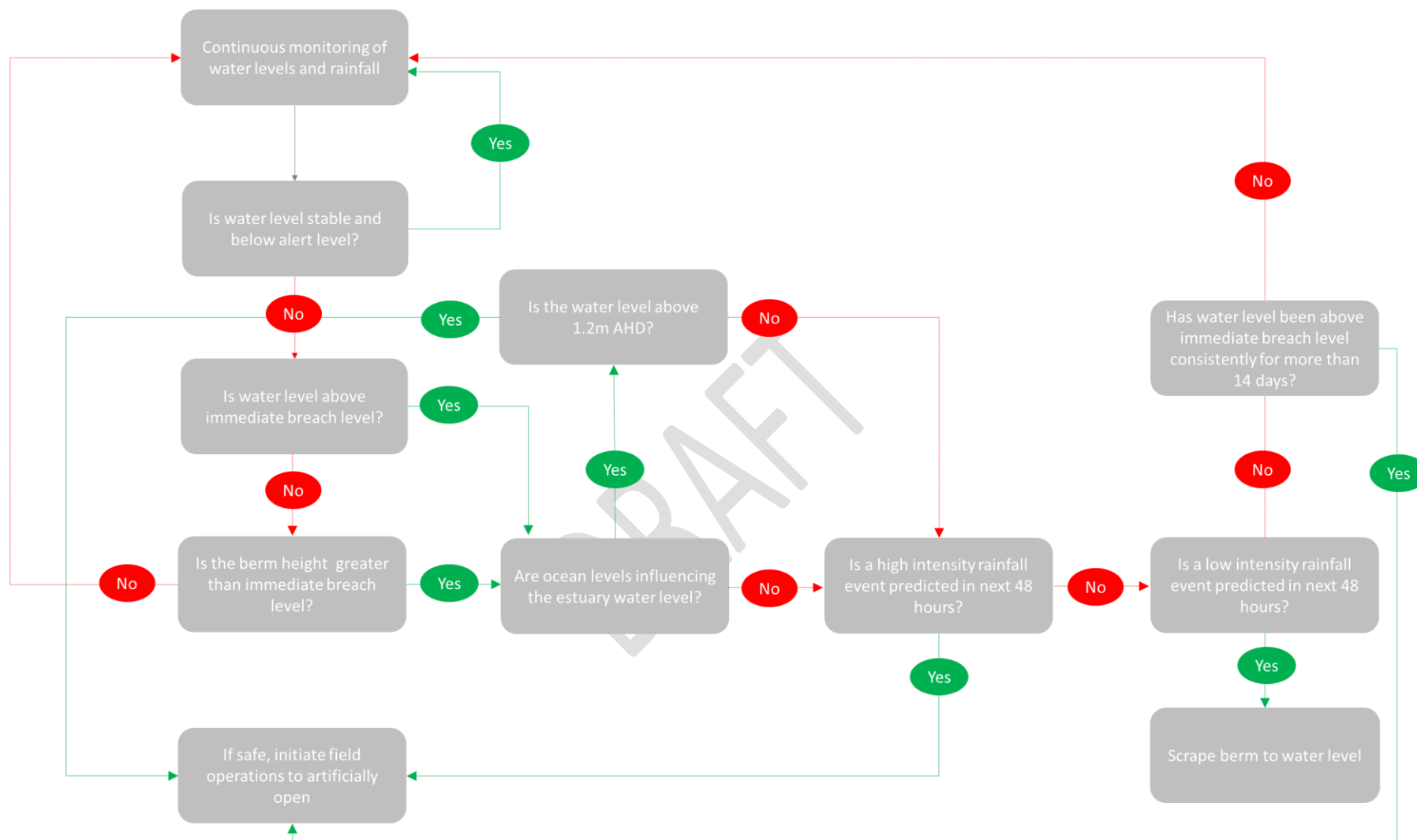


Figure 6. The decision support framework to inform the entrance management

5.2 Recommended approach

Location

The proposed entrance opening locations are shown in Figure 7. The entrance opening is to be excavated between the south east corner of Lot 10 DP 243218 and the northern extent of the 7(j) Scientific Zone, with the centreline being located approximately 10 m north of any authorised bird protection fence subject to any significant site constraints. This arrangement utilises the existing opening location during breeding season (Aug – Dec) throughout the year. However, when the predicted prevailing swell and wind direction is from the north to north east the northern opening location should be utilised to minimise impacts on the bird nesting area. Access to the site is from the north and outlined below in Section 5.10 in Figure 10.



Figure 7. The proposed opening arrangements for Belongil Creek estuary entrance

Method

Full opening

A breach channel should be dug from the ocean to 3 m from the interface with the estuary water level. The channel should be 3 m wide with a depth of approximately 0.2 m. The channel slope should be based on the berm slope heading towards the sea. The final 3 m zone should be scraped to the water level to allow for the gradual scouring of the entrance of the channel. An example from a recent breaching event is shown in Figure 8.



Figure 8. *The breached channel at Belongil Creek estuary during an opening event on the 26th of February 2019*

Scraping

Berm scraping can be undertaken to help facilitate more natural opening events during future rainfall. If the berm level is above the immediate breach level, the water level is below the immediate breach level and rainfall is predicted, the berm can be scraped to the water level. Berm scraping should occur across a 5 m zone (alongshore) of the berm crest. If high intensity rainfall and flash flooding is predicted, then a full opening should be undertaken to reduce any flood risk. This decision should be made by the Council flood engineer.

Scraping has not previously been undertaken in the Belongil Creek estuary. Given the low watch and immediate breach levels scraping alone may not facilitate an effective opening event due to the low hydraulic gradient. As a result, the effectiveness of scraping needs to be monitored and the framework modified if required. If scraping proves to be ineffective after several trials under varied conditions then it should be removed from the framework.

Remediation

Excess sand generated during the excavation works should be placed in accordance with the predicted prevailing wind and swell conditions. During periods when the swell direction is predicted to be coming from the north to north east, sand should be placed on the southern side of the channel to reduce southward channel migration. During east to south swells sand should be placed on the northern side of the channel to slow the northward migration.

Safety

All opening and scraping works need to follow Council's Work, Health and Safety guidelines and policies. This should consider working near water, public access, trench excavation heights and slopes and substrate stability.

5.3 Adaptive management

Sea level rise

Sea level rise associated with climate change will force the raising of the trigger levels over time. As sea levels rise the artificial opening events will become more and more frequent. The trigger level should be raised every five years in line with actual sea level rise. Additionally, significant changes in artificial opening frequency governed by Council's resources should be considered. For example, if opening is consistently required every month and this is beyond Council's resources then the watch level should be raised slightly (i.e. 1.0 m to 1.1

m). The ecological response in the estuary would then need to be monitored for several opening events to inform any future management responses.

Changes to estuary entrance location

The estuary entrance is a dynamic landscape. There is the potential for a breakthrough to occur further to the south of the current entrance. In this area there is a low point which has been partially created by pedestrian access across the dune system to the estuary. The dune is approximately 1 m higher than the hind side beach elevation (Figure 9). There is limited vegetation stabilising the 20 -30 m of sand deposits between the beach and estuary. If a breakout does occur at this location the entrance opening arrangements will need to be reviewed urgently.



Figure 9. *The vertical scarp of the dune which forms the high point along the potential cut through path across Belongil Spit*

The Belongil Spit, Belongil Creek estuary channel and entrance channel is migrating to the north. Without management action there is likely to be ongoing erosion of the littoral rainforest area and northern foreshore zone. It is estimated that bank retreat in this area is currently occurring at a rate of 3-5 m/ year. If this continues, it is likely the entrance opening location will need to be modified in the future.

To reduce the impacts on the littoral rainforest area and northern foreshore, options including shore normal buried groynes, a tripper wall, beach scraping and/or protective works should be investigated under the recently released NSW Coastal Management Framework. Investigations for such options should be pursued promptly and, if feasible, the triggers for implementing any desired options also determined.

5.4 Organisational responsibilities and communication

The Byron Shire Council is responsible for Belongil Creek entrance opening. When the trigger for opening or scraping has been reached based on the decision support framework outlined in Section 5.1, the following agencies should be notified:

1. NSW Department of Planning, Industry and Environment
2. NSW Department of Primary Industry – Fisheries
3. NSW Department of Primary Industry – Marine Parks
4. NSW Department of Industry – Crown Lands
5. National Parks and Wildlife Services

In addition, affected landholders, residents, businesses and environment and community groups should also be notified and include:

1. Byron Bay Bird Buddies
2. Belongil Catchment Drainage Board
3. Elements Resort
4. Council's communications team

5.5 Relevant legislation and approvals

The development of the Belongil Creek Entrance Opening Strategy is based on recommendations in the 2001 Belongil Creek Estuary Management Plan. The plan was prepared under the NSW Coastal Policy (1997) and the Estuary Management Manual 1992. Under the Crown Lands Act. 1989, a conditional two-year licence for the mechanical opening of the Estuary was issued to Council in 2001 and has since been extended. The licence is due for renewal in 7th December 2022. The relevant legislation considered includes:

1. Fisheries Management Act 1994
2. National Parks and Wildlife Act 1974
3. Water Management Act 2000
4. Marine Parks Act 1997
5. Marine Estate Management Act 2014
6. Marine Estate Management Strategy 2017
7. State Environmental Planning Policy (Coastal Management SEPP) 2018
8. State Environmental Planning Policy (Infrastructure) 2007
9. Biodiversity Conservation Act 2016
10. Environmental Planning and Assessment Act 1979, including Environmental planning instruments
11. Crown Land Management Act 2016
12. Threatened Species Conservation Act 1995
13. Commonwealth Environment Protection and Biodiversity Conservation Act 1999

The following licenses/approvals are required for the artificial entrance opening:

1. Crown lands license, administered under the Crown Lands Act 1989
2. Approval - NSW Department of Primary Industry – Fisheries and Marine Parks
3. Approval - NSW Department of Primary Industry – Marine Parks

5.6 Recommended monitoring

Monitoring of the environmental health of the Belongil Creek catchment associated with artificial estuary entrance opening events has been formally undertaken since 2001. The monitoring is a condition of the current Crown land interim license. The existing monitoring data collected includes:

1. Water level and salinity data from two permanent data loggers one located in the estuary and one in the upstream drainage system

2. Water quality data (pH, conductivity, temperature, turbidity, dissolved oxygen and salinity) collected by an in-situ logger located at Ewingsdale Bridge
3. Water quality data from samples taken at five locations within the estuary prior to an entrance opening event and continuing for seven days after
4. Vegetation assessments of two adjoining wetland communities.
5. Estuary opening records (opening date, initial level (m AHD), approximate opening time, tide at opening, width of opening and final level (m AHD))

Monitoring reports are compiled biannually and include any management recommendations based on the findings. A consistent sampling method needs to be maintained for all monitoring to ensure the datasets are comparable. For example, all water levels need to be routinely referenced to Australian Height Datum. The current monitoring arrangements are to be continued. In addition, the following additional monitoring is recommended:

1. **Entrance morphology dynamics** - There is currently limited understanding of the coastal and littoral processes which govern entrance opening and closing dynamics. An improved understanding of these processes could help in the future planning and design of entrance management works. The monitoring should include the regular collection of terrain data using RTK GPS surveying or drone technology. The use of current drone technology can also provide the additional benefit of aerial imagery to help interpret processes. The technology available to complete these surveys is rapidly improving and it is likely that better methods will emerge with time.
2. **Channel morphology dynamics** – The Belongil Creek channel just upstream of the entrance is migrating to the north resulting in significant loss of endangered littoral rainforest community. Rates of bank retreat should be monitored using aerial imagery and following significant flow/wave events. The rates of habitat loss can be used to inform management of this area.
3. **Spit morphology dynamics** – The Belongil Spit has narrowed substantially in recent decades. Ongoing narrowing of the spit could result in a breakout event and a new estuary entrance location. Rates of spit width retreat should be monitored using aerial imagery and following significant flow/wave events. The rates of retreat can be used to inform a management response which may include works to reduce rates of retreat or revising the entrance location.
4. **Water quality parameters** – Additional water quality parameters should be included for analysis including Total Nitrogen, Total Phosphorous and Faecal coliforms.
5. **Entrance opening records** – A description of the entrance opening should be included in the monitoring reports. This should include a description of earthworks, excavation depth, side of channel excess sand was deposited, swell height and direction, ocean level and description of what happens.
6. **Bird nesting area** – Spatial monitoring of the bird nesting area should be undertaken to provide information for the adaptive management of entrance opening location.

To aid in the morphology and entrance opening method monitoring, it is recommended that a permanent camera be set up overlooking the entrance. This will enable assessment of entrance behaviour prior to, during and following an artificial opening event. In addition, it is recommended that Council subscribe to targeted satellite imagery monitoring available from 'Planet Imagery'. This service provides access to high resolution satellite imagery (75cm) for a designated area of interest up to twice daily with archived images dating to 2014. This will allow for spatial and temporal analysis and provide valuable information on estuary and entrance behaviour under varied conditions.

It is recommended that all water level and water quality data be made publicly available.

5.7 Review period

Every 24 months the estuary Opening Strategy should be reviewed utilising the monitoring data outlined in Section 5.6. Key questions to be determined during the review should include:

1. Is the current opening frequency beyond Council's resources for opening?
2. Is scraping resulting in effective opening events?
3. Have there been any significant environmental or community concerns?

Based on the answer to these questions elements of the decision framework may need to be modified. All key stakeholders should be informed and involved in any changes or adaptation to the Opening Strategy. The development of a broader Coastal Management Program (CMP) for the Belongil Creek catchment is recommended. Upon finalisation of a CMP, the Opening Strategy should be reviewed to ensure consistency with objectives for the management of the catchment.

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5.8 Environmental management

Despite the extensive changes within the catchment, the Belongil Creek ICOLL and drainage system provides a large expanse of high-quality habitat for various terrestrial and aquatic species. The estuary opening strategy has been developed to limit the impacts of estuary opening events on the environmental values within the estuary and catchment. This includes:

1. Retaining the trigger level close to 1.0 m AHD as estuary and vegetation communities have adjusted to this regime over the last 20 years
2. Introducing beach scraping to promote more natural opening events following rainfall
3. Allowing some flexibility for ocean surge events to drain naturally prior to opening to reduce the volume of water (and pollutant load) drained from the catchment
4. Reducing the impact of opening on environmentally sensitive areas near the entrance including the littoral rainforest area and bird nesting habitat

However, the role estuary opening can play in improving the health of the estuary is limited. A broader program of catchment management is required. The recommended actions as part of a catchment management program are outlined in Section 5.9. Specific actions relating to estuary opening works are outlined in Section 5.10.

5.9 Catchment management

A broader catchment management program should seek to improve water quality entering the estuary and protect fringing ecological communities. The major issues in the catchment and a recommended framework for the development of a Belongil Creek catchment plan is outlined in the *Belongil Creek catchment issues study* (Alluvium, 2019). Key actions of the program include:

1. Improve water quality draining from urban areas through the use of water sensitive urban design treatment systems (i.e. wetlands, rain gardens etc.) similar to what was outlined in the Byron Bay Drainage Strategy
2. Improve water quality draining from agricultural areas by re-establishing floodplain wetland environments
3. Protect fringing ecosystem and habitat corridors
4. Investigate groundwater levels and rainfall-aquifer dynamics to better understand and assist management of acid runoff entering the estuary
5. Investigate stormwater and sewer cross-connections to limit sewage discharge to the estuary
6. The expansion of the Byron Bay recycled water reuse scheme to reduce flows in the estuary
7. Investigate the impacts of sea level rise on estuary and catchment health

The program of catchment management may be implemented as part of the NSW Coastal Management Framework. This will involve developing a Coastal Management Program for the Belongil Creek estuary.

5.10 Construction management

The access route to the estuary entrance to undertake opening or beach scraping works is shown in Figure 10. The route is from Bayshore Drive along the designated walkway to the beach. This route should be used to limit the impacts on the coastal environment. However, a significant portion of this route is across the beach and dunal zone. Traversing these areas has the potential to impact on a range of important values. These are discussed below.



Figure 10. *Opening locations and proposed access route from Bayshore Drive*

Flora and fauna

The Belongil Creek estuary entrance is part of the Belongil Seabird Habitat Precinct. Over 80 seabirds, shorebirds, waterbirds and other wetland associated birds have been identified in various surveys within this area. The most significant species are the endangered Little Tern, Black-necked Stork, and Beach Stone-Curlew. The Belongil Seabird Habitat Precinct is an important nesting habitat for many species including the Pied Oyster Catcher during breeding season which extends from August to December.

Prior to mobilising machinery, the access route should be inspected for the presence of native birds and other flora and fauna. An appropriate route down the dune and across the beach should be marked. If possible, the beach should be traversed across the hard-packed intertidal sand. If any significant species are identified an ecologist should be consulted. National Parks and Wildlife Services (NPWS) should also be notified prior to opening and also if any significant species are identified.

The breach channel and berm scraping area should also be marked and inspected prior to works based on the locations provided in Section 5.2. This area will be further to the north during breeding season (Aug – Dec) and approximately halfway between the permissible opening points during non-breeding season (Jan – Jul).

If any bird or subsurface turtle eggs are uncovered during excavations the works should be ceased and NPWS notified.

Public safety and beach usage

The excavation works have the potential to limit beach usage for a short period. Appropriate temporary signage and barriers should be placed around access routes and works areas to ensure public safety. If possible, a designated beach access route across the breach channel should be established during the works. All opening and scraping works need to follow Council's Work, Health and Safety guidelines and policies.

Dune stability

The opening channel and scraping zone is to be located in the designated area to limit erosion of the northern bank and dune system. Excess sand generated during the excavation of a breach channel or beach scraping should be placed with the designated disposal area along the northern embankment and dune system (see Figure 10). The excess sand will help mitigate the impacts resulting from northward migration of the channel and ensure the sand remains in the littoral zone.

A thorough inspection of this area for bird nesting areas and other fauna and flora should be undertaken prior to works. An appropriate location within the disposal area should be selected to minimise the impact on flora and fauna.

Cultural heritage

Access to the site and excavation works should comply with the Due Diligence Code of Practice for the Protection of Aboriginal Objects in NSW. If any identified or suspected Aboriginal objects are detected at any time, all disturbance work should immediately cease within 20 m of the find and temporary protective fencing erected around this 'no-go zone' pending further management advice from the NPWS and/or Arakwal Corporation. If the find consists of or includes human remains, the NSW Police Department and the OEH Environmental Line (ph 131 555) should also be notified as soon as practicable. Works may not recommence within the designated 'no-go zone' until appropriate formal written clearance to do so has been provided to the proponent.

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6 References

AWC and BMT WBM, 2016. "Capacity assessment of the Belongil Creek Drainage System – Development of a preferred STP effluent flow path"

Geolink environmental management and design, 2016, "Belongil Estuary Entrance Management Report – Stage 6 (October 2015 – March 2016)".

Pont, D. (2002), "Belongil Opening Report - September 2002"

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Attachment A
Initial findings report



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Attachment B Ecological assessment of Belongil Creek

