FINAL 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 mechanically opened when the water level at the Ewingsdale Road bridge gauge reaches 1 m AHD (Australian Height Datum).

The Belongil Creek estuary entrance has been mechanically opened under a conditional interim licence since 2001. Prior to 2001, the entrance was mechanically opened when the water level reached 1.2 m AHD. 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.

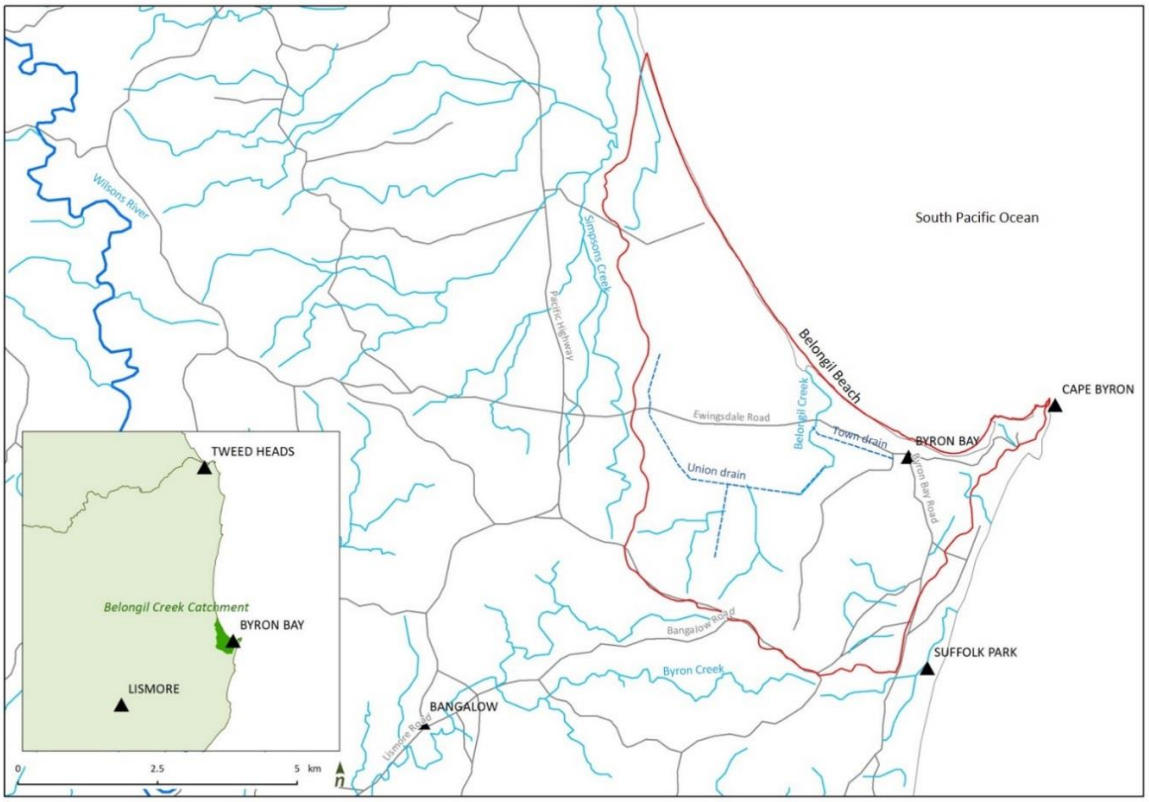


Figure 1. *Belongil Creek catchment study area*

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.

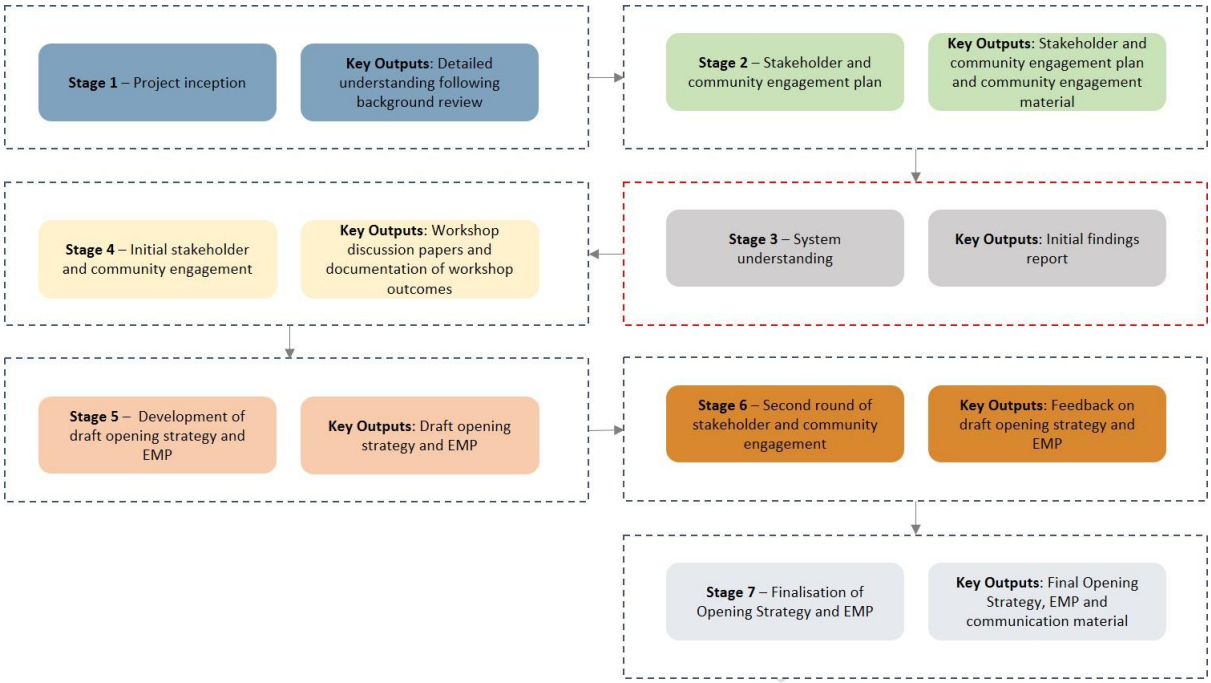


Figure 2. *Project stages and key outputs flow chart*

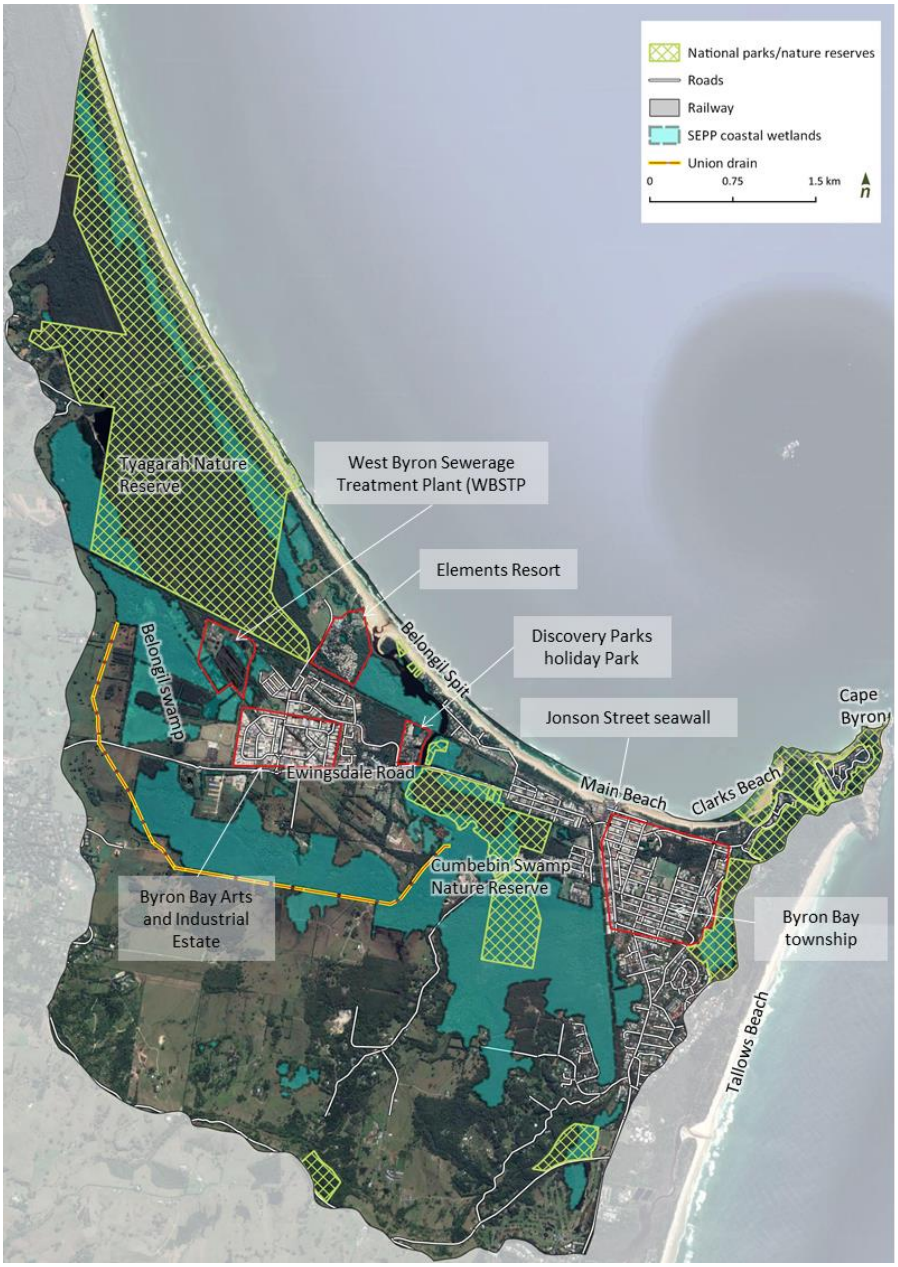
1.4 Report structure

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 1 provides an overview of the major features, assets and infrastructure 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
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 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)	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
Flood mitigation	1. Do not increase flood levels and frequency in existing land uses	1. Minimise stormwater volumes draining from the urban/industrial areas 2. Improve drainage of urban/industrial areas to limit impacts on the community
Water quality	1. Limit acidic runoff following artificial opening events 2. Limit deoxygenation following artificial opening events	1. Improve the water quality entering the estuary from the catchment
Urban and industrial land use	1. Do not increase flood levels and frequency in existing urban/industrial areas	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
Agricultural	1. Minimise any increases in flood levels and frequency in existing agricultural areas 2. Limit any increases in the duration of inundation events	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
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 the estuary entrance	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
Cultural/Indigenous values	1. Protect culturally significant plant species/communities 2. Protect culturally significant areas	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 license. 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 3. Importantly, the extent of inundation (Figure 3) 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.

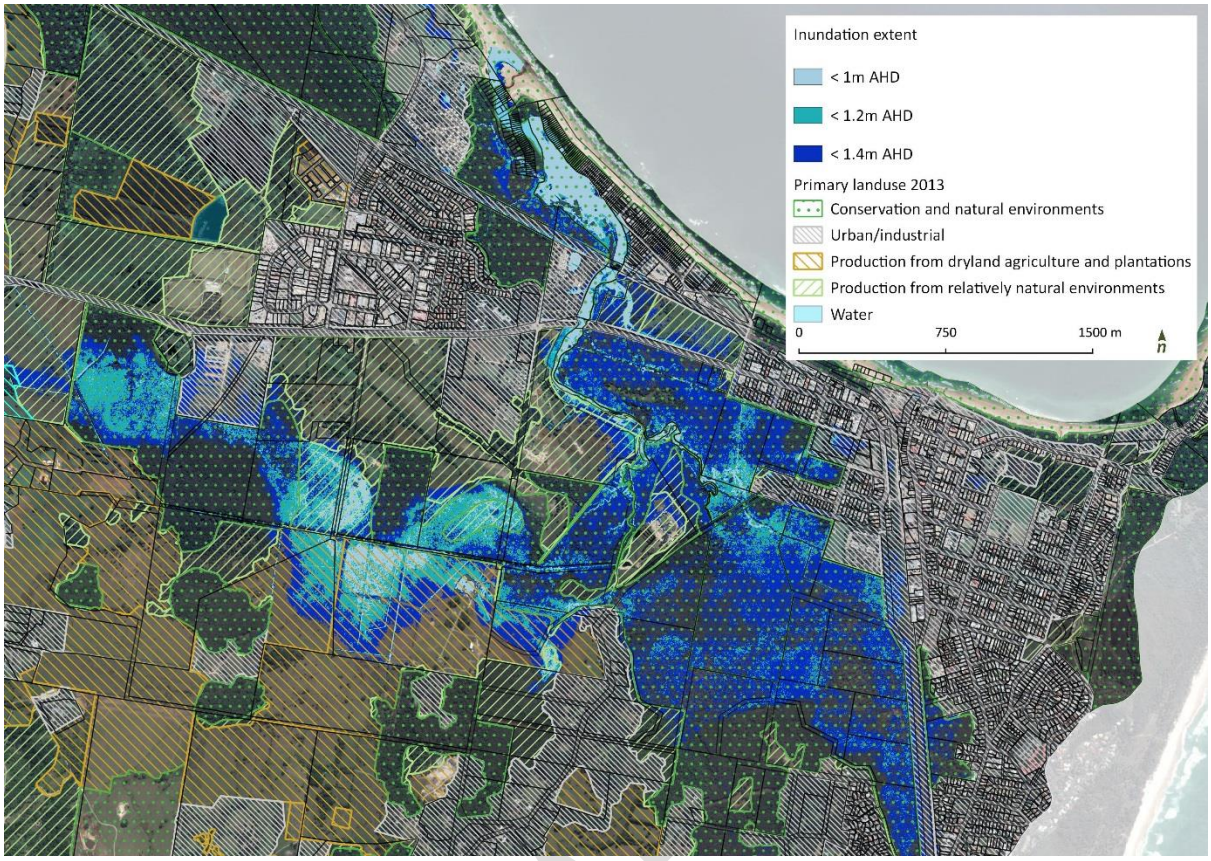


Figure 3. *Inundation extents of proposed trigger levels derived from 1m DEM with primary land use overlayed*

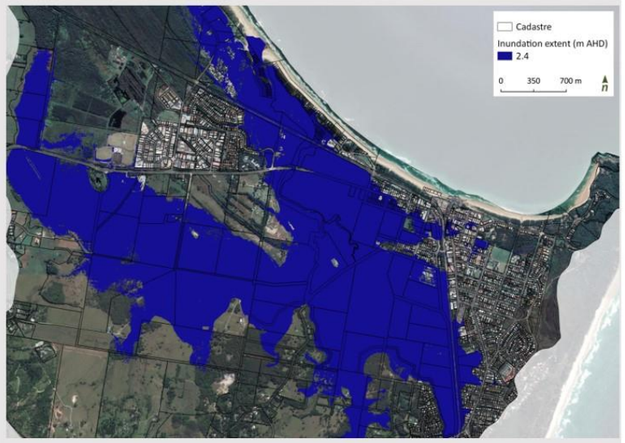
Table 2. Impacts of various artificial opening trigger levels on inundation and discharge volumes

Trigger level (m AHD)	Inundation extent - *Area below (*km²)	% area inundation extent increase	Volume Below (m³)	Volume increase from existing trigger level (m³)	% volume increase	Volume discharged following opening (assuming drained to 0.8mAHD) (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.

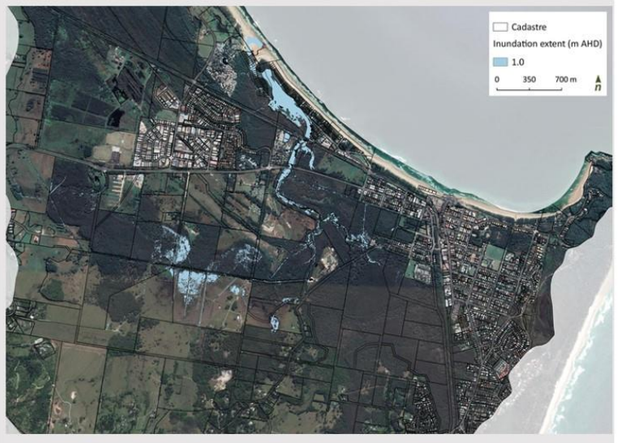
An assessment of each of the five management options is provided in Table 3 to Table 7. The assessment indicates Option 1B (i.e. 1.0 m AHD trigger level) scores highest against the range of objectives assessed. This option represents the current opening trigger level.

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

Opening option	Physical outcomes	Value	Management objective		Degree option achieves objective
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 ≈ 2.0 - 2.4 m AHD according to 2013 LiDAR).* 	• Natural range of water levels were much higher than existing (≈ 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 where 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		✗✗✗
			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		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	✓✓✓
		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		✗✗
			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 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
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).* 	• 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	✗ ✗ ✗
		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		?
			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 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
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.*	• 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 completive 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 (the 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	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		✓
			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		?

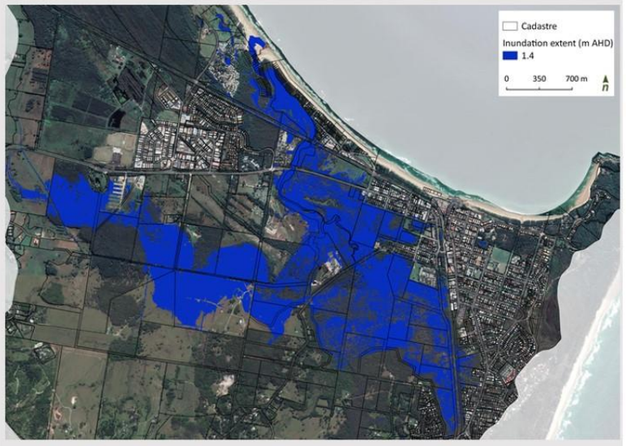
✓ = Slightly positive outcome ✓✓ = Moderately positive outcome ✓✓✓ = Significantly positive outcome ? = Some uncertainty ✗ = Slightly negative outcome ✗✗ = Moderately negative outcome ✗✗✗ = Significantly negative outcome

Table 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
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* 	• 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	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		✓
			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 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
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.* 	• 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	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		✓
			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

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.

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
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).*  	• Opening the entrance in this location is limiting the northward elongation of Belongil Spit and the resulting translation of the bird habitat • Entrance 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	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		?

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
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.*  	• 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		?

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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
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* 	• 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 closing • Potential 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	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 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
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*  	• 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
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.* 	• 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		?

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

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
Permanently opening the estuary *- Installing entrance training structures such as rock walls to inhibit berm formation and create a permanently opened estuary entrance* 	• 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 land • Shift 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 areas • Structures 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		✗ ✗
			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		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	✗ ✗ ✗
		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		✓ ✓ ✓
			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		?

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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
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* 	• 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		?

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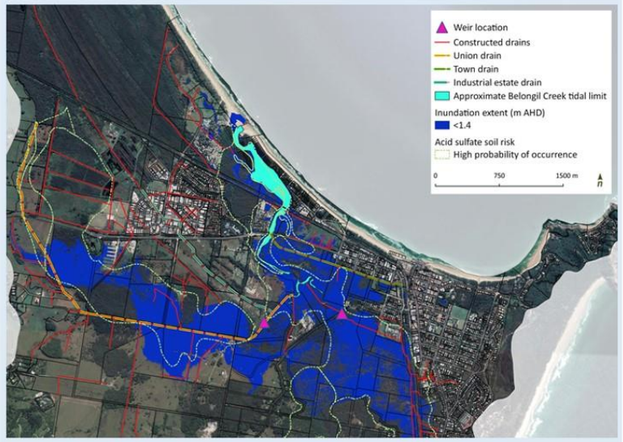
Table 15. Decoupling the catchment from the estuary option 3B – *Creating a weir at 1.4 m AHD* assessment against management objectives

Opening option	Physical outcomes	Value	Management objective		Degree option achieves objective
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* 	• 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		?

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

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 4. 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

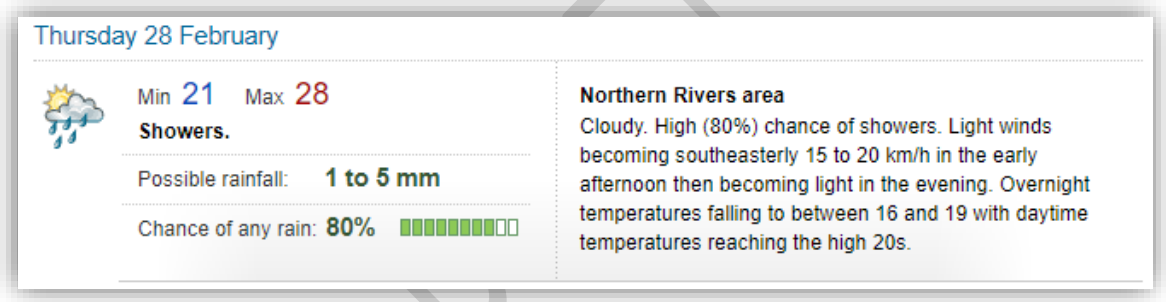


Figure 4. *Typical BoM rainfall forecast*

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 5. 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 eastuary 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.

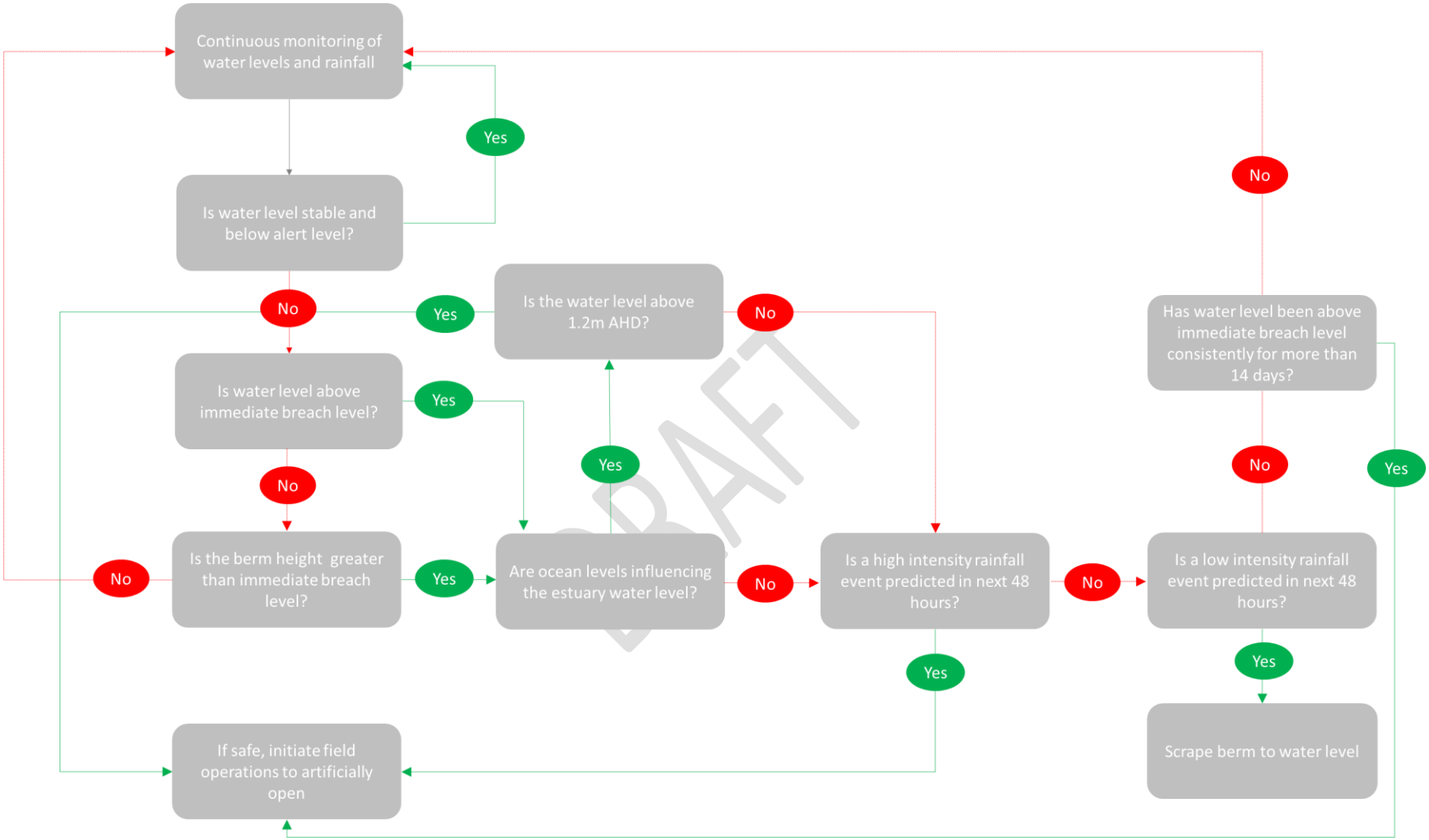


Figure 5. *The decision support framework to inform the entrance management*

5.2 Recommended approach

Location

The proposed entrance opening locations are shown in Figure 6. 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 9.

Figure 6. *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 7.

Figure 7. *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 8). 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 8. *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.

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 scaping works is shown in Figure 9. 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 9. *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 place 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 9). 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.

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”

Attachment A
Initial findings report

FINAL REPORT:

Belongil Creek entrance opening strategy – initial findings report

September 2019

Document history

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Author/s	Misko Ivezich (Alluvium) James Teague (Alluvium) David Wainwright (Salients) Simon Walker (Ecological Service Professionals) Mark Free (Blackwood Ecological Services)
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Contents

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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 is an Initial Findings Report based on a detailed system assessment and understanding. This assessment will form a key component in the development of the Opening Strategy and associated EMP.

1.1 Study overview and objectives

Belongil Creek is small intermittently closed and open lagoon (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 would form 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 mechanically opened when the water level at the Ewingsdale Road bridge gauge reaches 1 m AHD (Australian Height Datum).

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 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

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 and 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.

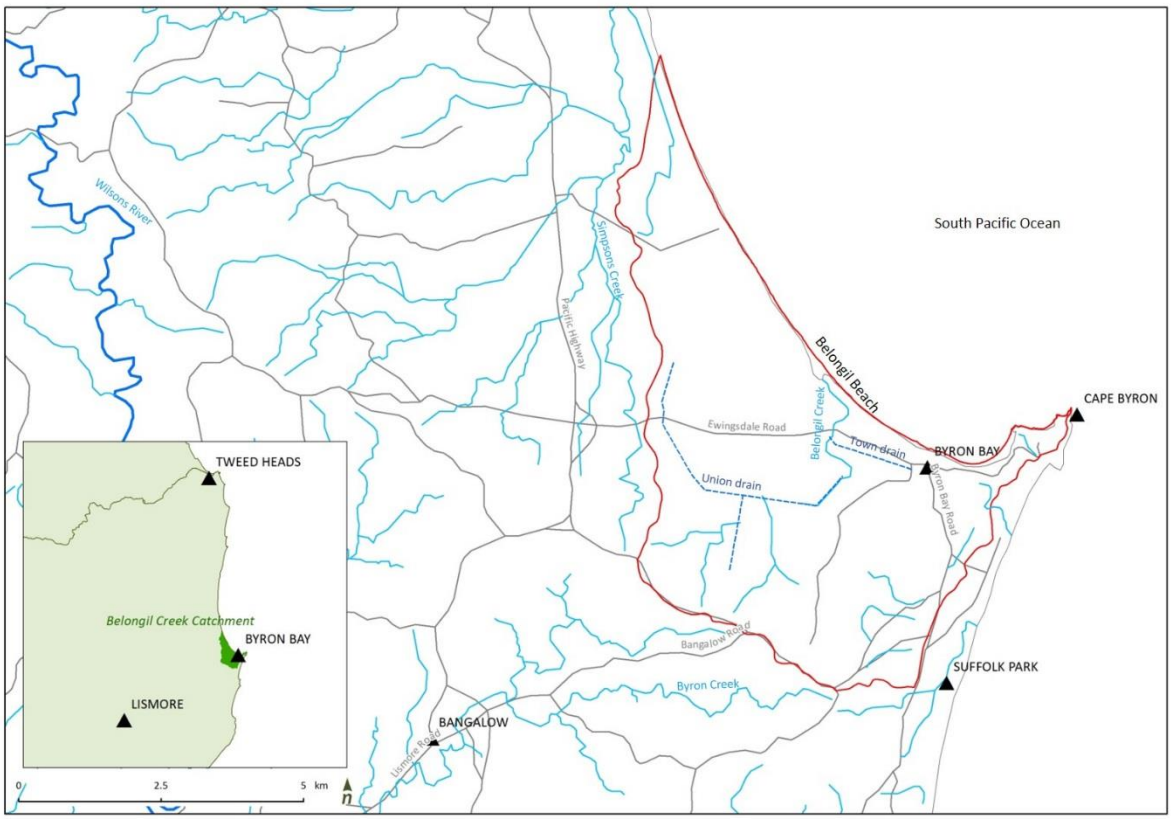

Figure 1 *Belongil Creek catchment study area*

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 initial finding report forms the primary output from stage three of the project.

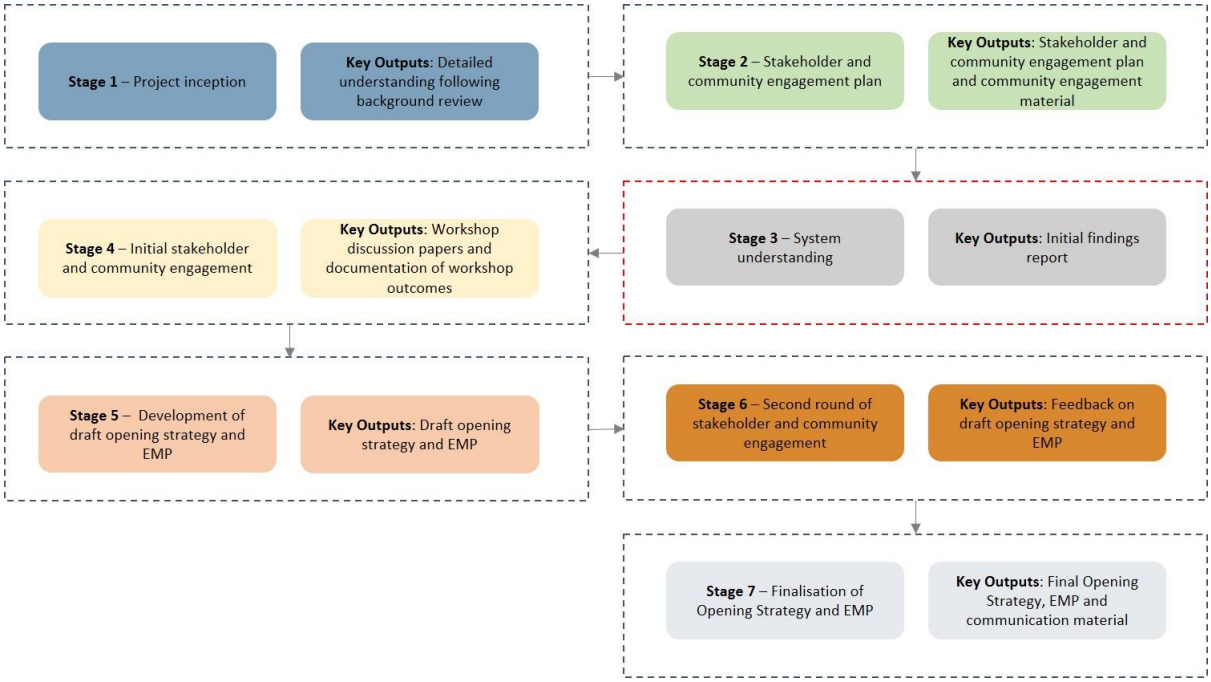

Figure 2 *Project stages and key outputs flow chart*

1.4 Report structure

This initial findings 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 an overview on catchment physiology
- **Section 3** - Outlines the coastal processes impacting the estuary entrance
- **Section 4** - Outlines the flooding and flow dynamics within the Belongil Creek catchment and the possible impacts of climate change
- **Section 5** - Outlines the impact of the estuary opening condition on water quality
- **Section 6** - Provides on overview on aquatic and terrestrial ecology within the estuary
- **Section 7** - Provides a review of historic and existing estuary management responses
- **Section 8** - Provides an overview of relevant NSW legislation and strategies
- **Section 9** – Provides a summary and outlines the next steps in developing the opening strategy and EMP

2 Catchment physiology

2.1 Overview

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 and 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 1 provides an overview of the major features, assets and infrastructure in the Belongil Creek catchment.

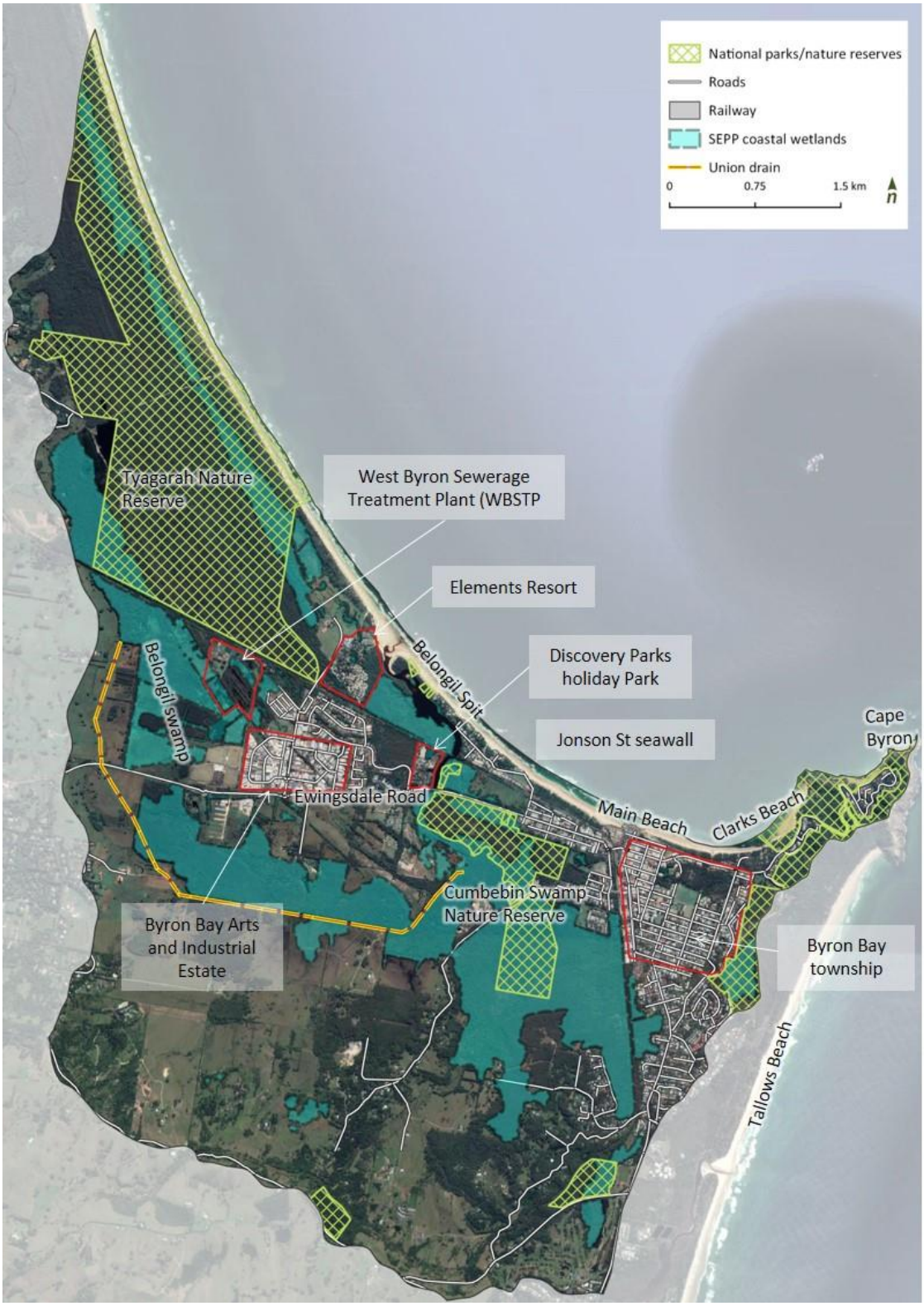

Figure 3 *Major features, assets and infrastructure within the Belongil Creek catchment*

2.2 Landscape setting

The Belongil Creek catchment is bound by steep basaltic hills and slopes falling from the Lismore Plateau in the west and south, beach ridges and back barrier embayment's along the coast to the north and the elevated slopes of Cape Byron in the east. Most of the catchment is flat to undulating, low lying terrain (below 4 m AHD), dominated by estuarine alluvial plains and swamps and wetlands (Willing & Partners Geomarine, 1996). Elevations range from approximately 160 m AHD at the southern catchment boundary near Mcleods Shoot to up to 6 m AHD along the beach ridges and back barrier embayment's in the north and up to 90 m on the eastern hillslopes of Cape Byron.

A significant proportion of the low lying catchment is considered to be a wetland. According to WetlandCare Australia (2005) there is approximately 10 km² of wetlands within the catchment (approximately 33 % of the catchment area) (Figure 4). The definition of wetland applied by WetlandCare Australia is as follows:

"The common thread in these definitions is that wetlands are lands that are inundated with water often enough, and for long enough, to produce a distinctive and identifiable assemblage of plants and soils. This definition would embrace the saltmarsh and mangroves of the estuary, the reeds and sedges of the wetter and lower-elevation zones of mid-catchment and places of water accumulation, and the large Melaleuca quinquenervia dominated areas of the mid- and upper-catchment. These wetland forests are inundated for varying periods in wet season, and the surface soils and litter layer tend to be exposed in the dry season, while usually also retaining moisture.

A further classification must be allocated to wetlands that have been severely degraded such that no aquatic plants or wetland surface soils can be found on the site. This is sometimes the case when wetlands have been cleared, drained, burned and managed for terrestrial agriculture for decades. The reality is that the wetland subsoils may exist as acid sulfate soils, the site is usually low-lying with a low slope, and will hold water in wet periods when aquatic plants may colonise. The land will often require intensive maintenance such as close slashing to keep wetland plants at bay. In the particular case of such an area being clearly part of a larger yet-to-be-rehabilitated wetland zone, all the lands complying substantially with the broad definitions should be regarded as wetlands."

Much of the wetland area located on the landward side of the beach ridges is considered a low-lying back barrier estuarine swamp with elevations generally below 2.5 m AHD, grading to alluvial footslope plains (DIPNR, 2004). The major geomorphic features of the swamp area as described by DIPNR (2004) are shown in Figure 4 and described below:

1. Sandy Pleistocene beach ridges, with an elevation of approximately 5-6 m AHD, underlain at 0.75-1.4 m by indurated 'coffee rock'. The younger ridges are broader, more widely spaced and higher; all are approximately parallel to the present coastline and are now largely contained within the Tyagarah Nature Reserve. These ridges are interspersed with depressions of various widths, which drain the northern extents of the catchment south eastwards towards the estuary.
2. Areas of low-lying, Pleistocene sandy plain up to 1 km wide, with an elevation of approximately 1.5-2.5 m AHD, generally underlain by indurated 'coffee rock';
3. Slopewash fans from adjacent bedrock hills with an elevation of 2.5 m AHD and greater (particularly well-represented to the south of the main part of the swamp);
4. Areas of low-lying, often peaty plain up to 1 km wide, with an elevation of approximately 2.0-2.6 m AHD, with peat and alluvium up to 2.5 m thick underlain by early Holocene sands and muds (e.g. part West Byron STP and re-use sites),
5. Low elevation terraces, possibly Pleistocene or early Holocene, with an elevation of approximately 1.2 - 2.0 m AHD;
6. A back barrier swamp basin, with an elevation of 0.8 - 1.2 m AHD, located wholly on the southern side of Ewingsdale Road. This basin is intersected by the Union Drain. The unit is now largely colonised by *Melaleuca quinquenervia* (Broad leaved paperbark), and there are signs of channel remnants visible;

7. Channels within the swamps gradually become more defined and join to form the Belongil Creek estuary.

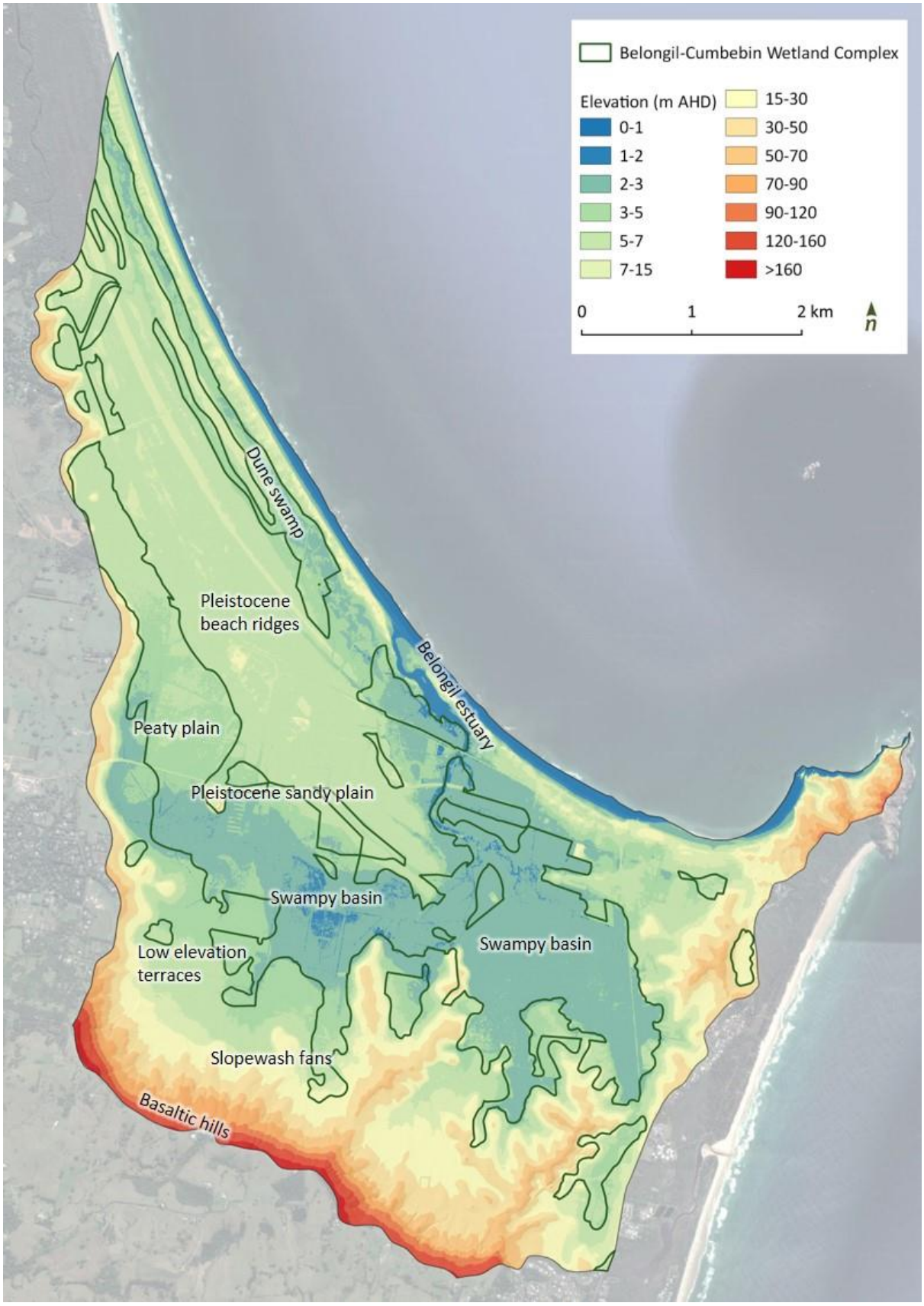

Figure 4 *Surface elevation for the Belongil Creek catchment and major geomorphologic units*

2.3 Geology/soils

The steep hillslopes bounding the south of the catchment are predominately made up of mafic volcanic rocks such as basalt that were erupted through volcanic activity in the Cainozoic period. The lower elevations of these slopes are dominated by Triassic-Jurassic sedimentary rocks including conglomerate and sandstone. The dominant geology of the eastern elevation of the catchment is Carboniferous sedimentary rocks including feldspar-rich sandstone, siltstone, mudstone and conglomerates. Quaternary coastal dune deposits make up the dominant geology of the remainder of the low-lying portions of the catchment (see Figure 5).

As classified under the Australian soil classification, the Pleistocene beach ridges are predominately podosols. Podosols generally contain aluminium and or iron, are highly sandy and acidic and found in high rainfall areas. The low-lying areas contain soils classified as hydrosols which are seasonally or permanently wet, there is a reasonable amount of diversity of soils types within this group. The footslopes and mid elevations contain kurosols which generally form from highly siliceous parent material and can be highly acidic. The steep basaltic hills have given rise to ferrosols which may suffer from acidification (The Australian Soil Classification).

The soils within the Belongil – Cumbebin swamp areas are complex due to slopewash and alluvial deposition from the surrounding hillslopes. Holocene peats, muds and clays and sandy Pleistocene layers with indurated coffee rock found at shallow depths can be found across the area. The occurrence of Acid Sulfate Soils (ASS) or Potential Acid Sulfate Soils (PASS) have been confirmed in the Holocene clays and peats and Pleistocene sands (DIPNR, 2004). A field study conducted in the upper Belongil Creek catchment (west of the Byron Bay Industrial Estate) by Slavich and Wood (1998) also confirmed the presence of both ASS and PASS. Figure 5 shows the probability of ASS occurrence within the greater catchment.

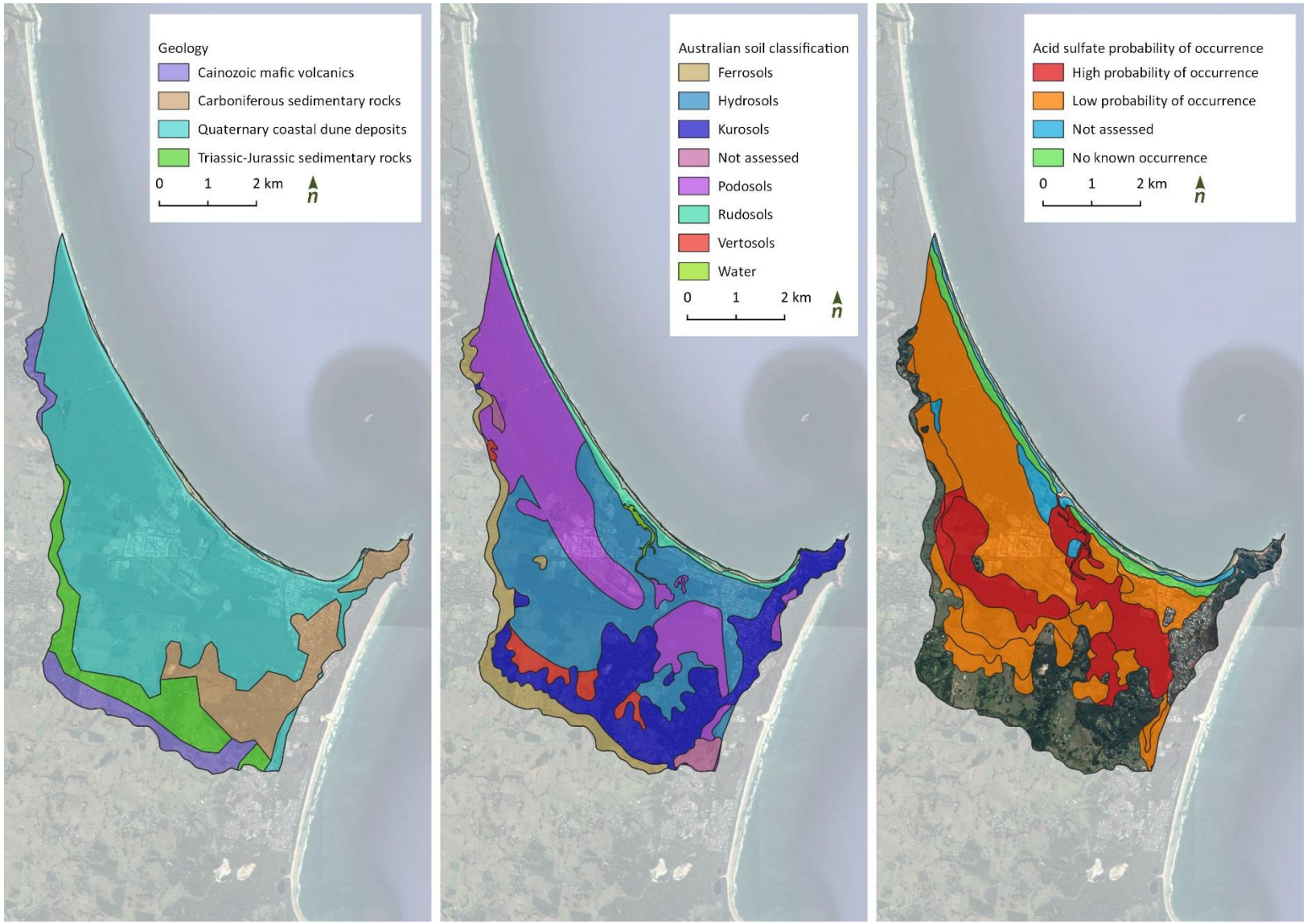

Figure 5 *Geology, soils and acid sulfate soils probability of occurrence within the Belongil Creek catchment*

2.4 Land use

Historically, much of the low lying land within the catchment would have been permanently or semi-permanently inundated with water forming swamps or wetlands. These areas would have been heavily vegetated by wet heath and swamp plant communities. In 1913 the Union Drain was constructed following wetland clearing to allow for agricultural production, residential and industrial uses. It is estimated that approximately 80% of land within the Belongil Creek catchment has either been cleared, drained or altered in some way (BMT WBM, 2017).

The Belongil Creek catchment currently supports a diverse mix of land uses. NSW land use mapping from 2013 indicates approximately 20 % of the catchment is used for nature conservation including Tyagarah Nature Reserve in the northwest of the catchment and Cumbebin Swamp Nature Reserve. Approximately 21 % of land area including Cape Byron State Conservation area and Arakwal National Park is classified as "Other minimal use area". Grazing of native vegetation or modified pastures is predominately located in the drained low lying lands and alluvial footslopes and plains in the southwestern quarter of the catchment and accounts for approximately 30% of the catchment. Residential and farm infrastructure accounts for approximately 18 % of the catchment. The remainder of the catchment is made up of smaller enterprises such as plantation forestry, horticulture and services. Under this land use classification only a small area (< 1%) has been classified as "Marsh/wetland". As outlined in section 2.1 the area classified as wetland under the coastal management SEPP is much larger than this. Much of the land that sits within the SEPP wetland area is classified as "Other minimal use" or "Grazing native vegetation" under the 2013 land use classes outlined below.

The land uses within the catchment are shown in Table 1 and Figure 6.

Table 1. 2013 land use within the Belongil Creek catchment

Land use (Primary class)	Land use (Secondary class - 2013)	Area (ha)	% of catchment area
Conservation and natural environments	1.1.0 Nature conservation	671	19.6
	1.2.0 Managed resource protection	22	<1
	1.3.0 Other minimal use	729	21.3
Production from relatively natural environments	2.1.0 Grazing native vegetation	497	14.5
Production from dryland agriculture and plantations	3.1.0 Plantation forestry	18	<1
	3.2.0 Grazing modified pastures	498	14.5
	3.3.0 Cropping	1	<1
	3.4.0 Perennial horticulture	3	<1
	3.5.0 Seasonal horticulture	1	<1
	3.6.0 Land in transition	20	<1
Intensive uses	5.1.0 Intensive horticulture	0	<1
	5.2.0 Intensive animal husbandry	8	<1
	5.3.0 Manufacturing and industrial	71	2.1
	5.4.0 Residential and farm infrastructure	622	18.1
	5.5.0 Services	136	4.0
	5.7.0 Transport and communication	87	2.5
	5.9.0 Waste treatment and disposal	23	<1
Water	6.2.0 Reservoir/dam	16	<1
	6.5.0 Marsh/wetland	1	<1
	6.6.0 Estuary/coastal waters	4	<1

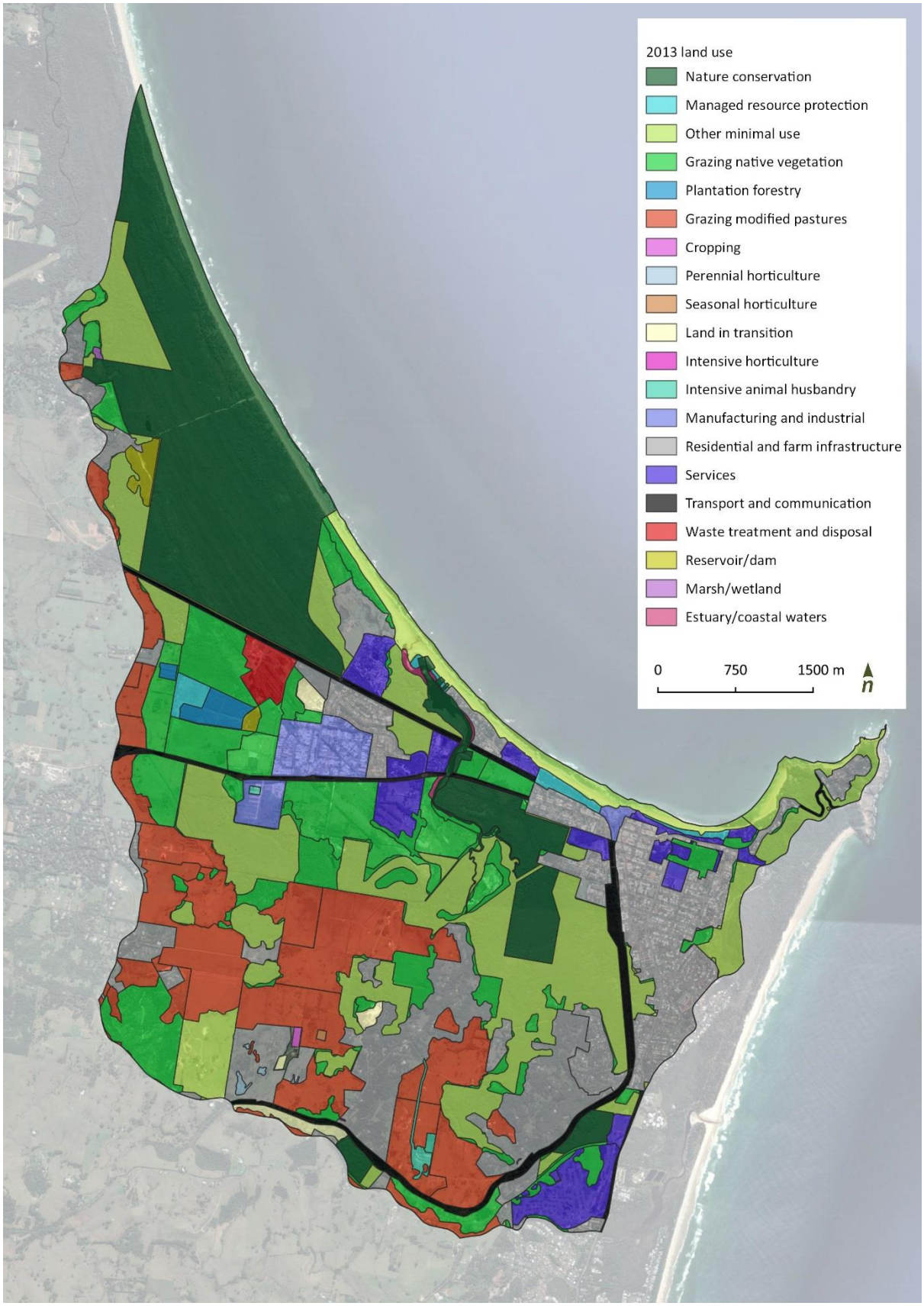

Figure 6 *Land use in Belongil Creek catchment based on the 2013 NSW land use mapping*

2.5 Coastal management zones

The revised Coastal Management State Environment Planning Policy (SEPP) came into effect on the 3rd of April 2018. The aim of the SEPP is to promote an integrated and co-ordinated approach to land use planning in the coastal zone in a manner consistent with the objectives of the Coastal Management Act 2016 (CM Act) (New South Wales Government, 2018). According to the Act the coastal zone is comprised of one or more of the following coastal management zones:

1. **Coastal Wetlands and Littoral Rainforests Areas -** defined as areas that display the characteristics of coastal wetlands or littoral rainforests that were previously protected by SEPP 14 and SEPP 26
2. **Coastal Vulnerability Area -** defined as the area subject to coastal hazards such as coastal erosion and tidal inundation
3. **Coastal Environment Area** - defined as the coastal waters of the state, estuaries, coastal lakes and foreshores including beaches, dunes, headlands and rock platforms as well as surrounding land
4. **Coastal Use Area –** defined as land adjacent to coastal waters, estuaries and coastal lakes and lagoons

The coastal management zones within the Belongil Creek catchment are shown in Figure 7**.** Significant areas of the catchment are classified as coastal wetlands. There is also a small area of littoral rainforest near the estuary opening**.** The Coastal Vulnerability Area has not yet been mapped and therefore is not displayed in the figure below. Due to the active coastal erosion of the Belongil Spit it is likely that this area will be classified as a Coastal Vulnerability Area.

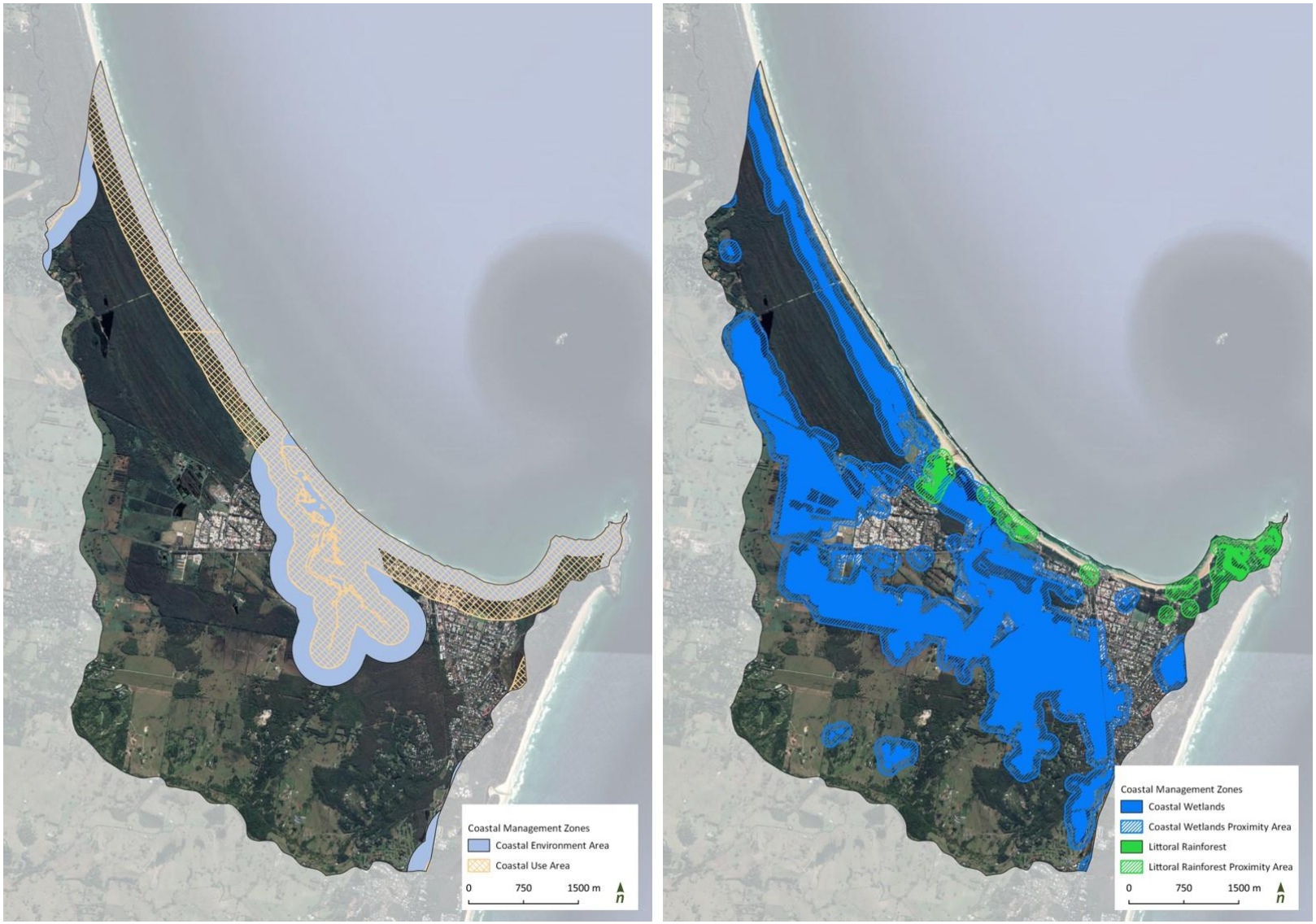

Figure 7 *Coastal management zones within the Belongil Creek catchment*

Local Environmental Plans (LEPs) will continue to establish zoning and permissible land uses for the local government area. Each coastal management zone has a series of development controls under the SEPP. The SEPP management zones are a planning overlay that identify the assets and values of the land and the SEPP development controls inform the development assessments undertaken by local government.

Considerable overlap exists between the four Coastal Management areas. If multiple management areas apply to a single parcel of land, the CM Act imposes a hierarchy as to which coastal management objectives apply (highest priority first):

1. Coastal Wetlands and Littoral Rainforest Area
2. Coastal Vulnerability Area
3. Coastal Environment Area
4. Coastal Use Area

2.6 Vegetation

Vegetation class mapping from 2017 is shown in Figure 8. Significant portions of the catchment have been cleared and/or drained for agricultural production and development causing widespread fragmentation of the vegetation communities. Coastal Swamp Forests dominate the Belongil - Cumbebin swamp and the low-lying wetland area to the west of the Tyagarah Nature Reserve. North Coast Wet Sclerophyll Forests and Planted Sclerophyll make up a significant portion of the south-eastern alluvial plain with pockets of Sub-tropical Rainforest. Planted and Sub-tropical Rainforests are the predominant vegetation classes on the footslopes of the basaltic plateau in the south western corner of the catchment. Isolated areas of Camphor laurel are also present within the southern half of the catchment.

The vegetation mapping identifies six dominant vegetation communities that immediately surround the Belongil Creek estuary (Figure 8). These include:

1. **Grassland** – Spinifex strandline grassland located at the end of the Belongil Spit.
2. **Littoral Rainforest** – A significant area of littoral rainforest on the north-western bank at the entrance of the estuary. Dominant species include *Cupaniopsis anacardioides* (Tuckeroo), *Alectryon coriaceus* (Birds Eye Alectryon), *Acronychia littoralis* (Beach acronychia) and *Banksia integrifolia* (Coast banksia).
3. **Coastal Dry Sclerophyll Forest** - Coast Banksia woodland and open forest of coastal dunes located on the dunes toward the end of Belongil Spit. Dominant species is *Banksia integrifolia* (Coast banksia).
4. **Coastal Swamp Forest** - Predominately located just upstream of the estuary mouth between the estuary and the railway. Some low-lying wetland areas on the southern side of the railway. Dominant species through these include *Meleleuca quinquenervia* (Broad-leaved paperbark), *Eucalyptus robusta* (Swamp mahogany) and *Casuarina glauca* (Swamp oak).
5. **Mangrove Swamps** – Areas including intertidal flats located along the banks of the estuary particularly downstream of the railway line. Dominant species include *Avicennia marina* (Grey mangrove) and *Aegiceras corniculatum* (River mangrove).
6. **Saltmarshes** - Predominantly located between the mangrove swamps and the coastal swamp forest between the railway and the estuary. Dominant species include *Juncus kraussii* (Salt marsh rush) *Sporobolus virginicus* (Saltwater couch) and Samphire.

The most significant vegetation community is the littoral rainforest. Due to the significant habitat values and the occurrence of threatened or nationally rare plant species, conservation of these remnant areas are considered vitally important (BSC, 2005). Under the Coastal Management SEPP, areas mapped as 'Coastal Wetlands and Littoral Rainforest Areas' come under the following recommended controls:

1. Any development such as clearing of vegetation, earthworks, draining the land, constructing a levee and environmental protection works will require development consent. Development for the

purposes of environmental protection may be carried out without development approval providing it has been identified in a relevant certified coastal management program, plan of management adopted under Division 2 part 2 of chapter 6 of the Local Government Act, 1993 or a plan of management approved and enforced under Division 6 Part 5 of the Crown Lands Act, 1989.

2. The consent authority may only grant consent if they are satisfied that "sufficient measures have been or will be taken to protect and where possible enhance, the biophysical, hydrological and ecological integrity of the coastal wetland or littoral rainforest." (OEH, 2018).

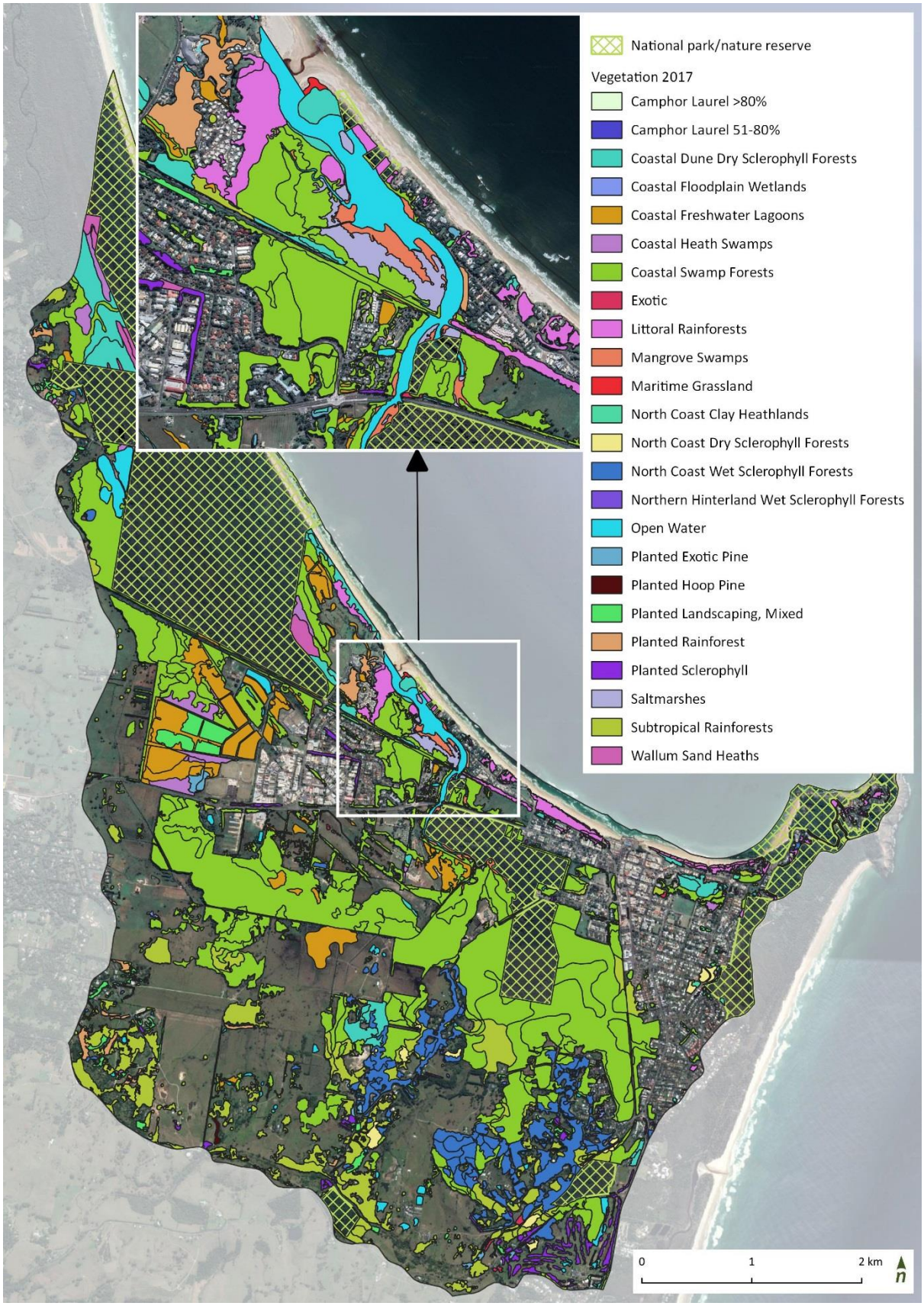

Figure 8 *Vegetation type within the Belongil Creek catchment (2017) with Belongil Creek estuary area focal inset map*

2.7 Post-European impacts

Prior to European settlement, the north coast of NSW supported one of the largest aboriginal populations in the state (Willings and Partners, 1997). The traditional owners of the Belongil Creek estuary are the Arakwal people part of the Bundjalung nation. The Belongil Creek estuary is likely to have been an important resource for its traditional owners providing sources of fish, crabs and shellfish.

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 major industry within the catchment between the 1840's and 1880's was timber cutting but other industries such as cropping, dairy farming and fishing grew in importance (Willings and Partners, 1997).

The construction of drains through the swamplands in Ewingsdale opened large areas for pasture. The Drainage Board has actively managed the construction and maintenance of drains in the Belongil Creek catchment since the inception of the Water Act in 1912. When the levels in the estuary began to encroach on pasture landholders would dig a channel through the beach berm to drain the wetland. In 1913, the meat processing plant was also constructed which ran until the early 1980's, leading to higher employment and further development within the catchment. The clearing accelerated in the 1960s and 1970s when large areas of the Cumbebin wetlands were cleared, drained and burnt as a fuel source for the local meatworks. Other major industries during the 1900's included the mining of zircon and rutile up until 1969 as well as whaling station that ran between 1954 and 1962 (Willings and Partners, 1997).

In the last 100 years there has been significant urban and industrial development within the Belongil Creek catchment. Several of these land use developments within the catchment have impacted the Belongil Creek estuary. These include:

1. filling to create railway embankments, blocking original drainage paths;
2. swamp drainage;
3. Ewingsdale Road which impacts drainage pathways;
4. sandmining, meat works, whaling station, fish processing and dairy products processing;
5. development of the Byron industrial estate which increased stormwater generation and influenced drainage;
6. operation of West Byron Sewerage Treatment Works and related discharge and reuse on;
7. development of Sunrise Beach Caravan Park and various other caravan parks;
8. draining of Cumbebin Swamp to the south-west;
9. Byron Bay landfill site;
10. routing township stormwater into Belongil Creek; and
11. regular openings of Belongil Creek to the ocean.

Figure 9 provides an aerial imagery comparison of the catchment between 1965 and 2018 indicating some of the major changes during that period.

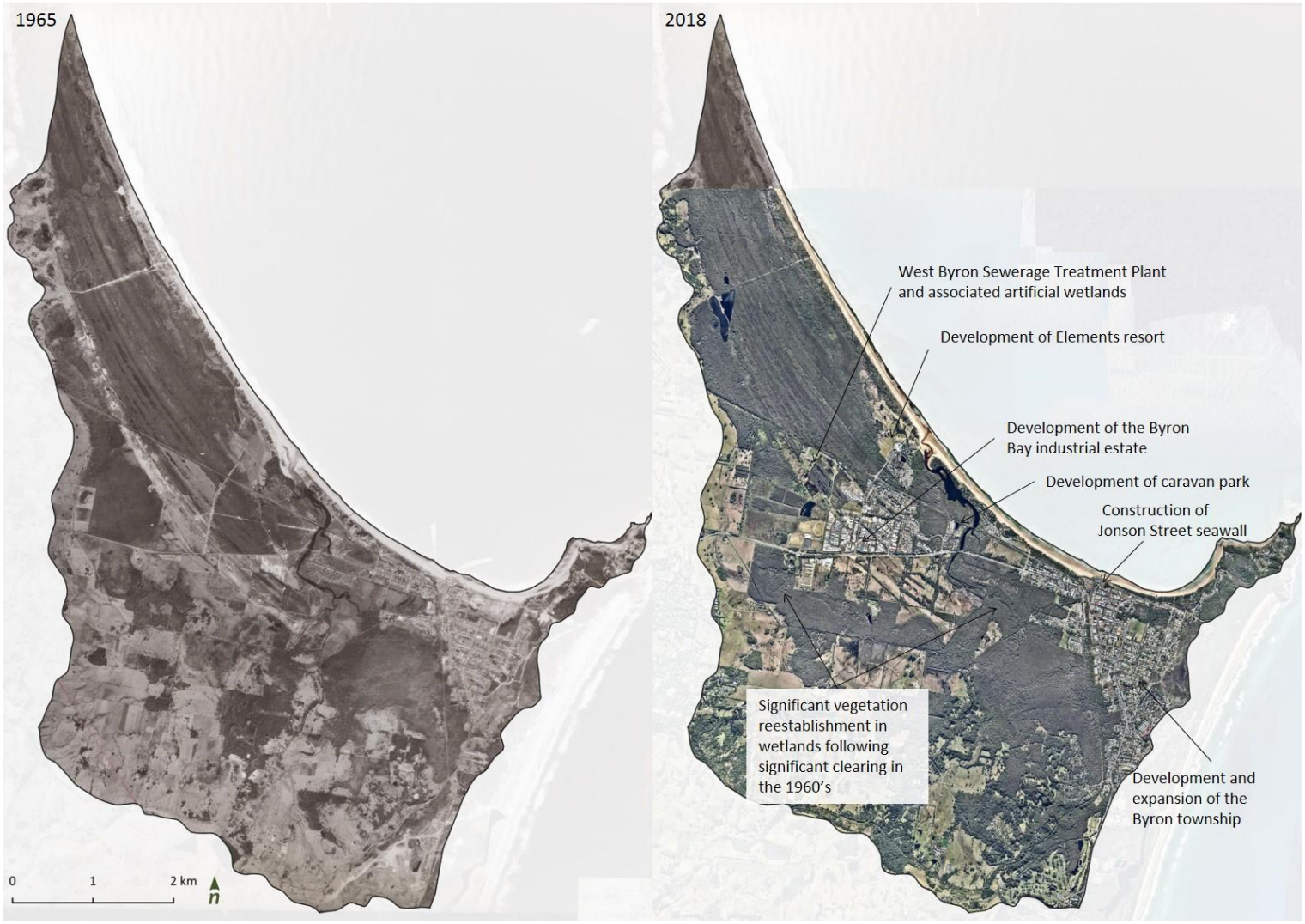

Figure 9 *Aerial imagery comparison of the Belongil Creek catchment between 1965 and 2018*

2.8 Drainage network

The Belongil Creek estuary discharges between Belongil Beach and Tyagarah Beach (Figure 10). Upstream from the entrance, the lower estuary turns immediately to the south east wrapping behind Belongil Spit. The estuary widens through this reach to around 200 m before turning southwards, narrowing to around 50 m and extending further upstream, passing below the railway line and then Ewingsdale Road, some 300 m further upstream. Immediately upstream of Ewingsdale Road, a constructed drain, known as the "Town Drain" or "Butler St Drain" conveys catchment runoff from the northern extents of Cumbebin Swamp and parts of the CBD of Byron Bay located east of the railway line. The locations of the main constructed drains across the lower floodplain are shown in Figure 10.

Upstream of Ewingsdale Road, the estuary again bends eastwards extending a further 660 m before dividing into its two main feeder tributaries. In total, the distance upstream to the Creek's tidal limit (the extent of the estuary) is some 3.5 km. The two main feeder tributaries presently drain most of the Belongil Creek catchment. One tributary extends upstream towards the south and east, draining the southern extents of Cumbebin Swamp. The second tributary extends to the south, before connecting to the constructed "Union Drain" which collects runoff from the western parts of the floodplain, including areas within a back-barrier depression west of the Pleistocene barrier ridges. The north western extent of this depression, to the north of Ewingsdale Road is referred to by some sources as Belongil Swamp.

Belongil Creek catchment's drainage system has been significantly altered over time to enable the expansion of urban and agricultural development across the catchment's extensive low-lying wetlands. Grazing has occurred in the catchment since before 1891, when papsulum was introduced as a fodder (PPK, 2001), since then drains have been constructed to aid agricultural land use. The Union Drain was constructed in 1913 by the Belongil Creek Drainage Union. It is estimated that there could be up to 40 km of secondary drains constructed within the catchment including council and private works (WetlandCare Australia, 2005). The use of modern excavators in drain maintenance has also resulted in the deepening and widening of many of the original constructed drains.

A series of secondary constructed drains drain the agricultural lands to the south of the Union Drain which includes inflows from the small tributaries on the northern side of the basaltic plateau. Runoff from the basaltic hills at the south eastern extent of the catchment flow through natural drainage lines to the north where they enter Cumbebin Swamp. Another significant drain is the Industrial Estate Drain which drains the Byron Bay Industrial Estate before entering the Union Drain approximately 300 m upstream of Belongil Creek.

The Pleistocene beach ridges that dominate the topography in the north of the catchment direct drainage north west to south east along the swales formed between ridges. Much of this area was mined for zircon and rutile during the 1960's which resulted in a number of the ridges being flattened and dredge water supply drains were constructed through to Belongil Creek. These were later intersected by the construction of the Industrial Estate which reduced drainage rate through these flow paths (PPK, 2001).

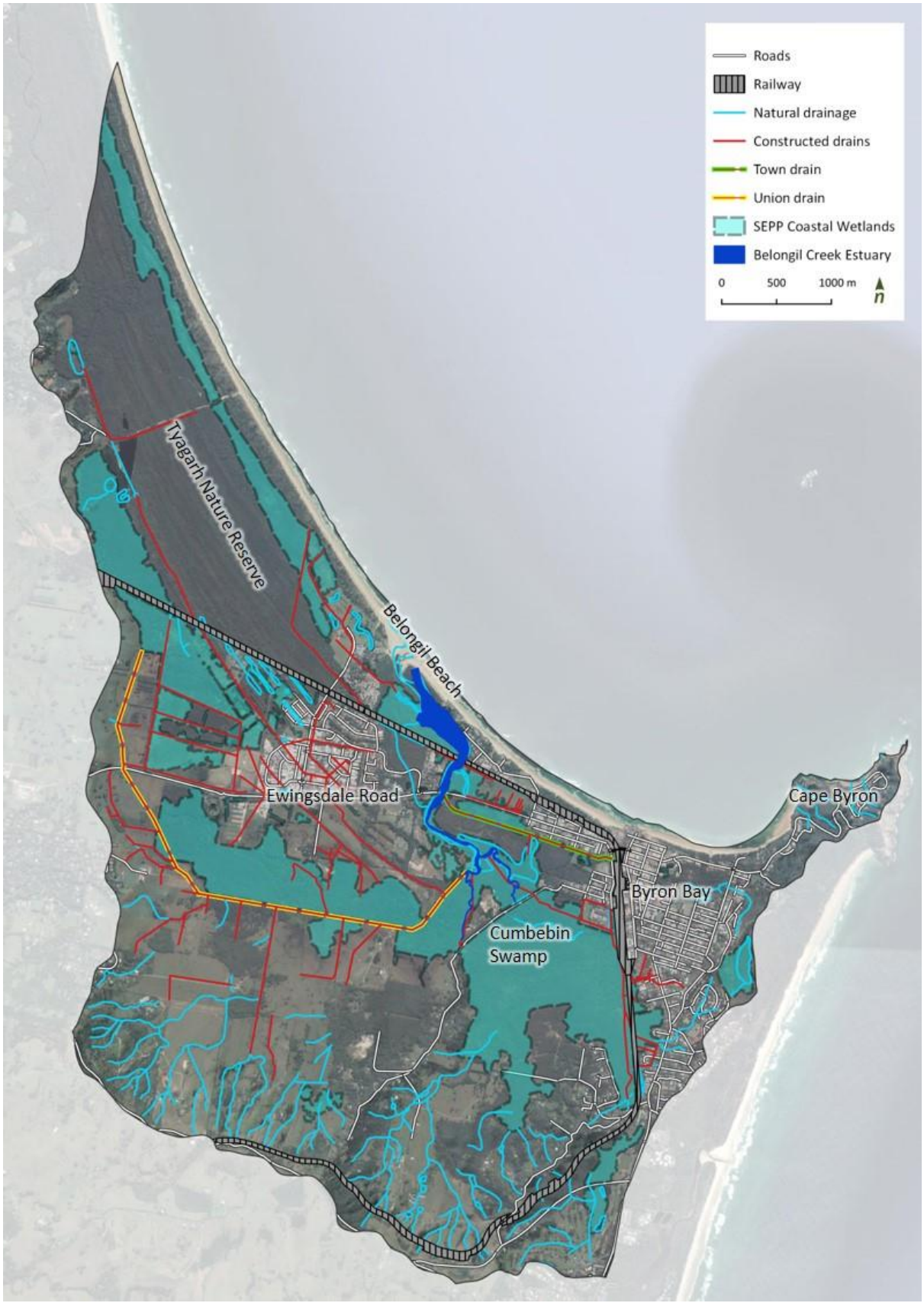

Figure 10 *Constructed and natural drainage network within the Belongil Creek catchment*

3 Coastal processes

The entrance of Belongil Creek marks the boundary between Tyagarah Beach to the north and Belongil Spit to the south. Several processes work in unison to influence the dynamic morphology of the entrance and the surrounds which have been studied extensively (e.g. Geomarine, 1997, Parker and Pont 2000, WBM 2000 & 2004, and Baldock at al., 2008). 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 would form a barrier creating a closed lake system. The beach berm is periodically eroded due to either coastal erosion, increased levels associated with rainfall or overtopping in large events. Construction of protection works at Main Beach, as well as several ad hoc erosion control structures south of the spit have influenced longshore littoral sand supply and erosional processes within the area.

3.1 Byron Bay embayment and longshore sand transport

The Byron Bay Embayment stretches from Cape Byron to Tyagarah. The embayment forms part of a gradient in net longshore sand transport from approximately 150,000-200,000m³/yr at the Clarence River to 550,000m³/yr at the Gold Coast (BTM WBM, 2017). The longshore transport gradient along the north coast of NSW is offset by net shoreward sand supply into the shore-face from the inner continental shelf associated with recent Holocene sea level rise. This shoreward sand supply effectively reduces the rate of beach recession that would otherwise be expected from such a transport gradient.

The Cape Byron Headland is a dominant control on coastal processes in this area. It is estimated that approximately 400,000-450,000m³/yr of sand moves northward past Cape Byron. The East Australian Current (EAC) results in approximately 50,000 m³ /yr of this nearshore transported sand is stored in the Byron Lobe which stretches north and south of the Cape Byron Headland. The remaining sand supply is roughly split between cross-embayment transport and littoral transport within the surf zone.

Wategos Beach is currently protected by a seawall along Marine Parade. The beach which is immediately north of the Cape Byron Headland experiences significant erosion-accretion variations in response to short to medium term wave climate variability and the longshore transport supply variability.

The stretch of coast from The Pass headland to Jonson Street protection works changes as a result of variations in longshore littoral sand supply. This section of coast can change rapidly during storm events resulting in significant dune scarp retreat.

The Jonson Street rock protection works provide a significant control protecting the Byron Bay town centre from coastal erosion and recession and helps maintain the alignment of Main Beach and Clarkes Beach. The rock protection works interrupt the natural sediment transport along the beach and have compartmentalised the beach into two sections (WorleyParsons 2014). Presently there are plans to upgrade the Jonson Street protection works which will reduce the footprint of the structure and improve the stability to mitigate risk from large storm events. To date erosion protection works along Belongil Spit have been ad hoc with significant areas with limited protection. The Belongil Spit is the most vulnerable coastal landscape in the Byron Bay Embayment with ongoing recession and breakthrough to Belongil Creek likely at some stage in the future depending on future management and sea level rise. These processes put significant built infrastructure at immediate risk. The overall sand transport processes and existing major coastal protection works within the Byron Bay embayment is shown in Figure 11.

Figure 11 *Processes, values and assets within the Byron Bay Embayment*

3.2 Erosion and spit morphology

Long term recession of the coastline is occurring due to the differences in longshore drift rates along the coast and direct losses of sand off Cape Byron. A recession range of 0.05 - 0.45m/yr. has been estimated for the shire with the Belongil Beach area sitting in the upper region predominately due to the influence of a series of ad-hoc sea walls introduced along Belongil Beach since the 1970's (WBM Oceanics, 2004). The walls aid in the protection of developed areas yet influence the morphology of the spit through the removal available sand stores and localising the concentration of regional long-term sand losses.

Due to long term recession there is a risk that Belongil Creek may eventually break through the spit south of its current entrance location. This may occur through continued erosion and wave overtopping at low dune sections (WBM 2004). The northward transport of sand and erosion of the spit elongates and pushes the entrance channel further north. This migration behaviour truncates the end of the spit and causes erosion of the northern embankment near Elements Resort. The aerial imagery analysis in Figure 12 illustrates how the processes described have influenced the thinning and north west migration of the spit.

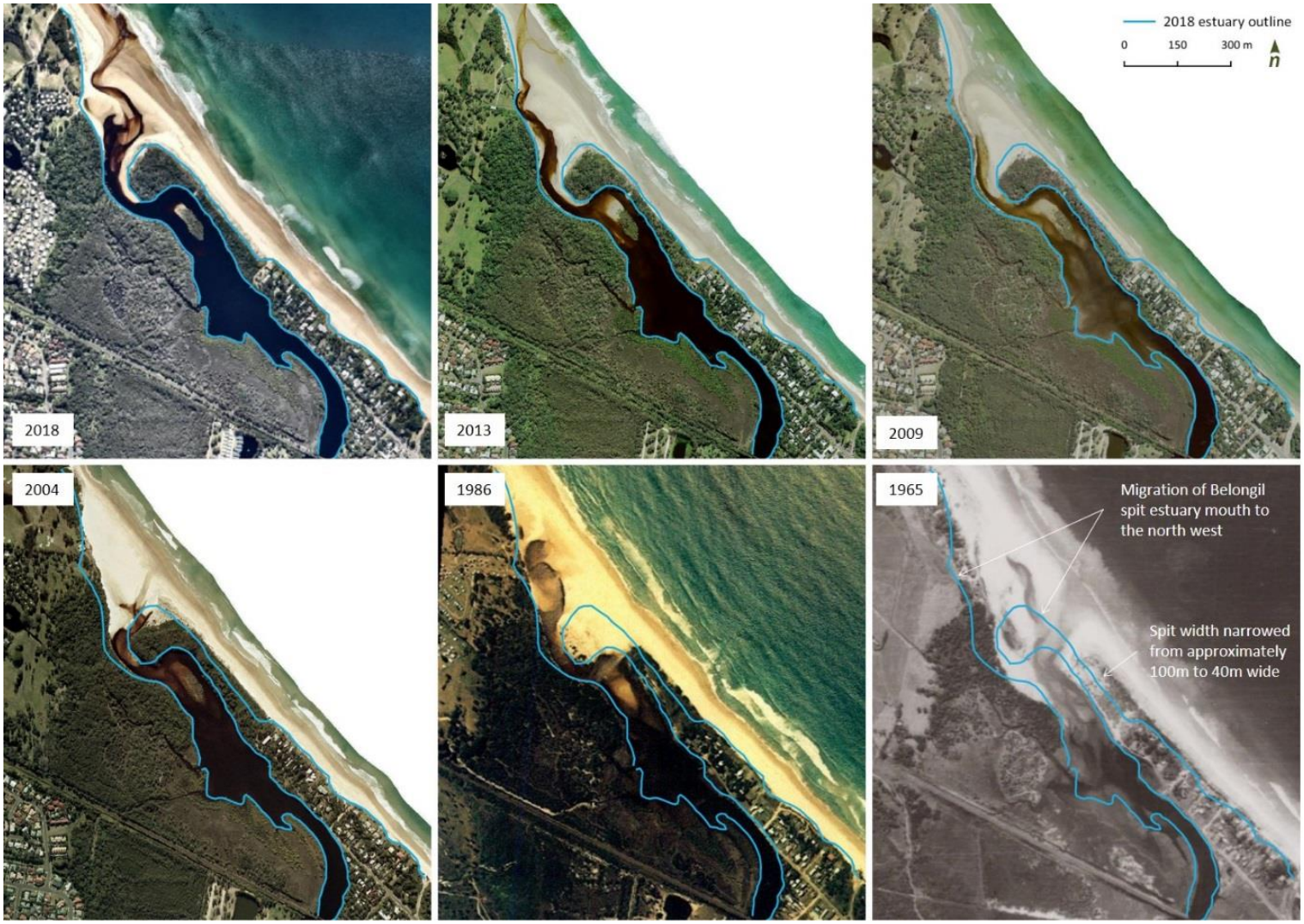

Figure 12 *Historical aerial imagery comparison of the Belongil estuary*

3.3 Berm formation, estuary opening and tidal flows

The Belongil Creek estuary is prone to closure at any time of the year through the build-up of a sand barrier (or "berm") at the ocean entrance which prevents tides from flowing in and out of the estuary. Berm formation is driven primarily by surf and tidal sediment transport through the entrance channel and then followed by swash sediment transport (Baldock et al., 2007). Onshore winds also influence berm formation by blowing sand into the mouth. Berm formation acts as a natural form of protection for the back-shore region and dune systems from storm activity

The lagoon entrance opens naturally following periods of heavy rainfall and subsequently closes (often rapidly) during dry periods. The morphodynamics of entrance breakout behaviour are mostly driven by the difference in water levels across the entrance berm (WBM 2007). Storms can also have an effect. Storm surge, wave set up in combination with hightides will periodically overtop the entrance berm and significantly impact entrance dynamics.

When the entrance is open, Belongil Creek exhibits regular but somewhat limited tidal behaviour up to Cumbebin Swamp. Along its 3 km length its width varies before narrowing at the entrance channel. The narrow channel width, shallow bed depth and relatively small tidal prism at the entrance act in unison to attenuate tidal range to about 0.3 m at the mouth and tidal velocities to about 0.5 m/s within the creek (Willing and Partners Geomarine 1997). Entrance dynamics and tidal hydraulics are described in more detail in Section 4.

4 Flooding and flow dynamics

4.1 Catchment characteristics

An overview of the Belongil Creek catchment including the topography is provided in Section 2. A significant proportion of the catchment is low lying and has been captured by drains. This can be seen qualitatively in Figure 13 and Figure 14 which shows that a third of the catchment (1100 ha) is below 2.8 m AHD, and a further third is below 5 m AHD. Of interest is the shape of the catchment immediately around 1.0 m AHD, the present "trigger" level for artificially opening the Creek. Representative values are presented in Table 2. These show that the area inundated increases by a factor of around 3.5 if the water surface elevation across the floodplain increases from 1.0 to 1.2m AHD. The waterway area is around 11ha.

Table 2 Stage Volume Relationship

Elevation (m AHD)	Area Below ($\times 10^5$ m^2)	Volume Below ($\times 10^5$ m^3)
0.8	2.87	3.15
0.9	3.16	3.04
1.0	3.45	3.30
1.1	6.76	3.80
1.2	12.0	4.72
1.3	21.1	6.33
1.4	33.2	9.03
1.5	43.6	12.9

The spatial distribution of areas inundated by the elevations between 1.0 and 1.5m AHD are shown in Figure 15. Importantly, the inundation extents of Figure 15 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 tides) and there are limited inflows from the catchment. The analysis indicates that, assuming no rainfall and a typical artificial entrance breaching event which lowers the water levels in the waterway from 1.0 to 0.8m AHD, a net volume of around 15ML would discharge through the entrance. Alternatively, if the water level starts at 1.2m AHD and falls to 0.8m AHD, around 160ML would discharge through the entrance (i.e. factor 10 increase). This difference is not insignificant.

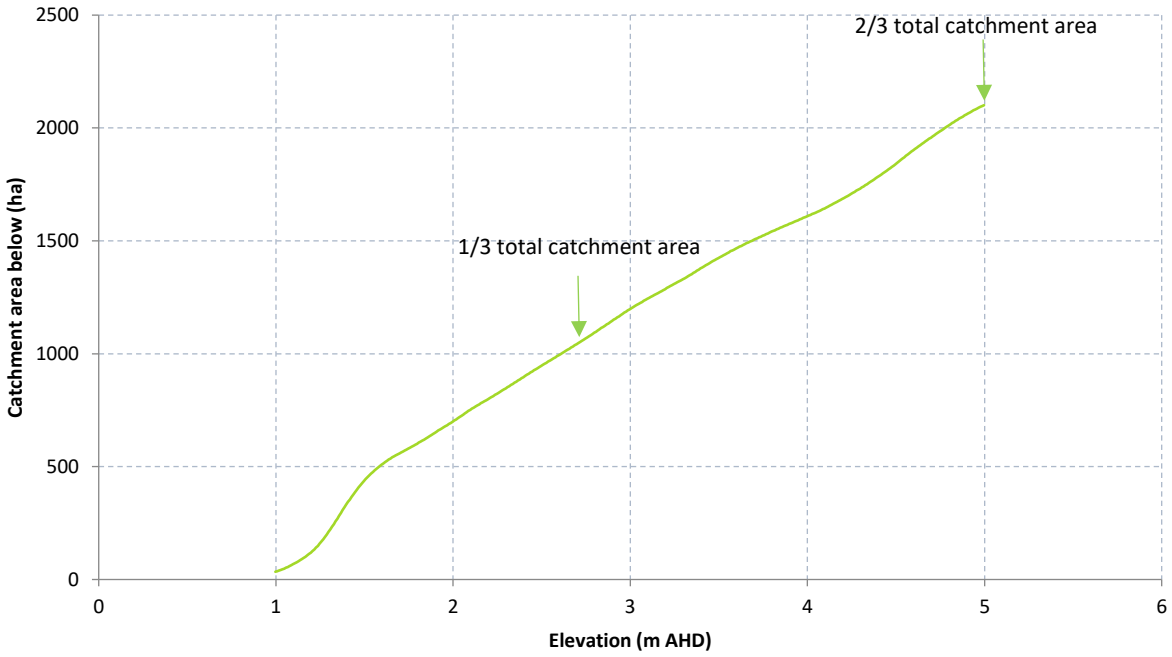

Figure 13 *Stage-area relationship for Belongil Creek floodplain (elevation below 5 m AHD)*

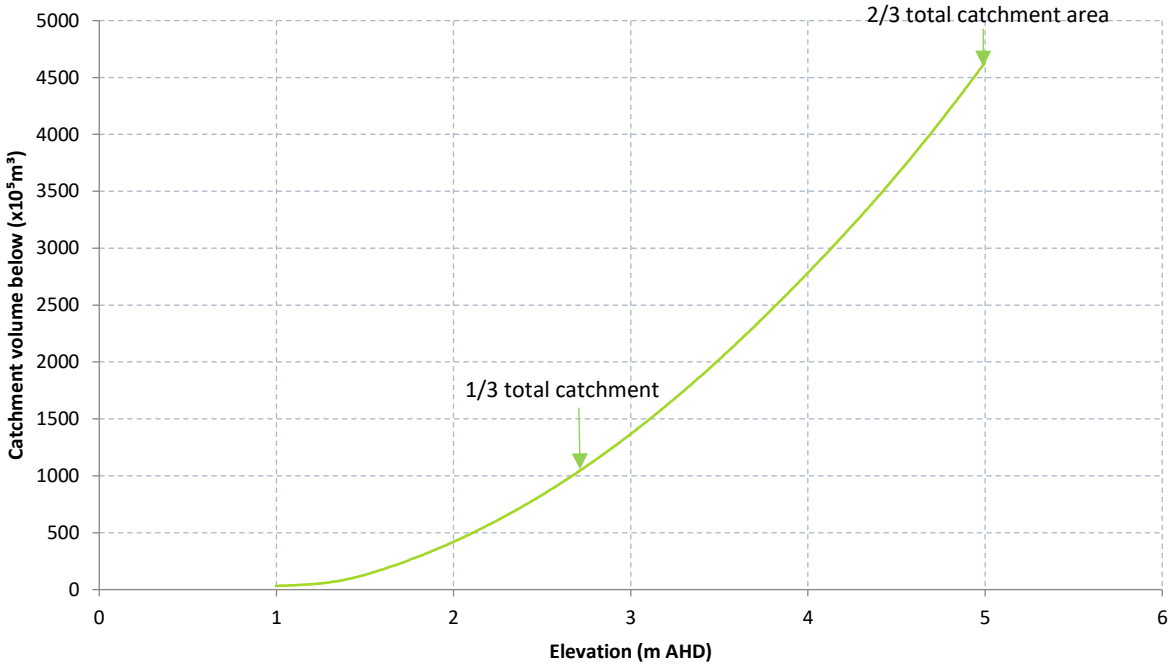

Figure 14 *Stage-volume relationship for Belongil Creek floodplain (elevation below 5 m AHD)*

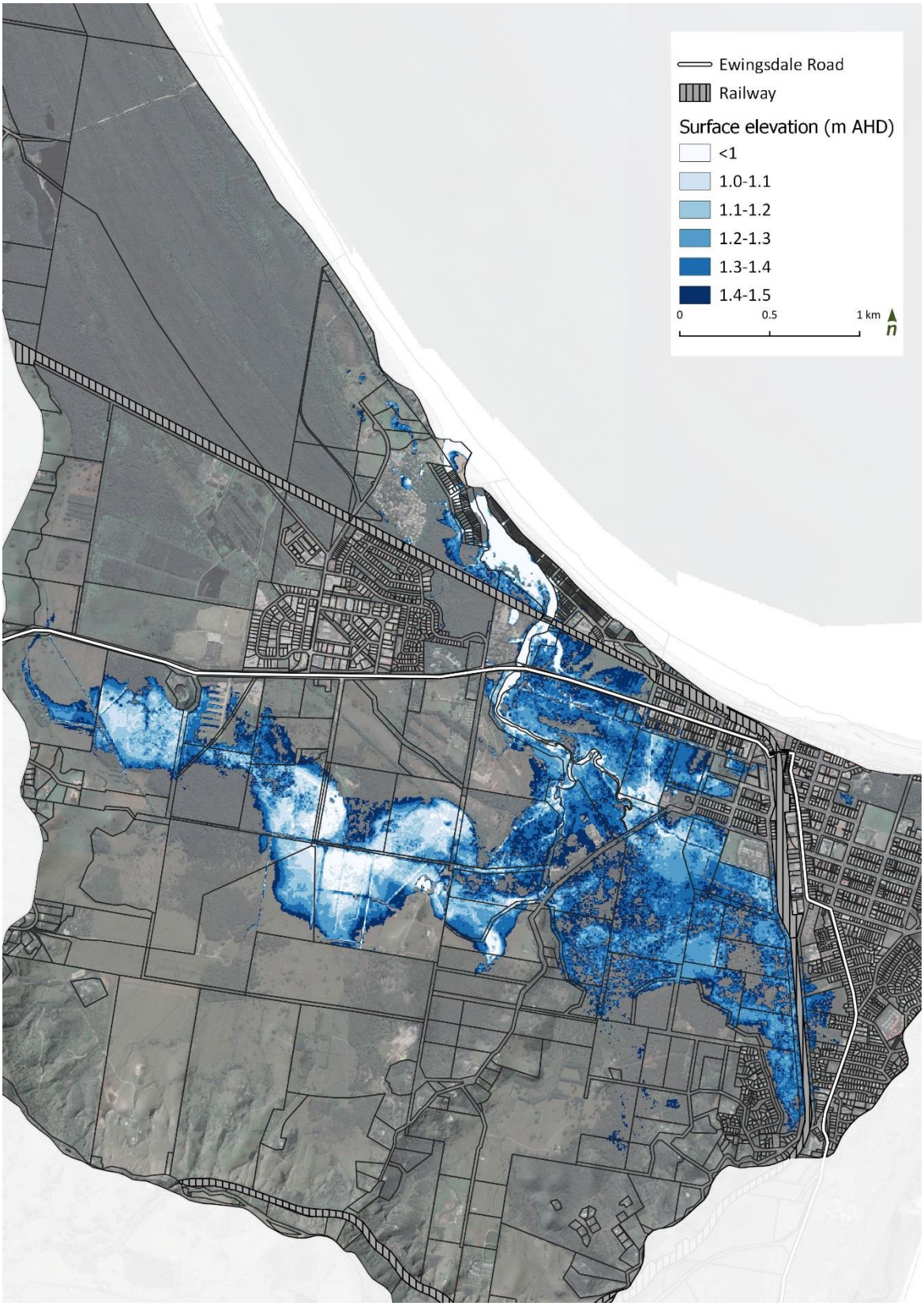

Figure 15 *Extents of Inundation for Level Water Surfaces*

Figure 16 shows several of the constructed features and other planning aspects that affect the estuary. As discussed above, bridges carry both the Railway and Ewingsdale Road over the Estuary. The relative elevation of these features means that most of the catchment discharge needs to pass below these two bridges. In addition, where the railway corridor runs adjacent to the Byron Bay CBD, its elevation presents a major constraint to stormwater and flood flows, with much of the discharge from the part of the CBD east of the railway conveyed by a single undersized culvert. This affects flooding in the CBD.

The extensive network of constructed drains across the floodplain help to drain standing water and minor flood flows towards the Belongil Creek. The artificially efficient drainage of the floodplain has made areas which were previously inundated for most of the time more amenable for agricultural use. However, as noted in Section 5, drainage of the floodplain has enabled the oxidation of previously waterlogged acid sulphate soils and the efficient movement of that acid and accumulated organic matter from these areas to the estuary following rainfall. These processes result in deteriorating water quality following periods of heavy rainfall. There also exists low lying areas in and around the Byron Bay township and the Byron Bay Industrial Estate. An increased flooding threat in these areas has been reported to result from water levels at the Ewingsdale Bridge exceeding 1.2m AHD (WP Geomarine, 1997).

The West Byron Sewage Treatment Plant (STP) opened in 1990, covers around 104 hectares and comprises primary and secondary treatment processes followed by polishing of water quality through several artificial wetlands. Presently, treated effluent is discharged to the west of the STP, into an area drained by the upper reaches of the Union Drain. Within this area, a topsoil layer of peat overlies coarse grey/brown sands with an acid generating potential which in turn overlie indurated sands that are argued to prevent the deep drainage to groundwater. Management of effluent in this manner, particularly following the closure of the South Byron Sewage Treatment Plant in 2006 and transfer of the sewage load previously handled by that plant to the West Byron STP, has been implicated in reducing acid discharge events (by elevating the water table which prevents oxidation of Acid Sulfate Soils) and a decreases the frequency with which the entrance to Belongil Creek needs to be artificially opened (AWC and BMT WBM, 2016). In 2016, the West Byron STP was discharging some 3ML/day into the Union Drain and a further 1ML/day was being used to irrigate a regenerating forest on the Belongil Creek floodplain. The discharge is projected to increase, and AWC and BMT WBM (2016) recommended that an alternative effluent release pathway be established through the Industrial Estate although a time frame for introducing this alternative release location was not established. An increase in discharge across the area west of the STP will increase the frequency of inundation of the floodplain surrounding the Union Drain network, making parts of that land less useful for agriculture.

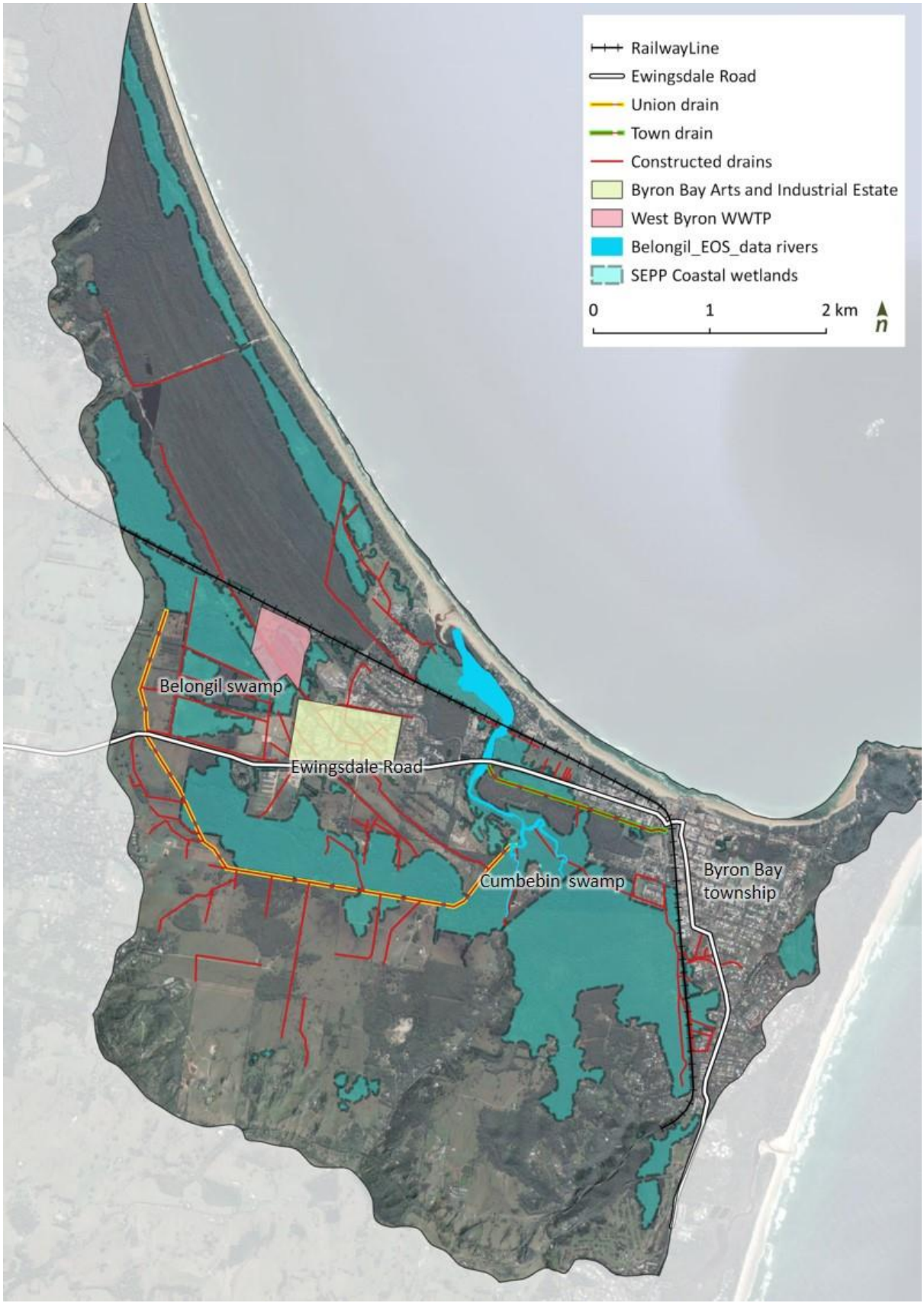

Figure 16 *Belongil Creek catchment hydrological features*

4.2 Climate and rainfall characteristics

Rainfall in Byron Bay is high compared to other coastal areas in New South Wales. Based on some 60 years of data at the Cape Byron Lighthouse, the average annual rainfall is 1737mm. Rainfall is notably seasonal, peaking in late summer / early autumn, with a pronounced minimum in September. Monthly averages, as derived by the Bureau of Meteorology, are presented in Figure 17.

The most intense rainfall events occur during February, March and April, typically caused by ex-tropical cyclone rain depressions moving from north to south along the coast and lasting for 2-3 days. Between May and October, the climate is characterised by offshore winds and clear days (Willing and Partners Geomarine, 1997).

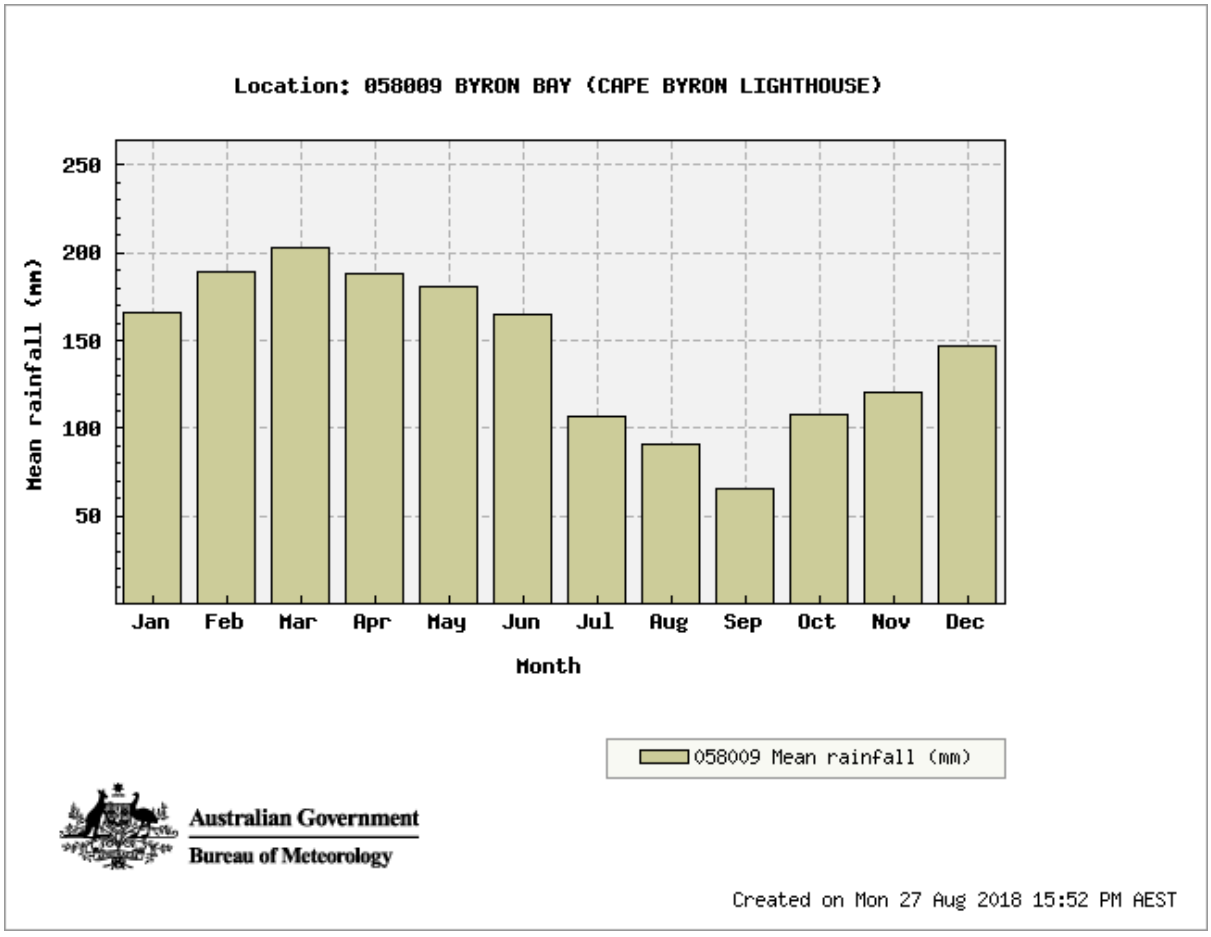

Figure 17 *Mean monthly rainfall amounts – Cape Byron lighthouse*

An estimated mean annual Potential Evapotranspiration, based on 26 years of synthesised data, is around 90% of the mean annual rainfall at 1520 mm (AWC and BMT WBM, 2016).

Rainfall events strongly influence entrance openings (both 'artificial' and 'natural') as most openings are preceded by a rainfall event in the local catchment (BMT WBM, 2007).

4.3 Tidal hydraulics, nuisance flooding and extreme flooding

Entrance dynamics and tidal hydraulics

The Belongil Creek ICOLL is naturally prone to closure at any time of the year through the build-up of a sand barrier (or "berm") at the ocean entrance which prevents tides from flowing in and out of the estuary.

Simplistically, in the absence of artificial breaching, the open or closed nature of the entrance is determined by a balance between:

1. The effect of rainfall, which tends to fill up the estuary, overflowing or 'breaching' any sand barrier present, encouraging flow out of the entrance and flushing sand into the adjacent ocean.

2. The effect of coastal sediment transport which carries marine sand towards and into the entrance to build the barrier. Eventually, after an opening event, the entrance becomes clogged with sand carried alongshore and into the entrance by tides, assisted by the stirring of coastal sediments by wave action. The entrance then closes to the tides and there is no measurable tide variation inside the estuary. At this stage, wave runup processes take over to build the entrance barrier, and the height to which the entrance barrier grows is approximately equivalent to the height to which waves are able to run-up the seaward face of the barrier (Baldock et al., 2008; Wainwright et al., 2013; Weir et al., 2004). When compared to beach areas adjacent to the entrance barrier, where dune vegetation can trap windblown sand, growth of the immediate entrance barrier above wave runup levels, through aeolian transport, is less significant.

Baldock et al. (2008) described a field experiment completed at the entrance to Belongil Creek following artificial breaching on 9th June, 2004. The entrance took around 3 days to close to the tides and measurements of the height of the barrier were subsequently taken until the 25th of June. Their results show a strong correlation between the height to which the barrier rapidly grew and the measured run up elevations of waves on the seaward face of the barrier. Importantly, this rapid growth of the barrier only occurs once the entrance has practically closed to the tides. This particular artificial breaching at Belongil was weak as the opening was prompted to relieve poor water quality and there was minimal threat of flooding or follow up rain (Baldock et al., 2008). Such rapid sub-tidal closure at Belongil Creek does not seem particularly common based on our review of entrance monitoring reports prepared for Council over the last decade.

WP Geomarine (1997) also describe a process of opening whereby erosive waves attack and lower the sand barrier, inducing scour and "breaching" the entrance. WP Geomarine claim that this process tends to be more common during winter months. This process is known to occur at other closed coastal entrances in NSW but has received relatively little attention in other studies and reports dealing with Belongil Creek. It is certainly feasible, given the typically low height of the barrier (normally not much higher than 1.0m AHD at its 'saddle' point when closed), that ocean storm surge conditions when combined with a high enough tide could superelevate water in the lower estuary and that the subsequent drainage of the excess water as the tide falls could scour the entrance and cause it to breach.

For large catchments, ongoing baseflow from the catchment is enough to overcome the processes that act to carry sand into the entrance, resulting in a permanently open entrance. For small catchments, such as Belongil Creek, the balance of these processes shifts strongly towards being closed for most the time. The issue is of some relevance to Belongil Creek as "baseflow" in the estuary has been augmented by discharges from the West Byron Sewage Treatment Plant since its construction and that discharge is set to increase in coming years, having already been implicated in reducing the frequency of artificial entrance opening (AWC and BMT WBM, 2016). BMT WBM (2007) indicated that the wastewater treatment plant contributed around 1-2% of the inflows to the Estuary, although later work highlighted that this 1-2% of the total catchment inflow is actually a more significant proportion at the location where the discharge occurs (AWC and BMT WBM, 2016).

When a coastal entrance is breached (either artificially or by scour) it typically takes a few hours for a viable entrance channel to develop, at which stage a "transcritical" flow regime develops, characterised by standing waves and "anti-dune" type bed forms which migrate upstream with time (Gordon, 1990; Wainwright, 2013). It is during this stage that a strong entrance scour channel develops. The development of an effective and persistent breach channel is strongly controlled by having a reasonable head difference across the barrier (i.e. high water levels in the lagoon and low water levels in the adjacent surf zone are ideal).

Given the very low trigger level (1.0m AHD) for artificial opening of Belongil Creek, and the present management strategy which encourages opening at a falling or low tide, it is likely that the development of the transcritical regime is impeded as most of the breach action occurs during a rising to high tide, when the head difference is minimised. We understand that the present management process is intentional, in that it aims to

reduce the “rapid flushing” of sand from the entrance and to avoid the rapid drainage of poor water quality from the upper catchment into the estuary (Byron Shire Council, 2005). However, management in this manner means that, occasionally, the attempt at breaching the entrance is not very effective at all, with the entrance closing rapidly with minimal fall of water level.

Once a viable entrance channel is developed, and water has drained from the estuary, the creek is again subject to tidal influence. Initially, this may mean that estuary water levels oscillate around a mean water level of around 0.2m AHD (slightly above mean sea level). Once opened, the creek becomes tidal for some 3.0 to 3.5km upstream of the entrance.

Regardless of how well opened the entrance is, historical reports indicate that attenuation of the tide over the remaining entrance shoals is marked (tidal range just upstream of the entrance is between around 50 and 20% of that in the ocean).

Over time, the entrance becomes more and more constrained, and the mean water level in the creek rises until the entrance closes. Analysis over a 13-month period in the 1990’s indicated that during the period between opening and closure, an average water level of 0.5 m could be expected inside the estuary (WP Geomarine, 1997).

Entrance closure is initiated by sand transported northwards along Belongil Spit and into the entrance. Belongil Spit elongates and pushes the entrance channel northwards. The process is illustrated via historical aerial photographs, obtained from Google Earth, taken 3 days after an entrance breaching event and some two months later as reproduced in Figure 18.

Figure 18 *Comparison of Entrance Configuration on 16 May 2013 (Top) and 22 July 2013 (Bottom). The entrance was opened on 13th May. (Source: Google Earth). Note the tendency towards northwards migration of the entrance channel driven by the dominant south to north alongshore drift.*

Tidal currents can be reasonably significant. When open, depths across the entrance are still comparatively shallow and surface currents approaching 0.50m/s have been measured for large ocean tides (WP Geomarine, 1997). The estuary deepens immediately upstream of the entrance and the deepest part of the estuary, at -2.0m AHD, is located at the Railway Bridge. Further upstream, at the Ewingsdale Road Bridge, peak velocities have also been measured, indicating that a peak discharge current speed of around 0.5m/s could be expected when the entrance is opened at a trigger level of 1.2m AHD. The corresponding value of around 0.25 m/s results from a trigger level of 1.0m AHD. It has been argued that this reduction in velocities during an entrance

breaching event prevents the resuspension of organic sediments along with the attendant issues of turbidity and a reduction in oxygen within the water column (Byron Shire Council, 2005).

Nuisance flooding

The issue of nuisance flooding has been discussed previously using bath tub analysis, assuming a closed barrier (see Figure 15 and Table 2). The bath tub analysis is reasonably representative of conditions while the entrance is closed and there are minimal inflows to the catchment, where the water in the estuary and tributaries will find an approximately flat surface.

However, moderate catchment inflows and tides will influence water levels at any given time and the system will vary from the approximated flat surface. The discharge of water from the West Byron STP will also raise groundwater levels and encourage additional inundation of the floodplain adjacent to the Union Drain and its network of feeder channels.

The flat topography across the upper floodplain also means that water levels need to be elevated in the upstream reaches to drive flow from the Union Drain network. Ultimately, it means that drainage is typically slow, and the floodplain is prone to ponding for extended periods of time. Prolonged ponding is a nuisance for landholders. When the entrance is closed, and there are inflows from the catchment, elevated water levels in the estuary means that water levels across the floodplain need to be further elevated to drive flows towards the estuary (In this scenario, land owners will likely contact council to resolve the issue through artificial opening of the entrance).

All nuisance inundation problems (and more extreme flood problems) will continue to be exacerbated by ongoing sea level rise. As a first pass estimate, both tidal water elevations and the water surface elevation when the entrance closes, the height to which the entrance barrier grows, and the height to which inundation across the floodplain upstream of the estuary tends to occur once the entrance is closed, will all rise at the same rate as mean sea level in the ocean. While the relationship is not exactly 1:1, stochastic modelling undertaken of an intermittent lagoon on the South Coast of NSW indicates that this is a reasonable approximation (Wainwright et al., 2013). Council may offset some of the impacts by opening the entrance more frequently, or investing more effort in individual entrance opening operations, however this will eventually become impractical and ineffective.

BMT WBM (2007) noted that, (our emphasis):

> *"Given projected levels of sea level rise, it […..is…..] possible that areas within the Byron Bay CBD will be affected by inundation by normal tidal conditions in Belongil Creek before the end of this century. This acute susceptibility to inundation should prompt action for flood risk mitigation as a matter of priority.* ***That is, steps should be taken now to ensure that future inundation minimises the risks to life and property"***

Planning for adaptation within the Byron Bay CBD to address the increasing risk of nuisance inundation from future sea level rise is required. In available reports, frequent reference is made to parts of the CBD being prone, or vulnerable to flooding once water levels reach 1.2m AHD at the Ewingsdale Bridge (for example: Byron Shire Council, 2005). Using the inundation overlay presented in Figure 15, which is based on a 1 m digital elevation model derived from LiDAR information captured in 2010 and published by Geosciences Australia, indicated that ground elevations below 1.2 m in the CBD are either non-existent or very minor (<< 1 square metre). Indeed, it appears that water surface elevations of above 1.3 m AHD are required in the CBD before they begin to inundate roads and residential yards. However, at levels of 1.1 to 1.3 m AHD it is expected that isolated water may be found high in street gutters and subsurface drainage infrastructure. In this situation, local rainfall on the CBD catchment has the capacity to rapidly fill the stormwater system and cause localised flooding.

Extreme flooding effects

While nuisance flooding is a genuine concern and often causes agitation in local communities, flooding which has the potential to damage property or cause death is more widely used for planning purposes in New South Wales. Uses include setting flood planning levels (used to set elevations of residential floors) planning for

evacuation and identifying areas where the flood risk is too excessive prompting the removal of existing development from the floodplain.

WP Geomarine (1997) referenced an early study of flooding undertaken by the NSW Department of Public Works (1986). That earlier study derived the flood levels presented in Table 3.

Table 3 Flood Levels derived by NSW Department of Public Works (1986)

Locations	Flood Elevation (m AHD)		
	5% AEP	1% AEP	Extreme Flood
Downstream of Railway Bridge	2.4	2.6	3.0
CBD, Cumbebin Swamp and Middle Estuary (upstream of Railway Bridge)	2.4	2.6	3.2
Belongil Swamp (North of Ewingsdale Rd.)	2.8	3.0	3.5

By today's standards, the computer modelling undertaken was relatively unsophisticated. More recently, SMEC (2009) developed a numerical flood model (using TUFLOW software) and applied upgraded hydrological methods and guidelines from the NSW government to derive representative flood elevations, velocities and derivative values for a wide variety of different magnitude events.

That model was subsequently improved by BMT WBM (2015) in preparing a floodplain risk management study and plan. Importantly, that study included the execution of flood simulations to incorporate Council's updated climate change and sea level rise policy. The BMT WBM findings have been considered further herein, given that the SMEC modelling was superseded.

The updated Council policy advocated consideration of a 0.4 m rise in mean sea level by 2050 and a 0.9 m rise in mean sea level by 2100. Additional climate change sensitivity analyses considered increases to storm rainfall intensity of between 10% and 30%.

Intriguingly, the results presented by BMT WBM (2015) indicated that there were no changes to flood levels resulting from the 0.4m sea level rise projected for 2050. Byron Shire Council's policy was subsequently reviewed[1]. A strict read of the policy indicates that, for both the existing and 2050 climate change scenarios, a peak tailwater of 2.6 m AHD is to be used, even though the 2050 climate change scenario purports to include a sea level rise of 0.4 m. The reasons for Council adopting this approach are unclear, although the policy hints that Council had historically included some allowance for sea level rise. It is understood Council based this assumption on the fact the 2.6 m level includes a 0.4 m component for sea level rise.

The model files were also inspected to determine how the entrance to the Creek had been considered in terms of likely morphology. The initial state of the entrance at the onset of a flood and the way in which the modelled entrance of a closed or constrained entrance evolves as the flood event progresses has been acknowledged for some time (Cooke et al., 2013; Lyons and Williams, 2012; Wainwright et al., 2004, 2011). Modelling the entrance as closed (high barrier) and not evolving over time will result in conservative estimates of catchment flood elevations whereas applying an open entrance will result in a non-conservative estimate. To some extent, the reverse applies for ocean inundation dominated events.

The original Public Works flood study (NSW Department of Public Works, 1986) took a conservative approach by applying a fixed entrance barrier height of 2.6 m AHD for the 1% AEP , effectively controlling the water levels in the downstream reaches of the model. In comparison, the SMEC study regarded a "closed" entrance as having the entrance bed elevations set at 0.0 m AHD. Their finding that upstream flood levels were reduced by this constrained entrance suggest that there was an error in SMECs configuration or interpretation of model results. In examining the files from the BMT WBM study, it is apparent that a clear channel with uniform depth of -2.0m AHD and extending well behind Belongil Spit for nearly 1300m upstream of the entrance has

[1] https://www.byron.nsw.gov.au/files/assets/public/hptrim/land-use-and-planning-planning-strategies-key-records-floodplain-management-shire-wide-2018/w2018-368-climate-change-strategic-planning-policy.pdf, accessed 8th September, 2018

been applied in the simulations used to derive flood elevations (and subsequent flood planning levels). Considering that WP Geomarine (1997) indicated the deepest part of the channel, near the Railway Bridge, was -2.0m AHD, the introduction of this scoured channel seems excessive. Furthermore, there doesn't appear to have been any consideration of the changes that will occur to likely bed elevations at the entrance with sea level rise, nor any consideration of how management of the entrance may change with increasing sea levels.

Overall, the morphology of the entrance has not been treated with rigour in the flood studies that have taken place to date. Our initial assessment is that it is likely the model configuration has resulted in somewhat non-conservative flood elevations in areas upstream of the Estuary.

Ultimately, two Flood Planning Levels were derived for use by Council. These were:

- **FPL1** based on a 1% AEP catchment flood occurring with 0.4m of sea level rise and a freeboard of 0.5m which is to be applied to "*All development with the exception of new release areas, re-zonings, critical infrastructure and special purpose facilities*"
- **FPL2** based on a 1% AEP catchment flood occurring with 0.9m of sea level rise and a freeboard of 0.5m which is to be applied to "*New release areas, re-zonings, critical infrastructure and special purpose facilities*"

These two flood planning levels are presented in Figure 19 and Figure 20 respectively.

Noting that the difference between the two FPLs is a projected sea level rise increase of 0.5m (between 2050 and 2100), the FPL's (and model results from which they are derived) illustrate that the impact of sea level rise for floodplain risk management diminishes upstream along Belongil Creek and underneath the railway but is still felt significantly across most of the floodplain.

Figure 21 and Figure 22 show the "Existing" condition peak model elevations for the 10% AEP ("1 in 10 year") and 1% AEP ("1 in 100 year") floods respectively. Comparison of these two figures shows that inundation caused by the 1% AEP event does not differ extensively from that for the 10% AEP Event. One notable difference is that there is overland flood connectivity within the Byron Bay CBD, east of the railway line, for the 1% event which is not present for the 10% event. . Inundation across the floodplain is typically 0.1 m deeper for the 1% AEP event when compared to the 10% AEP Event. Drainage in most flow events will be impacted by both local catchment rainfall patterns and the tailwater conditions in the primary drains and in the broader Cumbebin Swamp area. The tailwater level will be a major issue during very intense rainfall events.

Figure 23 and Figure 24 show the "Existing" condition peak model velocities for the 10% AEP ("1 in 10 year") and 1% AEP ("1 in 100 year") floods respectively. These figures show that velocities across the floodplain are typically small and comparable for both events, reflecting the slow drainage of the floodplain. In comparison, velocities in Belongil Creek downstream of the Railway and closer to the entrance are simulated as reaching close to 2.5m/s, although the simulated patterns of peak velocity are highly variable.

4.4 The need for entrance management

The primary reasons for entrance management have been touched upon in previous sections, however it should be noted that these have evolved with time. This is of importance when developing and entrance management strategy, as we need to understand exactly what it is we are trying to achieve. The entrance has been opened by Council for somewhere in the vicinity of 60 years (Byron Shire Council, 2005). Some of the key issues which have driven entrance opening are discussed below.

Inundation of property

The floodplain was drained in the early 20th century to enable agricultural development. Accordingly, Council historically opened the entrance of the creek at the request of property owners whose land was covered with water.

Flooding concerns in the CBD

As Byron Bay developed, concerns were raised about flooding in the CBD. Council settled into a pattern whereby the water level at Ewingsdale Bridge reached 1.2m above Australian Height Datum.

Water quality

More recently, the issue of water quality in the Estuary has taken prominence. Even so, the understanding of the actual water quality drivers has changed over time. For example, IERM (Integrated Ecosystem Research and Management, 2005) stated that the trigger level of 1.2m was lowered to 1.0m in 2001 to *"attempt to reduce turbidity observed in the estuary following artificial opening, through reduction of the water velocity of the existing water".* More recently, the understanding has evolved to focus on the role of acid drainage from the upper floodplain, particularly from the upper reaches of the Union Drain network.

Aside from lowering the pH of estuarine water as this drainage system discharges to Belongil Creek, the acidic conditions are also known to mobilise heavy metals which are then oxidised. A common symptom of this is red staining of the bed of the Estuary by iron oxides that have settled from the water column. Furthermore, the oxidation process causes a sag in dissolved oxygen levels in the Estuary for, typically, 6-7 days after opening. Historically, fish kills have been were noted in the Estuary during the 1980's and 1990's although notable fish kills have reportedly been absent since the trigger level was lowered from 1.2 to 1.0m AHD[2].

These varied drivers are intrinsically related to "issues" associated with both the historic and current approach to entrance management. These matters are outlined in more detail in Section 7.

[2] BMT WBM (2007) indicated that there were no fish kills in the preceding 5 years and subsequent, more recent monitoring reports by Geolink and Australian Wetlands Consulting only report a single fish kill event (6 individuals) on 4 March 2016.

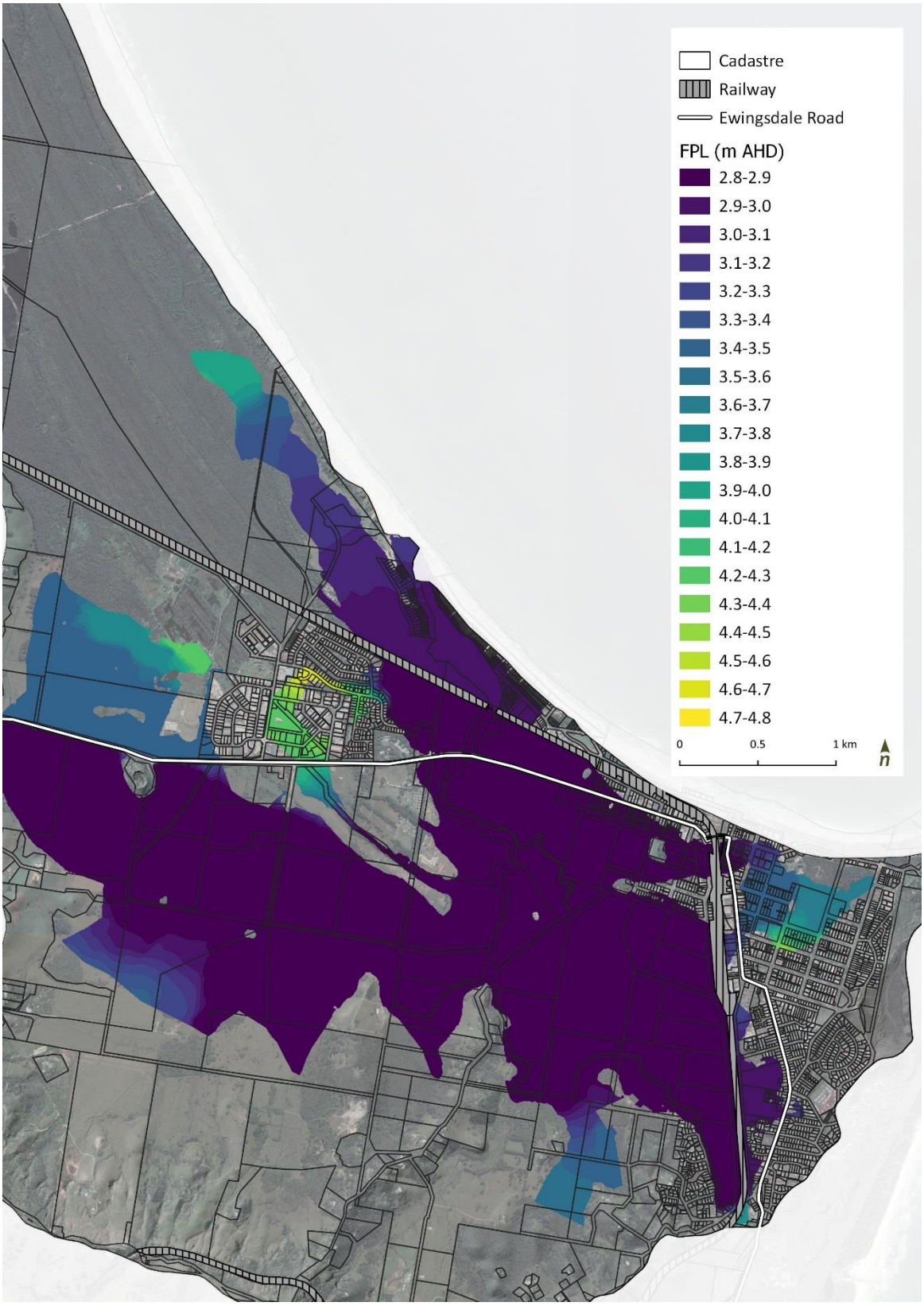

Figure 19 *Flood Planning Level 1 based on a 1% AEP catchment flood occurring with 0.4m of sea level rise and a freeboard of 0.5m*

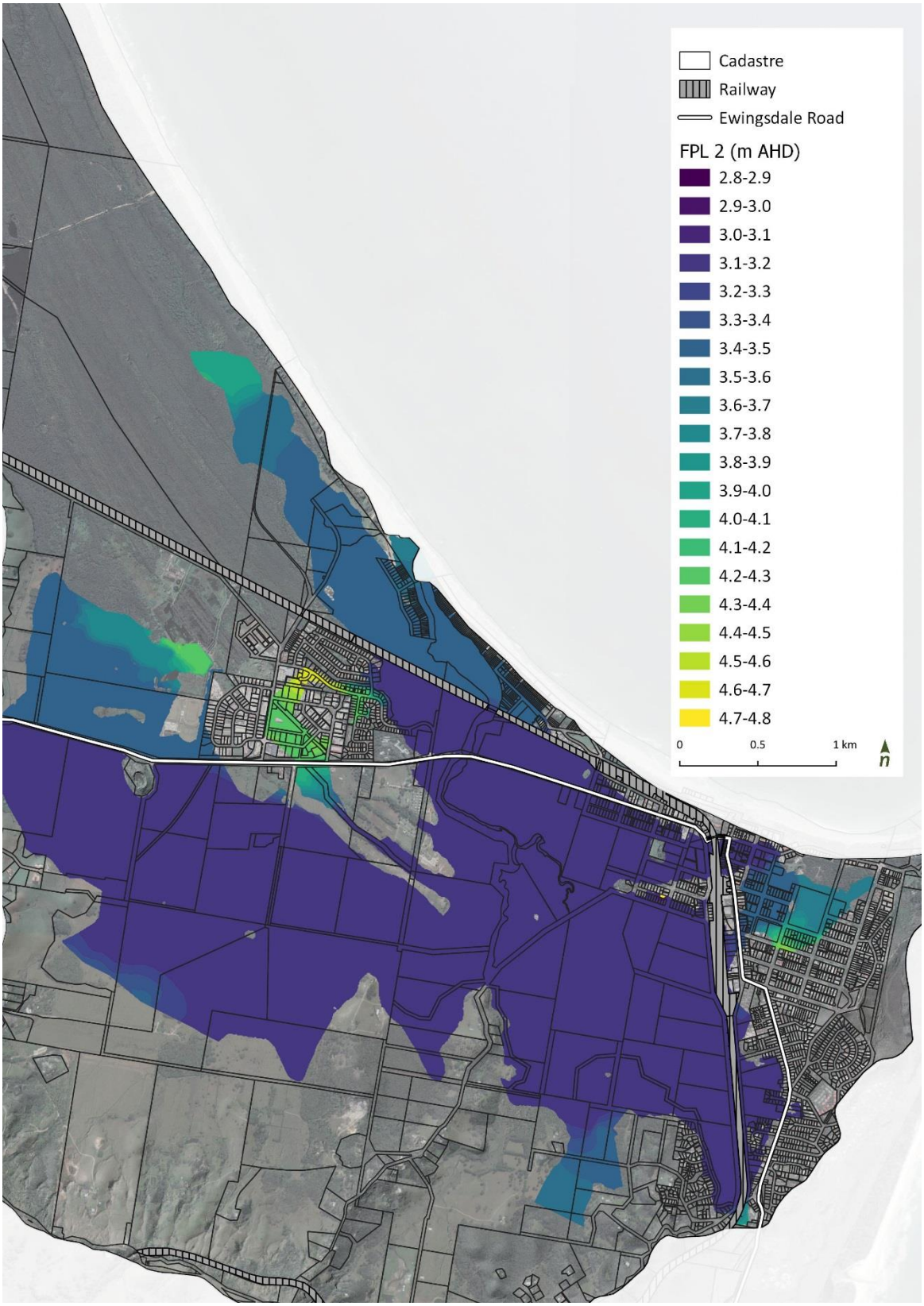

Figure 20 *Flood Planning Level 2 based on a 1% AEP catchment flood occurring with 0.9 m of sea level rise and a freeboard of 0.5m*

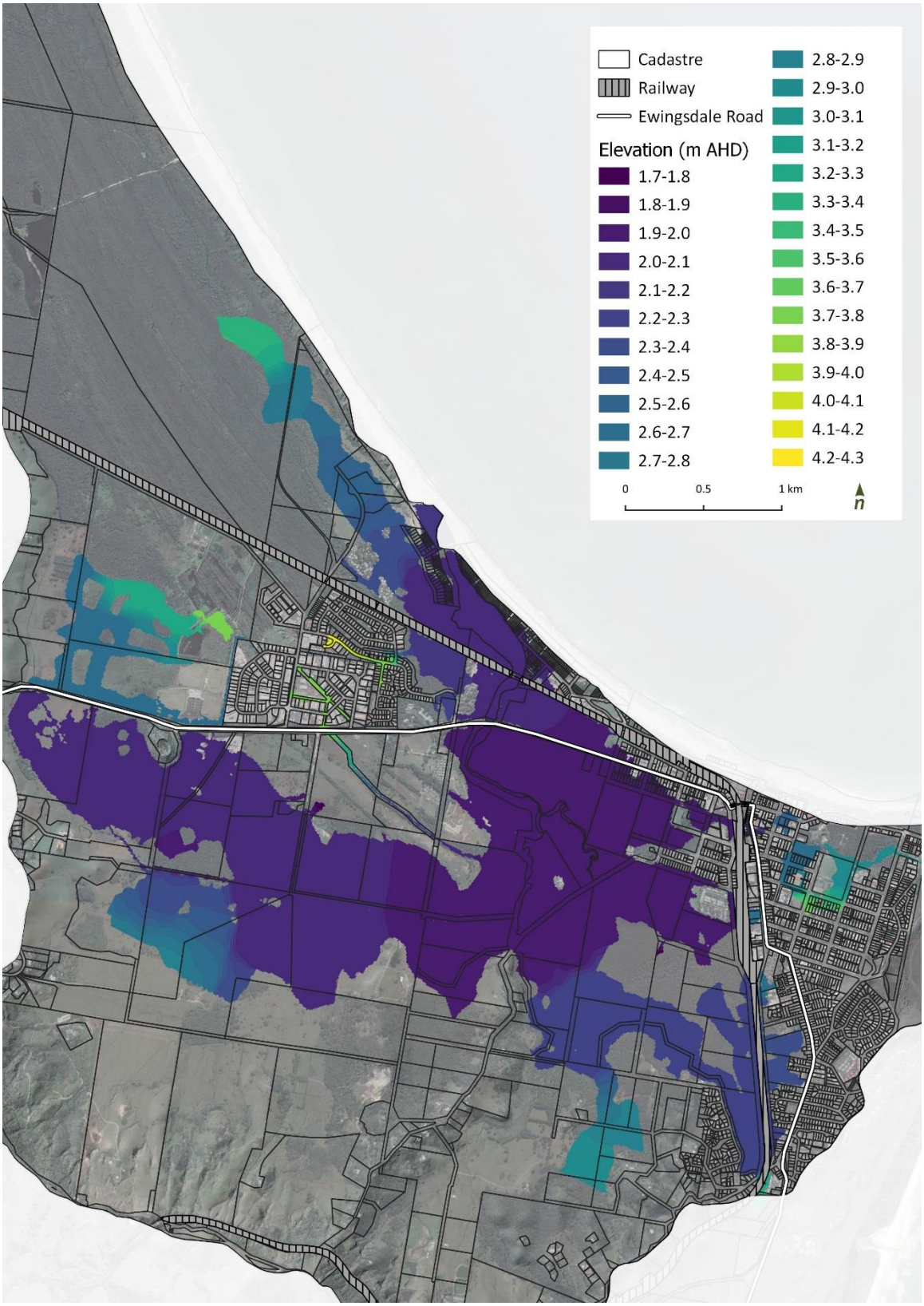

Figure 21 *10% AEP catchment flood peak elevations as determined during Floodplain Risk Management Study*

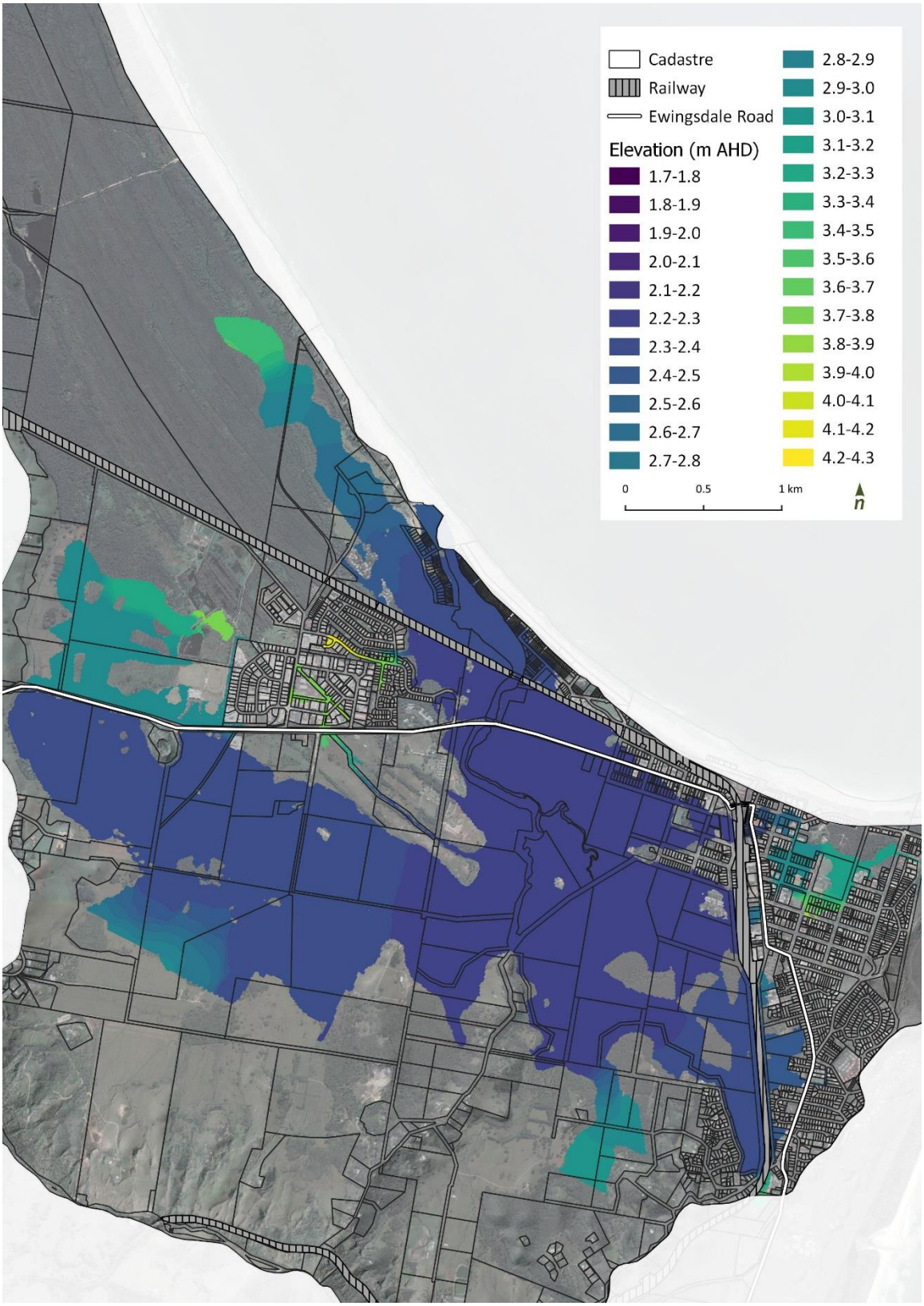

Figure 22 *1% AEP catchment flood peak elevations as determined during Floodplain Risk Management Study*

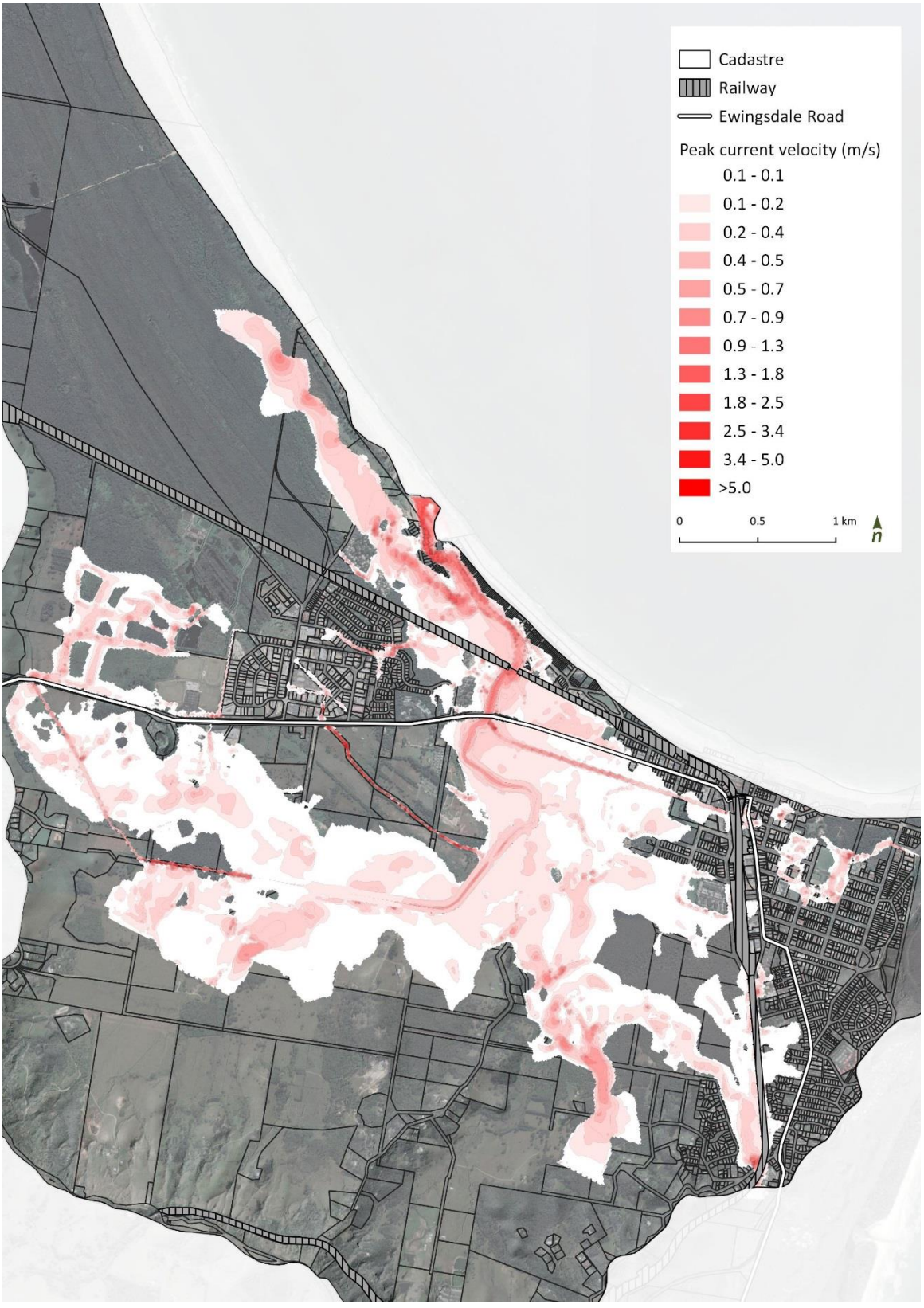

Figure 23 *10% AEP catchment peak flood velocities as determined during Floodplain Risk Management Study*

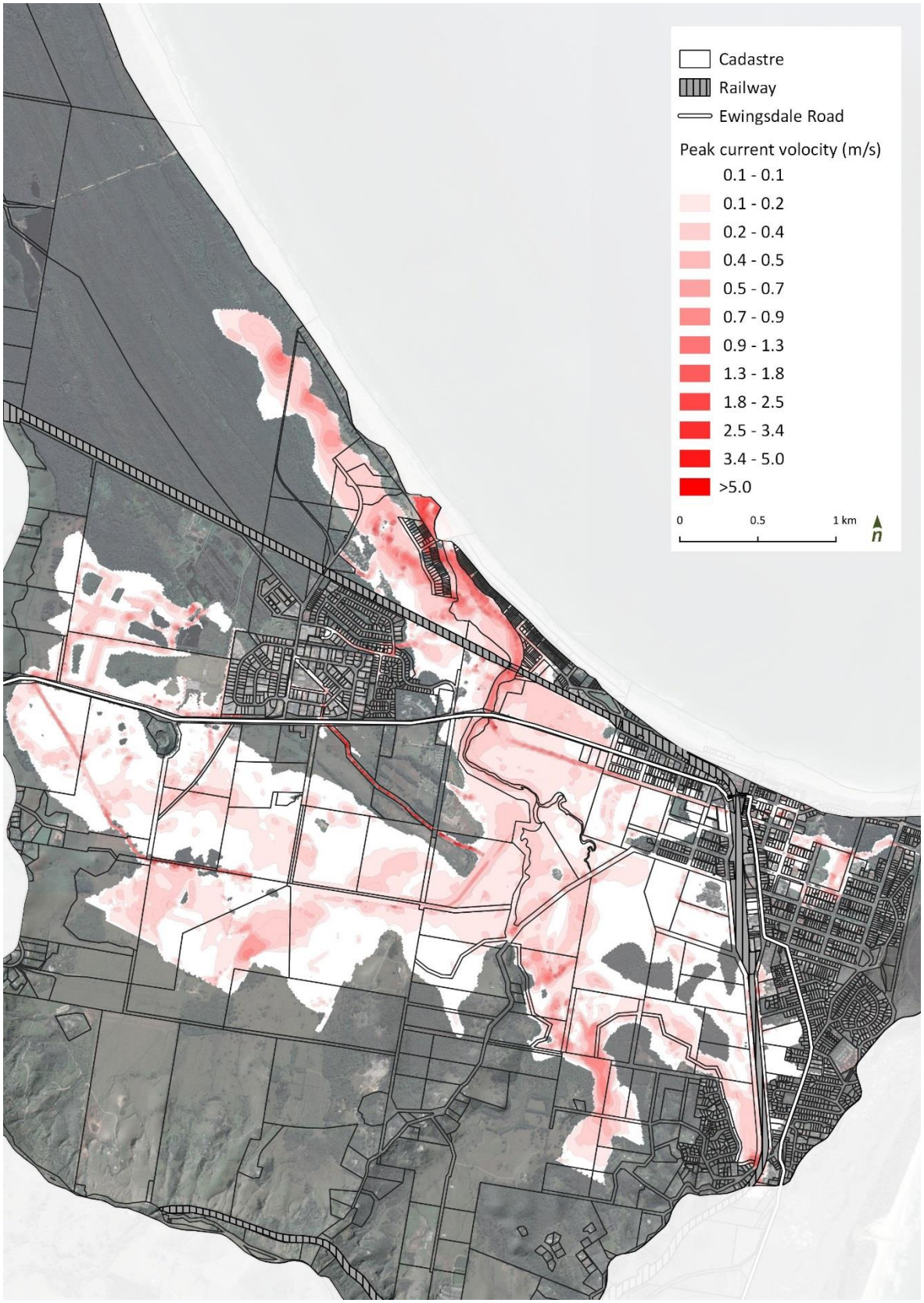

Figure 24 *1% AEP catchment peak flood velocities as determined during Floodplain Risk Management Study*

5 Water quality

Water quality in the Belongil Creek has previously been described as moderately impacted (WBM, 2001). The water quality within ICOLL systems such as the Belongil Creek estuary is naturally highly variable and dependent on many conditions and processes. When the entrance is open the system is influenced by regular tidal inundation and when the entrance is closed the ICOLL acts more like a lake. The long-term variation in entrance opening frequency gives rise to large variation in the physio-chemical properties of the water. The water quality is therefore heavily influenced by both freshwater and saline inflows as well factors such as catchment runoff, groundwater inflows, wetland drainage and direct rainfall.

One of the major drivers of estuary water quality in this system is the inputs from the catchment. Major changes in the catchment over the last 100 years has had significant impacts on the water quality in the estuary. The main factors that influencing the estuary water quality are outlined below.

Acid Sulfate Soils
Acid sulfate soils (ASS) are sediments containing the sulfidic mineral pyrite deposited under estuarine conditions (Tulau, 1999). Within the Belongil Creek catchment the occurrence of ASS has been confirmed in Holocene clays and peats and Pleistocene sands (DIPNR, 2004). In 1999 the Belongil Swamp was identified as one of the ASS 'hot spots' in NSW (Tulau, 1999). Recent NSW Government Environment Planning instrument (EPI) data on ASS within the catchment is shown in Figure 25. The data indicates:

1. Class 1 ASS which are "considered likely to be found on and below the natural ground surface" and are immediately adjacent to the lower estuary channel
2. Class 2 ASS which are "considered likely to be found below natural ground surface" and are indicated in areas surrounding the estuary and Cumbebin and Belongil Swamps
3. Class 3 ASS which are "likely to be found beyond 1 m below the natural ground surface" and are mostly mapped in the Pleistocene beach ridges in the north west as well as area on the northeast side of the Cumbebin Swamp.
4. Class 5 ASS which are "ASS not typically found but are located within 500m of Class 1,2,3 or 4 land" and are mapped predominately on the beach and primary dunes.

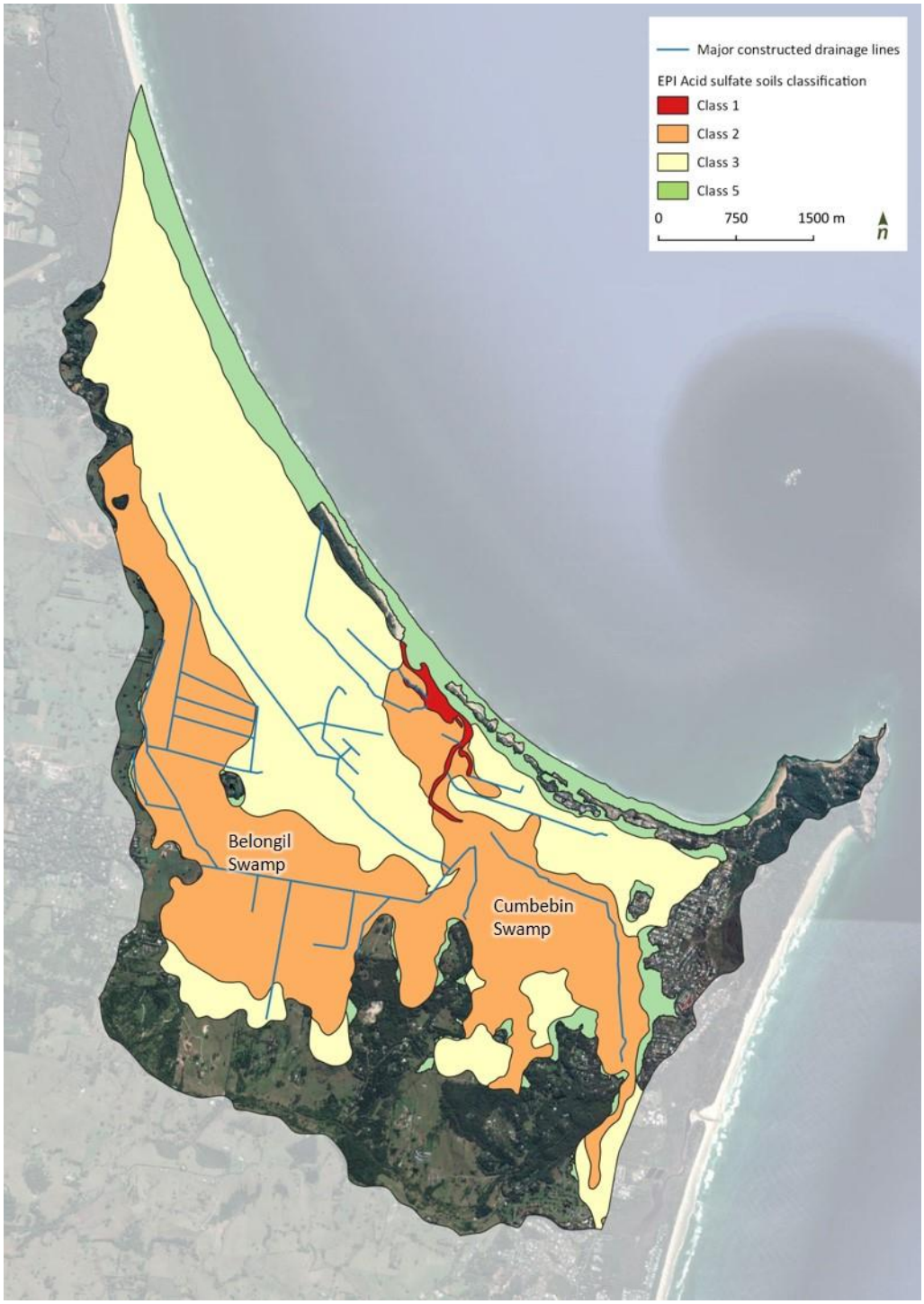

Figure 25 *EPI Acid sulfate soils class with the Belongil Creek catchment*

Under anoxic conditions, ASS are considered relatively stable and known as potential ASS (PASS). Once the sediments are exposed to oxygen the pyrite is oxidised resulting in the formation of sulfuric acid as well as soluble iron and aluminium into the surrounding soil and groundwater (DIPNR, 2004). The artificial drainage that has occurred in the catchment for over 100 years has led to the oxidation of ASS in the swamps through lowering of the water table and drying out the soil profile (particularly in the organic peat layer). Following a rainfall event, the drains convey surface runoff along with the oxidation products directly into the downstream estuary. Following entrance opening ponded surface water in the swamps is drained and groundwater levels are reduced. This process can result in acidic groundwater entering the drains and estuary (BMT WBM, 2007).

pH

The pH of the Belongil Creek estuary and drainage system is highly variable and dependent on numerous factors including but not limited to rainfall, entrance condition and tidal fluctuations. The variability in pH has been shown to correlate well to local rainfall events. The lowering of pH in the estuary is associated transport of acid discharge from the oxidization of ASS within the catchment. The entrance condition also plays a significant role fluctuation in pH between rainfall events. When the entrance is open, inflowing tidal waters will increase the pH due to the mixing of alkaline sea water. When the entrance is closed the quality of stored runoff upstream can become low in pH due to its interactions with ASS.

Iron and turbidity

The turbidity within the Belongil Creek estuary is predominately a product of tannins from the adjacent wetlands, suspended sediments and flocculated iron (BTM WBM, 2007). Observations of a distinctive reddish appearance to water is generally a sign flocculated iron which is indicative of the presence of ASS. Initial observations of the monitoring data suggest that following an opening event there is a drop in pH, an increase in turbidity and an increase in both iron and aluminium. It is likely that this response following the opening is related to low pH, iron and aluminium enriched waters within the upper drains and wetlands (backswamp water) draining into the estuary.

Urban and agricultural runoff

Significant development of the Byron Bay township and industrial estate has led to poor quality stormwater entering the estuary via the Town and Union drains. Typically, this water is characterised by high Biological Oxygen Demand (BOD), low oxygen demand and high inorganic nitrogen. Agricultural runoff is thought to be the primary source of nutrient loading into the estuary. High nutrient concentrations and poor flushing conditions, like when the estuary entrance is closed, can lead to phytoplankton blooms (IERM, 2005). Disturbance of ASS and PASS on agricultural land is also a likely contributor to acidic runoff.

Water quality analysis

Water quality parameters within the Belongil Creek Estuary are highly variable and influenced by many dynamic conditions such as rainfall, entrance opening condition and tidal fluctuations. To meaningfully analyse water quality trends, a continuous (or semi-continuous) dataset is required. A HANNA HI 7629829 multi parameter logger was deployed in August 2016 by Australian Wetland Consulting as a part of monitoring for their Belongil Entrance Management Reporting. The logger is located downstream of the Ewingsdale Bridge and records the following parameters on an hourly basis:

- pH
- Temperature (˚C)
- Conductivity (µS/cm)
- Turbidity (FNU)
- Dissolved Oxygen (mg/L)
- Salinity (ppt)

This data was made available by Council for the period between the 19th August 2016 and 23rd July 2018. There were several discontinuities in the data during this period due to factors such as maintenance, calibration and logger faults, but the dataset was still useful in identifying key trends. Weekly inspection sheets were also supplied by Council that report on the entrance opening condition. Inspection sheets were available for the period between 19th August 2016 and 9th October 2017, although there were also several discontinuities in this dataset.

A comparison of pH, daily rainfall and entrance opening condition is shown in Figure 26 as well as the recorded artificial openings during the analysis period. The graph shows that there is generally a drop in pH immediately following an artificial opening event. The most significant reductions in pH appear to coincide with periods of rainfall exceeding 40mm and when the entrance is open. When the entrance is open and there is little to no rainfall (i.e. between 1st August 2017 and 5th September 2017) pH is relatively stable with small fluctuations likely attributable to the tidal exchange of alkaline sea water. There was a significant drop in pH following the

artificial opening event in February 2018. Following this there was considerable fluctuation likely to be associated with significant rainfall flushing acidic waters from the upper catchment and changes in entrance opening condition.

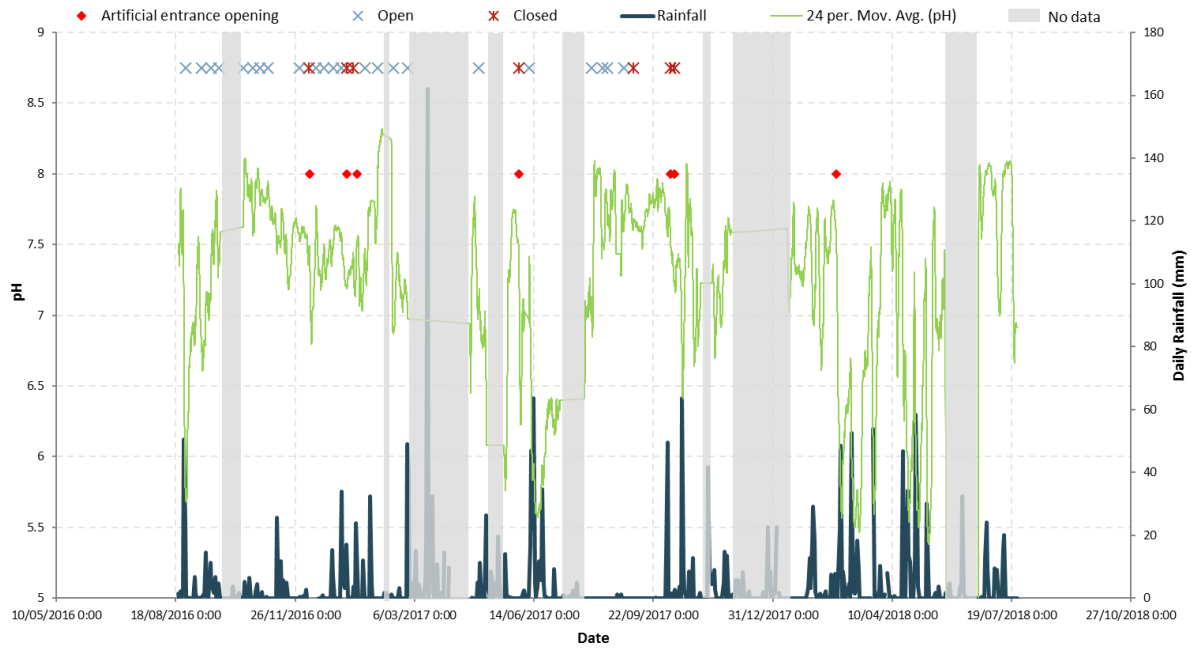

Figure 26. *Moving average of pH (data collected from HANNA multi parameter logger downstream of Ewingsdale Bridge), daily rainfall (Source:BOM) and entrance opening condition (data extracted from Council inspection sheets)*

A comparison of conductivity and salinity, daily rainfall and entrance opening condition is shown in Figure 27 and Figure 28 as well as the recorded artificial openings during the analysis period. Salinity and conductivity are closely correlated as any change in dissolved ions, in this case salinity, will directly impact the conductivity. The graph shows that there is significant variation in conductivity and salinity which is to be expected in an estuarine environment. Immediately following an artificial opening event there is typically a rapid decline in conductivity and salinity as fresh waters from the upper catchment flush through the system. If the entrance remains open, tidal exchange leads to a general increase in conductivity and salinity unless there is significant follow up rainfall which then leads to a reduction due to the increase in freshwater inflows.

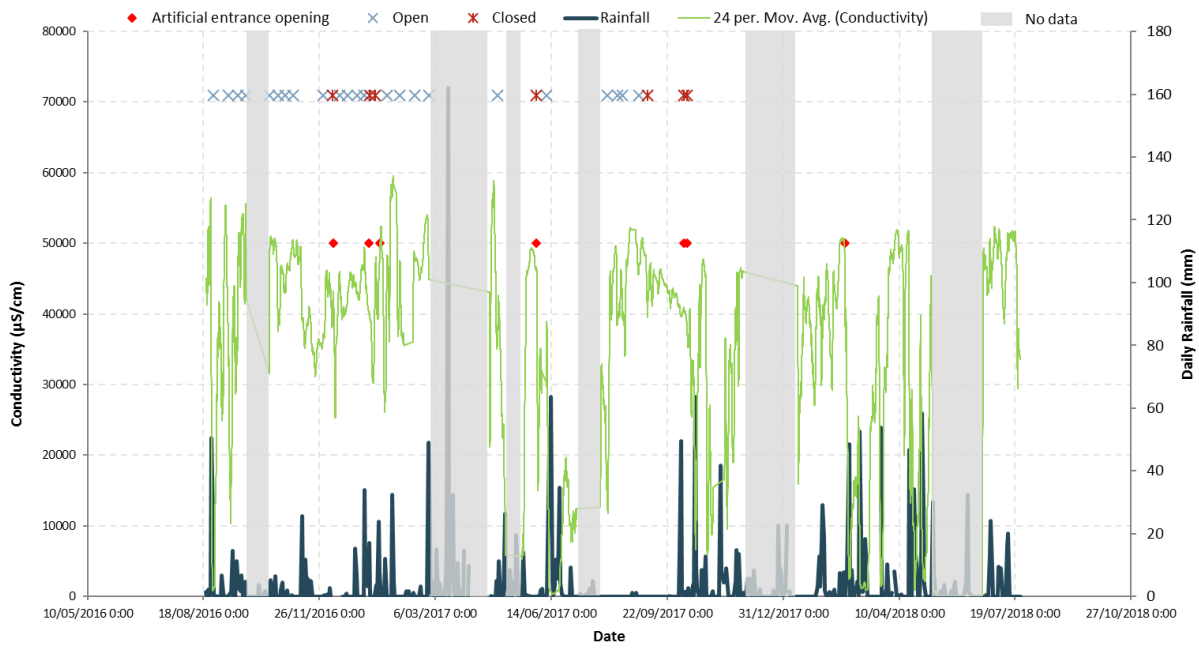

Figure 27. *Moving average of conductivity (data collected from HANNA multi parameter logger downstream of Ewingsdale Bridge), daily rainfall (Source:BOM) and entrance opening condition (data extracted from Council inspection sheets)*

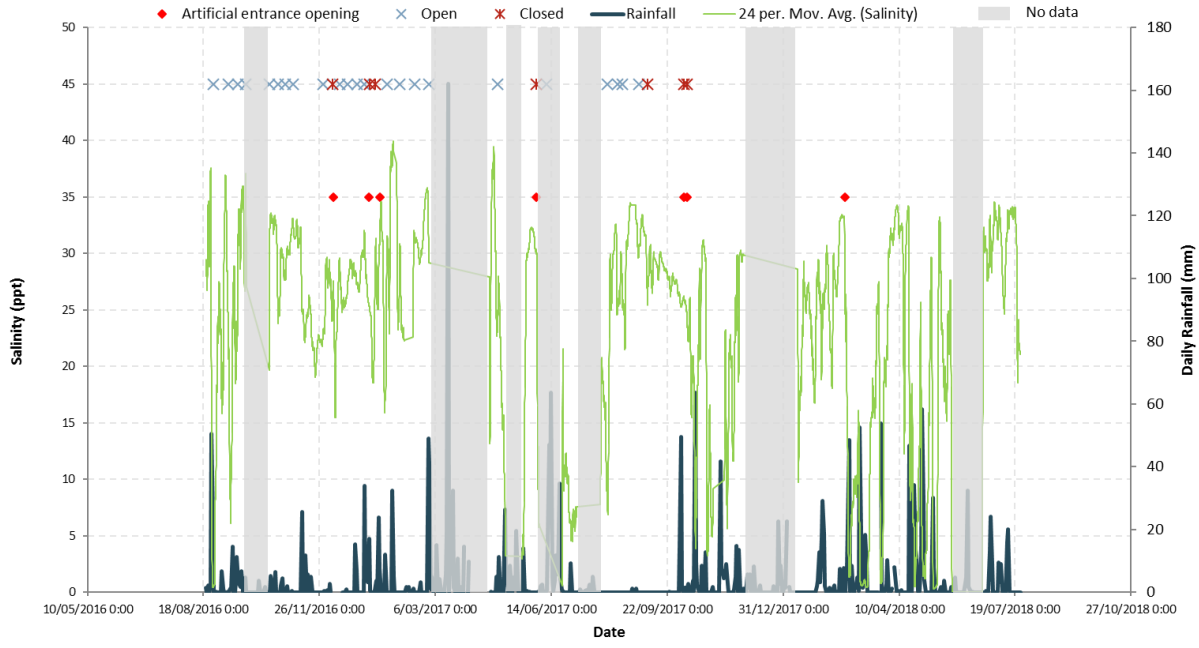

Figure 28. *Moving average of salinity (data collected from HANNA multi parameter logger downstream of Ewingsdale Bridge), daily rainfall (Source:BOM) and entrance opening condition (data extracted from Council inspection sheets)*

A comparison of turbidity, daily rainfall and entrance opening condition is shown in Figure 29 as well as the recorded artificial openings during the analysis period. The graph shows that generally there is an increase in turbidity following an artificial opening event. This is expected as water moving out of the catchment re suspends previously settled particulate matter. Iron and aluminium enriched waters associated with acidity derived from ASS within the upper drains and wetlands (backswamp water) also drain into the estuary impacting on turbidity. There is also some correlation between significant rainfall events and an increase in turbidity.

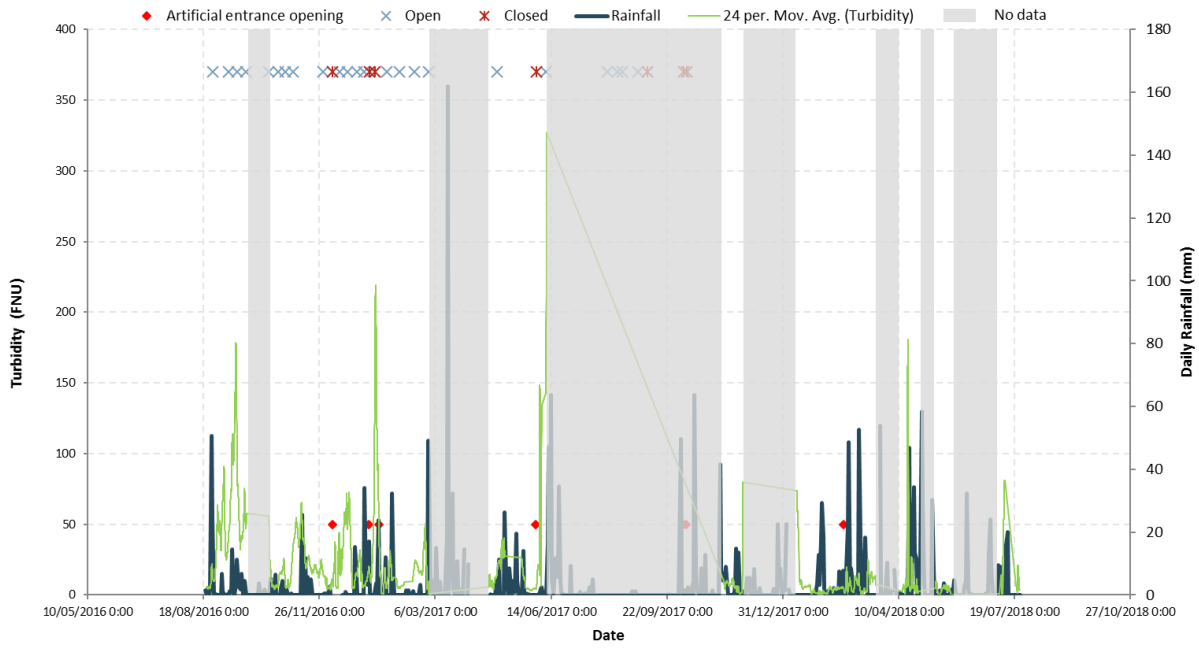

Figure 29. *Moving average of turbidity (data collected from HANNA multi parameter logger downstream of Ewingsdale Bridge), daily rainfall (Source:BOM) and entrance opening condition (data extracted from Council inspection sheets)*

A comparison of dissolved oxygen (DO), daily rainfall and entrance opening condition is shown in Figure 30 as well as the recorded artificial openings during the analysis period. The graph shows that there is significant variation in DO across the analysis period. DO levels tend to be lower during periods of higher rainfall as oxygen depleted water is advocated from the drains and swamps upstream. The periods with the highest DO generally correlate to the estuary entrance being open and low rainfall. Following artificial opening events DO levels generally drop. During this analysis period, DO levels dropped below 1 mg/L following six out of the seven artificial opening events.

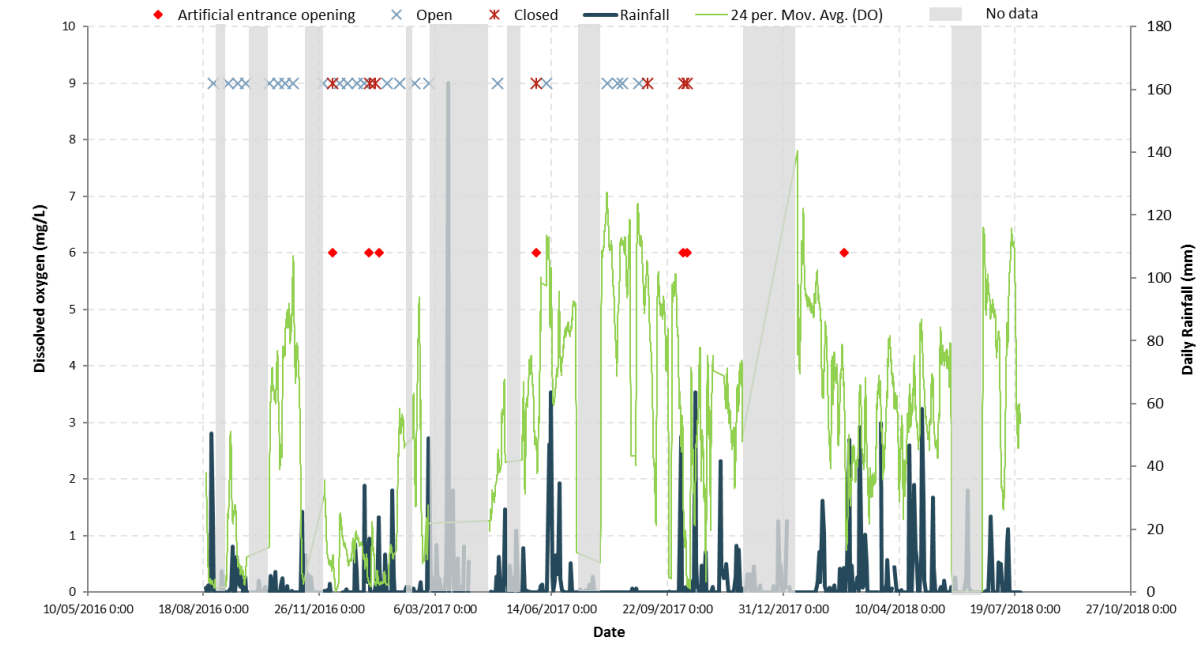

Figure 30. *Moving average of DO (data collected from HANNA multi parameter logger downstream of Ewingsdale Bridge), daily rainfall (Source:BOM) and entrance opening condition (data extracted from Council inspection sheets)*

Summary of water quality trends

From the analysis and the reviewed literature, some key trends with regards to water quality and entrance opening condition can be summarised as follows:

1. Rainfall events and associated catchment runoff generally result in: a reduction in pH, a reduction in DO, a reduction in salinity and an increase in dissolved iron in the estuary regardless of entrance condition
2. An entrance opening event, independent of rainfall, will generally result in: a reduction in pH, a reduction in DO and an increase in dissolved iron in the estuary
3. Following an opening event establishment of tidal conditions in the estuary increases pH, DO and salinity. There is significant variability with this due to varying tides (therefore ability for tidal exchange) and continued rainfall following opening resulting in continual flushing of estuarine waters.
4. Poor quality water (low pH, low DO, high nutrient concentrations, high inorganic nitrogen, and high iron and aluminium) is advected from the drains and swamps upstream following entrance opening
5. If the entrance channel remains open persistent tidal conditions in the system can result in localised groundwater drawdown which may lead to acidic discharge from the organic peat layers into the drains.
6. If the entrance is initially open and there is a significant rainfall event, catchment runoff will have less of an opportunity to be stored in the upper reaches and wetlands. The runoff is likely to have better water quality than if the entrance was closed as there is less residence time within the swamps and drains. The resident water in the estuary is also likely to be of better quality due to regular tidal exchange.
7. Important to note that most entrance opening coincide with significant rainfall events and associated runoff and therefore water quality conditions within the estuary can be associated with catchment runoff and reduced estuary water levels triggering upstream drainage.

6 Ecology

Alluvium consulting has engaged Ecological Service Professionals and Blackwood Ecological Services to undertake an assessment of the ecology of the Belongil Creek. The objective of the ecological assessment was to describe the historical and current condition of aquatic and terrestrial vegetation and fauna communities of Belongil Creek. The ecological assessment report is provided in Attachment A of this report. The key findings from the ecological assessment are outlined below.

6.1 Vegetation communities

The Belongil Creek catchment supports a diversity of vegetation community types typical of low-lying and seasonally inundated coastal areas on the NSW north coast. Major vegetation communities present (generally following Keith, 2006) consist of:

1. Coastal swamp forest dominated by Broad-leaved paperbark
2. Coastal swamp forest dominated by Swamp oak
3. Littoral rainforest
4. Saltmarsh
5. Mangrove swamp
6. Coastal dune mixed scrub

7. Maritime grasslands on coastal dunes
8. Coastal freshwater lagoons

The majority of these vegetation community types are protected as Threatened Ecological Community (TEC) types on the Biodiversity Conservation Act 2016. Smaller areas of Coastal heath swamp and Wallum sand heath occur in the northern part of the catchment. Vegetation communities in the catchment have been subject to varying degrees of disturbance as a result of clearance, drainage, weed invasion, fragmentation and other factors.

Coastal swamp forest dominated by Broad-leaved paperbark
Much of the low lying (Holocene age) Belongil catchment would have been a mosaic of *Melaleuca quinqenervia* forest, freshwater swamps, *Casuarina glauca* forest on slightly higher or more exposed ground, rainforest patches (often with *Melaleuca*) and saltmarsh. Boundaries would have been dynamic over time with shifts due to climate, fire or changes in the hydrology of the stream or other forces (IERM 2005).

Melaleuca quinqenervia forest is the dominant native vegetation community in low-lying areas with minimal saline influence, forming relatively extensive patches in the catchment and grading into freshwater wetland and heathland communities within Tyagarah nature reserve. *Melaleuca quinqenervia* also occurs as individual trees and small patches within grassland in flood-prone areas and localised drainage swales. Swamp mahogany occurs in relatively low numbers within this community with other common secondary species including Pink Euodia, Cabbage palm, Rainbow fern and Phragmites.

Artificial drainage of backswamp areas in the Belongil-Cumbebin system since the early 20th century has increased the hydrologic connectivity between the swamp and the estuary, resulting in a net lowering of ground and surface water levels (Talau, 2002 in IERM 2005). Surface drains reduce the time and spatial extent of ponding in the backswamps during the wet season, by increasing the hydraulic potential to transport water to the estuary (IERM 2005). These factors are likely to have led to Swamp sclerophyll forest on the margins being gradually replaced by “drier” community types.

Figure 31. *Example of coastal swamp forest dominated by Broad-leaved paperbark*

Coastal swamp forest dominated by Swamp oak
Swamp oak forest occurs in close association with *Melaleuca quinqenervia* forest and in relatively monospecific stands. It is most common in slightly drier areas and on drain margins. Some larger patches of

Swamp oak forest occur west of Ewingsdale Road. *Juncus krausii* and Mangrove fern are common understorey species in this community.

Figure 32. *Example of swamp oak forest bordering the estuary*

Littoral rainforest

Littoral rainforest is present on the northern side of the creek entrance. Parker (2013) mapped an area of 1.8ha of this community type. Common species within this community include Tuckeroo, Beach acronychia and Coast banksia. The Threatened species Stinking cryptocarya occurs within this community.

Erosion of the small area of littoral rainforest at the entrance is evident now due to bank undercutting and this process has been ongoing for some time (IERM 2005) see Figure 33.

Figure 33. *Littoral rainforest community in the lower estuary, some bank erosion evident (Photo taken approximately 250 m upstream of the estuary opening)*

Saltmarsh

The saltmarsh in the lower reaches of Belongil Creek (downstream of Ewingsdale Rd) are typically fringed on the Creek side by mangrove communities (dominated by grey and river mangroves) and casuarina forest (Figure 34). Paperbark swamp occurred on the landward side particularly in the lower reaches. The saltmarsh was in good condition and is dominated by sedges (*Juncus krausii* and *Baumea juncea*) and marine couch (*Sporobolous virginicus*) with occasional small patches of sea purslane (*Sesuvium portulacastrum*) and seablite (*Suaeda australis*) and prickly couch (*Zoysia macrantha*) towards the mouth of the estuary and on the dunes. Common reed (*Phragmites australis*) was present further upstream. Many of the saltmarsh areas (those dominated by marine couch, sedges and mangrove fern) assessed by ESP in September 2018 were inundated by approximately 0.2 m of water when the water level measured 1.0 m at the Ewingsdale Rd Bridge. The saltmarsh was well connected to the main creek channel either through directly connected via continuous mangroves or via a variety of smaller channels. There was no runnelling for drainage or substantial evidence of human disturbance to these areas of the lower reaches, although all areas have low relief and elevation, so would be easily flooded at times.

Figure 34. *Example of saltmarsh in Belongil Creek estuary, downstream of Ewingsdale Road, with fringing mangroves (Photo taken approximately 200 m downstream of railway crossing)*

Mangrove forests

The mangrove forests are dominated *by Avicennia marina* (Grey Mangrove) with *Aegiceras corniculatum* (River Mangrove) and are mid-high open to closed (mangrove) forest (Parker 1996). This was confirmed during a site visit by ESP in September 2018. The mangrove fern (*Acrostichum speciosum)* also grows in dense patches landward of the mangrove forest fringing the Creek and in patches within the saltmarsh. There were several shallow areas with recent recruitment of saplings, particularly at the lower end of the estuary on the accreting eastern bank, which demonstrates possible regeneration and stabilisation of habitats, but also possible encroachment of habitat types such as saltmarsh further upstream.

The mangrove forest was assessed as in moderate condition, with some signs of stress in the lower estuary where trees had been inundated for extended periods, including yellowing of leaves, black mould on leaves and extended growth of pneumatophores.

The mangrove forests fringing the estuary are primarily intact patches of habitat that are well connected to the main channel, tidal habitats and surrounding vegetation communities further up the shore (i.e. saltmarsh). There is good access to deeper water channels, which provides good value habitat for a variety of commercial and recreational fish species, particularly as potential nursery habitat.

Figure 35. *Example of dense mangrove forest fringing the main estuary channel (Photo taken approximately 800 m upstream of the entrance opening)*

Coastal dune mixed scrub
Small linear stands of mixed Coastal dune scrub occur along the frontal dune of Belongil Spit as well as north of the creek entrance. Common species include Coast banksia and Coast wattle as well as the introduced Horsetail she-oak and Bitou bush.

Maritime grasslands on coastal dunes
Dune grassland is typically sparse and open on sand seaward of the frontal dune, with Spinifex, Goat's foot convolvulus and Pigface typically grading into Coast wattle thickets further up the dune. Bitou bush is an occasional occurrence.

Coastal freshwater lagoons
More extensive areas of freshwater wetland occur in low lying swales north of Belongil Creek. This community type has also been mapped in the modified wetland system of the West Byron Sewage Treatment Plant (STP).

6.2 Fauna habitats

Closely associated with the distribution of vegetation communities, the Belongil Creek catchment provides the following major habitat types:

1. Freshwater, brackish and estuarine aquatic habitats.
2. Intertidal sandflats and mangrove communities.
3. Saline influenced saltmarsh and rushland communities.
4. Swamp sclerophyll forest dominated by Swamp oak.
5. Swamp sclerophyll forest dominated by Broad-leaved paperbark, including areas with a Cabbage palm and Pink-flowered doughwood midstorey.
6. A 1.8ha patch of littoral rainforest at the creek entrance.

7. Freshwater wetlands.
8. Periodically inundated grasslands.

Parker (1996) provides a discussion on fauna assemblages in the Belongil Creek Estuary, concluding that "the biodiversity of terrestrial fauna within the Belongil-Cumbebin drainage basin is extraordinary". The Belongil system contains a diversity of fauna habitats in relatively close proximity. Drainage in the catchment, changes in land-use and an increase in artificial openings of the creek entrance have favoured some fauna groups whereas the availability of habitat for others has decreased.

The specific habitat resources for key threatened fauna are discussed below.

Amphibians
The Belongil catchment represents relatively good quality habitat for native frogs. Saline influence and past disturbance may limit the suitability of habitats for several species. Areas of Swamp sclerophyll forest provide habitat for a range of tree frog species such as the Dwarf green tree-frog (*Litoria fallax*), Dainty green tree-frog (*Litoria gracilenta*), Green tree-frog (*Litoria caerulea*) and Peron's tree-frog (*Litoria peronii*). Burrowing frogs such as the Scarlet-sided pobblebonk (*Limnodynastes terraereginae*) and Ornate burrowing frog (*L. ornatus*) may also occur.

Habitats in the Cumbebin Swamp, Tyagarah Nature Reserve and wider Belongil catchment provide habitat for acid frogs including the Threatened Wallum sedge-frog (*Litoria olongburensis*) and the Wallum froglet (*Crinia tinnula*).

Frogs that occur in rainforest habitats at higher elevation, such as the barred frogs, are unlikely to occur. Cane toads are relatively common in the area and are likely to occur throughout.

Reptiles
Areas of Swamp sclerophyll forest provide habitat for a range of reptiles and the catchment provides a mosaic of varying habitat types that together provide a diversity of habitat niches for reptiles. Common species include: Green tree snake; Brown tree snake; Carpet python; Red-bellied black snake; Brown snake; Yellow-faced whip snake; Eastern water dragon; Bearded dragon; Lace monitor and several smaller skinks.

Marine turtles are common in coastal waters although nesting events on beaches in the locality are relatively rare.

Birds
However, bird diversity in the Belongil catchment over the course of a year is particularly high due to the close proximity of a variety of habitat types including sand and mudflats, ocean beaches, coastal heathlands, swampland, sclerophyll forest, wetland, open pasture and beachfront.

Nectarivorous birds such as honeyeaters and lorikeets move locally in response to changes in the availability of nectar and or pollen. Extensive areas of *Melaleuca quinquenervia* forest provide a good forage resource for these species when in flower.

Many insectivorous birds from higher latitudes spend winter in the locality visit the catchment seasonally or periodically. These include species such as the Fantail cuckoo, Rainbow bee-eater, Tree martin, Black-faced cuckoo-shrike, Cicada bird, Golden and Rufous whistler, Rose robin, White-throated gerygone, Silvereye, Olive-backed oriole and Spangled drongo.

Birds associated with permanent watercourses and wetland areas such as bitterns, rails and the Bush hen occur in the riparian and swampland margins of Belongil Creek. The catchment does not support a large number of mature trees with large hollows but may provide forage habitat for hollow-nesting birds that occur in areas of Blackbutt forest in the wider locality.

The Threatened Eastern osprey and White-bellied sea-eagle both forage over the Belongil Creek system.

Belongil Creek and the adjacent section of Belongil Beach provide suitable habitat for migratory and resident shorebird species. Although mudflats and sandflats within the Belongil Creek system are not extensive by the standards of most coastal waterways, they are of significance due to the relative lack of similar habitats in the local area and support a relatively high diversity of bird species over the course of a year.

Pied oystercatchers may nest in the dune system close to the Belongil Creek entrance. Little terns have nested in this area in the past and an area of the dunes south of the Belongil Creek entrance is managed as a bird nesting area to encourage future breeding events.

Mammals
A range of mammal species occur in the coastal strip between Tyagarah in the north and Broken Head to the south. Rare mammals that occur in heathland habitats in the locality, such as the Eastern chestnut mouse and the Long-nosed potoroo, may persist within Tyagarah Nature Reserve.

The Swamp wallaby, Short-beaked echidna, Northern brown bandicoot, Brown antechinus and Melomys are all widespread within the Study area. The Common brushtail and Ringtail possum are also common.

Koalas are regularly recorded within areas of suitable habitat in the catchment. Koalas have little reliance on habitats subject to inundation although Swamp mahogany trees are a preferred feed tree and often occur in association with Broad-leaved paperbark.

A diversity of microchiropteran bat species occur in the locality, although roosting habitat in the form of caves and hollow-bearing trees is relatively rare. The Grey-headed and Black flying-fox forage in various vegetation community types during peak flowering and fruiting times. The Common blossom bat is a relatively common occurrence.

6.3 Fish assemblages

The estuary supports a wide range of commercially and recreationally important fisheries species (including oysters, mud crabs, prawns, and fish) and is considered to be an important nursery habitat for juvenile fish (Schnierer 1988; Parker 1998).

The Belongil Creek estuary supports a typical fish community that is dominated by mullet (*Mugilidae*), whiting (*Sillagonidae*), bream (*Sparidae*), flathead (*Platycephalidae*), glassfish (*Ambassidae*) and tailor (*Pomatomidae*), with abundances varying strongly between the summer and winter seasons (Schnierer 1988). Many of the species found in the Belongil Creek estuary are commonly found in the region and neighbouring ICOLL systems such as Tallow Creek (WBM 2001) and are either permanent or temporary residents of the estuary.

A total of 58 species of fish, among which are two members of the pipefish family that are listed species under the Environment Protection and Biodiversity Act (1999), have been recorded from the Belongil Creek estuary. In a survey that included the entrance of the estuary, areas around the Ewingsdale Road bridge and the Union Drain, Schnierer (1988) recorded 52 species of fish occurring in the system. These species include commercially and recreationally important fishery species such as mullet (*Mugilidae*), whiting (*Sillaginidae*), bream and tarwhine (*Sparidae*), luderick (*Kyphosidae*), tailor (*Pomatomidae*) and flathead (*Platycephalide*). A large proportion (88%) of targeted species were juveniles, highlighting the importance of the estuary as a nursery for fish. Approximately a quarter (23%) of the fish species caught were marine species and are typically associated more with inshore reefs and were also recorded at nearby reefs such as Julian Rocks (Parker 1998). Only one exotic species, the mosquitofish (*Gambusia* sp.) has been recorded.

6.4 Estuarine invertebrates

Schnierer (1988) previously studied the composition of benthic organisms (infauna and epifauna) of Belongil Creek at sites between the entrance and the upstream drainage lines. The invertebrate community was typical of estuarine environments in sub-tropical eastern Australia, and was dominated by mollusc, crustacean, polychaete and insect species. The sites closest to the estuary mouth supported the most diverse assemblages. Total abundance of fauna was greatest in summer than in winter.

An assessment of the estuary for commercial and recreationally important fisheries is provided in the subsequent section. Commercially and recreationally important invertebrate species recorded in the Belongil Creek estuary (Schnierer 1988) include:

- Mud crab (*Scylla serrata*)
- Blue swimmer crab (*Portunus armatus*),
- greentail prawn (*Metapenaeus bennettae*),
- Sydney rock oyster (*Saccostrea glomerata* (originally listed as C. commercialis)), and
- Estuarine yabby (*Trypaea australiensis*).

6.5 Fish habitat and fisheries

Fish habitat is defined under the NSW *Fisheries Management Act 1994* as any area occupied, or periodically or occasionally occupied, by fish or marine vegetation (or both), and includes any biotic or abiotic component. This includes the water column, the substrate (such as sand, mud, cobbles or reef) and other features submerged by water which are used by fish to shelter, access food (such as aquatic vegetation and algae), to breed and which provide territorial markers for migration (NSW DPI 2013). Fisheries NSW are responsible for ensuring no net loss of key fish habitats.

Key mapped fish habitat in the study area of the Belongil Creek between the entrance and the Ewingsdale Road bridge includes:

1. open oceanic water, defined as extending from the intertidal zone to the oceans. This includes a range of habitats such as the water column, the continental shelf, beaches, rocky and coral reefs and seamounts. In the study area, this includes the beaches north and south of the creek entrance.
2. coastal lagoons and wetlands, a large open body of saline or brackish water which has a relatively narrow permanent or intermittent connection to the sea. Many coastal lakes and lagoons alternate between being open or closed to the ocean. These are known as Intermittently Closed and Open Lakes and Lagoons (ICOLLs).
3. estuarine wetlands: estuarine fish habitats where fresh water from rivers and streams mixes with the salty ocean water. This brackish water environment supports a variety of fish habitats, including mangroves, sandflats and deep pools. Estuaries provide important feeding, spawning and nursery sites for many aquatic animals. Many invertebrate (crabs and mosquitoes) and vertebrate groups (fish) rely on estuarine water to complete their life cycles and others, such as migratory shore birds, visit estuaries to feed and rest.

The majority of the fish habitat in the Belongil Creek catchment consists of estuarine and coastal wetlands that encompass the creek and drains themselves, and the surrounding low lying areas. The entrance of the creek and the coastal beaches are zoned as oceanic. Only a very small section of coastal lagoon is mapped to the east of the Belongil Creek entrance. The key fish habitat areas mapped within the Belongil Creek catchment are shown in Figure 36.

No commercial fisheries (for species such as rock oysters, mud crab, whiting or mullet, etc) exist in the Belongil Creek estuary. Recreational fishing is not allowed in the Belongil Creek estuary as it is zoned as a Special Purpose Zone in the Cape Byron Marine Park (Figure 37).

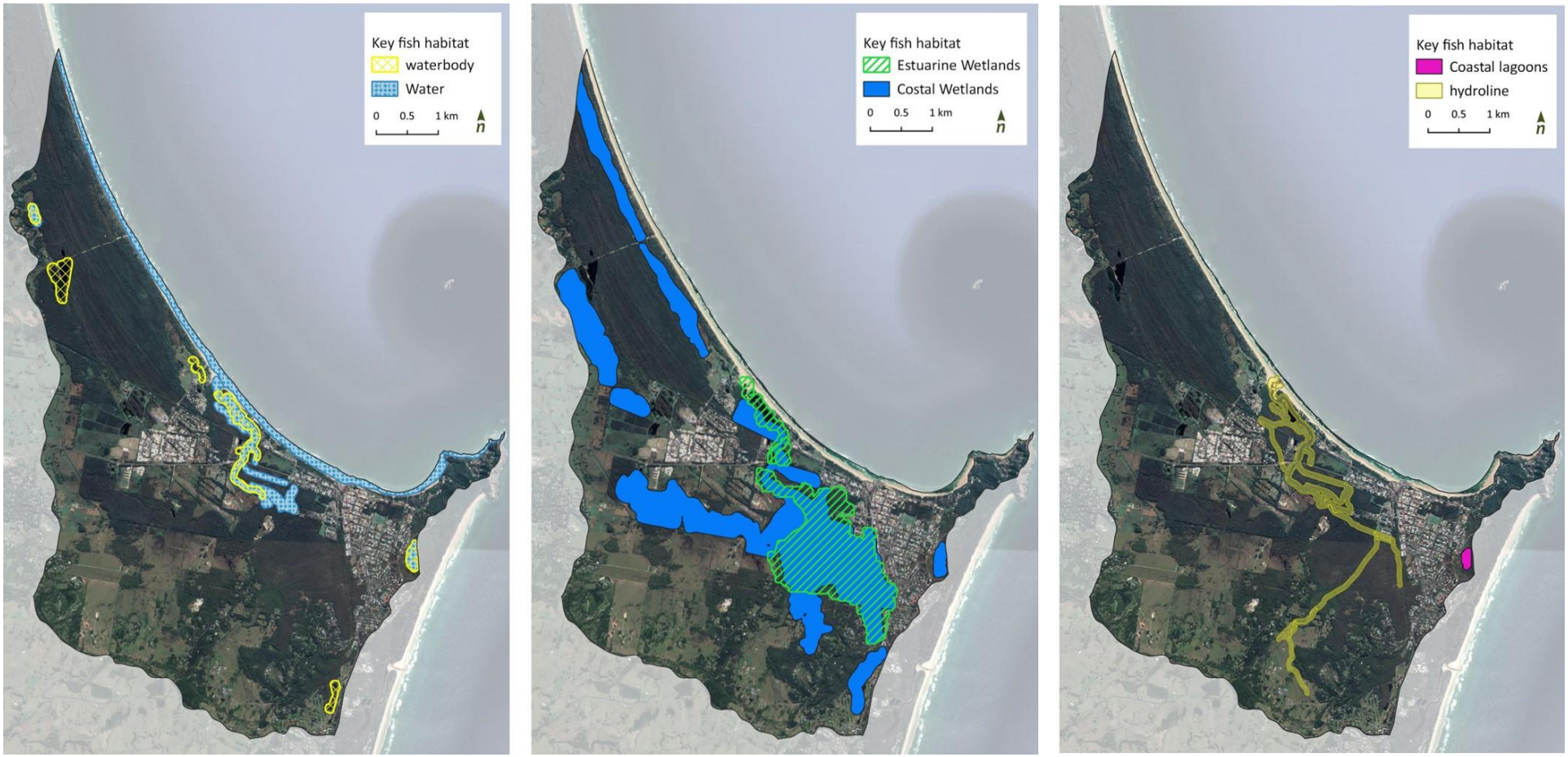

Figure 36. *Key Fish Habitat areas mapped in the Belongil Creek catchment*

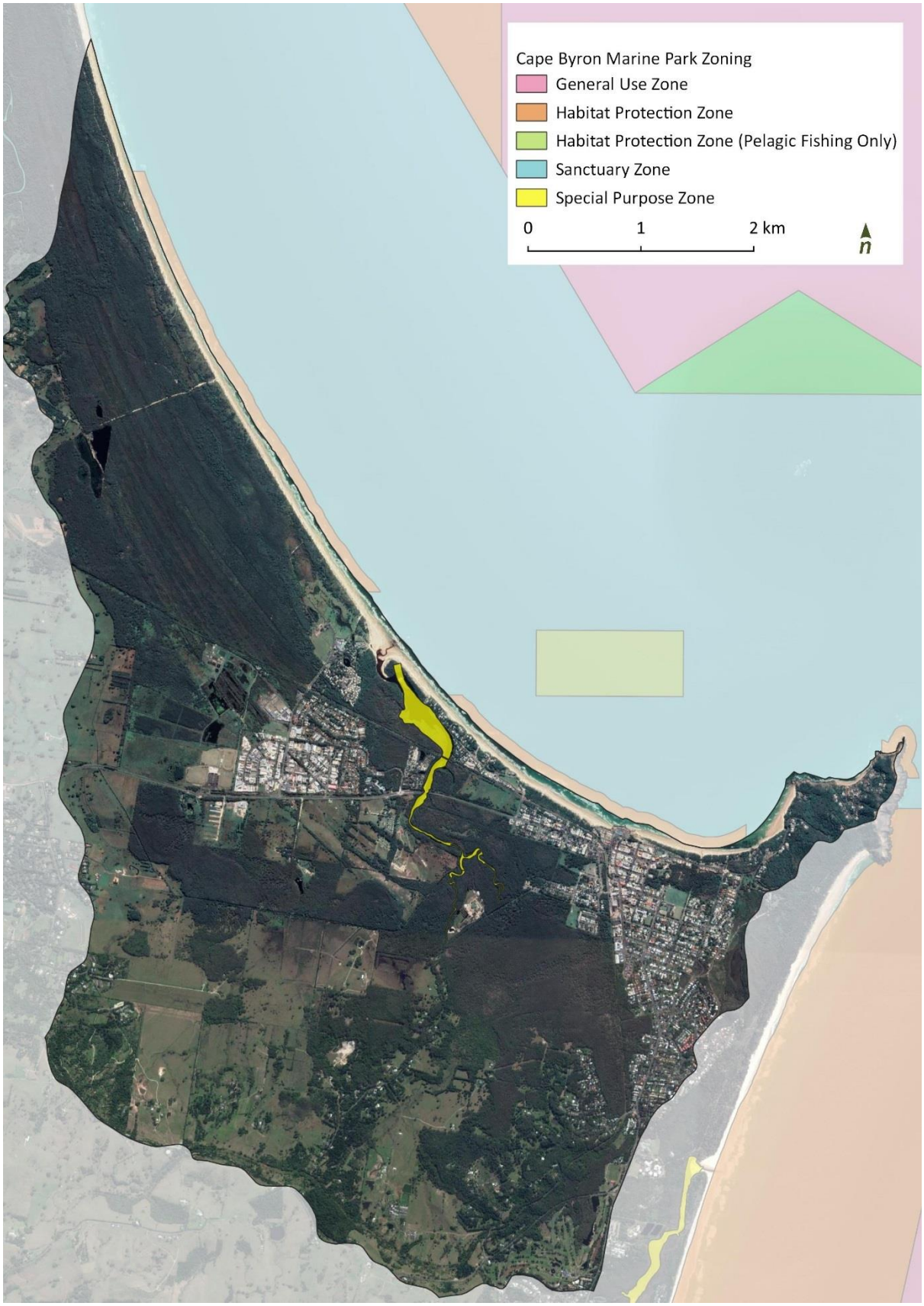

Figure 37. *Cape Byron Marine Park Zoning*

7 Entrance management process and associated issues

7.1 The artificial entrance opening process

Historically, the entrance to Belongil Creek has been artificially opened in response to requests from property owners. However, in recent decades, the entrance has been artificially opened once the water level at a recorder on Ewingsdale Bridge reaches a designated "Trigger" level. That trigger level was set at 1.2m AHD but was lowered to 1.0m AHD in 2001.

Also prior to 2001, the entrance was usually opened during flood or heavy weather conditions, without consideration of the stage of the tide. Since then, opening is typically undertaken on a falling or low tide, which has the effect of reducing the amount of water exiting the system during a breach and the rate at which this discharge occurs.

Artificial opening is achieved using an excavator to dig a pilot channel around 2 m wide across the closed beach barrier. Overall, the present procedure aims to dig a deeper pilot channel than historically, to encourage more rapid development of a viable scour channel. Council's draft Entrance Opening Strategy (Byron Shire Council, 2005) did not discuss the required depth of the channel, but recommended that the channel be "slightly shallower" during the dry season, such that estuary water levels were only slightly lowered. As part of the Estuary Study (Peter Parker Environmental Consultants Pty Ltd, 2001) it was further suggested that opening should occur during neap tides to avoid rapid drainage that could occur during an ebbing spring tide.

Prior to 2001, the location for the pilot channel was a "matter of judgement" (Byron Shire Council, 2005). However, the appropriateness of different locations is subject to constraints. To the south of the entrance, an area of protected bird habitat exists, and it is desirable to keep machinery and the channel a reasonable distance from that area. To the north, there are known problems with erosion adjacent to the Elements Resort and, should the channel migrate across the compartment to the north, that foreshore becomes exposed. Ultimately, present practice represents a compromise between these two factors and as a condition of the current interim licence, the channel is to be dug around halfway between the protected bird habitat and the eroding foreshore of the resort.

Prior to 2001, the entrance channel was oriented towards the south east, with the aim being to maximise the time the entrance was open and to allow the channel to "swing northwards around the beach and close"(Byron Shire Council, 2005). Present practice aims to dig the channel with a more shore normal orientation (see, for example, Figure 40) to minimise the potential for alongshore transport to be captured by the entrance.

Finally, the draft entrance management strategy refers to collecting a range of useful data in relation to each breach event including:

1. Length and location of the excavated channel
2. Ocean conditions
3. Rainfall
4. Time to develop the break-out conditions
5. Date of closure (including gauge height)

This information would be very useful to the present assessment, however this is not available.

7.2 Historic and existing management responses

Records on entrance management before the last two decades are limited. WP Geomarine (1997) reported that the entrance was opened "on average, every two to 3 weeks" and that opening of the entrance resulted in a "block of sand 3 metres deep and 4 metres wide". Both the frequency and amount of sand excavated here seem excessive given more recent records. In comparison, Byron Shire Council (2005) reported that the

entrance was opened “at least once a year” over a period of at least 20 years. Other references indicate that opening has been occurring for a much longer time.

With more careful recording over recent years, information on entrance opening events is available (Australian Wetlands Consulting, 2018; Byron Shire Council, 2005). The count of opening events from year to year since 1997 is shown in Figure 38. There is an apparent reduction in opening frequency since 2006. AWC and BMT WBM (2016) have claimed that this is related to the additional discharge from the West Byron STP since that time although they state that it may not be wholly attributable to an increase in flows from the STP.

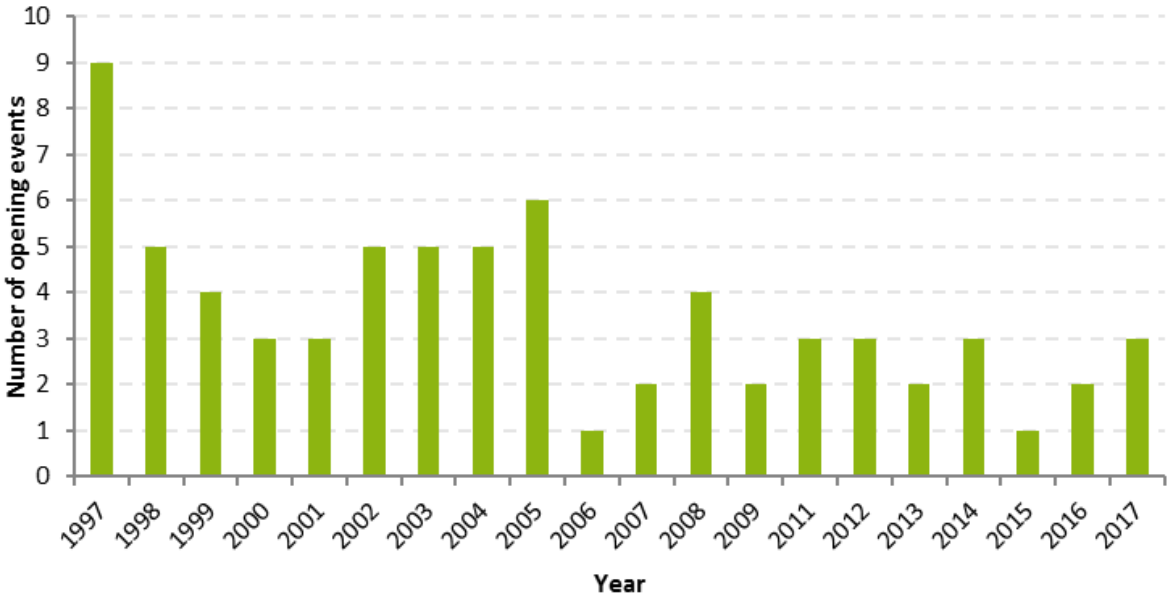

Figure 38 *Belongil Creek Count of Entrance Opening Events (1997-2017)*

Under the present management regime, as recommended by the Estuary Management Plan (Peter Parker Environmental Consultants Pty Ltd, 2001) the aim is to keep the estuary “open continuously” and for the water level to not exceed 1.0 m AHD at the Ewingsdale Bridge. However, the plan dictates that, during the dry period of the year, the Estuary is to be opened only if follow up rainfall is expected, unless “poor water quality” exists, although there is no quantitative guidance provided on what would constitute poor water quality.

As part of the Estuary Management Plan, the lowering of the trigger level was considered “interim”, subject to the monitoring of water quality, entrance width and time of opening and the trialling of drop boards which could be manipulated to separate areas of problematic acid drainage from the estuary to help keep acid sulfate soils inundated and to prevent the movement of poor water quality water into the estuary following breaching events. The call for the investigation of means for decoupling the catchment from the estuary has subsequently been repeated (BMT WBM, 2007; Byron Shire Council, 2005)[3]. However, this has not taken place.

A process for deciding whether to open the entrance to Belongil Creek was presented in the draft entrance opening strategy and this is replicated in Figure 39. However, at the time the draft strategy was published, no quantitative water quality nor ecological triggers were provided, meaning that decisions have typically been based on water levels.

[3] Some of the monitoring reports provided by AWC and Geolink to Byron Shire Council in the Past decade also repeat these recommendations.

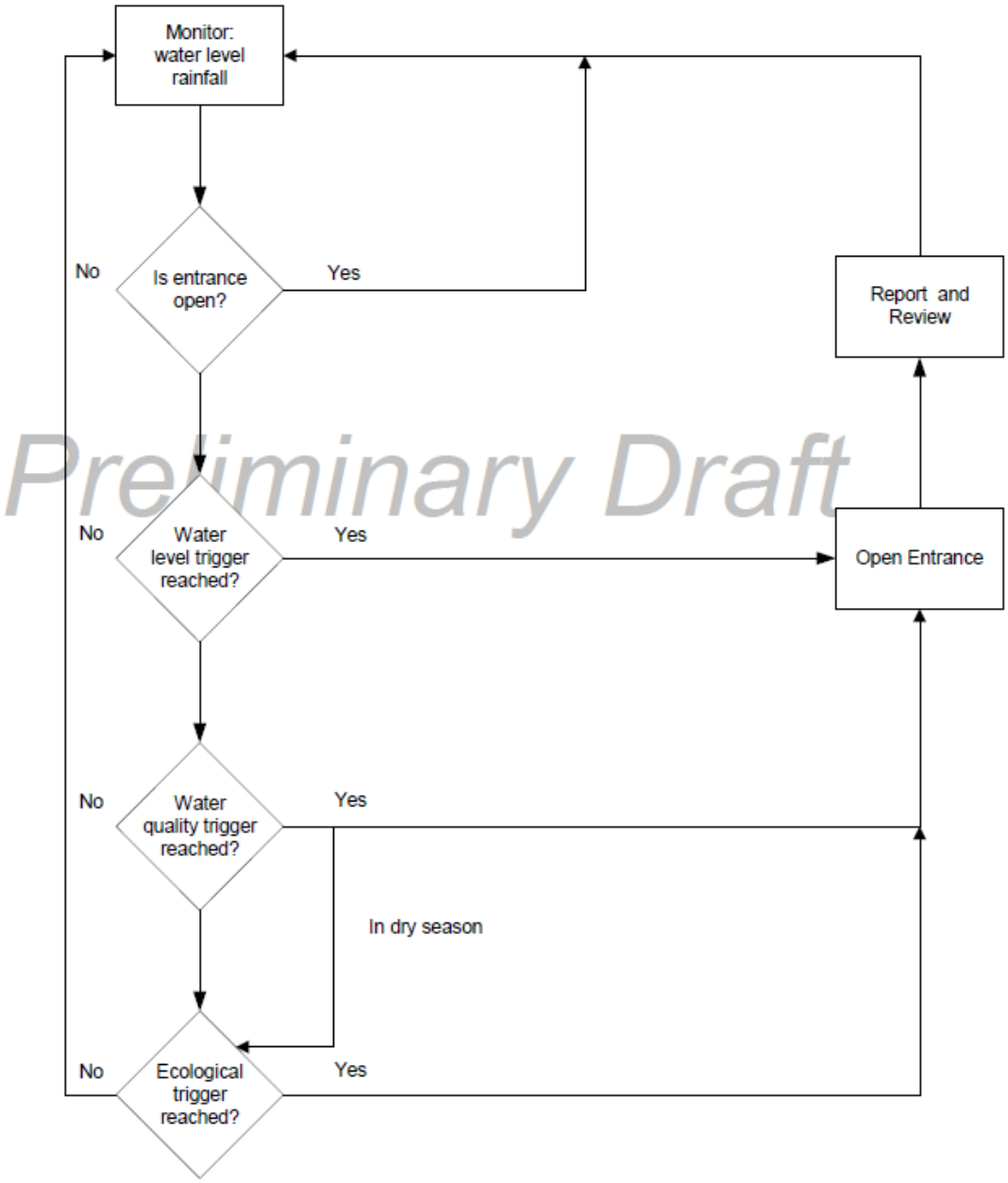

Figure 39 *Decision making flow chart for Belongil Creek entrance opening (Byron Shire Council, 2005).*

Current licence

Currently, the artificial opening of the Belongil Creek estuary entrance is conducted under a conditional interim licence issued by the Department of Primary Industries, administered under the Crown Lands Act 1989 – Section 34. The execution date of this licence was the 7/12/2012 and it expires 10 years from commencement on the 7/12/2022 unless otherwise revoked by the minister (*Licence, Crown Lands Act 1989, 2012*). The major requirements under the licence are as follows:

1. All works be undertaken in accordance with the Belongil Creek estuary Study and Management Plan (2001) and the environmental assessment submitted with the Licence Application. The entrance opening shall be excavated between the south east corner of Lot 10 DP 243218 (denoted A in Figure 40) and the northern extent of the 7(j) Scientific Zone (denoted B in Figure 40) (Schedule 2, item 54);

2. Artificial entrance opening shall only occur when the water level of Belongil Creek reaches or exceeds 1.0 metres AHD measured on the Ewingsdale Road Bridge gauge (Schedule 2, item 55);

3. An Entrance Management Strategy be developed that incorporates catchment remediation strategies (including native vegetation regeneration, effluent management, ASS runoff reduction and stormwater management strategies) as well as factors that address issues raised through monitoring prior to, during and after the opening of the estuary (Schedule 2, item 56);

4. Prior to entrance opening works taking place, the Council notifies officers of Land and Property Management Authority (Grafton), Department of Environment and Climate Change – Coast and Estuaries (Alstonville) and NSW Fisheries (Schedule 2, item 57);

5. Entrance opening works shall recognise the presence of threatened species (e.g. Little Terns) utilising the entrance area and avoid any disturbance to their activities;

6. During the period of this Licence, Council shall maintain an entrance opening record, including opening events – time, state of tide, location and width of opening channel, water level drawdown and duration of an 'open' and 'closed' entrance, water quality monitoring before during and after opening events, and assessment of adjoining wetland communities (using rapid wetland assessment technique) to determine possible shifts in community structure, health and biological diversity resulting from the lower water level opening trigger (Schedule 2, item 59)

7. Repair of damage to access locations as a result of the excavator (Schedule 2, item 60).

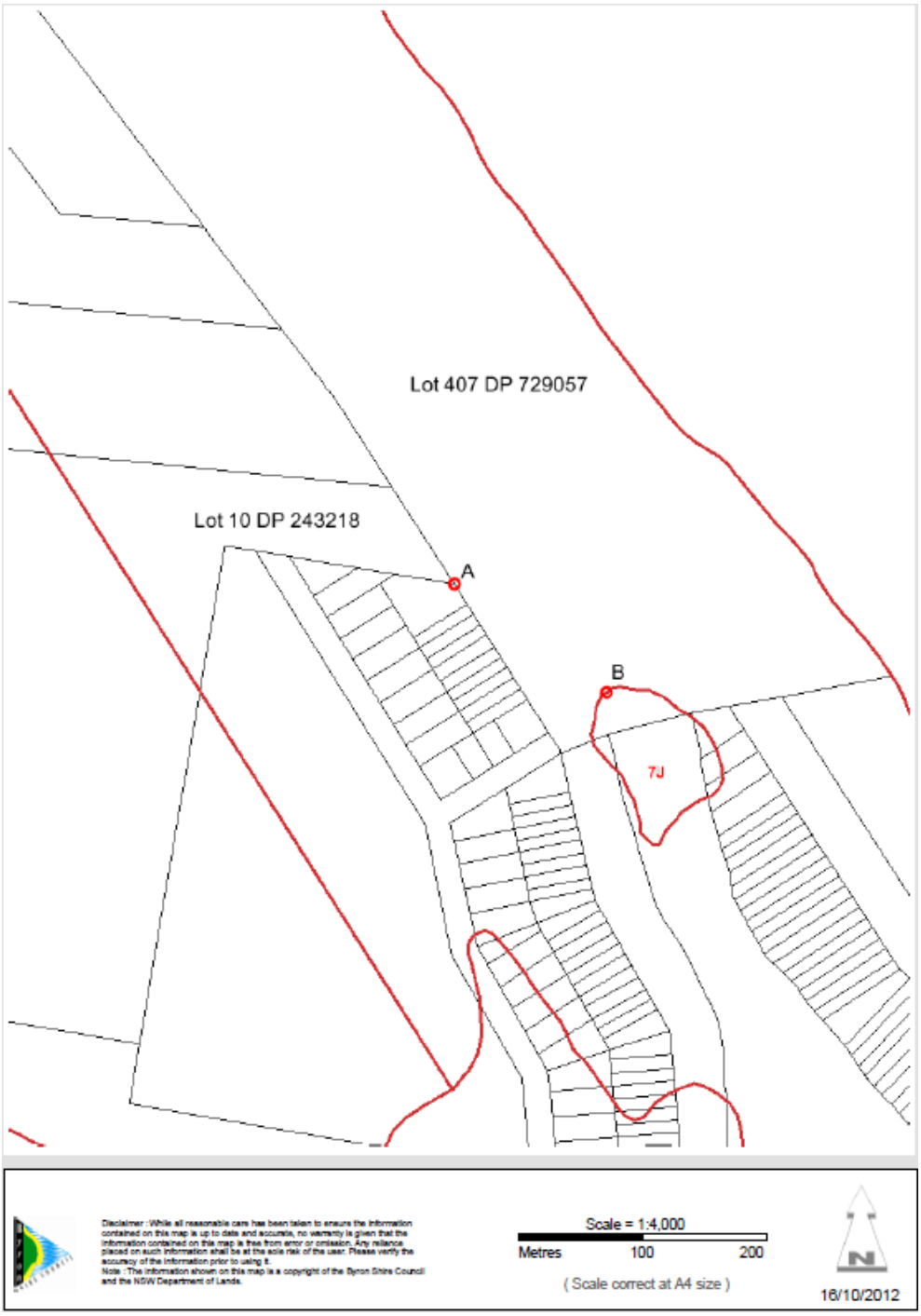

Figure 40. *Allowable mechanical entrance opening location (Source: Licence, Crown Lands Act 1989, 2012)*

7.3 Issues influencing entrance management decisions

Managing water quality: entrance manipulation vs. catchment activities

It is generally accepted now that manipulation of coastal entrances is, in most situations, not the most economical way of managing water quality within estuaries. This is particularly true in intermittent estuaries, where the concept of what "good" water quality means does not necessarily match the wide range of conditions that could be experienced naturally in a pristine system (Scanes et al., 2014, 2011). BMT WBM (2007) was particularly critical of one stated principle of the estuary management plan:

"to ensure that the estuary mouth is opened in such a way as to maintain the health and vigour of riparian vegetation, the biodiversity of aquatic organisms and meet the EPA water quality standards (i.e. protects aquatic ecosystems and allows safe swimming in the estuary)."

BMT WBM believed that this should be revisited. They produce compelling evidence in support of this noting that

1. Regardless of the entrance condition, rainfall will reduce pH, reduce dissolved oxygen and increase dissolved iron in the estuary.
2. Regardless of rainfall conditions, an entrance opening will reduce pH, reduce dissolved oxygen and increase dissolved iron in the estuary.

In combination, these points strongly suggest that the key process which causes water quality to deteriorate in the estuary is the movement of poor quality water from the catchment into the estuary. This can result from either opening of the entrance or rainfall on the catchment.

BMT WBM do note that, with more frequent opening events, water quality in the catchment will have a lesser chance to accumulate and deteriorate before being drawn into the estuary. Conversely, they note that an entrance that is open longer could induce consistently elevated tidal conditions within the drains, a situation which has the potential to cycle groundwater levels causing repeated recharge and discharge of acid sulfate bearing soils and enabling intermittent oxidation and transport of the resulting acid by the groundwater. The situation is complex and deserves more investigation.

It is for this reason that hydraulic decoupling of upper catchment from the estuary has been repeatedly recommended. Regardless, such a strategy needs to be approached with care.

The relative absence of fish kills since the entrance trigger level was lowered to 1.0m AHD is a consideration. Based on monitoring between 1995 and 1999 there were extensive fish kills associated with poor water quality in the Estuary (Byron Shire Council, 2005). While the occurrence of fish kills has reduced significantly, poor water quality continues to be recorded.

Entrance morphology and breach efficiency
There are two broad issues addressed here:

i. the presence of an eroding foreshore against the northern side of the entrance, and
ii. management of the entrance in a manner which controls the rate at which the estuary water level drops.

The stability of the creek entrance was listed as one of the high priority environmental issues by the Estuary Processes Study (WP Geomarine, 1997). However, their analysis of aerial photography demonstrated that there had been minimal change, in the past half century, to the path which the creek takes to the ocean, except at the immediate entrance. Therefore, stability at the immediate entrance is the issue of main concern.

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. The estuary study (Peter Parker Environmental Consultants Pty Ltd, 2001) claimed that more than 15 m of creek frontage had been eroded from that area. More recently, a revetment constructed from sand filled geotextile bags has been used to protect against erosion in this location (Figure 41).

A “tripper wall”, or moderate training structure which remains buried under sand for much of the time has been suggested as a means for addressing this issue and this will be assessed further as part of this project.

Figure 41 *Entrance to Belongil Creek 18 July 2018 looking upstream. Arrow shows the location of protective works*

At present the entrance is manipulated in a way which attempts to minimise the amount of water drained from the system and hence the harmful effects of acid drainage from the upper catchment. The Estuary management study recommended opening soon after the natural closure of the entrance with a view to reducing the "rapid flush-out effect" (Peter Parker Environmental Consultants Pty Ltd, 2001). BMT WBM (2007) indicated that flood risk management was a significant concern and that managing the water level below 1.2m AHD was also important. BMT WBM also contradicted the findings of Integrated Ecosystem Research and Management (2005), who implied that lowering the trigger level from 1.2 m to 1.0 m was significant. BMT WBM argued that, given the natural range of water levels likely extended much higher (~ 2.6 m AHD barrier) that lowering the trigger to 1.0 m would have only a marginal effect on ecological processes.

However, with regards to this lowering, it is worthwhile to consider the findings of Wainwright (2013) who found that an increase of around 0.13 m (1.17 m AHD, c.f. 1.04 m AHD) at Lake Tabourie, would increase the volume scoured from the entrance (by 10%) and increase the depth of the scoured channel. A larger scoured entrance channel takes longer to infill because of coastal sediment transport and will tend to remain open for longer.

Somewhat conversely, BMT WBM recommended that the Belongil Creek entrance be used as a "Water Control Structure" (BMT WBM, 2007) to hold waters back and maximise the inundation of acid sulfate soils within the upper floodplain, at least in the short term. Their ultimate recommendation is to use structures in the drainage systems in the upper catchment to keep the water levels elevated.

BMT WBM also recommended that the amount of entrance scour should be minimised. Their analysis showed that the development of significant tidal exchanges occurred after opening events that were followed by significant rainfall in the subsequent week. In other words, an effective entrance and persistent entrance channel is not formed when breached at RL 1.0m AHD unless there is follow up rainfall. BMT WBM recommend that Council wait until the rainstorm is finished and there is no forecast rainfall before opening.

Such an approach could well cause problems from a flood risk management perspective. Furthermore, as 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.

Impact of sea level rise
Ongoing sea-level rise will have an impact on the way Council manages the entrance in the future. There are significant unknowns relating to how the system will evolve.

Firstly, there is uncertainty regarding how Belongil Spit will evolve in response to coastal processes and future sea level rise. Much will depend on how much the coastal side of the spit continues to erode, and whether recession of this barrier and changes to the coastal wave climate affect the rate at which sand is supplied alongshore to the northern end of the spit and the entrance compartment.

WP Geomarine (1997) considered that the mouth may be more prone to remaining open as it evolves in response to these processes but, alternatively, that this tendency may be buffered by an inherent dynamic equilibrium in the system.

Of more certainty is that the entrance barrier, regardless of its location, and water level conditions inside the entrance will tend to rise, on par, with the rise of mean sea level. As noted by BMT WBM (2007) there will be a need to progressively adapt the entrance breakout range as sea levels rise. In conjunction with this, there will be a need to remove or control flows in the artificial drains in the upper catchment as their frequency of inundation will change. Similarly, adaptation of infrastructure and property which will be exposed to intolerable flooding risk because of sea level rise will need to be considered.

Which trigger level?
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. Towards the end of the 1990's in conjunction with a growing awareness of the issues associated with acid sulfate soils and their attendant water quality problems – the nature of poor water quality and fish kills in the Belongil Creek estuary began to be understood.

To mitigate against the effects of acid drainage, the trigger level was lowered to 1.0 m AHD. This level is very low, noting that an estuarine barrier at this level can be overtopped by large, purely astronomical tides. With ongoing sea-level rise, it is inevitable that the trigger level will need to be raised again as entrance management will become increasingly impractical.

Integrated Ecosystem Research and Management (2005) were critical of the initial decision to lower the trigger level, considering that there was no conclusive evidence that this would be beneficial with regards to fish kills. While data on fish kills from the last 20 years seems to have shown that there has indeed been a benefit, there was also a significant increase in the discharge of treated effluent from the West Byron STP from 2005 onwards, and this may have also improved the nature of acid drainage from the area surrounding the Union Drain by raising the water table and keeping potentially acid sulfate soils waterlogged.

Integrated Ecosystem Research and Management's (2005) analysis drew a somewhat unfair comparison between what the "natural" state of the estuary would have been and how much it has changed in criticising further lowering of the trigger level. As noted by BMT WBM, the Belongil Creek estuary is:

> *"a highly modified system artificially manipulated for many years and thus a return to natural conditions is not likely"*

And further, that:

> *"the change in artificial breakout level […from 1.2 to 1.0m AHD…] is unlikely to have any significant repercussions on the behaviour of the Belongil Creek Estuary. While there may be some minor modifications to some of the biophysical processes, it is considered that the water quality of Belongil Creek would essentially remain the same, and continue to be dominated by catchment inputs"*

We expect that the issue of flooding within Byron Bay is likely to overtake water quality as the driving reason behind entrance management and that maintaining water levels below 1.2m at Ewingsdale Bridge is going to become increasingly difficult as sea levels rise. The trigger level will need to rise and the

estuary opening strategy will need to have flexibility inbuilt to allow this. It is not realistic to believe that the entrance can continue to be managed at 1.0 m as it is presently into the medium-term future.

Minor and inexpensive manipulation of the entrance is highly unlikely to prevent increasing inundation within the upper catchment and activities such as raising infrastructure and property or isolating the acid generating areas of the upper catchment will most likely be required as part of a broader strategy.

Education the community about this complex issue will be important. As part of community consultation for the estuary study (Peter Parker Environmental Consultants Pty Ltd, 2001) the view was advanced by the community members that:

> *"is considered that waiting for the estuary to reach this level [1.2m AHD] is damaging to the ecological health of the estuary. A height of 1.2 m AHD results in the inundation of subtidal biological communities for too long a time period, the accumulation of poor quality water in the estuary and the inevitability of large flush-out effects from large volumes of water rushing across the entrance"*

Although the statement is true in some respects, the situation is more complex and will require some innovation to manage with rising sea-levels. Regardless, returning to a higher trigger level may prove very difficult to sell to the community, early planning, careful consultation and plenty of lead time will be required. We note also that there are ongoing concerns with the management of the adjacent Tallow Creek relating to water quality and fish kills where the water level is managed at around 2.2m AHD.

8 NSW legislation

Estuarine and coastal management context
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.

A condition of the licence requires that the council make progress on the development of a long-term entrance opening strategy, this process is managed by the Belongil Creek estuary Working Group which was appointed by Council. A draft opening strategy was prepared in 2005 and reviewed by IERM in 2005. The review makes several short-term recommendations, with the expectation that a future 'whole of catchment plan' would necessarily coordinate a holistic and integrated response to the complexity of the issue.

Since the review, the estuary has been mechanically opened as per the conditions of the licence and little progress has been made on the development of an overarching strategy. The recent coastal reforms however provide the suitable legislative environment for the development of a 'whole of catchment plan' and an integrated estuary opening strategy through the development of integrated Coastal Management Programs.

This policy reform has established a new strategic framework and objectives for the management of coastal issues in NSW. The new Coastal Management (CM) Act 2016 replaces the Coastal Protection Act 1979 and promotes strategic and integrated development of the coast under the principles of ecologically sustainable development (ESD). These principles include:

1. ***Precautionary principle****: Where there are threats of serious or irreversible environmental damage, lack of full scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation*
2. ***Intergenerational equity****: the present generation should ensure that the health, diversity and productivity of the environment is maintained or enhanced for the benefit of future generations.*
3. ***Conservation of Biological diversity****: conservation of biological diversity and ecological integrity should be a fundamental consideration.*
4. ***Improved valuation and pricing of environmental resources:*** *environmental factors should be included in the valuation of assets and services*

The 2007 technical review of the 2005 Draft Opening Strategy by WBM identified that the proposal of the lower breakout trigger level to be contrary to the precautionary principle. The basis was that the shift of the lower limit could cause irreversible environmental damage through the additional drainage and associated oxidation of ASS and acidic runoff into the estuary.

The CM Act 2016 introduces the Coastal Management Program (CMP) into the statutory land use planning framework for NSW. The CMP replaces Coastal Zone Management Plans and is intended to 'set the long-term strategy for the co-ordinated management of land within the coastal zone'. Council intends to develop a CMP for the western precincts of the Byron Bay Embayment, including Belongil beach. It is assumed that the Belongil Creek estuary opening strategy will support the objects of the CM Act 2016 and will nest within the overall strategy of the forthcoming CMP.

Overall statutory context
The 2005 Draft Belongil Creek Estuary Opening Strategy provides a good overview of the statutory context. Table 4 builds on this work by adding the relevant changes which have been made since the draft was written.

Table 4. Relevant Acts/planning instruments major objectives and goals and its application to the EOS

Act/Planning instrument	Objects and Goals	Application to EOS
Crown Land Management Act 2016	The *Crown Land Management Act 2016* (CLM act) came into effect on July 2018 and covers the management of Crown Land. Section 1.4 details the principles of Crown Land Management. These are: - (a) that environmental protection principles be observed in relation to the management and administration of Crown land, and - (b) that the natural resources of Crown land (including water, soil, flora, fauna and scenic quality) be conserved wherever possible, and - (c) that public use and enjoyment of appropriate Crown land be encouraged, and - (d) that, where appropriate, multiple use of Crown land be encouraged, and - (e) that, where appropriate, Crown land should be used and managed in such a way that both the land and its resources are sustained in perpetuity, and - (f) that Crown land be occupied, used, sold, leased, licenced or otherwise dealt with in the best interests of the State consistent with the above principles.	Recent reforms in coastal and Crown lands legislation are aimed to improve the way the State and the local government manage and develop the coast so that legacy issues are considered with new coastal use and development proposals. The changes increase sensitivity to the management of threats to key physical and ecological processes that support marine biodiversity, beach cleanliness and estuary health for the benefit of the public. Under the Act, Crown land will now be managed as if it were public land under the Local Government 1993 Act. This means that councils will be required to have plans of management in place for that land. A transition period of 3 years is given to councils. Part 5 Division 5.6 of the Act covers licences that authorise the use or occupation of Crown land. The entrance of Belongil Creek where entrance opening activities occur is vacant Crown Land described as: Lot 407 729057 Parish of Byron, County of Rous.
NSW Environmental Planning and Assessment Act, 1979	This Act provides the statutory framework for environmental planning in NSW. It integrates the planning of land use and natural resource development activities with measures for the assessment of impacts to the environment. The objects of the Act encourage: - The proper management development and conservation of natural and human resources - The orderly use of land - The provision of services; and	It is likely that the Entrance opening activity will require assessment under Part 4 or 5 of the Act. Part 4 deals with council consent for developments on land covered by a Local Environmental Plan (LEP), and Part 5 deals with developments that do not require development consent under Part 4 but need approval of a Minister or public authority. If a proposal requires development consent under Part 4 of the EP&A Act, then a development application must be lodged with the consent authority (Council) along with a report that addresses the environmental impacts of the proposal. This report either takes the form of a Statement of Environmental Effects or an Environmental Impact Statement for designated developments.

Act/Planning instrument	Objects and Goals	Application to EOS
	- The protection of the environment Recent changes to the Act aim to streamline the planning and approvals process. The changes allow for 'consent conditions to become dormant once equivalent conditions are included on other approvals or licences, like an environment protection licence. Responsibility for enforcing these conditions will then lie with the government agency who issued this other approval or licence' (DPE 2017)	If a proposal does not require development consent, then its environmental impacts must be assessed under Part 5 of the EP&A Act. When Council applied for a licence to open the estuary under the Crown Lands Act, 1989, the DLWC (now abolished) in consultation with relevant agencies undertook a part 5 assessment under the EP&A Act. This assessment was sufficient to grant the interim licence on 9 Aug 2001. EP&A Act is supplemented by a suite of revised Environmental Planning Instruments (EPIs), namely State Environmental Planning Policies (SEPPs), Regional Environmental Plans (REPs) and Local Environmental Plans (LEPs). The EPIs made under the EP&A Act 1979 that are relevant to the artificial opening of Belongil Creek are: Coastal Management SEPP, Infrastructure SEPP 2007 the Byron Local Environmental Plan 2014
Water Management Act, 2000	The *Water Management Act, 2000* came into effect on 1 January 2001 and provides for the integrated and sustainable management of all the State's waters including groundwater, riverine, estuarine and coastal waters to the three nautical mile limit. The principles and objectives of the *Water Management Act, 2000* provide for: - improved environmental health of the State's waters; - shared government and community responsibilities; and - greater economic and social benefits for individuals and communities.	Section 6 of the Act provides for a State Water Management Outcomes Plan (SWMOP) to detail state-wide over-arching policy and strategic outcomes for the management of the State's waters. The SWMOP sets long term outcomes which relate to estuaries and coastal waters and the following specifically to openings of coastal lagoons: - Primary ecological production maintained or improved - Degraded wetlands improved and significant wetlands protected and restored - Diversity and abundance of native aquatic animals and plants protected and restored
Fisheries Management Act, 1994	The objective of the *Fisheries Management Act 1994* is to conserve develop and share the fishery resources of the State for the benefit of present and future generations. In particular the Act aims to: - *conserve fish stocks and key fish habitats;* - *conserve threaten species, populations and ecological communities of fish and marine vegetation; and* - *promote ecologically sustainable development, including the conservation of biological diversity.*	Division 3 of the Act covers dredging and land reclamation. Dredging means work that involves excavating or removal of material from land permanently or intermittently submerged by water. This would cover Belongil Creek entrance opening activities. Dredging requires an authority permit issued by the Minister for Fisheries unless the work is authorised: - under the Crown Lands Act, 1989; or - by a relevant public authority (other than a local council).

Act/Planning instrument	Objects and Goals	Application to EOS
	The Act gives NSW Fisheries powers to regulate a range of activities that are potentially damaging to fish and fish habitat. These activities include dredging and reclamation, damage to mangroves, seagrasses and other marine vegetation, release or importation of fish, commercial and scientific collection of marine vegetation, commercial tourist activities in aquatic reserves.	In the case where a public authority proposes or authorises dredging work, then NSW Fisheries must be notified of the proposed work and any matters raised by NSW Fisheries must be considered in authorising the proposed work. NSW Fisheries has a policy for management of ICOLLs. As well as general policies for the conservation of fish, marine vegetation and aquatic habitats the following policies apply specifically to the management of ICOLLs: - NSW Fisheries supports minimum interference of estuarine lagoon barriers and natural processes being allowed to operate to the greatest extent possible; - NSW Fisheries will not support the artificial opening of a lagoon where there is little threat to public health or safety from flooding or water quality deterioration; NSW Fisheries supports using the estuary management planning process to analyse the issues relating to opening a particular lagoon, and to reaching consensus about when and under what conditions it can be artificially opened. Proposals for artificial openings, which are to be carried out according to the guidelines set down in a management plan, will be routinely approved.
Marine Estate Management Act 2014	The objective of the *Marine Estate Management Act 2014* is to provide for the management of the marine estate of NSW consistent with the principles of ecologically sustainable development. In particular the act aims to: - (a) promote biologically diverse, healthy and productive marine estate, and facilitate: o economic opportunities for the people of New South Wales, including opportunities for regional communities, and o the cultural, social and recreational use of the marine estate, and o the maintenance of ecosystem integrity, and o the use of the marine estate for scientific research and education,	Entrance opening activities for Belongil Creek occur within the Cape Byron Marine Park and approval to undertake the activities require consideration of: - *the objects of the Marine Parks Act, 1997;* - *the zoning plan for the park;* - *permissible uses of the area concerned;* - *and the concurrence of the relevant Ministers under the Act.* The *Marine Estate Management Act 2014* specifies the approvals required for development within a marine park (Part 5, Division 6, Section 55) Any development or works within a marine park require the consent authority or determining authority to obtain concurrence from the relevant Ministers (i.e. the Minister for Primary Industries and the Minister for the Environment). Similarly, a Minister (who is a determining Authority) must consult the relevant Ministers before granting approval. In each case, the objects of the *Marine Estate*

Act/Planning instrument	Objects and Goals	Application to EOS
	- (b) promote the co-ordination of the exercise, by public authorities, of functions in relation to the marine estate, - (c) provide for the declaration and management of a comprehensive system of marine parks and aquatic reserves.	*Management Act 2014*, the zoning applied in the zoning plan, and permissible use of the area under the regulation must be taken into consideration.
Coastal Management Act 2016	The objective of the *Coastal Management Act 2016* is to provide for the management of the Coastal environment of NSW consistent with the principles of ecologically sustainable development. In particular the act aims to: - (a) to protect and enhance natural coastal processes and coastal environmental values including natural character, scenic value, biological diversity and ecosystem integrity and resilience, and - (b) to support the social and cultural values of the coastal zone and maintain public access, amenity, use and safety, and - (c) to acknowledge Aboriginal peoples' spiritual, social, customary and economic use of the coastal zone, and - (d) to recognise the coastal zone as a vital economic zone and to support sustainable coastal economies, and - (e) to facilitate ecologically sustainable development in the coastal zone and promote sustainable land use planning decision-making, and - (f) to mitigate current and future risks from coastal hazards, taking into account the effects of climate change, and - (g) to recognise that the local and regional scale effects of coastal processes, and the inherently ambulatory and dynamic nature of the shoreline, may result in the loss of coastal land to the sea (including estuaries and other arms of the sea), and to manage coastal use and development accordingly, and - (h) to promote integrated and co-ordinated coastal planning, management and reporting, and	The objectives of the CM Act are supported through the Coastal SEPP and Coastal Management Programs (CMP). The CMP sets the long-term strategy for the co-ordinated management of land within the coastal zone. The Byron Shire is currently in the process of writing a CMP for the Byron Bay Embayment which includes Belongil Creek. Development of the CMP is a staged process through which key management issues are identified and addressed. In preparation of the CMP, the local council must: - consider and promote the objects of this Act, and - give effect to the management objectives for the coastal management areas covered by the program, and - consider the State and regional policies and plans prescribed by the regulations for the purposes of this section. Each of the mapped coastal management areas falls within the scope of the lands to be impacted by the opening of the creek. - Coastal wetlands and littoral rainforests area – objects listed in Part 2, Section 6.2 - Coastal environment area – objects listed in Part 2, Section 8.2 - Coastal use area – objects listed in Part 2, Section 9.2 The objects for Coastal vulnerability areas (Part 2, Section 7) should also be considered despite not being currently mapped. The location of the creek entrance is such that it will likely fall within the Coastal vulnerability area once it is mapped. It is worth noting that a provision (Part 2, Division 1 subclause 3) within the CM SEPP allows for environmental protection works to be carried out in Coastal Wetland and Littoral Rainforest areas without development consent. If the CMP frames the

Act/Planning instrument	Objects and Goals	Application to EOS
	- (i) to encourage and promote plans and strategies to improve the resilience of coastal assets to the impacts of an uncertain climate future including impacts of extreme storm events, and - (j) to ensure co-ordination of the policies and activities of government and public authorities relating to the coastal zone and to facilitate the proper integration of their management activities, and - (k) to support public participation in coastal management and planning and greater public awareness, education and understanding of coastal processes and management actions, and - (l) to facilitate the identification of land in the coastal zone for acquisition by public or local authorities in order to promote the protection, enhancement, maintenance and restoration of the environment of the coastal zone, and - (m) to support the objects of the *Marine Estate Management Act 2014*.	mechanical opening of the estuary as environmental protection works, then it may enable streamlined approval of the EOS (refer to CM SEPP notes below).
State Environmental Planning Policy (Coastal Management SEPP) 2018	The aim of the Coastal SEPP is to promote an integrated and co-ordinated approach to land use planning in the coastal zone in a manner consistent with the objects of the Coastal Management Act 2016, including the management objectives for each coastal management area, by: (a) managing development in the coastal zone and protecting the environmental assets of the coast, and (b) establishing a framework for land use planning to guide decision-making in the coastal zone, and The policy objectives in combination with the CM Act carry forward the relevant goals of the NSW Coastal Policy 1997 and SEPP 71.	While the Coastal SEPP provides extensive development controls for each of the coastal management areas, development consent may not be required within coastal wetlands and littoral rainforests for works classified as 'environmental protection works' that are identified within a: - relevant CMP - a plan of management prepared and adopted under Division 2 of Part 2 of Chapter 6 of the Local Government Act 1993, - a plan of management approved and in force under Division 6 of Part 5 of the Crown Lands Act 1989 However, the licence for the opening of the creek falls upon land classified as in *proximity to Coastal Wetlands*. It is necessary to determine if the provision described above (Part 2, Division 1 subclause 3) is also applicable to the proximity area. If it is then the mechanical opening could potentially classify as environmental protection works and not require development consent, thus streamlining approval. If the opening of the creek is considered to be development, then the consent authority must be satisfied that the strategy will not significantly impact on:

Act/Planning instrument	Objects and Goals	Application to EOS
		- the biophysical, hydrological or ecological integrity of the adjacent coastal wetland or littoral rainforest, or - the quantity and quality of surface and ground water flows to and from the adjacent coastal wetland or littoral rainforest. The licence also falls within the areas mapped as Coastal Environment Areas, development consent will depend on whether the development is likely to impact: - (a) the integrity and resilience of the biophysical, hydrological (surface and groundwater) and ecological environment, - (b) coastal environmental values and natural coastal processes, - (c) the water quality of the marine estate (within the meaning of the Marine Estate Management Act 2014), in particular, the cumulative impacts of the proposed development on any of the sensitive coastal lakes identified in Schedule 1, - (d) marine vegetation, native vegetation and fauna and their habitats, undeveloped headlands and rock platforms, - (e) existing public open space and safe access to and along the foreshore, beach, headland or rock platform for members of the public, including persons with a disability, - (f) Aboriginal cultural heritage, practices and places, - (g) the use of the surf zone. As the site also falls within the Coastal Use Area, consideration will also need to be given to the design of the development such that potential adverse impacts on the following are avoided or minimised: - existing, safe access to and along the foreshore, beach, headland or rock platform for members of the public, including persons with a disability, - the visual amenity and scenic qualities of the coast, including coastal headlands,

Act/Planning instrument	Objects and Goals	Application to EOS
		It is also highly likely that the site will also fall within Coastal Vulnerability Areas once these are mapped for the Shire.
State Environmental Planning Policy (Infrastructure) 2007	The Infrastructure SEPP dissolved SEPP 35 - Maintenance dredging of Tidal Waterways in 2008. The Infrastructure SEPP aims to facilitate the effective delivery of infrastructure in a timely, cost effective and environmentally responsible manner. As part of the coastal reform, provisions what were in Division 25 of the Infrastructure SEPP were replaced by new provisions in the Coastal Management SEPP.	Division 25 defines water way or foreshore activities to include 'instream management or dredging to rehabilitate aquatic habitat or to maintain or restore environmental flows or tidal flows for ecological purposes'. Division 25 also states that development for the purpose of waterway or foreshore management activities may be carried out by or on behalf of a public authority without consent on any land. However, Part 1 clause 8 states that in the case of inconsistency, that clauses 10,11 and 19 of the Coastal SEPP prevail such that consent would depend on entrance works ensuring no significant impact on: - the biophysical, hydrological or ecological integrity of the adjacent coastal wetland or littoral rainforest, or - the quantity and quality of surface and ground water flows to and from the adjacent coastal wetland or littoral rainforest. However, in the case of emergency works or routine maintenance, Part 1 clause 8 also provides for development for that purpose to the extent that any adverse effect on the land concerned is restricted to the minimum possible to allow for the works to be carried out.
Biodiversity Conservation Act 2016	The Biodiversity Act replaces the Threatened Species Conservation Act. It aims to maintain a healthy, productive and resilient environment in accordance with the principles of ecologically sustainable development. The Act lists threatened species, populations and ecological communities and lists key threatening processes. It combines with the EP&A Act to control the impact of developments on threatened species, populations or ecological communities. Under Part 7 Section3, the BC Act 2016 outlines a test to determine whether a proposed development or activity is likely to significantly affect threatened species of ecological communities or their habitats.	Activities which fall under Part 5 of the EP&A Act must apply a test of significance to determine whether the proposed activity is likely to significantly affect threatened species, ecological communities or their habitats For the activity of the entrance opening of Belongil Creek, the following endangered and vulnerable species have been identified: Plant species: Stinking Cryptocarva (*Cryptocarya foetida*); Red Lilly Pilly (*Syzygium hodgkinsoniae*); Durroby (*Syzygium moore*i); Swamp Orchid (*Phaius tancarvilleae*) and Arrowhead Vine (*Tinospora tinosporoides*). Shorebirds: little tern (Sterna albifrons- endangered), osprey (Pandion haliaetus- vulnerable), pied oystercatcher (Haematopus longirostris- vulnerable), and great knot (Calidris tenuirstris -vulnerable). The comb-crested jacana (Irediparra gallinacea – threatened) and beach stone curlew (Esacus neglectus- endangered)

Act/Planning instrument	Objects and Goals	Application to EOS
		Turtles: including the loggerhead turtle (Caretta caretta - endangered), the green turtle (Chelonia mydas-vulnerable), and leathery turtle (Dermochelys coriacea - vulnerable). Ecological communities: Subtropical and temperate coastal saltmarsh, coastal swamp oak (*Casuarina glauca*) forest and lowland rainforest of subtropical Australia. If the activity is likely to have a significant impact or is carried out in an area of outstanding value, the proponent must either apply the Biodiversity Offsets scheme or prepare a species impact statement. If the environmental impact of the activity will not have a significant impact on threatened species, it will continue to be assessed under s.111 of the EP&A Act 1979
Byron Local Environmental Plan 2014	The Byron Local Environmental Plan (LEP) aims to make local environmental planning provisions in accordance with relevant environmental planning instruments and following the principles of ecologically sustainable development. In particular, the LEP aims: - to integrate local planning provisions with applicable regional and State planning controls and policies - to provide a framework for land use management in Byron - to promote and coordinate the orderly and economic use and development of land, - (e) to build and sustain community resilience by encouraging a diversity of housing choice and affordable housing in appropriate localities, - (f) to encourage development that contributes to a vibrant, socially-diverse community, - (g) to encourage development that contributes to a strong, growing and diversified economy, - (h) to ensure the timely provision and coordination of community services and facilities, - (i) to protect, manage and restore the natural environment and biodiversity of Byron,	This plan is subject to the provisions of any state environmental planning policy that prevail over the Byron LEP as provided by section 36 of the EP&A Act 1979 Part 5.7 refers to development below mean high water mark, where: - (1) the objective of the clause is to ensure appropriate environmental assessment for development carried out on land covered by tidal waters. - (2) development consent is required to carry out development on any land below the mean high-water mark of any body of water subject to tidal influence (including the bed of any such water). The entrance of Belongil Creek where entrance-opening activities occur is principally within the 7(f1) – (Coastal Lands) (f1) Zone as prescribed by the Byron LEP. At times activities may impinge on the 7(j) – (Environmental Protection Scientific).

Act/Planning instrument	Objects and Goals	Application to EOS
	- (j) to protect the cultural heritage of Byron, including the conservation of built heritage and Aboriginal heritage, - (k) to provide for public involvement and participation in environmental planning and assessment, - (l) to minimise conflict between land uses within a zone and adjoining zones and ensure minimal impact of development on the amenity of adjoining and nearby land uses.	
Marine Estate Management Strategy 2017	The overarching strategy which coordinates the policy directions for managing the marine estate as a single continuous system over the next 10 years. All relevant NSW government agencies are integrated with local government, industry, stakeholders and communities. Eight management objectives are listed in the strategy - To improve water quality and reduce marine litter for the benefit of marine habitats, wildlife and the community - To protect coastal and marine habitats and associated species and enhance the health of the marine estate by improving design, quality and ongoing management of foreshore development, use and water way infrastructure - Understand, adapt and increase resilience, to help mitigate the impacts of climate change on the NSW marine estate - Work with Aboriginal communities in the management of Sea Country to reduce threats and risks to Aboriginal cultural heritage - To understand and mitigate threats to threatened and protected species in NSW - To ensure fishing and aquaculture is managed in such a way that is consistent with ecologically sustainable use while providing for the health heritage and social benefits of fishing and seafood consumption	The marine estate includes lakes lagoons and other partially enclosed bodies of water that are permanently, periodically or intermittently open to the sea. This includes Belongil Creek. The threat and risk assessment which accompanied the development of the strategy identified entrance modifications as one of the three greatest threats to the environment, the other two being climate change and urban/rural runoff/discharge. Saltmarsh, Seagrass, Beaches and Species under the Fisheries Management Act 1994 as under high risk of being threatened by estuary entrance modifications. The assessment also identified estuarine waters, mangroves, mudflats, shallow soft sediments and planktonic assemblages under moderate threat from the same activity, as well as species protected under the Biodiversity Conservation Act 2016.

Act/Planning instrument	Objects and Goals	Application to EOS
	- To balance the protection of coastal and marine habitats and species with ongoing access and safe and sustainable boating To improve the social, cultural and economic benefits that the NSW community derives from the marine estate by responding to priority threats.	

9 Summary and next steps

Belongil Creek catchment has been extensively modified since European settlement. Urbanisation, agricultural development, drainage works, and the removal of native vegetation have all had an extensive impact on the function of the estuary. However, despite these changes the catchment still supports significant aquatic and terrestrial ecological values.

Naturally the Belongil Creek estuary would have intermittently opened and closed as a result of coastal processes and catchment rainfall. The sand barrier which controls estuary water level is likely to have experienced significant fluctuations in elevation during build-up and break-out events. At its maximum the barrier is likely to have reached close to 2.6 m AHD. This would result in significantly higher water levels and widespread inundation of the catchment including current urban and industrial areas.

The estuary has historically been opened to allow agricultural and urban development within the catchment. Historically the entrance was artificially opened in response to requests from property owners. However, in recent decades, the entrance has been artificially opened once the water level at a recorder on Ewingsdale Bridge reaches a designated “trigger” level. That trigger level was formerly set at 1.2m AHD but was lowered to 1.0 m AHD in 2001.

The current 1.0 m AHD trigger level is very low, noting that an estuarine barrier at this level can be overtopped by large, purely astronomical tides. With ongoing sea-level rise, it is inevitable that the trigger level will need to be raised again as entrance management will become increasingly impractical.

We expect that the issue of flooding within Byron Bay is likely to overtake water quality as the driving reason behind entrance management and that maintaining water levels below 1.2 m AHD at Ewingsdale Bridge is going to become increasingly difficult as sea levels rise. In the future the trigger level will need to rise and the proposed estuary opening strategy will need to provide a framework to allow for this increase over time while also protecting community and built assets and the ecological values of the catchment.

The next steps in the development of the Belongil Creek estuary opening strategy and EMP include:

1. Working with key agencies, stakeholders and the community to develop management objectives for the Belongil Creek estuary and catchment (i.e. Stage 4)
2. Develop a range of different opening scenarios and assess each different approach against the management objectives and criteria (Stage 5)
3. Document a preferred opening arrangement including opening approach, triggers, key responsibilities and procedures (Stage 5)
4. Document an EMP which considers both site specific issues relating the estuary entrance opening and broader catchment wide responses (Stage 5)
5. Engage and educate the community on the need for ongoing entrance management and the issues that need to be addressed both now and into the future (Stage 6).

10 References

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Attachment B
Ecological assessment of Belongil Creek

Belongil Creek Entrance Opening Strategy

Ecology Assessment

Prepared for: Alluvium

Prepared by Ecological Service Professionals Pty Ltd

September 2018

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Executive Summary

Ecological Service Professionals was engaged by Alluvium to provide an assessment of the ecology of the Belongil Creek, as part of a broader assessment of the impact of the Belongil Creek Entrance Opening Strategy. Blackwood Ecological Services were engaged to provide an assessment of the terrestrial ecological components. This ecological assessment report describes the historical and current condition of aquatic and terrestrial vegetation and fauna communities of Belongil Creek in relation to the proposed opening strategy based on desktop review and brief site visits.

The Belongil Creek is situated north-west of the town of Byron Bay on the north coast of New South Wales, and lies within the Cape Byron Marine Park that stretches from Brunswick Heads in the north to Lennox Head in the south. The Belongil Creek catchment has been previously described as highly modified and relatively disturbed, and is impacted by urban development, historic draining of wetlands and land clearing. Most of the lower lying areas of the Belongil Creek Catchment are dominated by 'wetland' associated vegetation i.e. vegetation patterning and function that is primarily or very importantly controlled by hydrology, including seasonal or permanent groundwater levels and the retention of surface water following rain. Lower-lying areas of the catchment support 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.

The current vegetation in the Belongil catchment is affected by anthropomorphic stressors such as clearing, drainage, agricultural practices (grazing), urbanisation and the artificial opening of the Belongil Creek estuary. Where native vegetation is present in the catchment, it is likely to be representative of the pre-drainage and pre-artificial opening vegetation condition.

The estuary, beach and surrounding forests provide important habitat for a diverse range of native fauna including migratory shorebird species and freshwater and estuarine aquatic species. In particular, the estuary supports a range of commercially and recreationally important fisheries species (including crabs, prawns, and fish) and fish habitat that is important as a nursery habitat for juvenile fish.

1 Introduction

Ecological Service Professionals was engaged by Alluvium to provide an assessment of the ecology of the Belongil Creek, as part of a broader assessment of the impact of the Belongil Creek Entrance Opening Strategy. An assessment of the terrestrial ecology was completed by Blackwood Ecological Services and is attached as Appendix A.

This ecological assessment report describes the historical and current condition of aquatic and terrestrial vegetation and fauna communities of Belongil Creek in relation to the proposed opening strategy. Consideration of the potential impacts of the proposed opening strategy on local flora and fauna, including species of significance will be completed at a later date including providing mitigation measures to protect local species including advice regarding the proposed opening strategy, and identifying suitable strategies to improve ecosystem condition such as creation of artificial oyster reefs or other biogenic habitats to mitigate potential impacts to the system. Specifically, this assessment of the existing ecology provides:

- a desktop literature review of technical information/studies and plans on the Belongil Creek estuary, including Council's existing environmental data sets (as relevant to ecological matters), to confirm existing studies of the area and identify any existing knowledge gaps,
- a review of Threatened ecological communities and flora and fauna species known from, or considered likely to occur in, the Belongil Creek Catchment.
- a flora and fauna assessment of the study area.

1.1 Belongil Creek Entrance Opening Strategy

The Belongil Creek is situated north-west of the town of Byron Bay on the north coast of New South Wales, and lies within the Cape Byron Marine Park that stretches from Brunswick Heads in the north to Lennox Head in the south. There is currently a Draft Entrance Opening Strategy. The specific objectives of the Entrance Opening Strategy are to develop a long-term entrance opening strategy that:

1. Formalises the need and Council's responsibilities for entrance management within the context of applicable legislation and determines key responsibilities for management of the entrance including a procedure to be initiated by Council (and other authorities if applicable) for entrance operations including entrance breakouts.
2. Minimise interference with natural entrance opening processes and minimise associated impacts on ecological processes; and conserves or enhances the biological diversity and flora and fauna communities of the ICOLL system.
3. Investigates and compiles a list of opening triggers, needs, requirements and environmental triggers;
4. Informs and educates Council and the community on entrance opening, this should include discussion on how it can or can't protect the town from ocean level rise caused by Climate Change
5. Accommodates future climate change, sea level rise in particular;

6. Investigates and assesses and minimises risks to public and private safety associated with inundation of associated infrastructure;
7. Assesses effects of increases in effluent flow from West Byron Sewage Treatment Plant, in accordance with proposed upgrades to the plant and including proposed changes to effluent flow paths;
8. Details an operational procedure for monitoring of the creek entrance. Provides a mechanism for review and update of the strategy (when required) and considers options for an adaptive management approach due to uncertainties in climate. Considerations may include the use of decision –making triggers.
9. Considers how water quality could be improved in the catchment, including novel approaches such as constructed Oyster Reefs;
10. Investigates the benefits and issues of a 'Tripper Wall' as a solution to erosion and entrance creep issues at the mouth;
11. Determines key responsibilities for management of the entrance through and Environmental Management Plan;
12. Provides an information and education source for the greater community in an effort to gain community support for the entrance management.

A subsequent assessment of the impact of the opening strategy on the existing ecology of the Belongil Creek will contribute to Outcomes 2, 3, 7 and 9 and is yet to be completed.

2 Existing Environment

2.1 Desktop Review Methodology

To describe the existing environment, a desktop review and gap analysis reviewed all available literature provided by Alluvium including information provided by Council and database and literature searches was completed. Specifically, the desktop review was informed by:

- The Belongil Estuary Study and Management Plan (Parker and Pont 2001)
- The Draft Belongil Creek Entrance Management Strategy (Byron Shire Council 2005)
- The Belongil Creek Entrance Opening Strategy Review of Environmental Factors (IERM 2005)
- The Belongil Estuary Seabird and Shorebird Management Plan (Beacon 2007)
- The Technical Review of Entrance Opening Strategy for Belongil Creek, Byron Bay (BMT WBM 2007)
- a search of protected matters under the EPBC using the PMST (DEE 2018)

Based on the gap analysis, it was considered that there is sufficient ecological survey data available for the study area, and that a detailed flora and fauna survey (e.g. fauna trapping, flora survey transects/quadrats) is not required to inform the overall study. As such, flora and fauna assessments were completed to ground-truth the presence of communities and habitats within the study area and assess the likelihood of occurrence of specific fauna species identified as occurring based on habitat types and relevant searches. Where relevant, the current condition of wetlands within the survey area will be assessed using approaches such as the *Wetland Assessment Techniques Manual for Australian Wetlands* (WetlandCare Australia 2008).

A site visit was also completed by ESP ecologists in September 2018 to validate existing information from the desktop review. Habitats in the lower reaches of the estuary were described and their value assessed qualitatively, where access was permitted.

2.2 Description of Existing Physical Environment

2.2.1 Belongil Creek Catchment

The Belongil Creek Catchment is situated north-west of the town of Byron Bay on the north coast of New South Wales, and lies within the Cape Byron Marine Park that stretches from Brunswick Heads in the north to Lennox Head in the south. The lower section of the creek is estuarine in nature and Belongil creek enters approximately three kilometres northeast from the Belongil-Cumbebin Swamp into the waters of the Cape Byron Marine Park. The Belongil Creek estuary is characterised as an Intermittently Closed and Open Lake and Lagoon

(ICOLL) system due to alternating periods of sand build-up at the mouth of Belongil Creek, which intermittently closes and opens the mouth of the estuary.

The Belongil Creek catchment has been previously described as highly modified and relatively disturbed, and is impacted by urban development, historic draining of wetlands and land clearing. Lower-lying areas of the catchment support 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. These areas provide important habitat for a diverse range of native fauna including migratory shorebird species and freshwater and estuarine aquatic species. In particular, the estuary supports a range of commercially and recreationally important fisheries species (including crabs, prawns, and fish) and fish habitat important as a nursery habitat for juvenile fish (Schnierer 1988). At the mouth of Belongil Creek, where it enters the ocean, the coastal dunes and beach provide important foraging, roosting and nesting habitat for endangered and migratory shorebirds. Although, extensive intertidal flats for shorebird foraging are not present in the estuary.

The catchment receives inputs from a highly modified catchment of about 3000 ha (Byron Shire Council 2018), including via artificial drainages from the Union and Town drainages originating in the Byron Bay CBD (Byron Shire Council 2005). The catchment is characterised by several land uses including agriculture, commercial, industrial, and residential urban. Several possible point and diffuse sources of pollution exist in the catchment and are identified as the West Byron STP, Byron industrial estate, and Byron Bay Town itself (Byron Shire Council 2005). The estuary often has poor water quality, especially low concentrations of dissolved oxygen, low pH (acidic waters) and the presence of potential acid sulphate soils (PASS) in the catchment. The risk of flooding in agricultural, residential and industrial areas in the catchment (including parts of Byron Bay and the Byron Bay CBD) increases when the entrance of the Belongil Creek entrance becomes in-filled by sand transported along the ocean beach (IERM, 2005).

Alternating periods of sand build-up at the mouth of Belongil Creek and high-flow during wet seasons result in the entrance being intermittently closed or open. ICOLL systems such as the Belongil estuary typically close when the amount of sand transported northwards along the shore (through longshore drift) and across the entrance by swell and the incoming tide is greater than the amount of sand carried away by the outgoing tide and freshwater flow, flushing out into the ocean. Belongil Creek has a small tidal prism (volume of water entering and leaving the estuary), resulting in frequently closing of the entrance (BMT WBM 2007).

Opening of the estuary entrance occurs naturally when the sand berm between the estuary and the ocean is scoured by storm waves, or the barrier is breached due to rain or flood events in the catchment. The frequency of naturally occurring opening events is unknown; however, is likely to be less frequent and at a higher water level under pre-European settlement hydrology than under the current, artificially drained and managed system (IERM 2005). The Belongil Creek Estuary Processes study (Geomarine 1997) states that the mouth would breach under natural conditions at water levels equivalent to an elevation of 2.6 m AHD. This water level is equivalent to the height of the beach berm at the creek entrance (IERM 2005).

To mitigate and manage the potential flood risk to surrounding properties, Council instigated an entrance management policy.

2.2.2 Overview of Belongil Creek Water Quality

Water quality in the Belongil creek has previously been described as moderately impacted (WBM, 2001). Typically, ICOLLs are characterised by large variation in the physico-chemical properties of water, associated with long term variation in the entrance opening frequency.

The main factors influencing water quality that may also influence the ecology of Belongil estuary are provided by IERM (2005) and include:

- **ASS drainage**: Ingress of drain water can lead to temporarily severe acidification (pH < 3.0) along sections of the Union drain. ASS runoff has potentially high concentrations of dissolved metals (Iron), and flushing of drain water to the Belongil creek following rainfall can result in flocculation of metal hydroxides.
- **Tidal exchange**: Increased tidal influence in Belongil creek results in higher salinity throughout the system, greater flushing of nutrients can lead to higher water clarity.
- **Organic matter decomposition**: Seasonally low dissolved oxygen concentrations in the Belongil creek and drainage network during the summer wet season due to high temperatures and organic matter decomposition (WBM, 2001).
- **Phytoplankton blooms**: High nutrient concentrations and poor flushing during low–flow conditions lead to high phytoplankton biomass in the Belongil estuary and drainages (> 100 µg/L of chlorophyll-a).
- **Release of treated sewage effluent**: Effluent from the West Byron STW is released into the drainage network upstream of Ewingsdale Rd via constructed wetland cells. This release influences nutrient loads in the estuary especially during dry periods (ERM, 2001),
- **Urban runoff**: Poor water quality in the Town drain is characterised by high BOD, low dissolved oxygen and high dissolved inorganic nitrogen and flushes into the Belongil estuary during high flow and rain events,
- **Agricultural runoff** is the primary source of nutrient loading to the Belongil creek (WBM, 2001), and likely to contribute to both ASS runoff and organic matter loading,
- **Flooding** across the catchment in combination with the state of the Belongil estuary entrance (i.e. open or closed) can result in highly variable water quality during and post flooding events,
- **Climate variation:** climatic variation (i.e. rainfall patterns, temperature) imparts strong controls over water quality in coastal systems due to its' influence on water flows, ASS runoff and nutrient loading.

2.2.3 Overview of Entrance Management Policy and Flood Risk Mitigation Policy

The Byron Bay CBD to the west of Belongil Creek and the industrial estate to the south have the potential to flood when the entrance of Belongil creek is closed and the water levels measured at the gauge at Ewingsdale bridge rise above 1.2 m AHD. Flood mitigation practices for Belongil Creek include drainage of wetland areas through constructed channels and drains, as well as the artificial opening of the sand berm blocking the entrance of the estuary.

At present, the Byron Shire Council holds a license to mechanically open the blocked entrance of Belongil Creek once the water level reaches a pre-defined trigger level of 1 m AHD at the bridge over Ewingsdale Road, in accordance with the Draft Belongil Estuary Study and Management Plan (Australian Wetlands 2018). Artificial opening of the creek entrance is achieved by excavating a channel perpendicular to the shoreline to allow creek water to flow into the ocean.

Artificial opening of the Belongil estuary entrance has been undertaken for over 50 years (Parker and Pont 2001, IERM 2005) to mitigate the risks of flooding and poor water quality in the estuary over prolonged periods of time. Since 1997 and until March 2018 (Byron Shire Council 2005; Australian Wetlands 2018) the estuary has been artificially opened 71 times, or on average approximately three times per year. The width of the artificial opening channel ranges between two and four meters, and results in an average reduction of the water level at the gauge of 0.5 m AHD (Australian Wetlands 2018). Before 1997, anecdotal reports state that the estuary was artificially opened at least once pear year (Parker and Pont 2001)

Belongil Estuary Opening Strategy - Existing Environment

Map 1 - Belongil Creek Location

Data Sources
© Layers provided by Byron Shire Council

Project Number: 1813
Drawn: CB, 9/12/2018
Datum: GDA 1994

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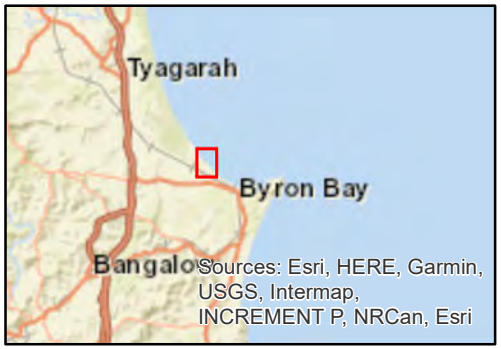


2.3 Matters of National Environmental Significance

The Environment Protection and Biodiversity Conservation Act 1999 (the EPBC Act) is the Australian Government's central piece of environmental legislation that provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities and heritage places. Under the EPBC Act, a referral is required where a proposed action is likely to have a significant impact on a Matter of National Environmental Significance (MNES).

Nine MNES are protected under the EPBC Act:

- World heritage properties
- National heritage places
- Wetlands of international importance (listed under the Ramsar Convention)
- Listed threatened species and ecological communities
- Migratory species protected under international agreements
- Commonwealth marine areas
- Great Barrier Reef Marine Park
- Nuclear actions (including uranium mines)
- A water resource, in relation to coal seam gas development and large coal mining development

Under the EPBC Act, a self-assessment determines if a referral to the federal minister for environment is required. In accordance with the EPBC Act:

- if this self-assessment determines the proposed action is not likely to have a significant impact on MNES or the environment (for actions on Commonwealth land), a referral to the Australian Government environment minister is not required
- if this self-assessment determines the proposed action is likely to have a significant impact on MNES or the environment (for actions on Commonwealth land) or if impacts are unclear, a referral to the Australian Government environment minister should be made for approval.

When an action is referred to the Australian Government environment minister, it is assessed to determine whether the action is likely to cause a significant impact on MNES or Commonwealth land (i.e. the referral decision). A referral decision will deem the action is:

- a controlled action, subject to the assessment and approval process under the EPBC Act
- not a controlled action, particular manner, where approval is not required if the action is taken in accordance with the manner specified
- not a controlled action, where approval is not required if the action is taken in accordance with the referral, or
- an action that is clearly unacceptable.

2.4 Protected Matters

The Protected Matters Search Tool was used to determine the presence of aquatic MNES in or near Belongil Creek. Three search areas were assessed (Attachment A):

- Belongil Creek Entrance (i.e. a buffer of 1.0 km)
- Belongil Creek Catchment (i.e. a buffer of 2.5 km), and
- Broader Region (i.e. a buffer of 10.0 km).

The results of the EPBC Act Protected Matters Search Tool are indicative only and further assessment based on the desktop review was required to confirm if the MNES are likely to occur in the area. The likelihood of threatened and migratory species occurring in the area was assessed according to the criterion outlined in Table 2.1. The assessment also considered the availability and distribution of habitat important to the recovery of species, even where these species may not presently occur.

Table 2.1 Likelihood of occurrence assessment criteria

Likelihood of Occurrence	Assessment Criteria
Unlikely	No previous records of the species within the estuary and one or more of the following criteria is met: • have not been recorded previously in the project area and surrounds and the project area is beyond the current known geographic range. • are only found in areas with specific habitat types or resources that do not occur. • considered extinct in the wild.
Possible	Species previously recorded within the wider region (within 10 km of Belongil Estuary) and one or more of the following criteria is met: • previously recorded in the region (i.e. vagrant / transient individuals). • potential habitat resources are present within the estuary or directly adjacent to the mouth.
Likely	Species previously recorded within the wider region (within 10 km of the study area) and one or more of the following criteria is met: • dependent on habitats or habitat resources that are available within the estuary or directly adjacent to the mouth. • suitable habitats are available that can support a resident population or individuals of the species.
Known	Species recorded during field surveys or previously recorded within the area.

2.4.1 Wetlands of International Importance

No wetlands of international importance are listed as occurring within 10 kilometres of the Creek.

2.4.2 Threatened Ecological Communities

Listed communities that are known to occur in the study area include (DoEE 2018):

- subtropical and temperate coastal saltmarsh

- coastal swamp oak (*Casuarina glauca)* forest of New South Wales and South East Queensland
- lowland rainforest of subtropical Australia

Subtropical and temperate coastal saltmarsh occurs in the estuary. These communities are best described as marine couch (*Sporobolus virginicus*) open grasslands. These grasslands included saltmarsh species such as sea purslane (*Sesuvium portulacastrum*) and seablite (*Suaeda australis*); and dune species such as prickly couch (*Zoysia macrantha*) and beach morning-glory (*Ipomoea pes-caprae* subsp. *brasiliensis*). Coastal Saltmarsh is a Threatened Ecological Community under the NSW Threatened Species Conservation Act 1995 (TEC) and a Vulnerable community under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC). The saltmarsh on the site generally meets the criteria for a Coastal Saltmarsh ecological community as protected under the EPBC Act. However, patches must be more than 0.1 ha in size in order to be considered as an ecological community that is a MNES. The total area of saltmarsh previously mapped in the study area by Council is 5.9 Ha (Table 2.2).

There are also areas of mangrove forest mapped in the estuary that are protected under the *Fisheries Management Act 1994* as marine plants (and not as threatened communities) and mapped as Coastal Wetlands under the State Environmental Planning Policy (SEPP) (Section 2.6).

A large proportion of the low-lying freshwater swamp areas of the catchment are dominated by coastal swamp oak forest and melaleuca forest. *Casuarina glauca* forest typically occurs on slightly higher or more exposed ground, rainforest patches (often with *Melaleuca*) and saltmarsh. Additional details of the threatened floral communities can be found in Appendix A.

Littoral rainforest is present on the northern side of the creek entrance. Common species within this community include tuckeroo, beach acronychia and coast banksia. The threatened species stinking cryptocarya occurs within this vegetation community. Erosion of the small area of littoral rainforest at the entrance is evident now due to bank undercutting (Figure 2.1). This process of erosion has been ongoing for some time (IERM 2005).

Figure 2.1 Bank erosion and littoral rainforest in the lower estuary

2.5 Vegetation Communities of Conservation Significance

The vegetation in the lower reaches of the Belongil Creek Catchment reflects the estuarine origin of the lower reaches and connectivity to swamps further upstream. Lower-lying areas of the Belongil catchment support 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. These have been described above and in Appendix A.

Most of the lower lying areas of the Belongil Creek Catchment are dominated by 'wetland' associated vegetation i.e. vegetation patterning and function that is primarily or very importantly controlled by hydrology, including seasonal or permanent groundwater levels and the retention of surface water following rain (IERM 2005). Descriptions of the key threatened ecological communities has been provided above (Section 2.4.2 and Appendix A). Parker (1996) has described the vegetation of the Belongil catchment in general terms based on forest type, including:

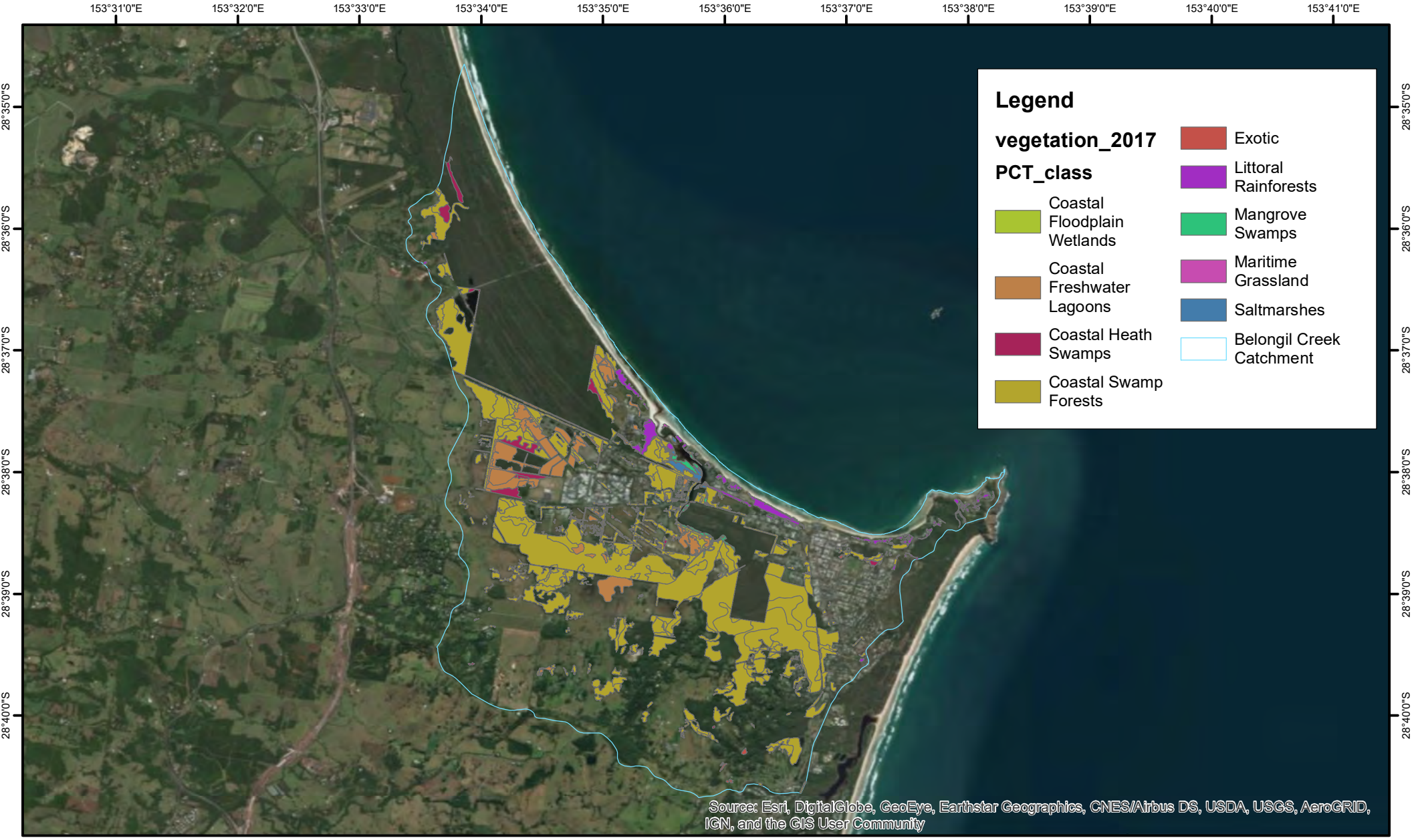
- littoral rainforest
- swamp forest
- mangrove forest
- frontal dune complex, and
- grassland (including saltmarsh).

Aquatic (freshwater and marine) associated plant community types mapped in the Belongil estuary between the estuary entrance and the Cumbebin Swamp include eight native and one exotic (Lantana) dominated communities. The native communities are (Map 2):

- Coastal Floodplain Wetlands,
- Coastal Freshwater Lagoons,
- Coastal Heath Swamps,
- Coastal Swamp Forests,
- Littoral Rainforests,
- Mangrove Swamps,
- Maritime Grasslands, and
- Saltmarshes.

The current vegetation in the Belongil catchment is affected by anthropomorphic stressors such as clearing, drainage, agricultural practices (grazing), urbanisation and the artificial opening of the Belongil Creek estuary. Where native vegetation is present in the catchment, it is likely to be representative of the pre-drainage and pre-artificial opening vegetation condition. The majority of the pre-settlement Belongil catchment would have been a mosaic of swamp forest dominated by *Melaleuca* and *Casuarina* species, littoral rainforest, mangrove forest and saltmarsh (IERM 2005).

Nine vegetation communities have previously been mapped in the Belongil Creek Catchment between the entrance and the Cumbebin Swamp (Table 2.2; Map 2 & Map 3) are listed as Endangered Ecological Communities. Three of these communities (Littoral Rainforest, Lowland Rainforest and Lowland Rainforest on Floodplain) are listed as 'critically endangered', while Coastal Saltmarsh is listed as 'vulnerable' under the EPBC Act.



Belongil Estuary Opening Strategy - Existing Environment

Map 2 - Vegetation Community Types

Data Sources
© Layers provided by Byron Shire Council

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Drawn: CB, 9/12/2018
Datum: GDA 1994

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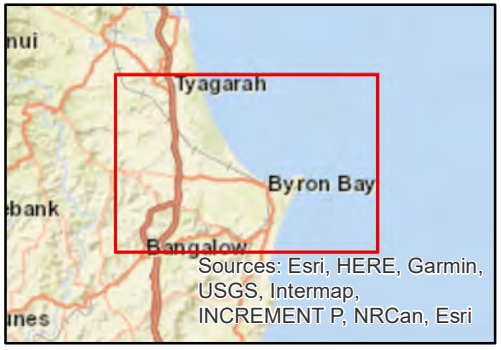


Table 2.2 Plant Community Types and Threatened Ecological Communities in the Belongil Creek Catchment.

Vegetation community	Habitat / Description (OEH 2018)	Species	Status	Area (ha) in study area
Byron Bay Graminoid Heath	Gently sloping clay ridges Low-growing, grasses and grass-like plants with patches of taller shrubs and occasional larger trees. The heath also provides habitat for a range of native animal species.	*Banksia oblongifolia* *Pultenaea villosa* *Themeda australis* *Lepidosperma laterale*	Endangered Ecological Community (EEC) under the TSC Act. Not listed under Commonwealth legislation.	1.1
Coastal Cypress Pine Forest	Restricted to North Coast Bioregion. Coastal Cypress Pine Forest characteristically has a closed to open canopy. The understorey of shrubs, sedges and herbs is typically open to sparse. Undisturbed stands of the community may have a woodland or forest structure, with Coastal Cypress Pine dominating the canopy, although larger trees, such as eucalypts may be emergent. Stands of the community that have been partially cleared in the past may be reduced to scattered trees. Post-fire regeneration of the community may create a shrubland or heathland.	Dominated by coastal cypress pine (*Callitris columellaris*)	Endangered Ecological Community (EEC) under the TSC Act. Not listed under Commonwealth legislation.	1.9
Freshwater Wetlands on coastal floodplains	Associated with coastal areas subject to periodic flooding and in which standing fresh water persists for at least part of the year in most years. Typically occurs on silts, muds or humic loams in low-lying parts of floodplains, alluvial flats, depressions, drainage lines, backswamps, lagoons.	Dominated by *Paspalum distichum* (water couch), *Leersia hexandra* (swamp rice-grass), *Pseudoraphis spinescens* (mud grass) and *Carex appressa* (tussock sedge). Depending on water regime: *Baumea articulata* *Eleocharis equisetina* *Lepironia articulate*	Endangered Ecological Community (EEC) under the TSC Act. Not listed under Commonwealth legislation.	55.4

Vegetation community	Habitat / Description (OEH 2018)	Species	Status	Area (ha) in study area
	Generally occur below 20 m elevation on level areas. Dominated by herbaceous plants. Varies both spatially and temporally depending on the water regime. Known from along the majority of the NSW coast	*Hydrocharis dubia* *Philydrum lanuginosum* *Ludwigia peploides* *Marsilea mutica* M*yriophyllum* spp. *Azolla filiculoides* *Ceratophyllum demersum* *Hydrilla verticillate* *Lemna* spp. *Nymphaea gigantea* *Nymphoides indica* *Ottelia ovalifolia* *Potamageton* spp. The threatened aquatic plants, *Aldrovanda vesiculosa* and *Najas marina*, also occur within this community		
Littoral Rainforest	Generally a closed forest, the structure and composition of which is strongly influenced by its proximity to the ocean. There is considerable floristic variation between stands and in particular areas, localised variants may be recognised. Occurs on sand dunes and on soil derived from underlying rocks. Stands on headlands exposed to strong wind-action may take the form of dense, wind-pruned thickets.	Dominated by rainforest species. Distinguishing features of species in littoral rainforest are compound leaves; vines may be a major component of the canopy. Scattered emergent individuals of sclerophyll species occur in many stands.	Endangered Ecological Community (EEC) under the TSC Act. Commonwealth EPBC Act status: Critically endangered	29.0
Lowland Rainforest	Subtropical rainforest and some related, structurally complex forms of dry rainforest. Closed canopy, characterised by a high diversity of trees whose leaves may be mesophyllous and	Lowland rainforest includes taxonomically diverse species at the genus and family levels. Some may have buttressed roots. A range of plant growth forms are present in Lowland Rainforest, including palms,	Endangered Ecological Community (EEC) under the TSC Act. Commonwealth EPBC Act	99.2

Vegetation community	Habitat / Description (OEH 2018)	Species	Status	Area (ha) in study area
	encompass a wide variety of shapes and sizes. The Hawkesbury River notionally marks the southern limit of Lowland Rainforest in the NSW North Coast and Sydney Basin bioregions.	vines and vascular epiphytes. In disturbed stands of this community the canopy cover may be broken, or the canopy may be smothered by exotic vines.	status: Critically endangered	
Lowland Rainforest on Floodplain	Occurs only as small remnants in scattered localities on the NSW north coast, less than 1000 ha remaining. Typically, dense canopy, supports a rich diversity of plants and animals. Generally occupies riverine corridors and alluvial flats with rich, moist silts often in subcatchments dominated by basic volcanic substrates. Remnants remain on the floodplains of the Tweed, Richmond, Clarence, Bellinger, Macleay, Hastings, Manning, and Hunter Rivers. Other minor river systems also support the community. Occurs on fertile soils in lowland river valleys.	Typical tree species include figs (*Ficus macrophylla*, *F. obliqua* and *F. watkinsiana*), palms (*Archontophoenix cunninghamiana* and *Livistona australis*), Silky Oak (*Grevillea robusta*), Black Bean (*Castanospermum australe*) and Brush Cherry (*Syzygium australe*).	Endangered Ecological Community (EEC) under the TSC Act. Commonwealth EPBC Act status: Critically endangered	42.9
Coastal Saltmarsh	Coastal Saltmarsh occurs in the intertidal zone on the shores of estuaries and lagoons that are permanently or intermittently open to the sea. It is frequently found as a zone on the landward side of mangrove stands.	*Sporobolus virginicus* *Juncus kraussi* *Phragmites australis* *Acrostichum speciosum* Species restricted to coastal saltmarshes include *Distichlis distichophylla* (Endangered), *Halosarcia pergranulata* subsp. pergranulata, *Wilsonia backhousei* (Vulnerable) and	Endangered Ecological Community (EEC) under the TSC Act. Commonwealth EPBC Act status: Vulnerable	5.9

Vegetation community	Habitat / Description (OEH 2018)	Species	Status	Area (ha) in study area
		Wilsonia rotundifolia (Endangered).		
Swamp Oak Floodplain Forest	Found on the coastal floodplains of NSW. Dense to sparse tree layer. The understorey is characterised by frequent occurrences of vines, a sparse cover of shrubs, and a continuous groundcover of forbs, sedges, grasses and leaf litter. The composition of the ground stratum varies depending on levels of salinity in the groundwater. Under less saline conditions prominent ground layer plants include forbs and ferns. On the fringes of coastal estuaries, where soils are more saline, the ground layer may include the threatened grass species and other saltmarsh species.	Dominated by *Casuarina glauca* (swamp oak). Other trees include lilly pilly, cheese trees and paperbarks.	Endangered Ecological Community (EEC) under the TSC Act. Commonwealth EPBC Act status: not listed	56.5
Swamp Sclerophyll Forest on Coastal Floodplains	Open to dense tree layer of eucalypts and paperbarks. The trees may exceed 25 m in height. The community also includes some areas of fernland and tall reedland or sedgeland, where trees are very sparse or absent. The groundcover is composed of abundant sedges, ferns, forbs, and grasses.	The most widespread and abundant dominant trees include *Eucalyptus robusta* (swamp mahogany), *Melaleuca quinquenervia* (paperbark). Other trees may be scattered throughout at low abundance or may be locally common at few sites, including *Callistemon salignus* (sweet willow bottlebrush), *Casuarina glauca* (swamp oak) and *Eucalyptus resinifera* subsp. *hemilampra* (red mahogany), *Livistona australis* (cabbage palm) and *Lophostemon suaveolens* (swamp turpentine).	Endangered Ecological Community (EEC) under the TSC Act. Commonwealth EPBC Act status: not listed	269.7

2.5.1 Coastal Saltmarsh

The saltmarsh in the lower reaches of Belongil Creek (downstream of Ewingsdale Rd) are typically fringed on the Creek side by mangrove communities (dominated by grey and river mangroves) and casuarina forest (Figure 2.2). Paperbark swamp occurred on the landward side particularly in the lower reaches. The saltmarsh was in good condition and is dominated by sedges (*Juncus krausii* and *Baumea juncea*) and marine couch (*Sporobolous virginicus*) with occasional small patches of sea purslane (*Sesuvium portulacastrum*) and seablite (*Suaeda australis*) and prickly couch (*Zoysia macrantha*) towards the mouth of the estuary and on the dunes. Common reed (*Phragmites australis*) was present further upstream. Many of the saltmarsh areas (those dominated by marine couch, sedges and mangrove fern) assessed by ESP in September 2018 were inundated by approximately 0.2 m of water when the water level measured 1.0 m at the Ewingsdale Rd Bridge. The saltmarsh was well connected to the main creek channel either through directly connected via continuous mangroves or via a variety of smaller channels. There was no runnelling for drainage or substantial evidence of human disturbance to these areas of the lower reaches, although all areas have low relief and elevation, so would be easily flooded at times.

A smaller section of saltmarsh was recorded towards the mouth of the estuary, which is currently not mapped by council.

Figure 2.2 Saltmarsh in Belongil Creek estuary with fringing mangroves.

2.5.2 Mangrove Forests

The mangrove forests are dominated by Avicennia marina (Grey Mangrove) with *Aegiceras corniculatum* (River Mangrove), and are mid-high open to closed (mangrove) forest (Parker 1996) (Figure 2.3). This was confirmed during a site visit by ESP in September 2018. The mangrove fern (*Acrostichum speciosum)* also grows in dense patches landward of the mangrove forest fringing the Creek and in patches within the saltmarsh (Figure 2.4).There were several shallow areas with recent recruitment of saplings, particularly at the lower end of the estuary on the accreting eastern bank (Figure 2.5), which demonstrates possible regeneration and stabilisation of habitats, but also possible encroachment of habitat types such as saltmarsh further upstream.

The mangrove forest was assessed as in moderate condition, with some signs of stress in the lower estuary where trees had been inundated for extended periods, including yellowing of leaves, black mould on leaves and extended growth of pneumatophores (Figure 2.6).

The mangrove forests fringing the estuary are primarily intact patches of habitat that are well connected to the main channel, tidal habitats and surrounding vegetation communities further up the shore (i.e. saltmarsh) (Figure 2.3). There is good access to deeper water channels, which provides good value habitat for a variety of commercial and recreational fish species, particularly as potential nursery habitat. Although the density of fish in the mangroves was not assessed directly by ESP in September 2018.

Figure 2.3 Dense mangrove forest fringing the main estuary channel

Figure 2.4 Dense stands of mangrove fern bordering saltmarsh

Figure 2.5 Recent establishment of mangrove saplings in the lower estuary

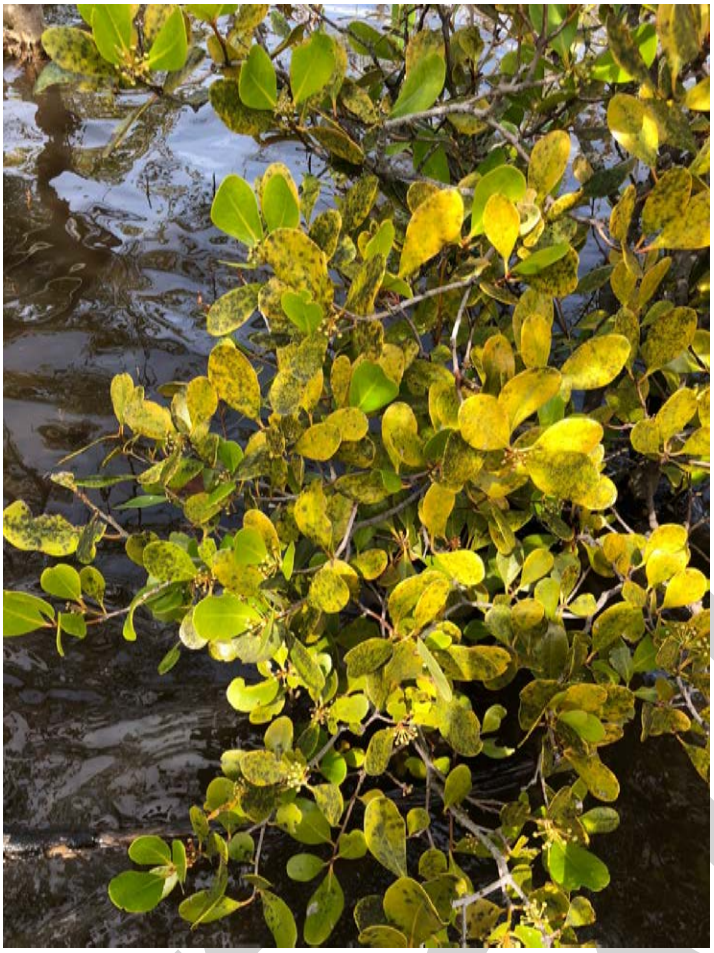
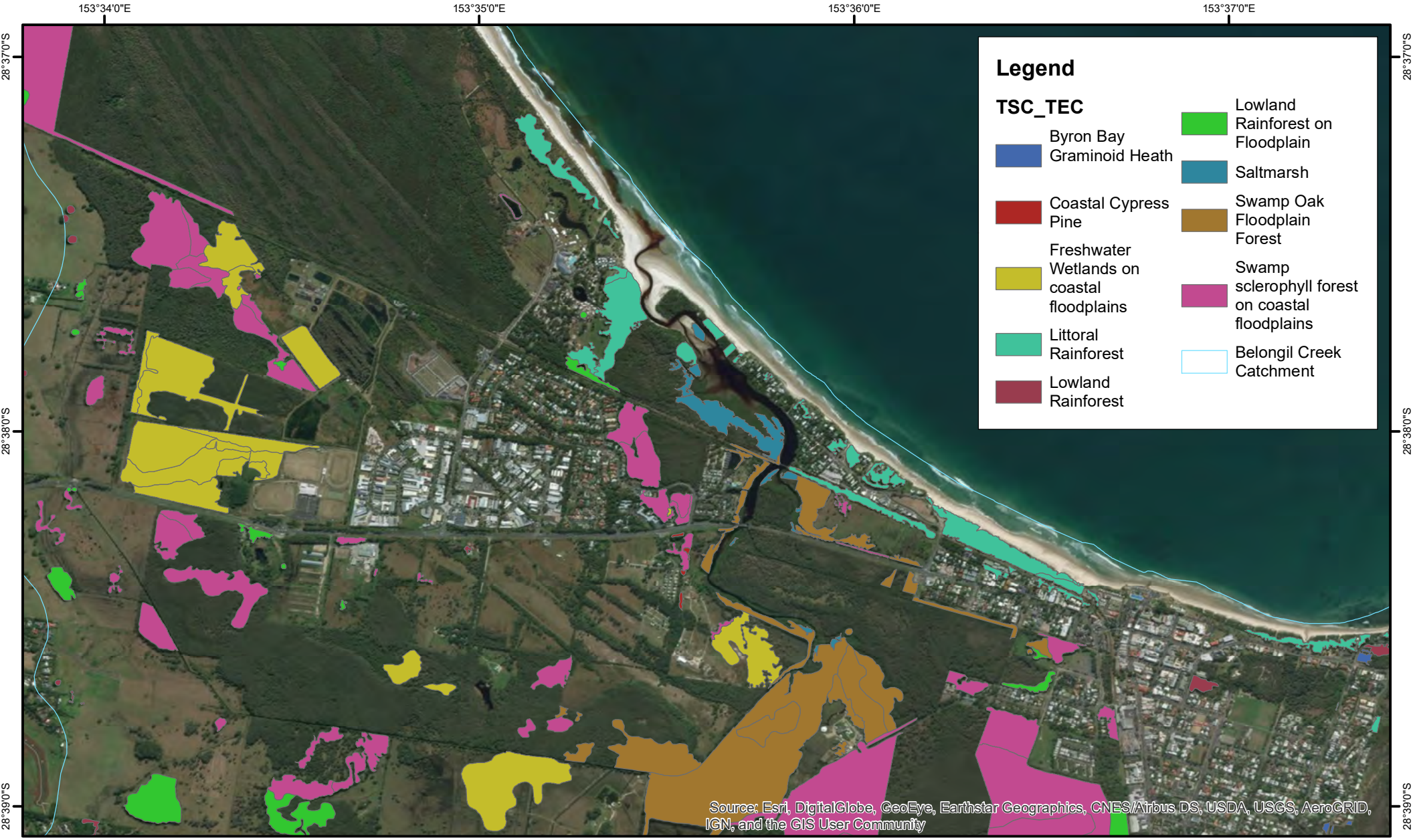


Figure 2.6 Yellowing leaves and black mould on *Aegiceras corniculatum*



Belongil Estuary Opening Strategy - Existing Environment

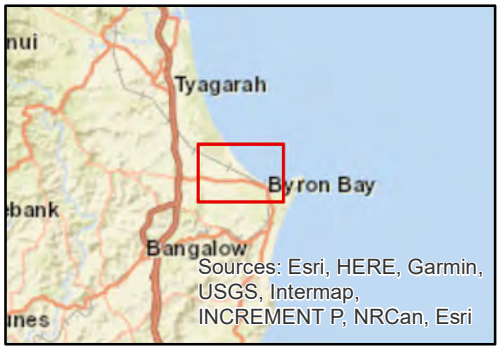
Map 3 - Threatened Ecological Communities

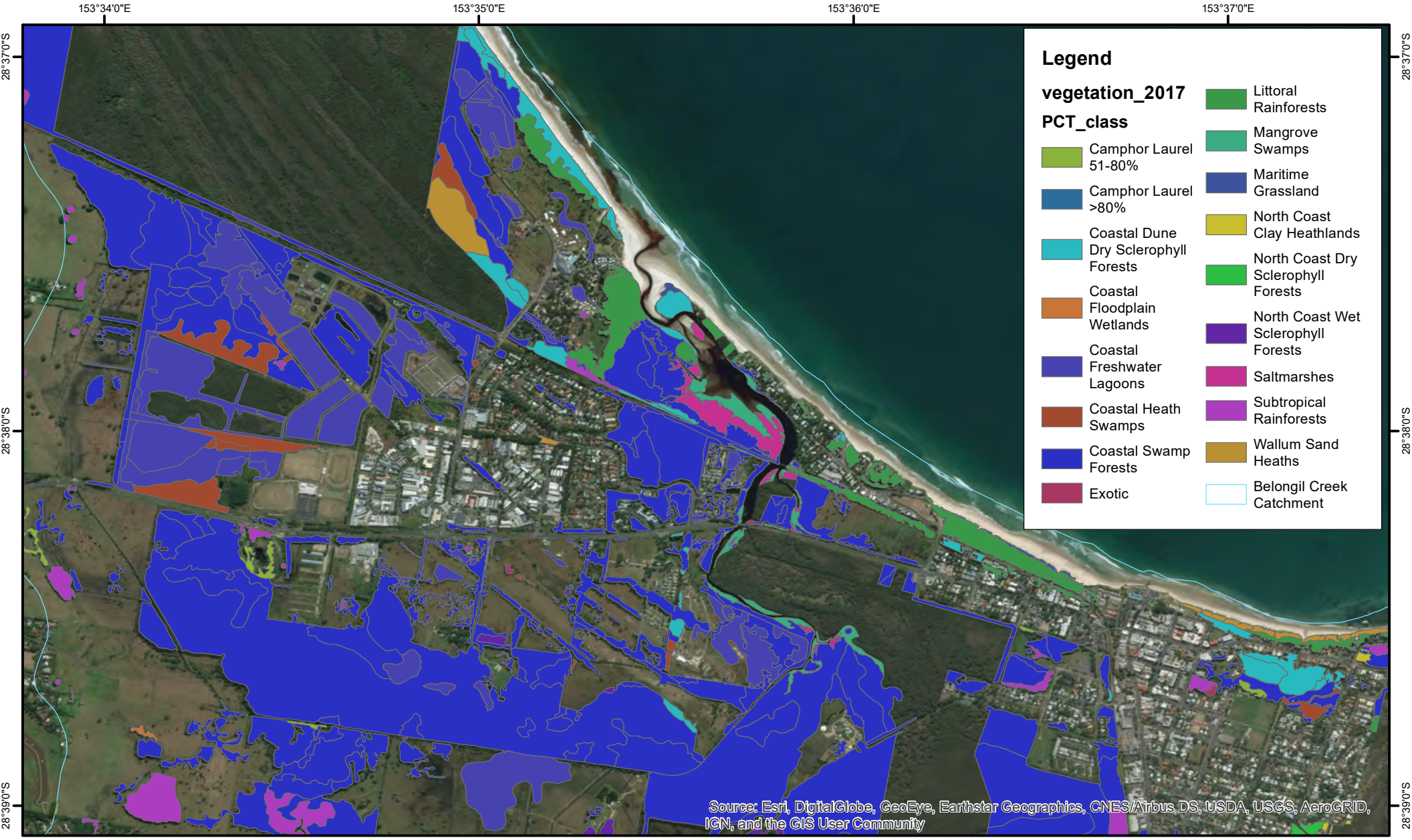
Data Sources
© Layers provided by Byron Shire Council

Project Number: 1813
Drawn: CB, 9/12/2018
Datum: GDA 1994

0 0.225 0.45 0.9 Kilometers

N





Belongil Estuary Opening Strategy - Existing Environment

Map 4 - Mapped Vegetation Communities

Data Sources
© Layers provided by Byron Shire Council

Project Number: 1813
Drawn: CB, 9/12/2018
Datum: GDA 1994

0 0.225 0.45 0.9 Kilometers

N

2.5.3 Existing Terrestrial Vegetation Communities

Parker (1996) recorded five threatened plant species listed in the schedules of the NSW Threatened Species Conservation Act, 1995 in the Belongil Creek catchment; with four found in the littoral rainforest: Stinking Cryptocarva (*Cryptocarya foetida*); Red Lilly Pilly (*Syzygium hodgkinsoniae*); Durroby (*Syzygium moore*i); and Arrowhead Vine (*Tinospora tinosporoides*). Stinking Cryptocarva was recorded from the vicinity of the eroding littoral rainforest at the mouth of the Creek. Another significant species recorded by Parker (1996) was the Swamp Orchid (*Phaius tancarvilleae*) in the Cumbebin Swamp in association with Melaleuca. Previous records of threatened flora are provided in Map 5.

Additional details and recent descriptions of the terrestrial flora in the Belongil Catchment are provided in Appendix A

2.6 State Environmental Planning Policy (SEPP)

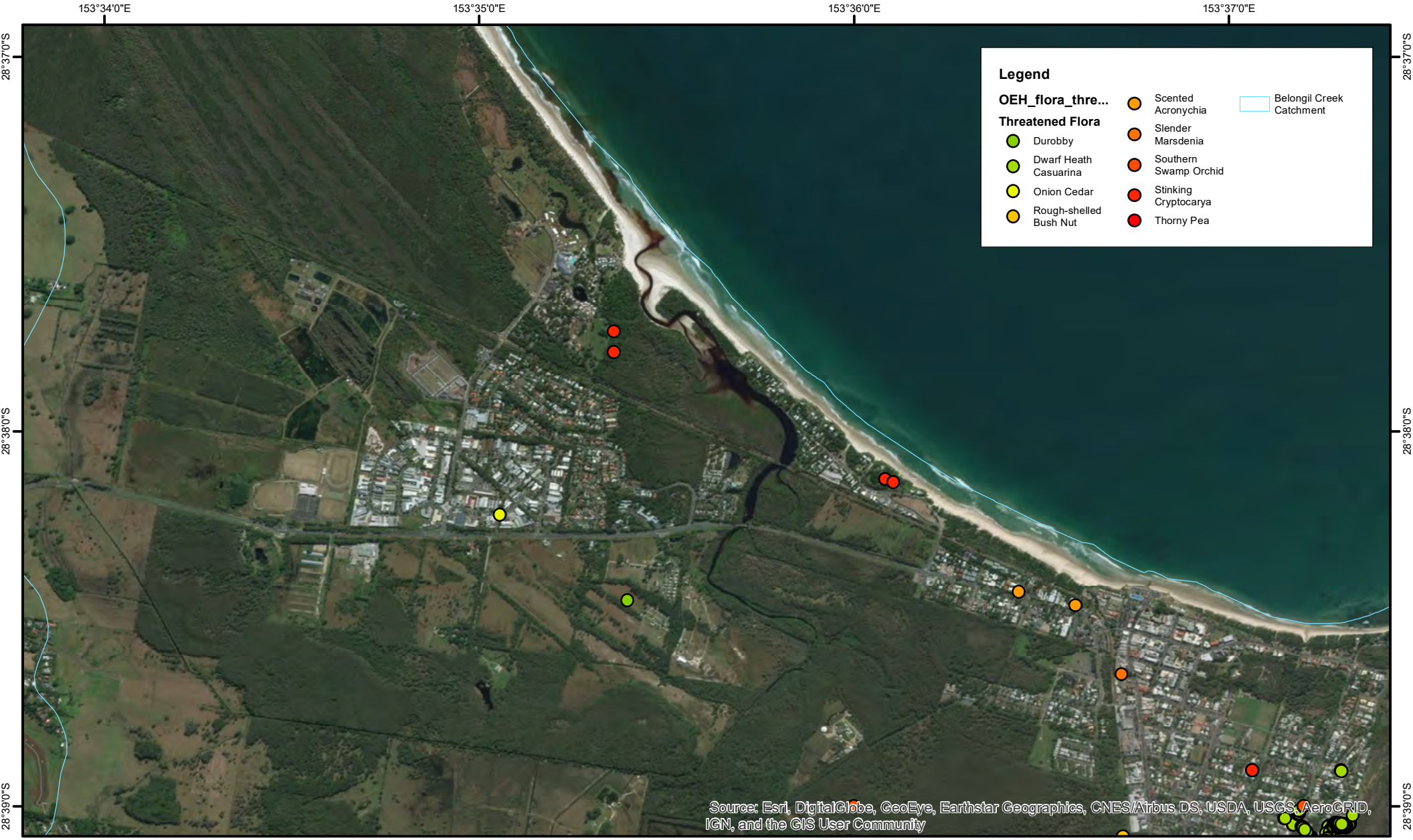
Belongil estuary, the Cumbebin Swamp, Union Drain and surrounding low-lying areas are classed as Coastal Management Areas under the SEPP (Map 6).

2.6.1 SEPP No. 14 Coastal Wetlands

Coastal wetlands under the SEPP are defined as coastal communities dominated by mangroves, freshwater and brackish swamps, sedge lands, melaleuca forests, casuarina forests, wet meadows and saltmarsh. Coastal wetlands are mapped on both banks of Belongil Creek, from the mouth of the estuary past the rail bridge and Ewingsdale Road bridge into Cumbebin swamp (refer to Map 6).

2.6.2 SEPP No. 26 Littoral Rainforest

Littoral rainforest (Figure 2.1; Map 3; TEC Section 2.4.2) is mapped on the western side of the estuary mouth in the vicinity of the area where the artificial opening to the creek mouth is located; and also in isolated patches on the eastern bank of the Belongil Creek between the estuary and the beach (low density residential area). Additional details of this forest type are provided in Appendix A.



Belongil Estuary Opening Strategy - Existing Environment

Map 5 - Threatened Flora

Data Sources
© Layers provided by Byron Shire Council

Project Number: 1813
Drawn: CB, 9/12/2018
Datum: GDA 1994

0 0.225 0.45 0.9 Kilometers

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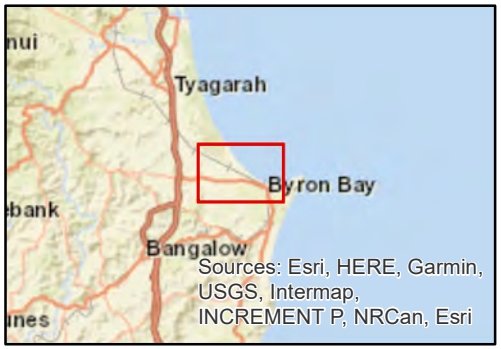
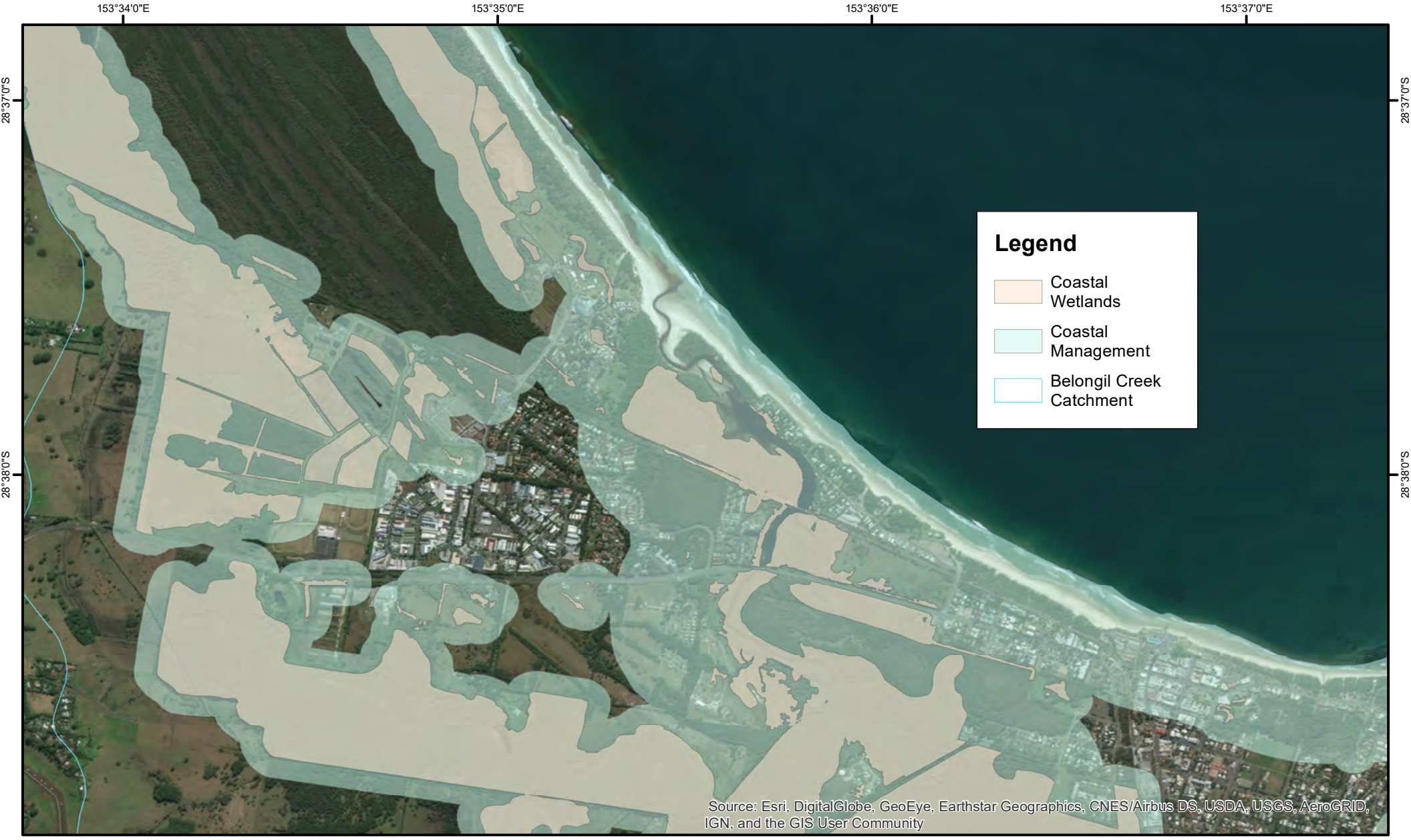




Belongil Estuary Opening Strategy - Existing Environment

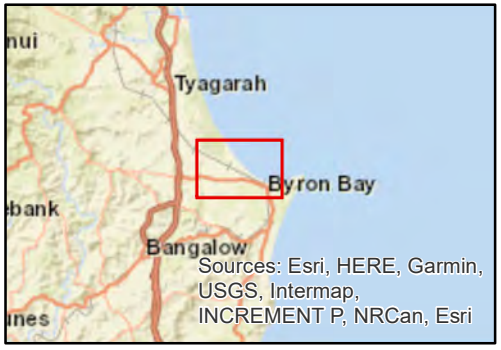
Map 6 - SEPP Zones

Data Sources
© Layers provided by Byron Shire Council

Project Number: 1813
Drawn: CB, 9/12/2018
Datum: GDA 1994

0 0.225 0.45 0.9 Kilometers

N



2.7 Cape Byron Marine Park

Belongil Creek and the estuary mouth (including upstream areas near Cumbebin swamp and the upstream reach near Skinner Shoot) are zoned as a special purpose zone of the Cape Byron Marine Park (areas below Highest Astronomical Tide - HAT) (Map 7). The special purpose zone provides for protection, traditional use and rehabilitation of Belongil Creek (Cape Byron Marine Park Zoning Guide, NSW DPI 2018). Recreational and commercial fishing without permit are not allowed.

The immediate area north and south of the creek entrance is zoned as sanctuary zone, extending approximately 300 m to the north, 500 m to the south, and several kilometres offshore (Map 7). Recreational and commercial fishing without permit are not allowed.

Adjoining the sanctuary zones in the waters on the beach to the north and south are two habitat protection zones extending along the beach for several kilometres. Recreational and commercial fishing and other recreational activities (collecting, boating) under the rules set out in the Cape Byron Marine Park Zoning Plan Users Guide (NSW DPI 2018) is allowed.

Formal approval under the NSW Marine Parks Act 1997 will be required for works to manage the entrance. The proposed entrance management is within the allowable uses for the zoning of the Creek entrance.

Belongil Estuary Opening Strategy - Existing Environment

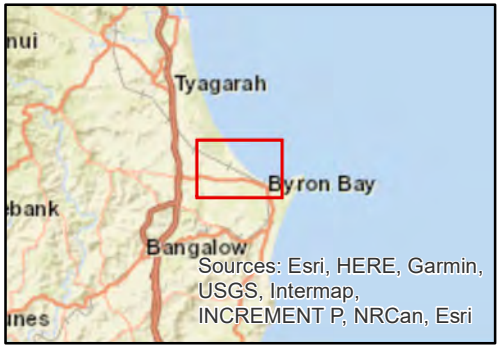
Map 7 - Cape Byron Marine Park Zoning

Data Sources
© Layers provided by Byron Shire Council

Project Number: 1813
Drawn: CB, 9/12/2018
Datum: GDA 1994

0 0.225 0.45 0.9 Kilometers

N



2.8 Fauna of Conservation Significance

2.8.1 Threatened Marine and Aquatic Fauna

Of the 85 listed marine or aquatic species and twelve whales and other cetaceans found using the Protected Matters Search Tool, the following were considered to possibly occur within 10 km of the estuary (i.e. within the estuary and surrounds, Table 2.3, Appendix B):

- Indo-Pacific bottlenose dolphin (*Tursiops aduncus*),
- Green turtle (*Chelonia mydas*), and the
- Loggerhead turtle (*Caretta caretta*).

In most cases, these species would be unlikely to enter the estuary due to the nature of the opening; however suitable habitat may occur within 5 – 10 km of the Belongil estuary mouth, especially in the offshore waters of the Cape Byron Marine Park, surrounding beaches (breeding habitat for turtles) and the rocky reefs around Julian Rocks (Map 1). However, pelagic species such as sharks, turtles and whales or reef–associated species such as protected fish, sharks and turtles are considered unlikely to occur in the Belongil estuary due to the lack of suitable habitat and nature of intermittent connectivity between the Creek and ocean. No marine pest species are currently known from the catchment (Australian Government 2018).

Table 2.3 Marine (aquatic) species listed under the EPBC Act

Common Name	Species	NC Act[a] Status	EPBC Act[b] Status	Preferred Habitat*	Likelihood of occurrence**
Mammals					
Australian humpback dolphin [c]	*Sousa sahulensis*	V	C, M	Sheltered offshore waters near reefs and islands.	Unlikely Study area near southern extreme of distribution, no records in NSW – very unlikely in Belongil estuary.
Blue whale	*Balaenoptera musculus*	E	C, T, M	Open ocean, unlikely in coastal seas.	Unlikely Recorded offshore SE NSW –very unlikely in Belongil estuary.
Bryde's whale	*Balaenoptera edeni*	–	M	Open ocean and near coastal seas.	Unlikely Not recorded in study area, not listed in NSW. EPBC status is data deficient. very unlikely in Belongil estuary.
Dugong	*Dugong dugon*	–, E	M	Shallow coastal waters, protected bays and mangrove channels in areas	Unlikely Only incidentally known from northern

Common Name	Species	NC Act[a] Status	EPBC Act[b] Status	Preferred Habitat*	Likelihood of occurrence**
				with seagrass meadows.	NSW –unlikely to permanently occur in Belongil estuary due to lack of seagrass meadows.
Humpback whale	*Megaptera novaeangliae*	V	C, T, M	Open ocean and coastal seas, regularly observed in NSW during biannual migration.	Unlikely Species is known from Byron Bay region, but inhabits nearshore waters –unlikely to occur in Belongil estuary due to a lack of suitable habitat.
Indo-Pacific bottlenose dolphin	*Tursiops aduncus*	LC	C	Coastal and shallow offshore waters in tropics and sub-tropics, estuaries, bays.	Possible Recorded in shallow coastal waters off Byron Bay. Likely to occur offshore from the Belongil estuary or near the entrance.
Irrawaddy dolphin [d]	*Orcaella heinsohni*	V	C, M [e]	Coastal and estuarine waters, creek mouths with proximity to seagrass beds.	Unlikely Not known from northern NSW, Belongil is at southern extreme of possible distribution. Unlikely to occur in Belongil estuary due to lack of seagrass meadows.
Orca	*Orcinus orca*	–	M	Open ocean, proximity to seal colonies. More common in cold deep waters, and along continental slope and shelf.	Unlikely Recorded in all states, but most recorded sightings in southern NSW, Victoria and South Australia. Unlikely to occur in Belongil estuary due to lack of suitable habitat and food sources.
Southern right whale	*Eubalaena australis*	E	C, T, M	Antarctic ocean in summer for feeding, shallow coastal seas in winter months, deeper than 5 metres.	Unlikely Known to occur in SE NSW, and incidental sightings in nearshore waters of Byron Bay. No known breeding or aggregation site in study area –unlikely to occur in Belongil estuary due to a lack of suitable habitat.

Common Name	Species	NC Act[a] Status	EPBC Act[b] Status	Preferred Habitat*	Likelihood of occurrence**
Fish					
Black rockcod	*Epinephelus daemelii*	V	T	Occurs from southern Queensland waters to Kangaroo Island off South Australia. It prefers coral reef and rocky shoal habitat in deep water (> 50 m). Juveniles can be found in rocky habitat in estuaries.	Unlikely The black rockcod has been recorded in waters offshore of the Cape Byron Marine Park (IERM 2005)). The species is unlikely to occur in the Belongil estuary due to a lack of suitable rocky habitat for juveniles and adult fish.
Grey nurse shark (east coast population)	*Carcharias taurus*	CE	T	Around rocky islands, deep gutters, occasionally in surf zone, most common between 15 – 40 m. Spawning aggregations in NSW and southern QLD.	Unlikely Aggregates at Julian Rocks, but unlikely to occur in Belongil estuary due to lack of suitable habitat.
Giant Manta Ray	*Manta birostris*	–	M	Offshore in shallow coral reefs, rocky islands. Migrates across open oceans.	Unlikely Known to occur at Julian Rocks in the Cape Byron Marine Park. Unlikely to occur in the Belongil estuary due to lack of suitable habitat.
Reef Manta Ray	*Manta alfredi*	–	M	Coastal oceans around reefs and rocky shoals. Short migrations to follow zooplankton.	Unlikely Known to occur at Julian Rocks in the Cape Byron Marine Park. Unlikely to occur in the Belongil estuary due to lack of suitable habitat.
Porbeagle Shark	*Lamna nasus*	–	M	Deep water of the continental shelf, occasionally in coastal waters.	Unlikely Recorded along the east coast of Australia. Unlikely to occur in the Belongil estuary due to lack of suitable habitat.
Whale shark	*Rhicodon typus*	V	T, M	Planktonic feeders in open oceans and coastal seas.	Unlikely Recorded along the east coast of

Common Name	Species	NC Act[a] Status	EPBC Act[b] Status	Preferred Habitat*	Likelihood of occurrence**
					Australia. Unlikely to occur in the Belongil estuary due to lack of suitable habitat.
White shark	*Carcharodon carcharias*	V	T, M	Widely distributed throughout temperate and subtropical regions, typically inhabits inshore rocky reefs and shallow coastal bays to the outer continental shelf and slope areas to depths of 100 m.	Unlikely Occasionally recorded in Byron Bay Marine Park, however there is a lack of suitable habitat in the Belongil estuary.
Reptiles					
Elegant seasnake	*Hydrophis elegans*	–	–	Widespread in tropical Australia, scattered in northern NSW. Uses a variety of marine and estuarine habitats, including sandy substrates in less than two metres of water to depths of approximately 80 m. Sometimes found in freshwater habitats as well as estuaries.	Unlikely Although suitable habitat exists in the Belongil estuary and the Byron Bay Marine Park, the species is unlikely to occur due to the area being at the southern extreme of the distribution.
Flatback turtle	*Natator depressus*	V	T, M	Found only in the tropical waters of northern Australia, Papua New Guinea, without a global distribution. Nesting is confined to Great Barrier Reef, NT and WA. Seldom found in temperate waters.	Unlikely Although habitat may occur in the greater Byron Bay area, the flatback turtle is unlikely to occur in the Belongil estuary, due to a lack of suitable habitat. The species has not been recorded within 10 km of the estuary mouth previously. Most sightings on east coast of Australia are north of Fraser Island (Robins 1995)
Green turtle	*Chelonia mydas*	V	T, M	Found around coral and rocky reefs in tropical and sub-tropical waters, near seagrass	Possible Species occurs in the waters off Byron Bay and around Julian Rocks. May occur in

Common Name	Species	NC Act[a] Status	EPBC Act[b] Status	Preferred Habitat*	Likelihood of occurrence**
				beds, as well as open water. Lays eggs on beach foredunes during summer and forages all year in marine waters. Scattered nesting in NSW but no known nesting aggregation in NSW.	estuary where water depth allows and near entrance although no previous observations or records within the estuary, unlikely to nest on beach at the mouth of the estuary.
Hawksbill turtle	*Eretmochelys imbricate*	V	T, M	Found in tropical and temperate oceans worldwide. Juveniles associated with floating marine plants. Adults forage around coral and rocky reefs in offshore waters and less frequently in near-coastal waters and seagrass beds. Nests in northern QLD, Northern Territory and Western Australia.	Unlikely Although the hawksbill turtle is found in the Cape Byron Marine Park around Julian Rocks, it is unlikely to occur in the Belongil estuary due to the lack of suitable habitat.
Leatherback turtle	*Dermochelys coriacea*	E	T, M	Pelagic, tropical to temperate oceans worldwide. Forages in mostly in open ocean, but has been recorded in coastal waters. Nesting sporadically in QLD. No nesting recorded in NSW since 1996.	Unlikely Species is commonly seen offshore eastern Australia, but is unlikely to occur in the Belongil estuary due to the lack of suitable habitat. Not known to nest on the beach at the mouth of the estuary.
Loggerhead turtle	*Caretta caretta*	E	T, M	Found around coral and rocky reefs in tropical and sub-tropical waters, near seagrass beds and muddy bays. Lays eggs on beach foredunes during summer and forages all year in marine waters. Sporadic nesting in northern NSW but no known nesting	Possible Species occurs in the waters off Byron Bay and around Julian Rocks. May occur in estuary and near entrance, sporadic nesting occurs in northern NSW but unlikely to nest in close proximity to the mouth of the estuary due to a lack of suitable habitat. Recorded nesting in

Common Name	Species	NC Act[a] Status	EPBC Act[b] Status	Preferred Habitat*	Likelihood of occurrence**
				aggregation in NSW.	Tyagarah Nature Reserve north of the Belongil Creek entrance (Australian Geographic 2016).
Olive Ridley turtle	*Lepidochelys olivacea*	E	T, M	Tropical shallow waters, no nesting on east coast of Australia. Migratory.	Unlikely Belongil estuary is at the southern most extreme of distribution. Unlikely to occur in the Belongil estuary due to the lack of suitable habitat. No previous records known.
Stokes' Seasnake	*Astrotia stokesii*	–	–	Tropical oceans, coral reefs, shallow muddy bays and tidal pools, northern Australia (QLD, WA, NT)	Unlikely Study area near southern extreme of distribution, only scattered records in NSW – considered unlikely to occur in Belongil estuary due to lack of suitable habitat.
Yellow-bellied seasnake	*Pelamis platurus*	–	–	Tropical and subtropical coastal seas, pelagic and not reef-associated.	Unlikely Unlikely to occur in the Belongil estuary due to lack of suitable habitat.

a the status of species under Queensland's *Nature Conservation Act 1992*; LC – least concern, V – vulnerable.
b the status of species under the *Environment Protection and Biodiversity Conservation Act 1999*; M – migratory, C – cetacean T – threatened.
c this species is listed under the *Environment Protection and Biodiversity Conservation Act 1999* under its previous classification, *Sousa chinensis.*
d this species is listed under the *Environment Protection and Biodiversity Conservation Act 1999* under its previous classification, *Orcaella brevirostris*.
* Sources:
Threatened Biodiversity Profile Search, NSW Government
https://www.environment.nsw.gov.au/threatenedSpeciesApp
Species Profile and Threats Database
http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl
Atlas of Living Australia
https://www.ala.org.au
** Likelihood of occurrence: L – Likely, P – Possible, U – Unlikely

Additionally, 30 pipefishes and seahorses (family Syngnathidae) are listed under the EPBC Act as marine species in Commonwealth waters. Some of these species occur in the area, or their habitat may occur in the search area. However, these species are specifically protected in Commonwealth marine waters, not in the State waters of the study area and surrounds and therefore have not been considered further, unless they were identified in species searches for the region. Two species of pipefish have been recorded in surveys Belongil

estuarine system (Table 2.4) in low abundances (i.e. single individuals). The presence of these species in the Belongil estuary has been recorded (Schnierer 1988, Parker 1996), but current status would need to be confirmed as previous recorded sightings occurred over two decades ago and only in low abundance.

2.8.2 Shorebirds

Based on the EPBC Protected Matters Search results, 13 vulnerable and 22 migrating shorebirds have been identified as occurring in the area, the latter (migratory shorebirds) relying on the estuary and mudflats as an important feeding ground en-route to breeding grounds in the arctic (Appendix A). Belongil Creek and the adjacent section of Belongil Beach provide suitable habitat for migratory and resident shorebird species. Although mudflats and sandflats within the Belongil Creek system are not extensive by the standards of most coastal waterways, they are of significance due to the relative lack of similar habitats in the local area and support a relatively high diversity of bird species over the course of a year (Appendix A). Eighty species of seabirds, shorebirds, waterbirds or wetland-associated birds have been identified within this area (Beacon 2007). The most significant species identified as occurring in the project area include the endangered, migrant little tern (*Sternula albifrons*, under the Biodiversity Conservation Act 2016 New South Wales), the near-threatened black necked stork (*Ephippiorhynchus asiaticus*) and the beach stone-curlew (*Esacus magnirostris,* listed as critically endangered under the Biodiversity Conservation Act 2016 (New South Wales)). The little tern is known to roost and breed at the mouth of Belongil Creek (see Map 8 Threatened Fauna).

The Belongil Creek entrance, the beaches north and south to the entrance and the wetlands in the Belongil catchment are not classified as RAMSAR sites. The nearest RAMSAR sites to Belongil Creek are situated in Moreton Bay approximately 100 km to the north. An area on the beach southeast of the entrance of the creek is zoned under the Local Environment Plan 1988 (Byron LEP 2014) as environmental protection scientific zone 7(j), which among visual and recreational objectives:

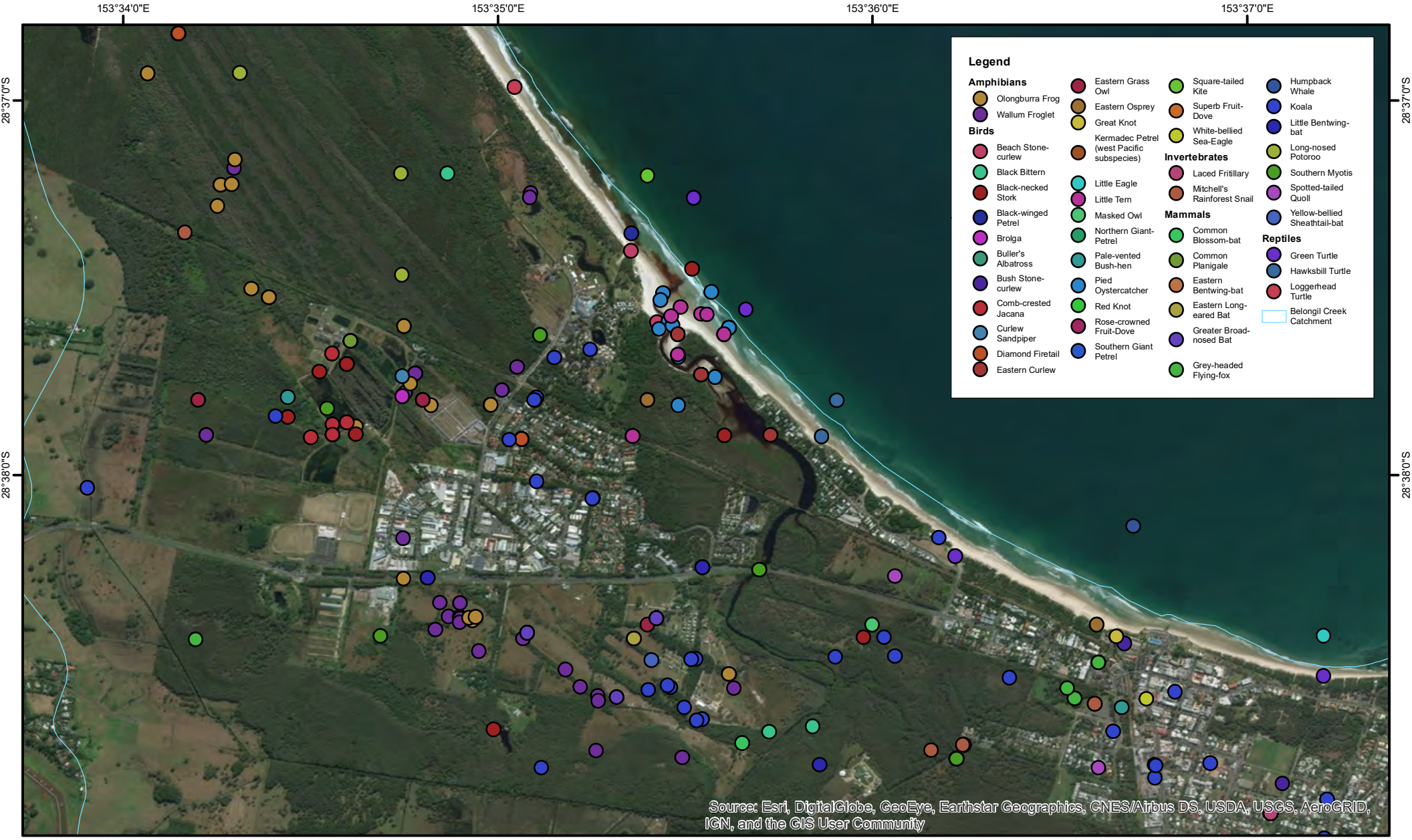
- identifies and protects areas of scientific interest,
- restricts and controls development within the zone, and
- prohibits any activity that may have a detrimental effect on the site.

The zoning highlights the importance of the beach and foreshore at the mouth of the estuary as a roosting and breeding habitat for shorebirds, noting that there are other more extensive estuarine areas and intertidal flats in the Region including the Ramsar listed wetlands of Moreton Bay.

2.8.3 Threatened Terrestrial Fauna

The nature of the Belongil Creek system allows for a variety of different habitat and forest types in relatively close proximity. The variety of habitats supports a high diversity of terrestrial fauna within the Belongil-Cumbebin drainage basin, which is described previously by Parker (1996) as extraordinary. Drainage in the catchment, changes in land-use and an increase in artificial openings of the creek mouth have favoured some fauna groups where the availability of habitat for others has decreased as a result of management of the water level and opening of the estuary.

Additional information on the variety of terrestrial fauna and fauna habitats of conservation significance is provided in Appendix A.



Belongil Estuary Opening Strategy - Existing Environment

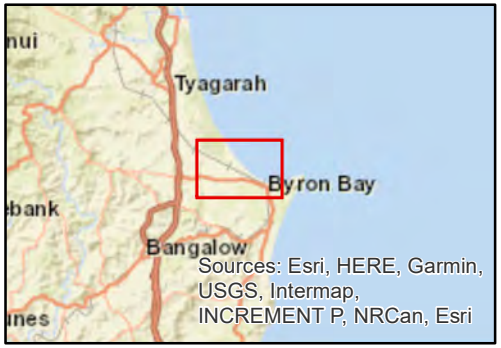
Map 8 - Threatened Fauna Observations

Data Sources
© Layers provided by Blackwood Ecological Services

Project Number: 1813
Drawn: CB, 9/12/2018
Datum: GDA 1994

0 0.225 0.45 0.9 Kilometers

N



2.9 Fish Assemblages

The estuary supports a wide range of commercially and recreationally important fisheries species (including oysters, mud crabs, prawns, and fish) and is considered to be an important nursery habitat for juvenile fish (Schnierer 1988; Parker 1998).

The Belongil estuary supports a typical fish community that is dominated by mullet (Mugilidae), whiting (Sillagonidae), bream (Sparidae), flathead (Platycephalidae), glassfish (Ambassidae) and tailor (Pomatomidae), with abundances varying strongly between the summer and winter seasons (Schnierer 1988). Many of the species found in the Belongil estuary are commonly found in the region and neighbouring ICOLL systems such as Tallow Creek (WBM 2001), and are either permanent or temporary residents of the estuary.

A total of 58 species of fish, among which are two members of the pipefish family that are listed species under the Environment Protection and Biodiversity Act (1999), have been recorded from the Belongil estuary. In a survey that included the entrance of the estuary, areas around the Ewingsdale road bridge and the Union drainage lines, Schnierer (1988) recorded 52 species of fish occurring in the system. These species include commercially and recreationally important fishery species such as mullet (Mugilidae), whiting (Sillaginidae), bream and tarwhine (Sparidae), luderick (Kyphosidae), tailor (Pomatomidae) and flathead (Platycephalide). A large proportion (88%) of targeted species were juveniles, highlighting the importance of the estuary as a nursery for fish. Approximately a quarter (23%) of the fish species caught were marine species and are typically associated more with inshore reefs, and were also recorded at nearby reefs such as Julian Rocks (Parker 1998). Only one exotic species, the mosquitofish (*Gambusia* sp.) has been recorded.

Table 2.4 Fish species recorded from the Belongil estuary

Family	Common name	Species	Distribution in estuary**	Abundance	Resident species[a]
Acanthuridae	surgeonfish[a]	*Acanthurus* sp.	Estuary mouth	low	No
Ambassidae	estuary glassfish[a, b]	*Ambassis marianus*	Estuary mouth to Cumbebin Swamp	high	Yes
Anguillidae	longfin eel[a, b]	*Anguilla reinhardtii*	Estuary mouth to Union Drain	moderate	Temporary
Antennariidae	Sargassum fish[a]	*Histrio histrio*	Estuary mouth	low	No
Apogonidae	cardinal fish[a]	*Apogon fasciatus*	Estuary mouth	low	No
Ariidae	fork-tailed catfish[a]	*Neoarius sp.*	Mid–estuary	low	Yes
Atherinidae	common hardyhead[a]	*Atherinomorus vaigiensis*	Estuary mouth	low	Yes
	Pacific blue eye[a]	*Pseudomugil signifer*	Estuary mouth	low	Yes
	slender hardyhead[b]	*Atherinomoris lacunosus*	NA	NA	NA

Family	Common name	Species	Distribution in estuary**	Abundance	Resident species[a]
Balistidae	triggerfish[a]	unidentified species	Estuary mouth	low	No
Belonidae	freshwater longtom[a]	*Strongylura krefftii*	Estuary mouth	low	Yes
Bleniidae	hairtail blenny[b]	*Xiphasia setifer*	NA	NA	NA
	oyster blenny[a]	*Omobranchus anolius*	Estuary mouth	low	Yes
Bothidae	largetooth flounder[a]	*Pseudorhombus arsius*	Estuary mouth	low	Temporary
	smalltooth flounder[a]	*Pseudorhombus jenynsii*	Estuary mouth	low	Temporary
Carangidae	silver trevally[a]	*Pseudocaranx georgianus*	Estuary mouth to mid–estuary	moderate	Temporary
Cheilodactylidae	magpie morwong[a]	*Cheilodactylus gibbosus*	Estuary mouth	low	No
Clupeidae	southern herring[a]	*Herklotsichthys castelnaui*	Estuary mouth to mid–estuary	moderate	Yes
	freshwater herring[a]	*Potamalosa richmondia*	Mid–estuary to Cumbebin swamp	low	Yes
Eleotridae	crimsontip gudgeon[a]	*Butis butis*	Estuary mouth to mid–estuary	low	Yes
	striped gudgeon[a]	*Gobiomorphus australis*	Estuary mouth to Cumbebin swamp	moderate	Yes
	empire gudgeon[a b]	*Hypseleotris compressa*	Union drain	low	Yes
	flathead gudgeon[b]	*Philypnodon grandiceps*	NA	NA	NA
Enoplosidae	old wife[a]	*Enoplosus armatus*	Estuary mouth	low	No
Gobiidae	Krefft's frillgoby[a]	*Bathygobius krefftii*	Estuary mouth	low	Yes
	crested oyster goby[a]	*Cryptocentrus gobioides*	Estuary mouth to mid–estuary	low	Yes
	compressed goby[a]	*Gobius australis*	Estuary mouth to mid–estuary	low	Yes
Kyphosidae	luderick[a]	*Girella tricuspidata*	Estuary mouth to mid–estuary	moderate	Temporary
Labridae	Guenther's wrasse[a]	*Pseudolabrus guentheri*	Estuary mouth	low	No
Monocanthidae	yellowfin leatherjacket[a]	*Meuschenia trachylepis*	Estuary mouth	low	Temporary
	chinamen leatherjacket[a]	*Nelusetta multiradiatus*	Estuary mouth	low	Temporary
Monodactylidae	diamondfish[a]	*Monodactylus argenteus*	Estuary mouth to mid–estuary	low	Temporary

Family	Common name	Species	Distribution in estuary**	Abundance	Resident species[a]
Mugilidae	goldspot mullet[a, b]	*Liza argentea*	Estuary mouth to Cumbebin swamp	high	Yes
	sea mullet[a b]	*Mugil cephalus*	Estuary mouth to Union drain	high	Temporary
	sand mullet[a b]	*Myxus elongatus*	Estuary mouth to Cumbebin swamp	high	Yes
Percichthydidae	Australian bass[a]	*Macquaria novemaculeata*	Cumbebin swamp	low	Yes
Platycephalidae	dusky flathead[a]	*Platycephalus fuscus*	Estuary mouth to Cumbebin swamp	high	Yes
Poeciliidae	gambusia[a, b]	*Gambusia* sp.	Estuary mouth	low	Yes (exotic)
Pomacentridae	lemon damsel[a]	*Pomacentrus moluccensis*	Estuary mouth	low	No
	damsel[a]	*Pomacentrus* sp.	Estuary mouth	low	No
Pomatomidae	tailor[a]	*Pomatomus saltatrix*	Estuary mouth to Cumbebin swamp	high	Temporary
Scatophagidae	striped scat[a]	*Selenotoca multifasciata*	Estuary mouth	low	No
Scorpaenidae	eastern fortescue[a]	*Centropogon australis*	Estuary mouth	low	Yes
	bullrout[a]	*Notesthes robusta*	Estuary mouth to Cumbebin swamp	moderate	Yes
Serranidae	greasy rockcod[a]	*Epinephelus tauvina*	Estuary mouth	low	Temporary
Siganidae	marbled spinefoot[a]	*Siganus rivulatus*	Estuary mouth to mid–estuary	low	Temporary
Sillaginidae	sand whiting[a]	*Sillago ciliata*	Estuary mouth to mid–estuary	moderate	Temporary
	winter whiting[a]	*Sillago maculata*	Estuary mouth to Cumbebin swamp	high	Temporary
Soleidae	narrowbanded sole[a]	*Synclidopus macleayanus*	Estuary mouth	low	Temporary
	black sole[b]	*Brachirus nigra*	NA	NA	NA
Sparidae	yellowfin bream[a]	*Acanthopagrus australis*	Estuary mouth to Cumbebin swamp	high	TE
	tarwhine[a]	*Rhabdosargus sarba*	Estuary mouth to mid–estuary	high	Temporary

Family	Common name	Species	Distribution in estuary**	Abundance	Resident species[a]
Syngnathidae	pugnose pipefish[a]	*Pugnaso curtirostris**	Estuary mouth	low	Yes
	mother-of-pearl pipefish[b]	*Venacampus margaritifer**	NA	NA	NA
Teraponidae	fourline striped grunter[a]	*Pelates quadrilineatus*	Estuary mouth to mid–estuary	low	Temporary
	eastern striped grunter[b]	*Helotes sexlineatus*	NA	NA	NA
Tetraodontidae	common toadfish[a, b]	*Tetractenos hamiltoni*	Estuary mouth	low	Temporary
	banded toadfish[a]	*Marilyna pleurosticta*	Estuary mouth	low	Temporary

a Schnierer, 1988, A report on the aquatic organisms of the Belongil Creek and swamp drains. Report submitted to the Byron Shire Council

b Parker, 1998, Fish assemblages at Julian Rocks and the adjacent waters of northern New South Wales, Australia. Australian Zoologist 31(1).

* listed species under the Environment Protection and Biodiversity Act (1999)

** Distribution in estuary:
Estuary mouth: survey sites were located at the Belongil estuary mouth downstream of the railway line
mid-estuary: survey site was located between the railway line and the Ewingsdale bridge
Cumbebin swamp: survey site was located near the Cumbebin Swamp Nature Reserve
Union drain: survey sites were located in the Union drainage system

2.10 Estuarine Invertebrates

Schnierer (1988) previously studied the composition of benthic organisms (infauna and epifauna) of Belongil Creek at sites between the entrance and the upstream drainage lines. The invertebrate community was typical of estuarine environments in sub-tropical eastern Australia, and was dominated by mollusc, crustacean, polychaete and insect species. The sites closest to the estuary mouth supported the most diverse assemblages. Total abundance of fauna was greatest in summer than in winter.

An assessment of the estuary for commercial and recreationally important fisheries is provided in the subsequent section. Commercially and recreationally important invertebrate species recorded in the Belongil estuary (Schnierer 1988) include:

- mud crab (*Scylla serrata*)
- blue swimmer crab (*Portunus armatus*),
- greentail prawn (*Metapenaeus bennettae*),
- Sydney rock oyster (*Saccostrea glomerata* (originally listed as *C. commercialis)*), and
- estuarine yabby (*Trypaea australiensis*).

2.11 Fish Habitat and Fisheries

Fish habitat is defined under the NSW *Fisheries Management Act 1994* as any area occupied, or periodically or occasionally occupied, by fish or marine vegetation (or both), and includes any biotic or abiotic component. This includes the water column, the substrate (such

as sand, mud, cobbles or reef) and other features submerged by water which are used by fish to shelter, access food (such as aquatic vegetation and algae), to breed and which provide territorial markers for migration (NSW DPI 2013). Fisheries NSW are responsible for ensuring no net loss of key fish habitats.

Key mapped fish habitat (Map 9) in the study area of the Belongil Creek between the entrance and the Ewingsdale road bridge includes:

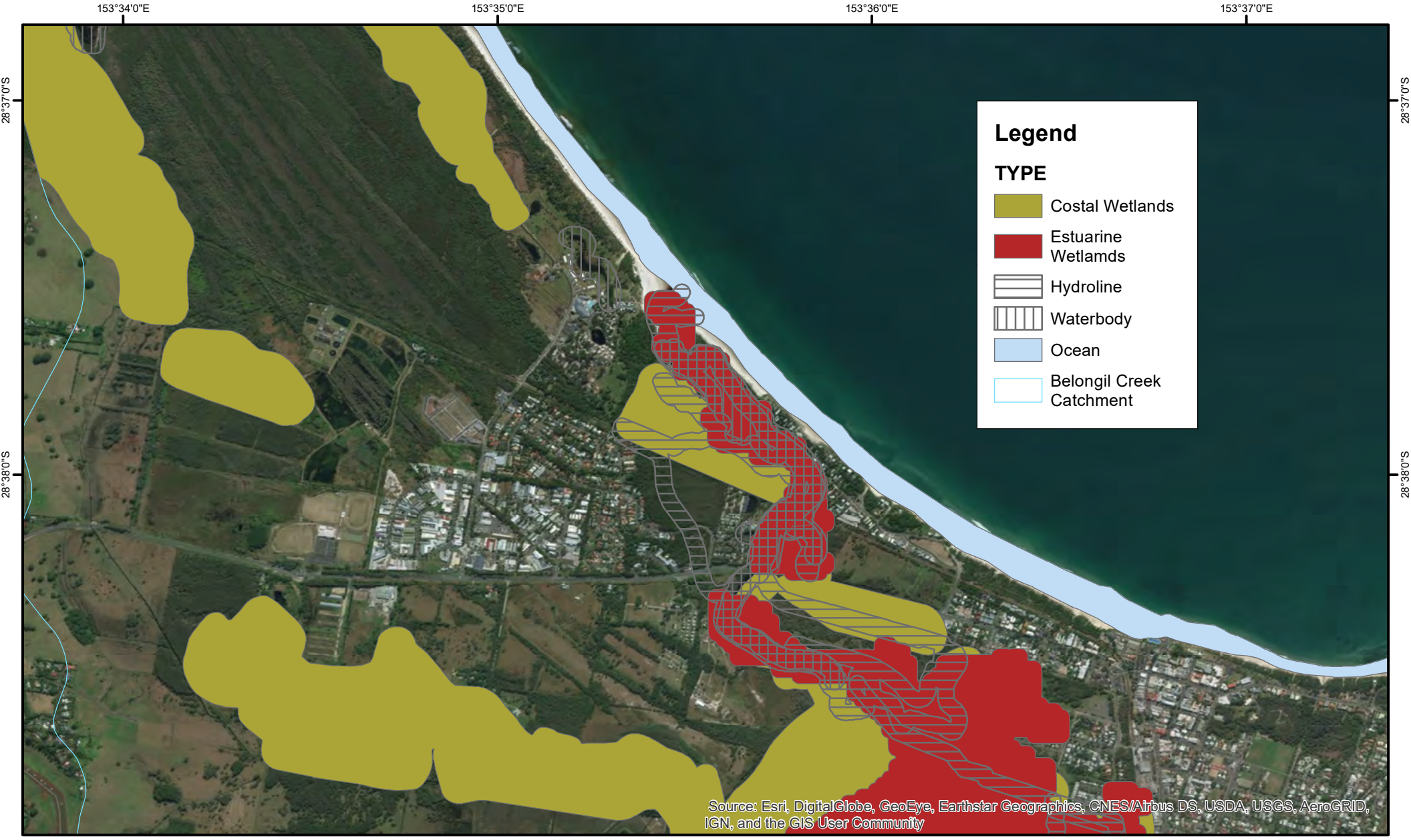
- open oceanic water, defined as extending from the intertidal zone to the oceans. This includes a range of habitats such as the water column, the continental shelf, beaches, rocky and coral reefs and seamounts. In the study area, this includes the beaches north and south of the creek entrance.

- coastal lagoons and wetlands, a large open body of saline or brackish water which has a relatively narrow permanent or intermittent connection to the sea. Many coastal lakes and lagoons alternate between being open or closed to the ocean. These are known as Intermittently Closed and Open Lakes and Lagoons (ICOLLs).

- estuarine wetlands: estuarine fish habitats where fresh water from rivers and streams mixes with the salty ocean water. This brackish water environment supports a variety of fish habitats, including mangroves, sandflats and deep pools. Estuaries provide important feeding, spawning and nursery sites for many aquatic animals. Many invertebrate (crabs and mosquitoes) and vertebrate groups (fish) rely on estuarine water to complete their life cycles and others, such as migratory shore birds, visit estuaries to feed and rest.

The majority of the fish habitat in the Belongil Creek catchment consists of estuarine and coastal wetlands that encompass the creek and drains themselves, and the surrounding low lying areas (Map 9). The entrance of the creek and the coastal beaches are zoned as oceanic. Only a very small section of coastal lagoon is mapped to the east of the Belongil Creek entrance.

No commercial fisheries (for species such as rock oysters, mud crab, whiting or mullet, etc) exist in the Belongil Creek estuary. Recreational fishing is not allowed in the Belongil Creek estuary as it is zoned as a Special Purpose Zone in the Cape Byron Marine Park (see Section 2.7).



Belongil Estuary Opening Strategy - Existing Environment

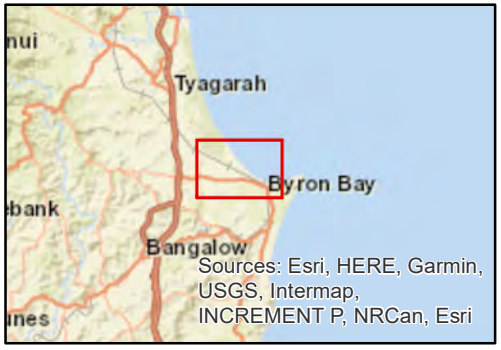
Map 9 - Key Fish Habitat

Data Sources
© Layers provided by Byron Shire Council

Project Number: 1813
Drawn: CB, 9/12/2018
Datum: GDA 1994

0 0.225 0.45 0.9 Kilometers

N



3 Assessment of Proposed Opening Strategy

We understand that the proposed opening strategy will continue the practice of the Draft Opening Strategy (Byron Shire Council 2005). The Draft Opening Strategy (Byron Shire Council 2005) for Belongil Creek provides guidance for the sustainable management of the creek's entrance. It seeks to achieve the entrance management objective of the adopted Belongil Estuary Management Plan, which was

"To ensure that the estuary mouth is opened in such a way as to maintain the health and vigour of riparian vegetation, the biodiversity of aquatic organisms and meet the EPA water quality standards (i.e. protects aquatic ecosystems and allows safe swimming in the estuary)"(BSC, 2001).

Under the current and proposed strategy, the license holder (Byron Shire Council) is permitted to mechanically open the blocked entrance of Belongil Creek once the water level reaches a pre-defined trigger level of 1 m AHD at the bridge over Ewingsdale Road.

Artificial opening of the creek entrance is achieved by excavating a channel perpendicular to the shoreline to allow creek water to flow into the ocean.

An assessment of the potential impacts to the flora and fauna of Belongil Creek will be completed at a later date.

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Appendix A Belongil Creek Entrance Opening Strategy – Terrestrial Ecology Assessment

BLACKWOOD ECOLOGICAL SERVICES

DRAFT
Belongil Creek Entrance Opening Strategy Terrestrial Ecology Study

September 2018

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NOTE

We have prepared this report for Byron Shire Council, Environmental Service Professionals and Alluvium Consulting for the specific purpose only for which it is supplied. This report is strictly limited to the Purpose and the facts and matters stated in it and does not apply directly or indirectly and will not be used for any other application, purpose, use or matter. In preparing this report we have assumed that all information and documents provided to us by the Client or as a result of a specific request or enquiry were complete, accurate and up-to-date. Where we have obtained information from a government register or database, we have assumed that the information is accurate. Where an assumption has been made, we have not made any independent investigations with respect to the matters the subject of that assumption. We are not aware of any reason why any of the assumptions are incorrect.

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Document Verification

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BLACKWOOD ECOLOGICAL SERVICES

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Background

Blackwood Ecological Services has been engaged by Ecological Service Professionals Pty Ltd to complete a terrestrial ecology study to form part of the Belongil Creek Entrance Opening Strategy study. The study is to include assessment of vegetation communities above HAT (Highest Astronomical Tide) and terrestrial fauna habitats within the study area.

1.2 Belongil Creek Entrance Opening Strategy study

The specific objectives of the Entrance Opening Strategy are to develop a long-term entrance opening strategy that:

1. Formalises the need and Council's responsibilities for entrance management within the context of applicable legislation and determines key responsibilities for management of the entrance including a procedure to be initiated by Council (and other authorities if applicable) for entrance operations including entrance breakouts.
2. Minimise interference with natural entrance opening processes and minimise associated impacts on ecological processes; and conserves or enhances the biological diversity and flora and fauna communities of the ICOLL system.
3. Investigates and compiles a list of opening triggers, needs, requirements and environmental triggers;
4. Informs and educates Council and the community on entrance opening, this should include discussion on how it can or can't protect the town from ocean level rise caused by Climate Change
5. Accommodates future climate change, sea level rise in particular;
6. Investigates and assesses and minimises risks to public and private safety associated with inundation of associated infrastructure;
7. Assesses effects of increases in effluent flow from West Byron Sewage Treatment Plant, in accordance with proposed upgrades to the plant and including proposed changes to effluent flow paths;
8. Details an operational procedure for monitoring of the creek entrance. Provides a mechanism for review and update of the strategy (when required) and considers options for an adaptive management approach due to uncertainties in climate. Considerations may include the use of decision –making triggers.
9. Considers how water quality could be improved in the catchment, including novel approaches such as constructed Oyster Reefs;
10. Investigates the benefits and issues of a 'Tripper Wall' as a solution to erosion and entrance creep issues at the mouth;
11. Determines key responsibilities for management of the entrance through and Environmental Management Plan;
12. Provides an information and education source for the greater community in an effort to gain community support for the entrance management.

1.3 Terrestrial ecology study

The aim of this study is to provide an assessment of existing vegetation communities and fauna habitats within the Belongil Creek catchment and the extent to which these communities, habitats and fauna populations may be affected by different entrance opening strategies that may be considered for Belongil Creek. This report includes:

- Review of existing literature of technical information/studies and plans on the Belongil Creek estuary, and Council's existing environmental data sets.
- A description of vegetation community types present within the Belongil Creek catchment.
- A description of fauna habitat types present within the Belongil Creek catchment.
- A review of Threatened ecological communities and flora and fauna species known from, or considered likely to occur in, the Belongil catchment.
- Consideration of potential ecological impacts associated with different entrance opening strategies considered as part of the overall study.

2 LITERATURE REVIEW

2.1 Previous ecological reports

Relevant ecological assessments, survey reports, management plans and other studies have been reviewed in the course of this assessment. A summary on the findings of these studies is provided below.

2.1.1 Ecological assessments

Australian Wetlands Consulting (2010) **Ecological Assessment. West Byron Project.** This Ecological assessment was completed for a 58ha area of land bordering Belongil Creek on the southern side of Ewingsdale Road. The site includes large areas of cleared land as well as patchy growth of native vegetation communities including Coastal swamp forest dominated variously by Broad-leaved paperbark, Swamp oak and Swamp mahogany, Fernland, Cypress pine forest, Brushbox forest, Wallum sand heath, Freshwater wetland, Saltmarsh and Mangrove.

This assessment recorded one Threatened flora species (planted Durobby trees) and 13 Threatened fauna species (including from prior surveys): Olongburra frog, Wallum froglet, Black bittern, Masked owl, Osprey, Common blossom bat, Eastern and Little bentwing bat, Greater broad-nosed bat, Grey-headed flying-fox, Eastern long-eared bat, Yellow-bellied sheathtail bat and Koala.

BEACON (2007) **Belongil Estuary Seabird and Shorebird Management Plan.** This plan was produced in response to Council's DCP No. 18 that identified a Seabird Habitat Precinct of 19.6ha located in the mouth of the Belongil Creek estuary, upstream from the coastal mean high water mark to the railway bridge. BEACON conclude that the Belongil estuary remains the most significant roosting and breeding area for shorebirds and seabirds in Byron Shire with 80 seabirds, shorebirds, waterbirds and other wetland associated birds having been identified in various surveys within the shorebird area. The most significant species are the endangered Little Tern, Black-necked Stork, and Beach Stone-Curlew. Thirteen species are identified as Vulnerable to extinction: Lesser (Mongolian) Sand-Plover, Sanderling, Terek Sandpiper, Great Knot, Greater Sand Plover, Sooty Tern, Pied Oystercatcher, Sooty Oystercatcher, Osprey, Black Bittern, Australasian Bittern, Bush-hen and Brolga.

Blackwood Ecology (2011) **Ecological Assessment & Vegetation Management Plan. Lot 237 DP 755695 Ewingsdale Road, Byron Bay.** Blackwood Ecology prepared an Ecological assessment and Vegetation Management Plan for a proposed Environmental Facility at Lot 237 DP 755695, Ewingsdale Road, Byron Bay. Three vegetation types were identified on the Subject site. Community One consists of an open canopy of Swamp oak with occasional Broad-leaved paperbark. There is an understorey of mixed sedges and rushes including *Baumea juncea*, *Phragmites australis* and Salt rush. Community two has an open canopy of Broad-leaved paperbark with occasional Swamp oak and midstorey shrubs including Coast wattle, Blueberry ash and Psydrax. Community three is characterised by dense growth of sedges and rushes including *Baumea juncea*, *Phragmites australis* and Salt rush as well as some patches of Mangrove fern. There are scattered Swamp oak and some Broad-leaved paperbark throughout.

No Threatened (NSW TSC Act 1995; Commonwealth EPBC Act 1999) or ROTAP (Briggs & Leigh 1995) flora species were recorded and no Threatened fauna species were recorded.

Integrated Ecosystem Research & Management (2005) **Belongil Creek Entrance Opening Strategy. Review of Environmental Factors.** IERM produced an REF that included a synthesis of the available ecological data and literature for the Belongil catchment. IERM note that much of the low lying (Holocene age) Belongil catchment would have been a mosaic of Broad-leaved paperbark forest, freshwater swamps, Swamp oak forest on slightly higher or more exposed ground, rainforest patches (often with Melaleuca) and saltmarsh. Boundaries would have been dynamic over time with shifts due to climate, fire or changes in the hydrology of the stream or other forces. IERM consider the potential occurrence of Threatened fauna species known from the locality and their sensitivity to changes in the entrance opening strategy.

Landmark et al (1999) **Byron Flora and Fauna Study.** Landmark et al. (1999) map and discuss vegetation patterns, threatened species and weed invasion in the Belongil catchment as part of a Byron Shire-wide study. Vegetation classification units of Landmark *et al.* (1999) for Belongil Creek are broadly similar to those of Parker (1996). The Byron Flora and Fauna Study concludes that Belongil is best characterised as an ecological area of significance due to the presence of large native vegetation patches. It notes the presence of one threatened flora species and five threatened fauna species, two of which (Comb-crested jacana and Beach stone-curlew) are of limited occurrence in the Shire known from less than 10 locations.

The ecological significance attributes of Belongil are based on:

- Diversity of vegetation types;
- Relative lack of ecological survey effort (at the time of the study in 1999);
- Presence of riparian vegetation and
- Proximity to a protected area or areas.

Parker, P. (1996) **A Biologic Profile of the Belongil Estuary.** Parker (1996) describes seven vegetation 'associations', based on the floristic/structural classification of Walker and Hopkins (1990). The Parker communities are:

- Littoral rainforest
  Cupaniopsis anacardioides (Tuckeroo), *Acronychia imperforata* (Beach Acronychia), *Banksia integrifolia* (Coast Banksia) simple notophvll mid-high to tall forest
- Swamp forest
  1. *Melaleuca quinquenervia* (Broad-Leaved Paperbark), *Casuarina glauca* (Swamp Oak), *Phragmites australis* (Common Reed) mid-high to tall woodland to closed forest
  2. *Casuarina glauca*, *Juncus krausii* (Maritime Rush) ± *Acrostichum speciosum* (Mangrove Fern) mid-high to tall open to closed forest
- Mangrove forest
  Avicennia marina (Grey Mangrove), *Aegiceras corniculatum* (River Mangrove) mid-high open to closed (mangrove) forest
- Frontal dune complex
  Banksia integrifolia, *Casuarina equisitifolia* (Horse-Tail Oak), *Acacia sophorae, Chrysanthemoides monilifera* spp *rotundata* (Bitou Bush) mid—high woodland to open forest
- Grassland
  1. *Juncus krausii*, *Phragmites australis*, *Acrostichum speciosum* tall closed grassland
  2. *Sporobolus virginicus* (Marine Couch), *Juncus krausii* low to tall closed sod grassland

The *J. kraussi/P. australis/A. speciosum* and *S. virginicus* communities make up saltmarsh vegetation. There are areas of *Baumea juncea* sedgeland as well.

Parker (1996) recorded five threatened plant species listed in the schedules of the NSW Threatened Species Conservation Act, 1995 within the Belongil catchment. Four are from littoral rainforest: Stinking Cryptocarva (*Cryptocarya foetida*); Red Lilly Pilly (*Syzygium hodgkinsoniae*); Durroby (*Syzygium moore*i); and Arrowhead Vine (*Tinospora tinosporoides*). *C. foetida* was recorded from the vicinity of the eroding littoral rainforest at the mouth of the Creek,.

The other and most significant species recorded by Parker (1996) is the Swamp Orchid (*Phaius tancarvilleae*) in the Cumbebin Swamp in association with Melaleuca.

Parker, P. & Pont, D. (2001) **Belongil Estuary Study and Management Plan**. This study listed lists 55 threatened fauna species which have been recorded or are likely to occur in the Belongil estuary catchment. These include one snail (Mitchell's rainforest snail – *Thersites mitchellae*), 2 frogs (Wallum froglet – *Crinia tinnula*; Wallum treefrog – *Litoria olongburiensis*), 34 birds and 19 mammals (including 14 bat species). Vegetation community descriptions are generally based on those of Parker (1996) as described above.

Peter Parker Environmental Consultants Pty Ltd (2013) **North Byron Beach Resort. Central Facilities. Flora and Fauna Assessment**. This report relates specifically to the proposed development of facilities within the existing managed area of the North Byron Beach Resort (formerly Becton) site. It includes vegetation mapping and flora and fauna records from previous assessments on the site. The assessment maps 1.8ha of Littoral rainforest on the northern side of the Belongil Creek mouth as well as various Swamp sclerophyll forest, shrubland/sedgeland and saltmarsh vegetation communities. The report shows the location of records of Stinking Cryptocarya, with these records located within the interior and western edge of Littoral rainforest and Swamp sclerophyll forest over 70m from the creek edge.

WBM Oceanics (2000) **Tallow and Belongil Ecological Studies**. This comprehensive study provides detailed data on existing environmental conditions in Belongil Creek as well as Tallow Creek and Jerusalem Creek, including water and sediment quality, vegetation, aquatic and terrestrial fauna and water, salt and nutrient budgeting. This study includes a list of bird species recorded from Belongil Creek which includes the Osprey, Pied oystercatcher and several migratory shorebird species.

WetlandCare Australia & Australian Wetlands (2004) **Draft Restoration Strategy. Belongil/Cumbebin Wetland Complex. Part 1 – Technical Review**. The Restoration Strategy of the Belongil-Cumbebin Wetland complex is part of the Northern Rivers Catchment Management Board (NRCMB) strategy to provide better management of the natural resources within the Northern Rivers catchment. The strategy summarises flora and fauna records from previous reports. The report notes that Davis (2001) listed the number of plant species found in association with the Melaleuca wetlands in the Study area as: 32 trees, 4 shrubs, 2 Eucalyptus or swamp box trees, 1 palm tree, 1 casuarina, 2 tree ferns, 6 figs, 10 reeds, 3 grasses, 5 ground ferns, 4 epiphyte ferns, 1 moss, 2 orchids, 12 herbs, 12 vines, 1 cunjevoi, 6 others (including liverwort, grass trees, broad-leaved palm-lily, and narrow-leaved palm-lily, and mistletoe).

The strategy notes that Davis (2001) supported Bolton's (2001) assessment that paperbark wetlands were once extensive across the Belongil floodplain and refers to surveyors' field notes from the early 1900s to support this conclusion. BEACON (1981) estimate that these wetlands were reduced by about two thirds of the original area by 1981 due to clearing for agriculture.

None of Davis's (2001) individual study sites were considered to have as high a level of connectivity as a pristine wetland. Drains affected every study site and not only altered the natural hydrology of wetlands, but their presence was also considered a major barrier to the movements of non- flying terrestrial animals. Only one site was far enough from roads to be considered unaffected by this type of barrier. The presence of weeds was the other main indicator (94% of sites) signifying the wetlands' reduced ability to perform their ecological functions.

3 VEGETATION COMMUNITIES

3.1 Introduction

The Belongil Creek catchment supports a diversity of vegetation community types typical of low-lying and seasonally inundated coastal areas on the NSW north coast. Major vegetation communities present (generally following Keith, 2006) consist of:

- Coastal swamp forest dominated by Broad-leaved paperbark
- Coastal swamp forest dominated by Swamp oak
- Littoral rainforest
- Saltmarsh
- Mangrove swamp
- Coastal dune mixed scrub
- Maritime grasslands on coastal dunes
- Coastal freshwater lagoons

The majority of these vegetation community types are protected as Threatened Ecological Community (TEC) types on the Biodiversity Conservation Act 2016. Smaller areas of Coastal heath swamp and Wallum sand heath occur in the northern part of the catchment. Vegetation communities in the catchment have been subject to varying degrees of disturbance as a result of clearance, drainage, weed invasion, fragmentation and other factors.

3.2 Vegetation communities

3.2.1 Coastal swamp forest dominated by Broad-leaved paperbark

Much of the low lying (Holocene age) Belongil catchment would have been a mosaic of *Melaleuca quinqenervia* forest, freshwater swamps, *Casuarina glauca* forest on slightly higher or more exposed ground, rainforest patches (often with *Melaleuca*) and saltmarsh. Boundaries would have been dynamic over time with shifts due to climate, fire or changes in the hydrology of the stream or other forces (IERM 2005).

Melaleuca quinqenervia forest is the dominant native vegetation community in low-lying areas with minimal saline influence, forming relatively extensive patches in the catchment and grading into freshwater wetland and heathland communities within Tyagarah nature reserve. *Melaleuca quinqenervia* also occurs as individual trees and small patches within grassland in flood-prone areas and localised drainage swales. Swamp mahogany occurs in relatively low numbers within this community with other common secondary species including Pink Euodia, Cabbage palm, Rainbow fern and Phragmites.

Artificial drainage of backswamp areas in the Belongil-Cumbebin system since the early 20th century has increased the hydrologic connectivity between the swamp and the estuary, resulting in a net lowering of ground and surface water levels (Talau, 2002 in IERM 2005). Surface drains reduce the time and spatial extent of ponding in the backswamps during the wet season, by increasing the hydraulic potential to transport water to the estuary (IERM 2005). These factors are likely to have

led to Swamp sclerophyll forest on the margins being gradually replaced by "drier" community types.

3.2.2 Coastal swamp forest dominated by Swamp oak

Swamp oak forest occurs in close association with *Melaleuca quinqenervia* forest and in relatively monospecific stands. It is most common in slightly drier areas and on drain margins. Some larger patches of Swamp oak forest occur west of Ewingsdale Road. *Juncus krausii* and Mangrove fern are common understorey species in this community.

3.2.3 Littoral rainforest

Littoral rainforest is present on the northern side of the creek entrance. Parker (2013) mapped an area of 1.8ha of this community type. Common species within this community include Tuckeroo, Beach acronychia and Coast banksia. The Threatened species Stinking cryptocarya occurs within this community.

Erosion of the small area of littoral rainforest at the entrance is evident now due to bank undercutting and this process has been ongoing for some time (IERM 2005).

3.2.4 Saltmarsh

Saltmarsh communities are discussed in detail in the aquatic ecology report (ESP 2018).

3.2.5 Mangrove swamp

Mangrove communities are discussed in detail in the aquatic ecology report (ESP 2018).

3.2.6 Coastal dune mixed scrub

Small linear stands of mixed Coastal dune scrub occur along the frontal dune of Belongil Spit as well as north of the creek entrance. Common species include Coast banksia and Coast wattle as well as the introduced Horsetail she-oak and Bitou bush.

3.2.7 Maritime grasslands on coastal dunes

Dune grassland is typically sparse and open on sand seaward of the frontal dune, with Spinifex, Goat's foot convolvulus and Pigface typically grading into Coast wattle thickets further up the dune. Bitou bush is an occasional occurrence.

3.2.8 Coastal freshwater lagoons

More extensive areas of freshwater wetland occur in low lying swales north of Belongil Creek. This community type has also been mapped in the modified wetland system of the West Byron Sewage Treatment Plant (STP).

3.3 Weeds

A relatively high diversity of exotic weed species occurs throughout the Belongil catchment although ongoing weed control and bush regeneration efforts have controlled the spread of exotic species in many parts of the catchment. Saline influence in the lower part of the creek prevents or restricts the spread of weeds in proximate areas. Camphor laurel is a common weed tree in the Shire and, in the Study area, occurs generally as isolated trees within Broad-leaved paperbark forest or in open situations. There are few of the extensive stands of Camphor laurel that are common further inland on previously cleared land. Lantana is another common weed that has limited presence within the Study area. Groundsel bush can persist in saltmarsh and swamp sclerophyll communities and is present in the lower catchment. Salvinia is present in low densities in drains upstream of Ewingsdale Road.

Weeds of Broad-leaved paperbark forest include Umbrella tree, Broad-leaved pepper tree, Winter senna, Glory lily, Singapore daisy, Ground asparagus and a range of garden escapees that often dominate the edges of this community type. Swamp oak forest features some of these same weed species which are typically present at a lower density.

In rainforest areas Camphor laurel, Ground asparagus and Umbrella tree may be present and invasive vines such as Madeira vine and Passionfruit vines require regular control. Dune scrub grows in conditions often unfavourable for most weed species although Coastal morning glory is an everpresent invasive vine. Bitou bush was introduced to the dune system as a dune stabiliser and has spread prolifically along the NSW coast. This species has been subject to intensive control efforts in recent years and its distribution has been substantially reduced in many places.

Weeds within Tyagarah Nature Reserve are subject to regular control although the Draft Plan of Management (OEH 2016) notes that weeds including Crofton weed, Camphor laurel, Bitou bush, Groundsel, Lantana and Coast tea-tree are all occasional to common and a number of other weed species occur at lower denstities.

4 FAUNA HABITATS

4.1 Introduction

Closely associated with the distribution of vegetation communities, the Belongil Creek catchment provides the following major habitat types:

- Freshwater, brackish and estuarine aquatic habitats.
- Intertidal sandflats and mangrove communities.
- Saline influenced saltmarsh and rushland communities.
- Swamp sclerophyll forest dominated by Swamp oak.
- Swamp sclerophyll forest dominated by Broad-leaved paperbark, including areas with a Cabbage palm and Pink-flowered doughwood midstorey.
- A 1.8ha patch of littoral rainforest at the creekmouth.
- Freshwater wetlands.
- Periodically inundated grasslands.

Parker (1996) provides a discussion on fauna assemblages in the Belongil Estuary, concluding that "the biodiversity of terrestrial fauna within the Belongil-Cumbebin drainage basin is extraordinary". The Belongil system contains a diversity of fauna habitats in relatively close proximity. Drainage in the catchment, changes in land-use and an increase in artificial openings of the creekmouth have favoured some fauna groups whereas the availability of habitat for others has decreased.

This section provides a general discussion of habitat types for the various terrestrial vertebrate fauna groups. The following section discusses specific habitat resources available for Threatened fauna.

4.2 Amphibians

The Belongil catchment represents relatively good quality habitat for native frogs. Saline influence and past disturbance may limit the suitability of habitats for several species. Areas of Swamp sclerophyll forest provide habitat for a range of tree frog species such as the Dwarf green tree-frog (*Litoria fallax*), Dainty green tree-frog (*Litoria gracilenta*), Green tree-frog (*Litoria caerulea*) and Peron's tree-frog (*Litoria peronii*). Burrowing frogs such as the Scarlet-sided pobblebonk (*Limnodynastes terraereginae*) and Ornate burrowing frog (*L. ornatus*) may also occur.

Habitats in the Cumbebin Swamp, Tyagarah Nature Reserve and wider Belongil catchment provide habitat for acid frogs including the Threatened Wallum sedge-frog (*Litoria olongburensis*) and the Wallum froglet (*Crinia tinnula*).

Frogs that occur in rainforest habitats at higher elevation, such as the barred frogs, are unlikely to occur. Cane toads are relatively common in the area and are likely to occur throughout.

4.3 Reptiles

Areas of Swamp sclerophyll forest provide habitat for a range of reptiles and the catchment provides a mosaic of varying habitat types that together provide a diversity of habitat niches for reptiles. Common species include: Green tree snake; Brown tree snake; Carpet python; Red-bellied black snake; Brown snake; Yellow-faced whip snake; Eastern water dragon; Bearded dragon; Lace monitor and a number of smaller skinks.

Marine turtles are common in coastal waters although nesting events on beaches in the locality are relatively rare.

4.4 Birds

However, bird diversity in the Belongil catchment over the course of a year is particularly high due to the close proximity of a variety of habitat types including sand and mudflats, ocean beaches, coastal heathlands, swampland, sclerophyll forest, wetland, open pasture and beachfront.

Nectarivorous birds such as honeyeaters and lorikeets move locally in response to changes in the availability of nectar and or pollen. Extensive areas of *Melaleuca quinquenervia* forest provide a good forage resource for these species when in flower.

Many insectivorous birds from higher latitudes spend winter in the locality visit the catchment seasonally or periodically. These include species such as the Fantail cuckoo, Rainbow bee-eater, Tree martin, Black-faced cuckoo-shrike, Cicada bird, Golden and Rufous whistler, Rose robin, White-throated gerygone, Silvereye, Olive-backed oriole and Spangled drongo.

Birds associated with permanent watercourses and wetland areas such as bitterns, rails and the Bush hen occur in the riparian and swampland margins of Belongil Creek. The catchment does not support a large number of mature trees with large hollows but may provide forage habitat for hollow-nesting birds that occur in areas of Blackbutt forest in the wider locality.

The Threatened Eastern osprey and White-bellied sea-eagle both forage over the Belongil Creek system.

Belongil Creek and the adjacent section of Belongil Beach provide suitable habitat for migratory and resident shorebird species. Although mudflats and sandflats within the Belongil Creek system are not extensive by the standards of most coastal waterways, they are of significance due to the relative lack of similar habitats in the local area and support a relatively high diversity of bird species over the course of a year.

Pied oystercatchers may nest in the dune system close to the Belongil Creek entrance. Little terns have nested in this area in the past and an area of the dunes south of the Belongil Creek entrance is managed as a bird nesting area to encourage future breeding events.

4.5 Mammals

A range of mammal species occur in the coastal strip between Tyagarah in the north and Broken Head to the south. Rare mammals that occur in heathland habitats in the locality, such as the Eastern chestnut mouse and the Long-nosed potoroo, may persist within Tyagarah Nature Reserve.

The Swamp wallaby, Short-beaked echidna, Northern brown bandicoot, Brown antechinus and Melomys are all widespread within the Study area. The Common brushtail and Ringtail possum are also common.

Koalas are regularly recorded within areas of suitable habitat in the catchment. Koalas have little reliance on habitats subject to inundation although Swamp mahogany trees are a preferred feed tree and often occur in association with Broad-leaved paperbark.

A diversity of microchiropteran bat species occur in the locality, although roosting habitat in the form of caves and hollow-bearing trees is relatively rare. The Grey-headed and Black flying-fox forage in various vegetation community types during peak flowering and fruiting times. The Common blossom bat is a relatively common occurrence.

5 THREATENED SPECIES ASSESSMENT

5.1 Introduction

A large number of Threatened species[1] are known from the Belongil catchment, are occasional visitors to areas within the Belongil Creek catchment or are considered possible occurrences based on records from similar habitats in the wider locality.

5.2 Terrestrial flora

The NSW Atlas of NSW Wildlife produces records for a search area of 10km x 10km. The following **TABLE 1** includes records based on an analysis of Threatened species locations within this search area, with species included in the table where the Atlas shows records located within, or within close proximity to, the Belongil catchment.

[1] Includes species listed as Threatened on the Schedules of the NSW Biodiversity Conservation Act (2016) and/or Commonwealth Environment Protection and Biodiversity Conservation Act (1999).

BLACKWOOD ECOLOGICAL SERVICES

TABLE 1 THREATENED FLORA AND ENDANGERED ECOLOGICAL COMMUNITIES KNOWN FROM THE STUDY AREA

Scientific name	Common name	BC status	EPBC status	Parker (1996)	NPWS data base	Notes
Acronychia littoralis	Scented Acronychia	E	E		x	The Atlas of NSW Wildlife shows records of this species close to the township of Byron Bay. May occur in littoral rainforest habitats.
Archidendron hendersonii	White Laceflower	V			x	May occur in littoral rainforest habitats.
Arthraxon hispidus	Hairy joint grass	V	V		x	Know from recently grazed grassy wetland habitat south of Ewingsdale Road.
Cryptocarya foetida	Stinking Cryptocarya	V	V	x	x	Known from littoral rainforest habitat near the creek mouth.
Marsdenia longiloba	Slender Marsdenia	E	V		x	The Atlas of NSW Wildlife shows records of this species close to the township of Byron Bay.
Phaius tancarvilleae *Phaius australis*	Swamp Orchids	E	E	x	x	Potential occurrence in wetter heathland and heathy swampland habitats.
Syzygium hodgkinsoniae	Red Lilly Pilly	V	V	x	x	The Atlas of NSW Wildlife shows records of this species around Tyagarah Nature Reserve. May occur in littoral rainforest habitats.
Syzygium moorei	Durobby	V	V	x	x	Several records of planted specimens in the catchment.
Tinospora tinosporoides	Arrowhead Vine	V		x	x	Relatively common in rainforest patches in the locality.
Coastal Saltmarsh in the NSW North Coast, Sydney Basin and South East Corner Bioregions		E	V	x	x	Patchy growth on the margins of Belongil Creek closer to the creek mouth.
Freshwater wetlands on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions		E	-	x	x	Freshwater wetlands occur within Tyagarah Nature Reserve and the West Byron STP with isolated patches elsewhere.
Littoral rainforest in the NSW North Coast, Sydney Basin and South East Corner bioregions		E	CE	x	x	Small patch on the northern side of Belongil Creek closer to the creek mouth.
Lowland Rainforest on Floodplain in the New South Wales North Coast Bioregion		E	CE		x	Isolated patches in the upper catchment.

Scientific name	Common name	BC status	EPBC status	Parker (1996)	NPWS data base	Notes
Swamp sclerophyll forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions		E	-	x	x	The dominant native vegetation type on low-lying land with minimal saline influence.
Coastal cypress pine forest in the NSW North Coast Bioregion		E	-	x	x	Small patches present in the West Byron URA (Australian Wetlands 2010).
Subtropical coastal floodplain forest of the NSW North Coast Bioregion		E			x	Largely cleared but some elements of this community remain as isolated trees and small patches of vegetation.

5.3 Terrestrial fauna

Parker & Pont (2001) present a table of Threatened terrestrial fauna known from or considered possible occurrences in the study area. **TABLE 2** includes these species together with a number of additional species known from NPWS database records in the catchment area or otherwise considered possible occurrences.

TABLE 2
THREATENED TERRESTRIAL FAUNA KNOWN FROM OR CONSIDERED POSSIBLE OCCURRENCES IN THE STUDY AREA

Scientific name	Common name	NSW status	EPBC status	Parker & Pont (2001)	NPWS database	Notes
Invertebrates						
Thersites mitchellae	Mitchell's rainforest snail	E	CE	x	x	Mitchell's rainforest snail is known from several locations around the fringes of Cumbebin wetland. The local population of Mitchell's rainforest snail is likely to rely on a relatively narrow band of habitat on the wetland margins as sites where the snail is generally found are located on slightly elevated ground on the margins of coastal wetlands (NPWS 2001).
Petalura gigantea	Giant dragonfly	E				This species has been recorded from the Suffolk Park area (Byron Shire Council 2004). It is not known from the Belongil catchment. Suitable permanent freshwater wetlands occur in Tyagarah Nature Reserve to the north and Cumbebin and Belongil wetlands should also provide areas of suitable habitat for this species.
Amphibians						
Crinia tinnula	Wallum froglet	V		x	x	The Wallum froglet was considered by Parker & Pont (2001) to be "relatively common in heath and fernland of Tyagarah Nature Reserve and Cumbebin Swamp". This species is also known from the West Byron Sewage Treatment Plant (Fowler 2004) and from the West Byron Urban Release Area (AWC 2010).

Scientific name	Common name	NSW status	EPBC status	Parker & Pont (2001)	NPWS database	Notes
Litoria olongburensis	Olongburra Frog	V	V	x	x	Parker & Pont (2001) note that the Wallum sedgefrog has been recorded "from Wallum habitat in heath and fernland of the Cumbebin". This species is also known from the West Byron Sewage Treatment Plant (Fowler 2004) and from the West Byron Urban Release Area (AWC 2010).
Reptiles						
Caretta caretta	Loggerhead turtle	E	E			These turtle species occur in the waters off Byron Bay and are relatively common around Julian Rocks. These turtles generally nest in warmer climates but nesting events in this part of their range do occur.
Chelonia mydas	Green Turtle	V	V		x	
Birds						
Anseranas semipalmata	Magpie Goose	V		x		Rare occurrence in wetland habitats in the locality.
Grus rubicunda	Brolga	V		x	x	These species are occasional visitors to wetland habitats in the Belongil catchment. They are adapted to take advantage of temporally inundated floodplain habitats (including brackish environments), including grasslands on the margins of wetland habitats.
Ephippiorhyncus asiaticus	Black-necked stork	E			x	
Botaurus poiciloptilus	Australasian Bittern	V		x		The Australasian bittern generally prefers freshwater habitats although it may also use dense saltmarsh vegetation in estuaries and flooded grasslands. Reported by BEACON (2007) as recorded within the Seabird Habitat Precinct.
Ixobrychus flavicollis	Black Bittern	V		x	x	This species occupies forested fresh rivers, tidal creeks and coastal inlets. Habitats range from freshwater to saline. This species has been recorded within the West Byron Urban Release Area (AWC 2010). Reported by BEACON (2007) as recorded within the Seabird Habitat Precinct.
Circus assimilis	Spotted Harrier	V			x	
Pandion haliaetus	Eastern Osprey	V		x	x	A resident breeding pair of Ospreys is known from the vicinity of Belongil Creek. Ospreys forage in coastal

Scientific name	Common name	NSW status	EPBC status	Parker & Pont (2001)	NPWS database	Notes
						rivers and streams and along beaches. Recorded foraging over Belongil Creek in this study.
Haliaeetus leucogaster	White-bellied sea-eagle	V		x	x	Recorded foraging over Belongil Creek in this study. May nest in the catchment.
Erythrotriorchis radiatus	Red Goshawk	E		x		Unlikely to still occur in the Belongil area.
Amaurornis olivaceus	Pale-vented Bush-hen	V		x	x	The Bush hen is normally associated with moist stands of deep rank grass along permanent running streams. Parker and Pont report this species from the Byron Bay Beach Club and the Cumbebin Swamp.
Rostratula benghalensis	Painted Snipe	V	V	x		Parker & Pont (2001) considered this species likely to occur on mudflats in the Belongil Creek. The Byron Biodiversity Study considers that this species has not been recorded in the shire and there are no records in the NPWS database for the Shire.
Limicola falcinellus	Broad-billed Sandpiper	V		x		These migratory shorebird species may forage on sandflats, mudflats and open beaches in the Belongil Creek area during the Southern hemisphere summer. BEACON (2007) report records of Lesser (Mongolian) Sand-Plover, Sanderling, Terek Sandpiper, Great Knot and Greater Sand Plover within the Belongil Creek Seabird Habitat Precinct.
Calidris alba	Sanderling	V		x		
Calidris ferruginea	Curlew Sandpiper	E	CE		X	
Calidris tenuirostris	Great Knot	V		x	x	
Xenus cinereus	Terek Sandpiper	V		x		
Limosa limosa	Black-tailed Godwit	V		x		
Charadrius leschenaultii	Greater Sand Plover	V		x		
Charadrius mongolus	Lesser Sand Plover	V		x		
Numenius madagascariensis	Eastern curlew		CE			
Irediparra gallinacea	Comb-crested Jacana	V		x	x	This species lives on floating vegetation in freshwater lakes and ponds. It is known from the West Byron STP (Parker & Pont 2001). Habitats in the lower estuary are not well suited for the Comb-crested jacana.
Haematopus longirostris	Pied Oystercatcher	V		x	x	The Pied oystercatcher currently occurs at the mouth of Belongil Creek and breeding has been recorded within the fenced off area at the southern side of the

Scientific name	Common name	NSW status	EPBC status	Parker & Pont (2001)	NPWS database	Notes
						Creek mouth. Pied oystercatchers occur on ocean beaches as well as estuarine habitats.
Esacus neglectus	Beach Stone-curlew	E		x	x	Parker & Pont (2001) report records of the Beach stone-curlew in Belongil Creek from the 1980's. It is now rarely recorded in the shire but was recorded at Marshall's Creek, Brunswick Heads in the late 1990's (pers. obs.).
Haematopus fuliginosus	Sooty Oystercatcher	V		x		The Sooty oystercatcher prefers rocky shore habitats, but does occur in soft-substrate intertidal habitats. Reported by BEACON (2007) as recorded within the Seabird Habitat Precinct.
Gygis alba	White Tern	V		x		May occur as a vagrant on ocean beaches.
Anoous stolidus	Common Noddy	V		x		
Sterna fuscata	Sooty Tern	V		x		
Sterna albifrons	Little Tern	E		x	x	It is thought that, in NSW, the Little tern now exists as a medium sized, non-breeding population and a small, threatened breeding population (NPWS 1999). Little terns have historically nested at the mouth of Belongil Creek with up to 30 pairs having used the site in the past. It was most recently used for nesting by a single pair in 1992/3 (NPWS 2003), although Little terns still regularly visit the site. The traditional nesting site on the southern side of the creek mouth is still managed for the purpose of retaining its value as a Little tern nesting site.
Ptilinopus regina	Rose-crowned Fruit-dove	V		x		These rainforest pigeons are nomadic and can travel long distances in search of rainforest fruits. These species are known from patches of rainforest vegetation in and around Cumbebin swamp (Parker and Pont).
Ptilinopus superbus	Superb Fruit-dove	V		x	x	
Ptilinopus magnificus	Wompoo Fruit-dove	V		x	x	
Pezoporus wallicus	Ground Parrot	V		x		Parker and Pont (2001) suggest that Ground parrots recorded from the Byron Bay area may be from the

Scientific name	Common name	NSW status	EPBC status	Parker Pont (2001)	& NPWS database	Notes
						Ballina/Lennox Head population. Suitable heathland habitat occurs within Tyagarah Nature Reserve.
Tyto capensis	Grass Owl	V		x	x	There are numerous Grass owl records in the catchment and the Belongil creek area does provide areas of taller grassland and sedgeland that provide potential roosting habitat and suitable foraging habitat is available.
Todiramphus chloris	Collared Kingfisher	V		x		Neither of these species are known to currently occur in the Belongil estuary. Artifical opening of the creek mouth has favoured both of these species by encouraging the spread of the mangrove vegetation that provides their preferred habitat.
Lichenostomus fasciogularis	Mangrove Honeyeater	V		x		
Monarcha leucotis	White-eared Monarch	V		x		These two species may occur in patches of rainforest and swamp forest with a rainforest component in the upper parts of the catchment.
Coracina lineata	Barred Cuckoo-shrike	V		x		
Mammals						
Planigale maculata	Common Planigale	V		x	x	This species occurs in Tyagarah Nature Reserve and has been recorded near Skinner's Shoot (NPWS database). Common planigales occupy a wide range of habitats including rainforest, sclerophyll forest, grasslands and marshlands.
Phascolarctos cinereus	Koala	V		x	x	Koalas occur in and around the township of Byron Bay and further north in Tyagarah Nature Reserve. They are known from the West Byron URA and North Byron Parklands. Koalas have little reliance on habitats subject to inundation although Swamp mahogany trees are a preferred feed tree and often occur in association with Broad-leaved paperbark.
Potorous tridactylus	Long-nosed Potoroo	V	V	x	x	Previously known from heathland areas in Tyagarah Nature Reserve, recent surveys indicate this species is no longer present in the Belongil catchment (abc.net.au July 2018).

Scientific name	Common name	NSW status	EPBC status	Parker & Pont (2001)	NPWS database	Notes
Pteropus poliocephalus	Grey-headed flying-fox	V	V			Flying-foxes forage on Broad-leaved paperbark, eucalypts, rainforest trees and other vegetation throughout the catchment. Flying-fox camps occur in Butler Street and Middleton Street in the Byron Bay township.
Nyctimene vizcaccia	Torresian Tube-nosed Bat	V		x		This species is known from rainforest areas in the Nightcap, Tweed and Burringbar ranges and near Mt Warning (NPWS 2002). It is not known to occur in the study area.
Syconycteris australis	Common Blossom-bat	V		x		Common Blossom Bats in NSW, the Southern part of their range, feed mostly on nectar. They are known from Tyagarah Nature Reserve and have been recorded at the Byron Bay Beach Club site (Parker & Pont 2001). Common blossom bats typically roost in littoral rainforests and in Cabbage palms within Paperbark forests. Recorded at the West Byron URA site.
Saccolaimus flaviventris	Yellow-bellied Sheathtail-bat	V	x			This insectivorous bat roosts in tree hollows in a wide range of habitats. Recorded at the West Byron URA site.
Kerivoula papuensis	Golden-tipped Bat	V		x		This species occurs in rainforest habitats. It has not been recorded in littoral rainforest on the north coast.
Mormopterus norfolkensis	Eastern Freetail-bat	V		x		It is doubtful whether these species currently occur in the Belongil catchment. They are known to roost in tree hollows.
Mormopterus beccarii	Beccari's Freetail-bat	V		x		
Falsistrellus tasmaniensis	Eastern False Pipistrelle	V		x		
Vespadelus troughtoni	Eastern Cave Bat	V		x		These locally rare species roost in caves, cliff crevices or old mines. They feed in nearby dry open forest and woodland (NPWS 2002) and are not known to occur in the Study area.
Chalinolobus dwyeri	Large-eared pied bat	V	V	x		
Scoteanax rueppellii	Greater Broad-nosed Bat	V		x	x	This species forages over a range of habitats, including rainforest and moist forests. Creeks and small rivers are favoured corridors (Hoye and Richards 1995). Recorded at the West Byron URA site.

Scientific name	Common name	NSW status	EPBC status	Parker Pont (2001)	& NPWS database	Notes
Myotis adversus	Large-footed Myotis	V		x	x	This species forages over fresh and saline waterbodies and is likely to forage throughout the Belongil creek system. It roosts in caves, mines, tunnels and under bridges as well as in tree hollows. Recorded foraging over the estuary mouth (Peter Parker 2013).
Chalinolobus nigrogriseus	Hoary Wattled Bat	V		x		This species is more often found in drier eucalypt forests.
Nyctophilus bifax	Eastern Long-eared Bat	V		x		This species typically roosts in old growth trees with hollows, which are generally absent from the site. It may occasionally roost in dense forested vegetation and dead rainforest foliage. Recorded at the West Byron URA site.
Miniopterus schreibersii	Common Bentwing-bat	V		x		These species generally roost in caves and tunnels during the day and forage for insects beneath the canopy of forested habitats at night. Both recorded at the West Byron URA site. Little bentwing known from the North Byron Parklands site.
Miniopterus australis	Little Bentwing-bat	V		x	x	

Notes: The Atlas of NSW Wildlife includes records of pelagic (oceanic) bird species that have little or no reliance on terrestrial habitats. These species are not included in this table.

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Appendix B Protected Matters Search Reports

Australian Government
Department of the Environment and Energy

EPBC Act Protected Matters Report

This report provides general guidance on matters of national environmental significance and other matters protected by the EPBC Act in the area you have selected.

Information on the coverage of this report and qualifications on data supporting this report are contained in the caveat at the end of the report.

Information is available about Environment Assessments and the EPBC Act including significance guidelines, forms and application process details.

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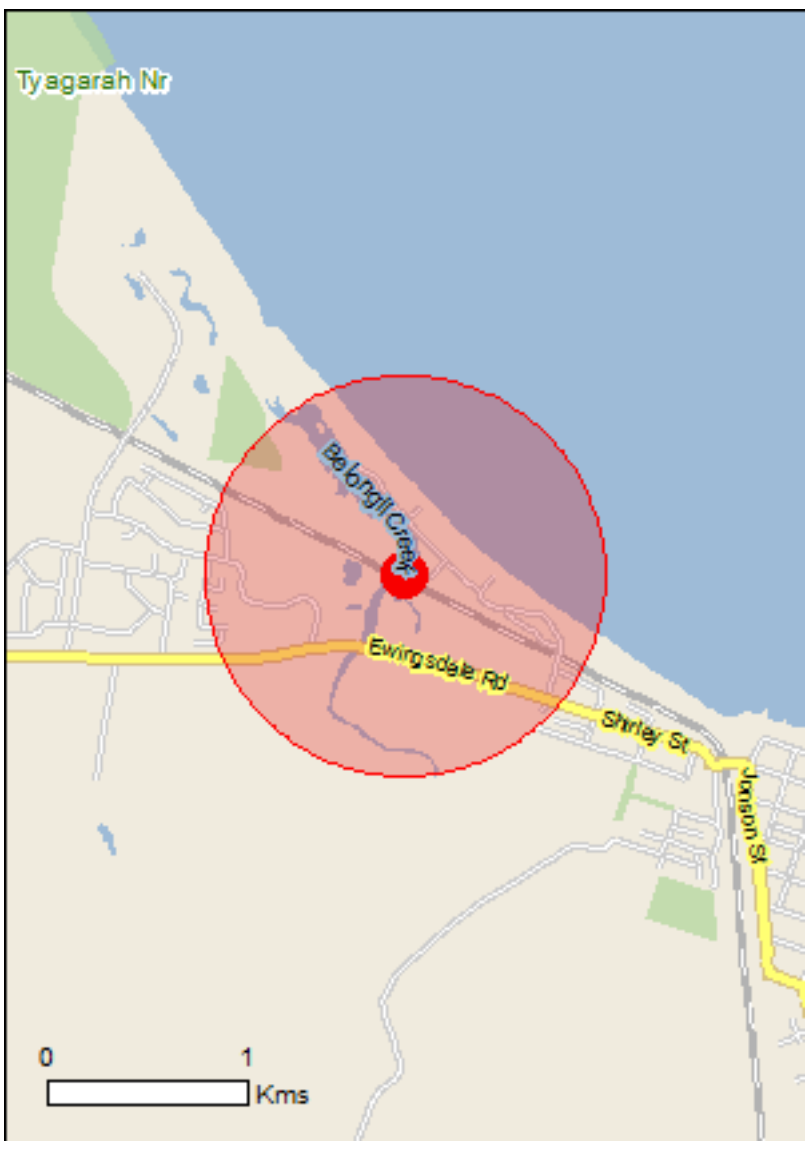

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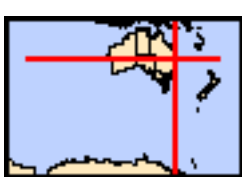

Summary

Matters of National Environmental Significance

This part of the report summarises the matters of national environmental significance that may occur in, or may relate to, the area you nominated. Further information is available in the detail part of the report, which can be accessed by scrolling or following the links below. If you are proposing to undertake an activity that may have a significant impact on one or more matters of national environmental significance then you should consider the Administrative Guidelines on Significance.

World Heritage Properties:	None
National Heritage Places:	None
Wetlands of International Importance:	None
Great Barrier Reef Marine Park:	None
Commonwealth Marine Area:	None
Listed Threatened Ecological Communities:	2
Listed Threatened Species:	74
Listed Migratory Species:	54

Other Matters Protected by the EPBC Act

This part of the report summarises other matters protected under the Act that may relate to the area you nominated. Approval may be required for a proposed activity that significantly affects the environment on Commonwealth land, when the action is outside the Commonwealth land, or the environment anywhere when the action is taken on Commonwealth land. Approval may also be required for the Commonwealth or Commonwealth agencies proposing to take an action that is likely to have a significant impact on the environment anywhere.

The EPBC Act protects the environment on Commonwealth land, the environment from the actions taken on Commonwealth land, and the environment from actions taken by Commonwealth agencies. As heritage values of a place are part of the 'environment', these aspects of the EPBC Act protect the Commonwealth Heritage values of a Commonwealth Heritage place. Information on the new heritage laws can be found at http://www.environment.gov.au/heritage

A permit may be required for activities in or on a Commonwealth area that may affect a member of a listed threatened species or ecological community, a member of a listed migratory species, whales and other cetaceans, or a member of a listed marine species.

Commonwealth Land:	None
Commonwealth Heritage Places:	None
Listed Marine Species:	84
Whales and Other Cetaceans:	12
Critical Habitats:	None
Commonwealth Reserves Terrestrial:	None
Australian Marine Parks:	None

Extra Information

This part of the report provides information that may also be relevant to the area you have nominated.

State and Territory Reserves:	1
Regional Forest Agreements:	1
Invasive Species:	35
Nationally Important Wetlands:	None
Key Ecological Features (Marine)	None

Details

Matters of National Environmental Significance

Listed Threatened Ecological Communities [Resource Information]

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

Name	Status	Type of Presence
Coastal Swamp Oak (Casuarina glauca) Forest of New South Wales and South East Queensland ecological community	Endangered	Community likely to occur within area
Subtropical and Temperate Coastal Saltmarsh	Vulnerable	Community likely to occur within area

Listed Threatened Species [Resource Information]

Name	Status	Type of Presence
Birds		
Anthochaera phrygia Regent Honeyeater [82338]	Critically Endangered	Species or species habitat likely to occur within area
Botaurus poiciloptilus Australasian Bittern [1001]	Endangered	Species or species habitat known to occur within area
Calidris canutus Red Knot, Knot [855]	Endangered	Species or species habitat known to occur within area
Calidris ferruginea Curlew Sandpiper [856]	Critically Endangered	Species or species habitat known to occur within area
Cyclopsitta diophthalma coxeni Coxen's Fig-Parrot [59714]	Endangered	Species or species habitat may occur within area
Diomedea antipodensis Antipodean Albatross [64458]	Vulnerable	Species or species habitat may occur within area
Diomedea antipodensis gibsoni Gibson's Albatross [82270]	Vulnerable	Species or species habitat may occur within area
Diomedea epomophora Southern Royal Albatross [89221]	Vulnerable	Species or species habitat may occur within area
Diomedea exulans Wandering Albatross [89223]	Vulnerable	Species or species habitat may occur within area
Erythrotriorchis radiatus Red Goshawk [942]	Vulnerable	Species or species habitat likely to occur within area

Name	Status	Type of Presence
Fregetta grallaria grallaria White-bellied Storm-Petrel (Tasman Sea), White-bellied Storm-Petrel (Australasian) [64438]	Vulnerable	Species or species habitat likely to occur within area
Lathamus discolor Swift Parrot [744]	Critically Endangered	Species or species habitat likely to occur within area
Limosa lapponica baueri Bar-tailed Godwit (baueri), Western Alaskan Bar-tailed Godwit [86380]	Vulnerable	Species or species habitat known to occur within area
Limosa lapponica menzbieri Northern Siberian Bar-tailed Godwit, Bar-tailed Godwit (menzbieri) [86432]	Critically Endangered	Species or species habitat may occur within area
Macronectes giganteus Southern Giant-Petrel, Southern Giant Petrel [1060]	Endangered	Species or species habitat may occur within area
Macronectes halli Northern Giant Petrel [1061]	Vulnerable	Species or species habitat may occur within area
Numenius madagascariensis Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species habitat known to occur within area
Pachyptila turtur subantarctica Fairy Prion (southern) [64445]	Vulnerable	Species or species habitat known to occur within area
Phoebetria fusca Sooty Albatross [1075]	Vulnerable	Species or species habitat may occur within area
Poephila cincta cincta Southern Black-throated Finch [64447]	Endangered	Species or species habitat may occur within area
Pterodroma leucoptera leucoptera Gould's Petrel, Australian Gould's Petrel [26033]	Endangered	Species or species habitat may occur within area
Pterodroma neglecta neglecta Kermadec Petrel (western) [64450]	Vulnerable	Foraging, feeding or related behaviour may occur within area
Rostratula australis Australian Painted-snipe, Australian Painted Snipe [77037]	Endangered	Species or species habitat may occur within area
Thalassarche cauta cauta Shy Albatross, Tasmanian Shy Albatross [82345]	Vulnerable	Species or species habitat may occur within area
Thalassarche cauta steadi White-capped Albatross [82344]	Vulnerable	Foraging, feeding or related behaviour likely to occur within area
Thalassarche eremita Chatham Albatross [64457]	Endangered	Species or species habitat may occur within area
Thalassarche impavida Campbell Albatross, Campbell Black-browed Albatross [64459]	Vulnerable	Species or species habitat may occur within area
Thalassarche melanophris Black-browed Albatross [66472]	Vulnerable	Species or species habitat may occur within area

Name	Status	Type of Presence
[Thalassarche salvini](#) Salvin's Albatross [64463]	Vulnerable	Species or species habitat may occur within area
[Turnix melanogaster](#) Black-breasted Button-quail [923]	Vulnerable	Species or species habitat may occur within area
Fish		
[Epinephelus daemelii](#) Black Rockcod, Black Cod, Saddled Rockcod [68449]	Vulnerable	Species or species habitat likely to occur within area
Frogs		
[Litoria olongburensis](#) Wallum Sedge Frog [1821]	Vulnerable	Species or species habitat known to occur within area
[Mixophyes fleayi](#) Fleay's Frog [25960]	Endangered	Species or species habitat may occur within area
Insects		
[Argynnis hyperbius inconstans](#) Australian Fritillary [88056]	Critically Endangered	Species or species habitat may occur within area
[Phyllodes imperialis smithersi](#) Pink Underwing Moth [86084]	Endangered	Species or species habitat may occur within area
Mammals		
[Balaenoptera musculus](#) Blue Whale [36]	Endangered	Species or species habitat may occur within area
[Chalinolobus dwyeri](#) Large-eared Pied Bat, Large Pied Bat [183]	Vulnerable	Species or species habitat likely to occur within area
[Dasyurus maculatus maculatus (SE mainland population)](#) Spot-tailed Quoll, Spotted-tail Quoll, Tiger Quoll (southeastern mainland population) [75184]	Endangered	Species or species habitat known to occur within area
[Eubalaena australis](#) Southern Right Whale [40]	Endangered	Species or species habitat likely to occur within area
[Megaptera novaeangliae](#) Humpback Whale [38]	Vulnerable	Species or species habitat known to occur within area
[Petauroides volans](#) Greater Glider [254]	Vulnerable	Species or species habitat may occur within area
[Phascolarctos cinereus (combined populations of Qld, NSW and the ACT)](#) Koala (combined populations of Queensland, New South Wales and the Australian Capital Territory) [85104]	Vulnerable	Species or species habitat known to occur within area
[Potorous tridactylus tridactylus](#) Long-nosed Potoroo (SE mainland) [66645]	Vulnerable	Species or species habitat likely to occur within area
[Pseudomys novaehollandiae](#) New Holland Mouse, Pookila [96]	Vulnerable	Species or species habitat likely to occur within area
[Pteropus poliocephalus](#) Grey-headed Flying-fox [186]	Vulnerable	Foraging, feeding or related behaviour known to occur within area

Name	Status	Type of Presence
Xeromys myoides Water Mouse, False Water Rat, Yirrkoo [66]	Vulnerable	Species or species habitat likely to occur within area
Other		
Thersites mitchellae Mitchell's Rainforest Snail [66774]	Critically Endangered	Species or species habitat known to occur within area
Plants		
Acronychia littoralis Scented Acronychia [8582]	Endangered	Species or species habitat likely to occur within area
Allocasuarina thalassoscopica [21927]	Endangered	Species or species habitat likely to occur within area
Arthraxon hispidus Hairy-joint Grass [9338]	Vulnerable	Species or species habitat likely to occur within area
Baloghia marmorata Marbled Balogia, Jointed Baloghia [8463]	Vulnerable	Species or species habitat may occur within area
Cryptocarya foetida Stinking Cryptocarya, Stinking Laurel [11976]	Vulnerable	Species or species habitat likely to occur within area
Cryptostylis hunteriana Leafless Tongue-orchid [19533]	Vulnerable	Species or species habitat may occur within area
Cynanchum elegans White-flowered Wax Plant [12533]	Endangered	Species or species habitat may occur within area
Davidsonia jerseyana Davidson's Plum [67219]	Endangered	Species or species habitat may occur within area
Endiandra floydii Floyd's Walnut [52955]	Endangered	Species or species habitat may occur within area
Floydia praealta Ball Nut, Possum Nut, Big Nut, Beefwood [15762]	Vulnerable	Species or species habitat likely to occur within area
Macadamia integrifolia Macadamia Nut, Queensland Nut Tree, Smooth-shelled Macadamia, Bush Nut, Nut Oak [7326]	Vulnerable	Species or species habitat may occur within area
Macadamia tetraphylla Rough-shelled Bush Nut, Macadamia Nut, Rough-shelled Macadamia, Rough-leaved Queensland Nut [6581]	Vulnerable	Species or species habitat likely to occur within area
Owenia cepiodora Onionwood, Bog Onion, Onion Cedar [11344]	Vulnerable	Species or species habitat likely to occur within area
Phaius australis Lesser Swamp-orchid [5872]	Endangered	Species or species habitat likely to occur within area
Randia moorei Spiny Gardenia [10577]	Endangered	Species or species habitat likely to occur within area
Syzygium hodgkinsoniae Smooth-bark Rose Apple, Red Lilly Pilly [3539]	Vulnerable	Species or species habitat likely to occur

Name	Status	Type of Presence
		within area
Syzygium moorei		
Rose Apple, Coolamon, Robby, Durobby, Watermelon Tree, Coolamon Rose Apple [12284]	Vulnerable	Species or species habitat known to occur within area
Thesium australe		
Austral Toadflax, Toadflax [15202]	Vulnerable	Species or species habitat may occur within area
Reptiles		
Caretta caretta		
Loggerhead Turtle [1763]	Endangered	Breeding known to occur within area
Chelonia mydas		
Green Turtle [1765]	Vulnerable	Species or species habitat known to occur within area
Dermochelys coriacea		
Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Congregation or aggregation known to occur within area
Eretmochelys imbricata		
Hawksbill Turtle [1766]	Vulnerable	Species or species habitat known to occur within area
Lepidochelys olivacea		
Olive Ridley Turtle, Pacific Ridley Turtle [1767]	Endangered	Breeding likely to occur within area
Natator depressus		
Flatback Turtle [59257]	Vulnerable	Species or species habitat known to occur within area
Sharks		
Carcharias taurus (east coast population)		
Grey Nurse Shark (east coast population) [68751]	Critically Endangered	Species or species habitat known to occur within area
Carcharodon carcharias		
White Shark, Great White Shark [64470]	Vulnerable	Species or species habitat known to occur within area
Rhincodon typus		
Whale Shark [66680]	Vulnerable	Species or species habitat may occur within area

Listed Migratory Species [Resource Information]

* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.

Name	Threatened	Type of Presence
Migratory Marine Birds		
Anous stolidus		
Common Noddy [825]		Species or species habitat likely to occur within area
Apus pacificus		
Fork-tailed Swift [678]		Species or species habitat likely to occur within area
Ardenna carneipes		
Flesh-footed Shearwater, Fleshy-footed Shearwater [82404]		Species or species habitat likely to occur within area
Calonectris leucomelas		
Streaked Shearwater [1077]		Species or species habitat known to occur within area
Diomedea antipodensis		
Antipodean Albatross [64458]	Vulnerable	Species or species habitat may occur within area
Diomedea epomophora		
Southern Royal Albatross [89221]	Vulnerable	Species or species

Name	Threatened	Type of Presence
		habitat may occur within area
Diomedea exulans Wandering Albatross [89223]	Vulnerable	Species or species habitat may occur within area
Fregata ariel Lesser Frigatebird, Least Frigatebird [1012]		Species or species habitat known to occur within area
Fregata minor Great Frigatebird, Greater Frigatebird [1013]		Species or species habitat likely to occur within area
Macronectes giganteus Southern Giant-Petrel, Southern Giant Petrel [1060]	Endangered	Species or species habitat may occur within area
Macronectes halli Northern Giant Petrel [1061]	Vulnerable	Species or species habitat may occur within area
Phoebetria fusca Sooty Albatross [1075]	Vulnerable	Species or species habitat may occur within area
Sternula albifrons Little Tern [82849]		Breeding likely to occur within area
Thalassarche cauta Tasmanian Shy Albatross [89224]	Vulnerable*	Species or species habitat may occur within area
Thalassarche eremita Chatham Albatross [64457]	Endangered	Species or species habitat may occur within area
Thalassarche impavida Campbell Albatross, Campbell Black-browed Albatross [64459]	Vulnerable	Species or species habitat may occur within area
Thalassarche melanophris Black-browed Albatross [66472]	Vulnerable	Species or species habitat may occur within area
Thalassarche salvini Salvin's Albatross [64463]	Vulnerable	Species or species habitat may occur within area
Thalassarche steadi White-capped Albatross [64462]	Vulnerable*	Foraging, feeding or related behaviour likely to occur within area
Migratory Marine Species		
Balaena glacialis australis Southern Right Whale [75529]	Endangered*	Species or species habitat likely to occur within area
Balaenoptera edeni Bryde's Whale [35]		Species or species habitat may occur within area
Balaenoptera musculus Blue Whale [36]	Endangered	Species or species habitat may occur within area
Carcharodon carcharias White Shark, Great White Shark [64470]	Vulnerable	Species or species habitat known to occur within area
Caretta caretta Loggerhead Turtle [1763]	Endangered	Breeding known to occur within area

Name	Threatened	Type of Presence
Chelonia mydas Green Turtle [1765]	Vulnerable	Species or species habitat known to occur within area
Dermochelys coriacea Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Congregation or aggregation known to occur within area
Dugong dugon Dugong [28]		Species or species habitat may occur within area
Eretmochelys imbricata Hawksbill Turtle [1766]	Vulnerable	Species or species habitat known to occur within area
Lamna nasus Porbeagle, Mackerel Shark [83288]		Species or species habitat may occur within area
Lepidochelys olivacea Olive Ridley Turtle, Pacific Ridley Turtle [1767]	Endangered	Breeding likely to occur within area
Manta alfredi Reef Manta Ray, Coastal Manta Ray, Inshore Manta Ray, Prince Alfred's Ray, Resident Manta Ray [84994]		Species or species habitat known to occur within area
Manta birostris Giant Manta Ray, Chevron Manta Ray, Pacific Manta Ray, Pelagic Manta Ray, Oceanic Manta Ray [84995]		Species or species habitat may occur within area
Megaptera novaeangliae Humpback Whale [38]	Vulnerable	Species or species habitat known to occur within area
Natator depressus Flatback Turtle [59257]	Vulnerable	Species or species habitat known to occur within area
Orcinus orca Killer Whale, Orca [46]		Species or species habitat may occur within area
Rhincodon typus Whale Shark [66680]	Vulnerable	Species or species habitat may occur within area
Sousa chinensis Indo-Pacific Humpback Dolphin [50]		Species or species habitat likely to occur within area
Migratory Terrestrial Species		
Cuculus optatus Oriental Cuckoo, Horsfield's Cuckoo [86651]		Species or species habitat may occur within area
Hirundapus caudacutus White-throated Needletail [682]		Species or species habitat known to occur within area
Monarcha melanopsis Black-faced Monarch [609]		Species or species habitat known to occur within area
Monarcha trivirgatus Spectacled Monarch [610]		Species or species habitat known to occur within area
Motacilla flava Yellow Wagtail [644]		Species or species habitat known to occur within area

Name	Threatened	Type of Presence
[Myiagra cyanoleuca](#) Satin Flycatcher [612]		Species or species habitat known to occur within area
[Rhipidura rufifrons](#) Rufous Fantail [592]		Species or species habitat known to occur within area
Migratory Wetlands Species		
[Actitis hypoleucos](#) Common Sandpiper [59309]		Species or species habitat known to occur within area
[Calidris acuminata](#) Sharp-tailed Sandpiper [874]		Species or species habitat known to occur within area
[Calidris canutus](#) Red Knot, Knot [855]	Endangered	Species or species habitat known to occur within area
[Calidris ferruginea](#) Curlew Sandpiper [856]	Critically Endangered	Species or species habitat known to occur within area
[Calidris melanotos](#) Pectoral Sandpiper [858]		Species or species habitat likely to occur within area
[Gallinago hardwickii](#) Latham's Snipe, Japanese Snipe [863]		Species or species habitat may occur within area
[Limosa lapponica](#) Bar-tailed Godwit [844]		Species or species habitat known to occur within area
[Numenius madagascariensis](#) Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species habitat known to occur within area
[Pandion haliaetus](#) Osprey [952]		Breeding known to occur within area
[Tringa nebularia](#) Common Greenshank, Greenshank [832]		Species or species habitat likely to occur within area

Other Matters Protected by the EPBC Act

Listed Marine Species [Resource Information]

* Species is listed under a different scientific name on the EPBC Act - Threatened Species list.

Name	Threatened	Type of Presence
Birds		
[Actitis hypoleucos](#) Common Sandpiper [59309]		Species or species habitat known to occur within area
[Anous stolidus](#) Common Noddy [825]		Species or species habitat likely to occur within area
[Anseranas semipalmata](#) Magpie Goose [978]		Species or species habitat may occur within area

Name	Threatened	Type of Presence
[Apus pacificus](#) Fork-tailed Swift [678]		Species or species habitat likely to occur within area
[Ardea alba](#) Great Egret, White Egret [59541]		Species or species habitat known to occur within area
[Ardea ibis](#) Cattle Egret [59542]		Species or species habitat may occur within area
[Calidris acuminata](#) Sharp-tailed Sandpiper [874]		Species or species habitat known to occur within area
[Calidris canutus](#) Red Knot, Knot [855]	Endangered	Species or species habitat known to occur within area
[Calidris ferruginea](#) Curlew Sandpiper [856]	Critically Endangered	Species or species habitat known to occur within area
[Calidris melanotos](#) Pectoral Sandpiper [858]		Species or species habitat likely to occur within area
[Calonectris leucomelas](#) Streaked Shearwater [1077]		Species or species habitat known to occur within area
[Diomedea antipodensis](#) Antipodean Albatross [64458]	Vulnerable	Species or species habitat may occur within area
[Diomedea epomophora](#) Southern Royal Albatross [89221]	Vulnerable	Species or species habitat may occur within area
[Diomedea exulans](#) Wandering Albatross [89223]	Vulnerable	Species or species habitat may occur within area
[Diomedea gibsoni](#) Gibson's Albatross [64466]	Vulnerable*	Species or species habitat may occur within area
[Fregata ariel](#) Lesser Frigatebird, Least Frigatebird [1012]		Species or species habitat known to occur within area
[Fregata minor](#) Great Frigatebird, Greater Frigatebird [1013]		Species or species habitat likely to occur within area
[Gallinago hardwickii](#) Latham's Snipe, Japanese Snipe [863]		Species or species habitat may occur within area
[Haliaeetus leucogaster](#) White-bellied Sea-Eagle [943]		Species or species habitat known to occur within area
[Hirundapus caudacutus](#) White-throated Needletail [682]		Species or species habitat known to occur within area
[Lathamus discolor](#) Swift Parrot [744]	Critically Endangered	Species or species habitat likely to occur within area

Name	Threatened	Type of Presence
Limosa lapponica Bar-tailed Godwit [844]		Species or species habitat known to occur within area
Macronectes giganteus Southern Giant-Petrel, Southern Giant Petrel [1060]	Endangered	Species or species habitat may occur within area
Macronectes halli Northern Giant Petrel [1061]	Vulnerable	Species or species habitat may occur within area
Merops ornatus Rainbow Bee-eater [670]		Species or species habitat may occur within area
Monarcha melanopsis Black-faced Monarch [609]		Species or species habitat known to occur within area
Monarcha trivirgatus Spectacled Monarch [610]		Species or species habitat known to occur within area
Motacilla flava Yellow Wagtail [644]		Species or species habitat known to occur within area
Myiagra cyanoleuca Satin Flycatcher [612]		Species or species habitat known to occur within area
Numenius madagascariensis Eastern Curlew, Far Eastern Curlew [847]	Critically Endangered	Species or species habitat known to occur within area
Pachyptila turtur Fairy Prion [1066]		Species or species habitat known to occur within area
Pandion haliaetus Osprey [952]		Breeding known to occur within area
Phoebetria fusca Sooty Albatross [1075]	Vulnerable	Species or species habitat may occur within area
Puffinus carneipes Flesh-footed Shearwater, Fleshy-footed Shearwater [1043]		Species or species habitat likely to occur within area
Rhipidura rufifrons Rufous Fantail [592]		Species or species habitat known to occur within area
Rostratula benghalensis (sensu lato) Painted Snipe [889]	Endangered*	Species or species habitat may occur within area
Sterna albifrons Little Tern [813]		Breeding likely to occur within area
Thalassarche cauta Tasmanian Shy Albatross [89224]	Vulnerable*	Species or species habitat may occur within area
Thalassarche eremita Chatham Albatross [64457]	Endangered	Species or species habitat may occur within area
Thalassarche impavida Campbell Albatross, Campbell Black-browed Albatross [64459]	Vulnerable	Species or species habitat may occur within

Name	Threatened	Type of Presence
		area
Thalassarche melanophris Black-browed Albatross [66472]	Vulnerable	Species or species habitat may occur within area
Thalassarche salvini Salvin's Albatross [64463]	Vulnerable	Species or species habitat may occur within area
Thalassarche steadi White-capped Albatross [64462]	Vulnerable*	Foraging, feeding or related behaviour likely to occur within area
Tringa nebularia Common Greenshank, Greenshank [832]		Species or species habitat likely to occur within area
Fish		
Acentronura tentaculata Shortpouch Pygmy Pipehorse [66187]		Species or species habitat may occur within area
Campichthys tryoni Tryon's Pipefish [66193]		Species or species habitat may occur within area
Corythoichthys amplexus Fijian Banded Pipefish, Brown-banded Pipefish [66199]		Species or species habitat may occur within area
Corythoichthys ocellatus Orange-spotted Pipefish, Ocellated Pipefish [66203]		Species or species habitat may occur within area
Festucalex cinctus Girdled Pipefish [66214]		Species or species habitat may occur within area
Filicampus tigris Tiger Pipefish [66217]		Species or species habitat may occur within area
Halicampus grayi Mud Pipefish, Gray's Pipefish [66221]		Species or species habitat may occur within area
Hippichthys cyanospilos Blue-speckled Pipefish, Blue-spotted Pipefish [66228]		Species or species habitat may occur within area
Hippichthys heptagonus Madura Pipefish, Reticulated Freshwater Pipefish [66229]		Species or species habitat may occur within area
Hippichthys penicillus Beady Pipefish, Steep-nosed Pipefish [66231]		Species or species habitat may occur within area
Hippocampus kelloggi Kellogg's Seahorse, Great Seahorse [66723]		Species or species habitat may occur within area
Hippocampus kuda Spotted Seahorse, Yellow Seahorse [66237]		Species or species habitat may occur within area
Hippocampus planifrons Flat-face Seahorse [66238]		Species or species habitat may occur within area
Hippocampus trimaculatus Three-spot Seahorse, Low-crowned Seahorse, Flat-faced Seahorse [66720]		Species or species habitat may occur within

Name	Threatened	Type of Presence
		area
Hippocampus whitei White's Seahorse, Crowned Seahorse, Sydney Seahorse [66240]		Species or species habitat may occur within area
Lissocampus runa Javelin Pipefish [66251]		Species or species habitat may occur within area
Maroubra perserrata Sawtooth Pipefish [66252]		Species or species habitat may occur within area
Micrognathus andersonii Anderson's Pipefish, Shortnose Pipefish [66253]		Species or species habitat may occur within area
Micrognathus brevirostris thorntail Pipefish, Thorn-tailed Pipefish [66254]		Species or species habitat may occur within area
Microphis manadensis Manado Pipefish, Manado River Pipefish [66258]		Species or species habitat may occur within area
Solegnathus dunckeri Duncker's Pipehorse [66271]		Species or species habitat may occur within area
Solegnathus hardwickii Pallid Pipehorse, Hardwick's Pipehorse [66272]		Species or species habitat may occur within area
Solegnathus spinosissimus Spiny Pipehorse, Australian Spiny Pipehorse [66275]		Species or species habitat may occur within area
Solenostomus cyanopterus Robust Ghostpipefish, Blue-finned Ghost Pipefish, [66183]		Species or species habitat may occur within area
Solenostomus paradoxus Ornate Ghostpipefish, Harlequin Ghost Pipefish, Ornate Ghost Pipefish [66184]		Species or species habitat may occur within area
Stigmatopora nigra Widebody Pipefish, Wide-bodied Pipefish, Black Pipefish [66277]		Species or species habitat may occur within area
Syngnathoides biaculeatus Double-end Pipehorse, Double-ended Pipehorse, Alligator Pipefish [66279]		Species or species habitat may occur within area
Trachyrhamphus bicoarctatus Bentstick Pipefish, Bend Stick Pipefish, Short-tailed Pipefish [66280]		Species or species habitat may occur within area
Urocampus carinirostris Hairy Pipefish [66282]		Species or species habitat may occur within area
Vanacampus margaritifer Mother-of-pearl Pipefish [66283]		Species or species habitat may occur within area
Mammals		
Dugong dugon Dugong [28]		Species or species habitat may occur within area
Reptiles		
Astrotia stokesii Stokes' Seasnake [1122]		Species or species

Name	Threatened	Type of Presence
		habitat may occur within area
Caretta caretta Loggerhead Turtle [1763]	Endangered	Breeding known to occur within area
Chelonia mydas Green Turtle [1765]	Vulnerable	Species or species habitat known to occur within area
Dermochelys coriacea Leatherback Turtle, Leathery Turtle, Luth [1768]	Endangered	Congregation or aggregation known to occur within area
Eretmochelys imbricata Hawksbill Turtle [1766]	Vulnerable	Species or species habitat known to occur within area
Hydrophis elegans Elegant Seasnake [1104]		Species or species habitat may occur within area
Lepidochelys olivacea Olive Ridley Turtle, Pacific Ridley Turtle [1767]	Endangered	Breeding likely to occur within area
Natator depressus Flatback Turtle [59257]	Vulnerable	Species or species habitat known to occur within area
Pelamis platurus Yellow-bellied Seasnake [1091]		Species or species habitat may occur within area

Whales and other Cetaceans		[Resource Information]
Name	Status	Type of Presence
Mammals		
Balaenoptera acutorostrata Minke Whale [33]		Species or species habitat may occur within area
Balaenoptera edeni Bryde's Whale [35]		Species or species habitat may occur within area
Balaenoptera musculus Blue Whale [36]	Endangered	Species or species habitat may occur within area
Delphinus delphis Common Dophin, Short-beaked Common Dolphin [60]		Species or species habitat may occur within area
Eubalaena australis Southern Right Whale [40]	Endangered	Species or species habitat likely to occur within area
Grampus griseus Risso's Dolphin, Grampus [64]		Species or species habitat may occur within area
Megaptera novaeangliae Humpback Whale [38]	Vulnerable	Species or species habitat known to occur within area
Orcinus orca Killer Whale, Orca [46]		Species or species habitat may occur within area
Sousa chinensis Indo-Pacific Humpback Dolphin [50]		Species or species habitat likely to occur within area

Name	Status	Type of Presence
Stenella attenuata		
Spotted Dolphin, Pantropical Spotted Dolphin [51]		Species or species habitat may occur within area
Tursiops aduncus		
Indian Ocean Bottlenose Dolphin, Spotted Bottlenose Dolphin [68418]		Species or species habitat likely to occur within area
Tursiops truncatus s. str.		
Bottlenose Dolphin [68417]		Species or species habitat may occur within area

Extra Information

State and Territory Reserves [Resource Information]

Name	State
Cumbebin Swamp	NSW

Regional Forest Agreements [Resource Information]

Note that all areas with completed RFAs have been included.

Name	State
North East NSW RFA	New South Wales

Invasive Species [Resource Information]

Weeds reported here are the 20 species of national significance (WoNS), along with other introduced plants that are considered by the States and Territories to pose a particularly significant threat to biodiversity. The following feral animals are reported: Goat, Red Fox, Cat, Rabbit, Pig, Water Buffalo and Cane Toad. Maps from Landscape Health Project, National Land and Water Resouces Audit, 2001.

Name	Status	Type of Presence
Birds		
Acridotheres tristis		
Common Myna, Indian Myna [387]		Species or species habitat likely to occur within area
Anas platyrhynchos		
Mallard [974]		Species or species habitat likely to occur within area
Carduelis carduelis		
European Goldfinch [403]		Species or species habitat likely to occur within area
Columba livia		
Rock Pigeon, Rock Dove, Domestic Pigeon [803]		Species or species habitat likely to occur within area
Lonchura punctulata		
Nutmeg Mannikin [399]		Species or species habitat likely to occur within area
Passer domesticus		
House Sparrow [405]		Species or species habitat likely to occur within area
Streptopelia chinensis		
Spotted Turtle-Dove [780]		Species or species habitat likely to occur within area
Sturnus vulgaris		
Common Starling [389]		Species or species habitat likely to occur within area
Frogs		

Name	Status	Type of Presence
Rhinella marina Cane Toad [83218]		Species or species habitat known to occur within area
Mammals		
Bos taurus Domestic Cattle [16]		Species or species habitat likely to occur within area
Canis lupus familiaris Domestic Dog [82654]		Species or species habitat likely to occur within area
Felis catus Cat, House Cat, Domestic Cat [19]		Species or species habitat likely to occur within area
Feral deer Feral deer species in Australia [85733]		Species or species habitat likely to occur within area
Lepus capensis Brown Hare [127]		Species or species habitat likely to occur within area
Mus musculus House Mouse [120]		Species or species habitat likely to occur within area
Oryctolagus cuniculus Rabbit, European Rabbit [128]		Species or species habitat likely to occur within area
Rattus norvegicus Brown Rat, Norway Rat [83]		Species or species habitat likely to occur within area
Rattus rattus Black Rat, Ship Rat [84]		Species or species habitat likely to occur within area
Sus scrofa Pig [6]		Species or species habitat likely to occur within area
Vulpes vulpes Red Fox, Fox [18]		Species or species habitat likely to occur within area
Plants		
Alternanthera philoxeroides Alligator Weed [11620]		Species or species habitat likely to occur within area
Anredera cordifolia Madeira Vine, Jalap, Lamb's-tail, Mignonette Vine, Anredera, Gulf Madeiravine, Heartleaf Madeiravine, Potato Vine [2643]		Species or species habitat likely to occur within area
Asparagus aethiopicus Asparagus Fern, Ground Asparagus, Basket Fern, Sprengi's Fern, Bushy Asparagus, Emerald Asparagus [62425]		Species or species habitat likely to occur within area
Asparagus plumosus Climbing Asparagus-fern [48993]		Species or species habitat likely to occur within area
Cabomba caroliniana Cabomba, Fanwort, Carolina Watershield, Fish Grass, Washington Grass, Watershield, Carolina Fanwort, Common Cabomba [5171]		Species or species habitat likely to occur within area
Chrysanthemoides monilifera Bitou Bush, Boneseed [18983]		Species or species habitat likely to occur

Name	Status	Type of Presence
		within area
Chrysanthemoides monilifera subsp. rotundata Bitou Bush [16332]		Species or species habitat likely to occur within area
Eichhornia crassipes Water Hyacinth, Water Orchid, Nile Lily [13466]		Species or species habitat likely to occur within area
Genista sp. X Genista monspessulana Broom [67538]		Species or species habitat may occur within area
Lantana camara Lantana, Common Lantana, Kamara Lantana, Large-leaf Lantana, Pink Flowered Lantana, Red Flowered Lantana, Red-Flowered Sage, White Sage, Wild Sage [10892]		Species or species habitat likely to occur within area
Pinus radiata Radiata Pine Monterey Pine, Insignis Pine, Wilding Pine [20780]		Species or species habitat may occur within area
Sagittaria platyphylla Delta Arrowhead, Arrowhead, Slender Arrowhead [68483]		Species or species habitat likely to occur within area
Salvinia molesta Salvinia, Giant Salvinia, Aquarium Watermoss, Kariba Weed [13665]		Species or species habitat likely to occur within area
Senecio madagascariensis Fireweed, Madagascar Ragwort, Madagascar Groundsel [2624]		Species or species habitat likely to occur within area
Reptiles		
Hemidactylus frenatus Asian House Gecko [1708]		Species or species habitat likely to occur within area

Caveat

The information presented in this report has been provided by a range of data sources as acknowledged at the end of the report.

This report is designed to assist in identifying the locations of places which may be relevant in determining obligations under the Environment Protection and Biodiversity Conservation Act 1999. It holds mapped locations of World and National Heritage properties, Wetlands of International and National Importance, Commonwealth and State/Territory reserves, listed threatened, migratory and marine species and listed threatened ecological communities. Mapping of Commonwealth land is not complete at this stage. Maps have been collated from a range of sources at various resolutions.

Not all species listed under the EPBC Act have been mapped (see below) and therefore a report is a general guide only. Where available data supports mapping, the type of presence that can be determined from the data is indicated in general terms. People using this information in making a referral may need to consider the qualifications below and may need to seek and consider other information sources.

For threatened ecological communities where the distribution is well known, maps are derived from recovery plans, State vegetation maps, remote sensing imagery and other sources. Where threatened ecological community distributions are less well known, existing vegetation maps and point location data are used to produce indicative distribution maps.

Threatened, migratory and marine species distributions have been derived through a variety of methods. Where distributions are well known and if time permits, maps are derived using either thematic spatial data (i.e. vegetation, soils, geology, elevation, aspect, terrain, etc) together with point locations and described habitat; or environmental modelling (MAXENT or BIOCLIM habitat modelling) using point locations and environmental data layers.

Where very little information is available for species or large number of maps are required in a short time-frame, maps are derived either from 0.04 or 0.02 decimal degree cells; by an automated process using polygon capture techniques (static two kilometre grid cells, alpha-hull and convex hull); or captured manually or by using topographic features (national park boundaries, islands, etc). In the early stages of the distribution mapping process (1999-early 2000s) distributions were defined by degree blocks, 100K or 250K map sheets to rapidly create distribution maps. More reliable distribution mapping methods are used to update these distributions as time permits.

Only selected species covered by the following provisions of the EPBC Act have been mapped:

- migratory and
- marine

The following species and ecological communities have not been mapped and do not appear in reports produced from this database:

- threatened species listed as extinct or considered as vagrants
- some species and ecological communities that have only recently been listed
- some terrestrial species that overfly the Commonwealth marine area
- migratory species that are very widespread, vagrant, or only occur in small numbers

The following groups have been mapped, but may not cover the complete distribution of the species:

- non-threatened seabirds which have only been mapped for recorded breeding sites
- seals which have only been mapped for breeding sites near the Australian continent

Such breeding sites may be important for the protection of the Commonwealth Marine environment.

Coordinates

-28.634686 153.596912

Acknowledgements

This database has been compiled from a range of data sources. The department acknowledges the following custodians who have contributed valuable data and advice:

-Office of Environment and Heritage, New South Wales
-Department of Environment and Primary Industries, Victoria
-Department of Primary Industries, Parks, Water and Environment, Tasmania
-Department of Environment, Water and Natural Resources, South Australia
-Department of Land and Resource Management, Northern Territory
-Department of Environmental and Heritage Protection, Queensland
-Department of Parks and Wildlife, Western Australia
-Environment and Planning Directorate, ACT
-Birdlife Australia
-Australian Bird and Bat Banding Scheme
-Australian National Wildlife Collection
-Natural history museums of Australia
-Museum Victoria
-Australian Museum
-South Australian Museum
-Queensland Museum
-Online Zoological Collections of Australian Museums
-Queensland Herbarium
-National Herbarium of NSW
-Royal Botanic Gardens and National Herbarium of Victoria
-Tasmanian Herbarium
-State Herbarium of South Australia
-Northern Territory Herbarium
-Western Australian Herbarium
-Australian National Herbarium, Canberra
-University of New England
-Ocean Biogeographic Information System
-Australian Government, Department of Defence
Forestry Corporation, NSW
-Geoscience Australia
-CSIRO
-Australian Tropical Herbarium, Cairns
-eBird Australia
-Australian Government – Australian Antarctic Data Centre
-Museum and Art Gallery of the Northern Territory
-Australian Government National Environmental Science Program
-Australian Institute of Marine Science
-Reef Life Survey Australia
-American Museum of Natural History
-Queen Victoria Museum and Art Gallery, Inveresk, Tasmania
-Tasmanian Museum and Art Gallery, Hobart, Tasmania
-Other groups and individuals

The Department is extremely grateful to the many organisations and individuals who provided expert advice and information on numerous draft distributions.

Please feel free to provide feedback via the Contact Us page.

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