3 Review of State, National and International Entrance Management

3.1 Background to ICOLL entrance management

ICOLLs are naturally occurring, and self-regulating systems and it is generally considered preferable not to artificially change these systems due to the adverse impacts that can occur. The opening and closing process is natural, and the ecosystem including the aquatic, plant and animal communities have adapted to these changing environmental conditions resulting in healthy ICOLLs when left alone. When ICOLL entrances open naturally, the outflow scours the entrance resulting in wide entrances that stay open for long periods of time. If these entrances are artificially opened when the water level is low, then the outflow of water does not scour the entrance as effectively. This results in the entrance closing more quickly due to the deposition of sand from wave action.

Generally, artificial management of ICOLLs involves opening the entrance at a lower level than the natural breakout range or changing the height, location or configuration of the beach berm so that natural breakout range is lowered. Training walls or other permanent actions, while possible, are generally not used as they will permanently open the estuary. This can have significant environmental impacts and is discussed in more detail below (Stephens & Murtagh, 2011; Coffs Harbour City Council, 2018).

ICOLLs are considered as the most sensitive type of estuary to artificial change resulting from human intervention. This is due to their connection to the ocean meaning that their management is often considered one of the most difficult tasks facing coastal engineers today (Haines, 2008). Hence, it is important to consider each ICOLL individually, and plan their management effectively and consider all impacts of artificial change.

While there are many environmental impacts of artificially interfering in the management of ICOLLs, around half of the ICOLLs in NSW are in fact artificially managed due to mitigation of flood inundation for the urbanised catchment around their foreshores. The main reason for artificially opening an ICOLL is to mitigate potential damage to low-lying properties and other assets at risk due to rising water levels from flood events. This is often due to increased pressure from local communities for Council to protect their assets (Stephens & Murtagh, 2011). Another trigger for opening entrances is “alleviating actual or perceived water quality problems, through the introduction of tidal processes” (Haines, 2008).

A review of entrance management policies and procedures of ICOLLs across State, National and International levels has been undertaken and detailed discussion is available in **Appendix B**. A summary of key findings is presented below.

3.2 NSW ICOLL entrance management

3.2.1 Narrabeen Lagoon in NSW context

Narrabeen Lagoon is the largest ICOLL in the Sydney Metropolitan area and is a unique waterway with respect to its size and catchment urbanisation. Of the approximately 170 estuaries in NSW, Narrabeen Lagoon is in the top 25% for both estuary size and catchment size (refer **Figure 3-1**). In comparison, Dee Why Lagoon and Curl Curl Lagoon are both around the 50% mark, or median value for estuary size and in the bottom 25% for catchment size, and Manly Lagoon is around the 50% mark, or median value for both estuary size and catchment size.

In 2008 Haines considered a number of different features of the lagoon and determined that Narrabeen Lagoon represents a relatively unique instance of an ICOLL (refer **Figure 3-2**). Over the long term Narrabeen Lagoon:

- is mostly open;
- has potential for tidal water exchange under the right conditions, which sees the exchanging of ocean and lagoon waters (note this predominantly occurs in the entrance);
- can maintain water quality even with pollution entering from the catchment; and,
- usually maintains a similar water level.

In combination, these factors demonstrate that Narrabeen Lagoon has relatively stable and favourable conditions with respect to public amenity (i.e. visual and recreational).

In summary, in the context of NSW, Narrabeen Lagoon represents a large estuary (more specifically ICOLL), in terms of both estuary surface area and catchment area, that is on average over the long term open to the ocean. The Lagoon exhibits both stable water quality and quantity that provides favourable conditions for the community in both visual and recreation amenity.

The Lagoon is situated in a highly urbanised area, and as a result of the favourable stable conditions, the local community has become accustomed to certain level of ‘service’ provided by the Lagoon (e.g. acceptable water quality and water level). When this level of ‘service’ is no longer provided Council receives a significant amount of public feedback; distinguishing management of Narrabeen Lagoon as having a relatively high sensitivity to community awareness and feedback when compared to other ICOLLs on the NSW coastline.

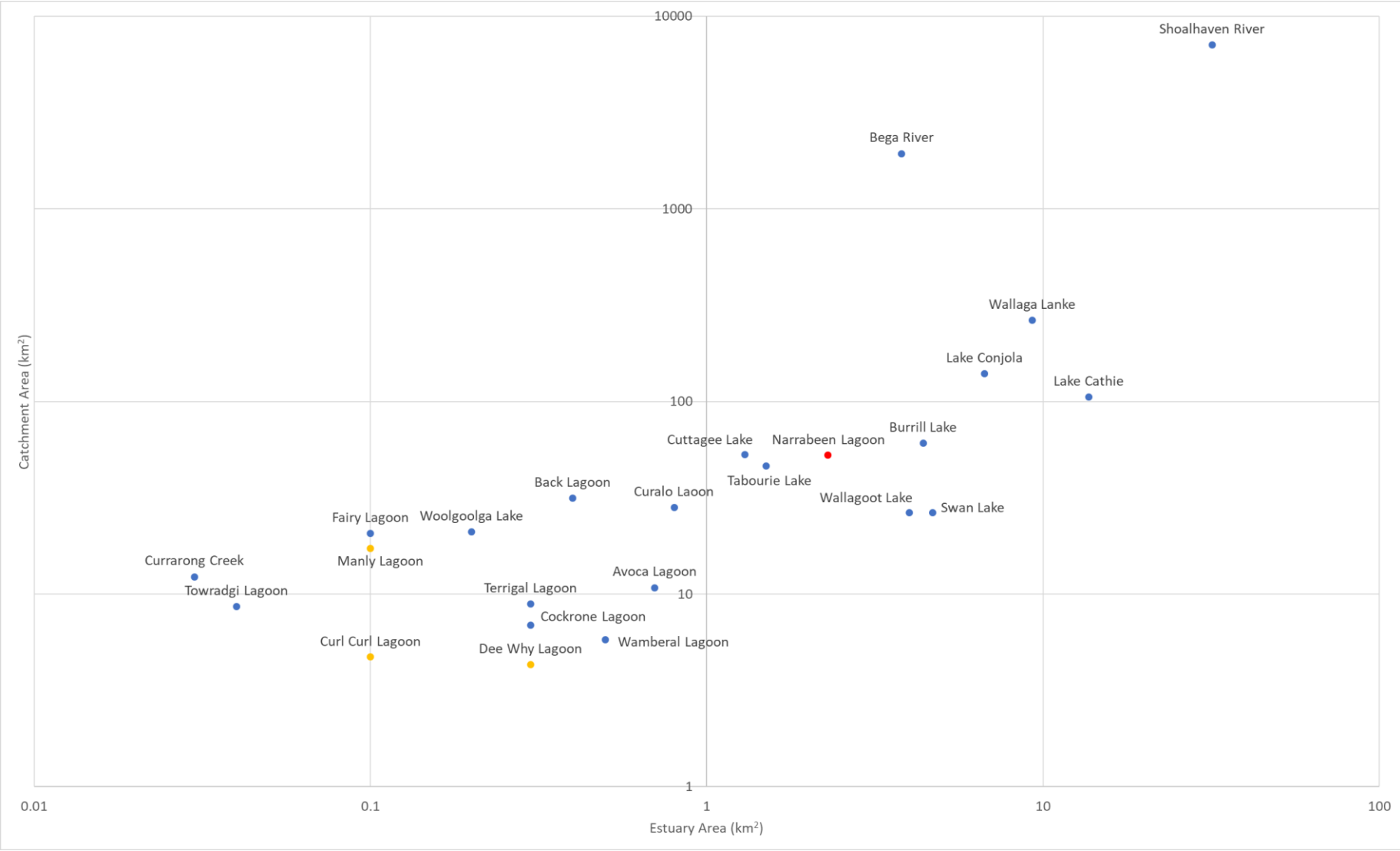


Figure 3-1: Narrabeen Lagoon in selected NSW context (estuary size vs. catchment size)

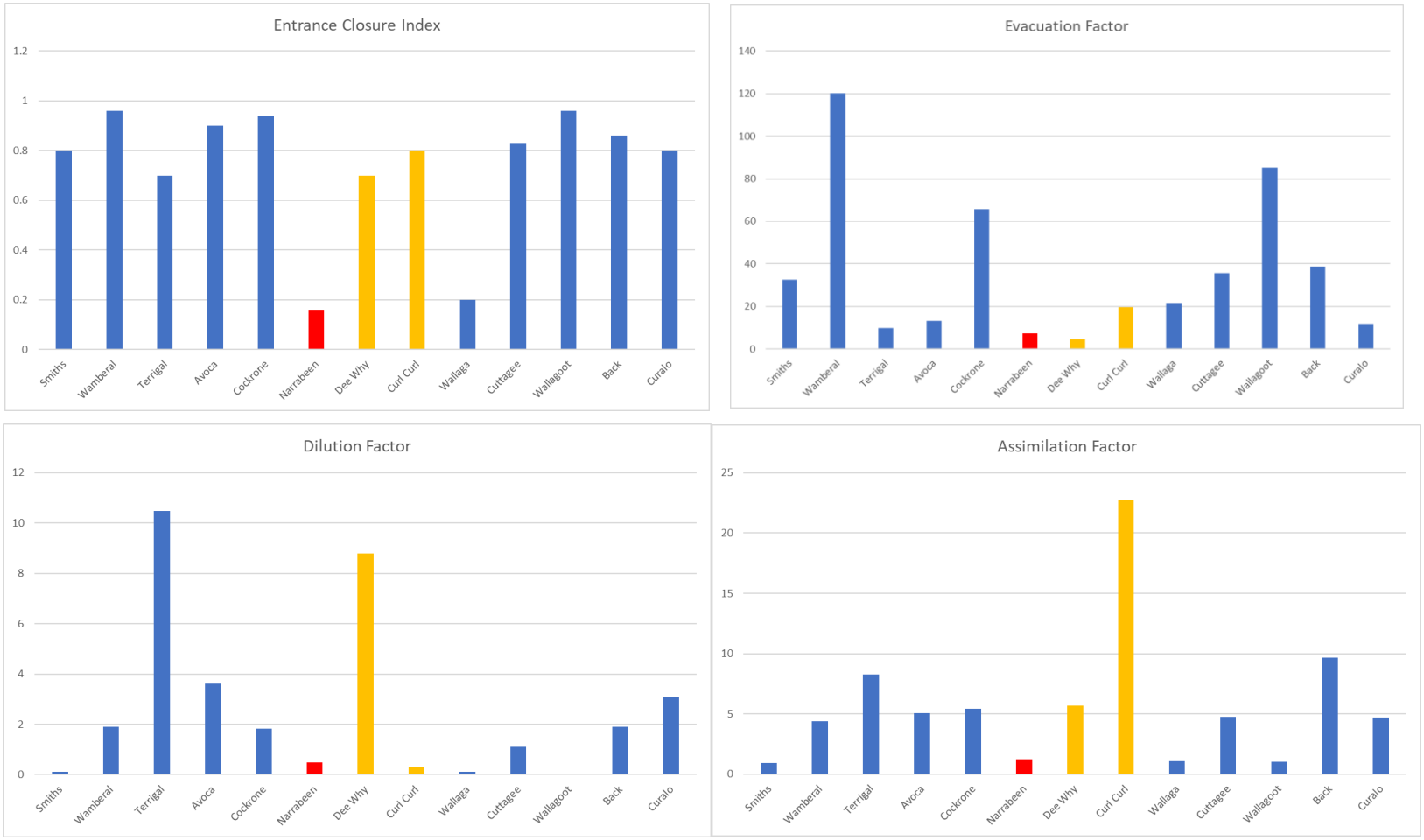


Figure 3-2: Morphometric factors of selected NSW lagoons (Haines, 2008)

Entrance Closure Index: indicates how often the entrance is closed over the long term. The lower the score the more often it is open.
Evacuation Factor: a low number here, which Narrabeen Lagoon has, indicates that there is potential for tidal water flushing.
Dilution Factor: mg/L; a low number here, like Narrabeen Lagoon, indicates that the lagoon has a higher potential to maintain its water quality even when pollution is entering from the catchment.
Assimilation Factor: a low number here indicates that Narrabeen Lagoon has a relatively stable water level.

3.2.2 ICOLL Entrance Management at other NSW Councils

The review of policies from other NSW Councils made it apparent that there are many similar lagoon entrance management philosophies up and down the NSW coast (refer **Table 3-1**). All councils had set appropriate trigger levels, based on a range of factors to ensure that floods were mitigated as efficiently as possible, as part of their estuary management plans. These councils all had detailed procedures for monitoring ICOLL entrances. All trigger levels were considered carefully for each ICOLL and set to ensure a reduction in flood risk while conserving the ecosystems within the lake based on current water depths and future rainfall. However, differences arose in respect to the factors that impacted either the trigger water level or when artificial intervention was allowed. Some of these differences are summarised below:

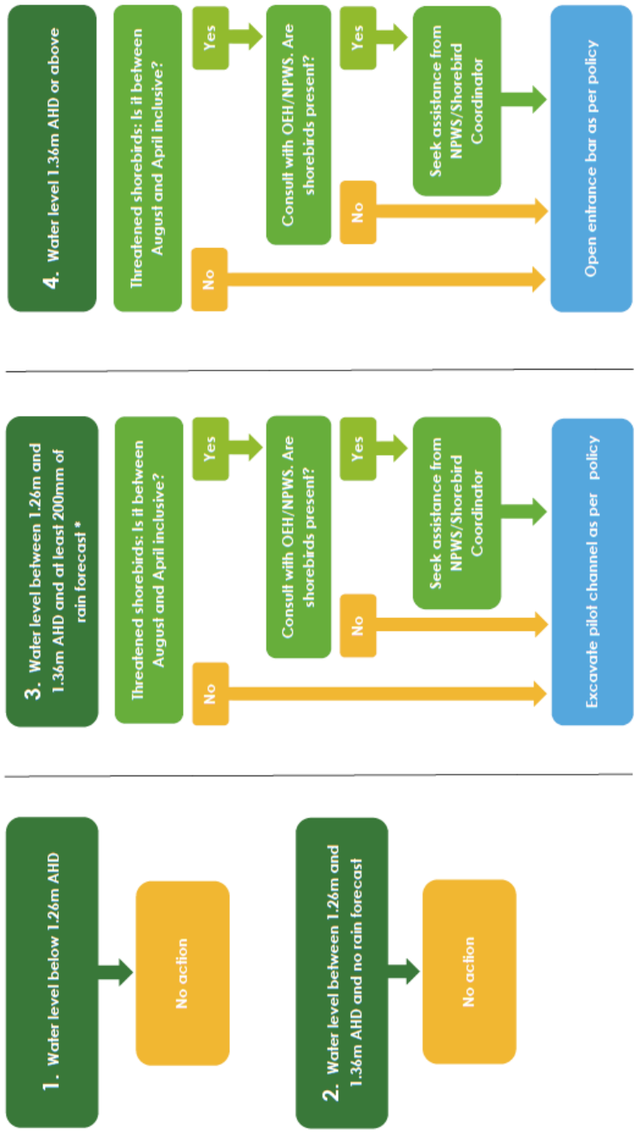
- Greater Taree Council had salinity and water quality indicators impacting the trigger levels due to the oyster and shellfish production requirements.
- Port Macquarie-Hastings Council had triggers impacted by salinity levels.
- In Bega Valley Council and Shoalhaven City Council, while there were still triggers to open entrances to avoid flooding, this was impacted by endangered shorebird nesting. The mechanical opening of the entrance could only be operated during months where shorebirds did not nest and after surveying that the mechanical openings would not impact their nesting. The Shoalhaven River had similar reasons for trigger levels being set as Narrabeen, as they were based on the water level in the river (head difference) to ensure scouring of the pilot channel.

Individual trigger levels were set for all ICOLLs (refer **Table 3-1**) and carefully considered based on a number environmental, social and economic factors. Example entrance management decision trees for Bega, Port Macquarie and Shoalhaven City Councils are provided in **Figure 3-3**.

Table 3-1: Selected NSW entrances – short term response trigger levels and entrance management policies

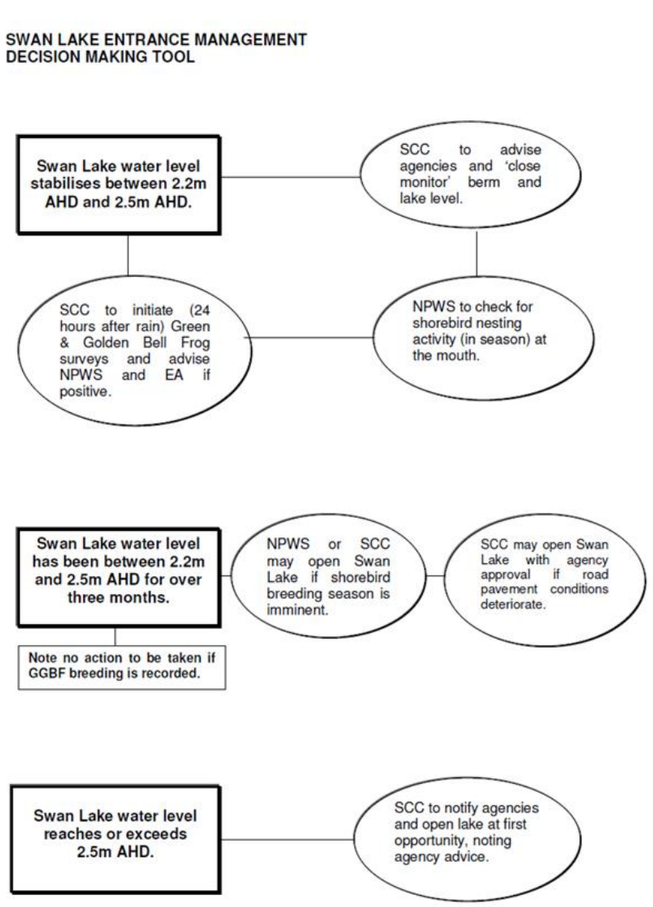
Responsible	Entrance	Warning Trigger Level (m AHD)	Emergency Trigger Level (m AHD)	Entrance Management Policies
Bega Valley Shire Council	Back Lake	1.2	1.4	• Decision tree for management decision(s) (refer **Figure 3-3**) • Minimal intervention in the long term; returning to a 'natural as possible' breakout regime. • Progressive and opportunistic raising of assets to levels above 3m AHD. • Progressive and opportunistic removal of assets that are currently affected by inundation close to or just above the trigger level. • Maintaining a buffer of no new development within close proximity to and below an elevation of 3.0m AHD around water body.
	Bega River	1.26	1.36	
	Curalo Lagoon	1.0	1.2	
	Cuttagee Lake	1.8		
	Wallagoot Lake	1.2	1.4	
	Wallaga Lake	1.1	1.25	
Mid Coast Council (Formerly Greater Taree City Council)	Farquhar Inlet	2.0		• (TBC[3]) Triggers for entrance opening works (Excavation of Notch through Berm): 1. A flood level of 1.6m AHD is reached at the Farquhar Inlet gauge 2. Salinity levels at Farquhar Inlet fall to below 12 ppt 3. Closure of the Scotts Creek shellfish harvest area for more than 120 consecutive days, combined with a weekly rainfall reading at Taree Airport greater than 80mm • (TBC) Dredging of temporary pilot channel to connect main river water body and entrance. • (TBC) Dredging of permanent pilot channel, including Training wall, to connect main river water body and entrance.
Central Coast Council (Formerly Gosford City Council)	Wamberal Lagoon	2.4		• Artificial opening of lagoon entrance at predefined trigger water levels to prevent flooding of surrounding properties. • reduction in catchment pollution via stormwater runoff through implementation of vegetated buffer zones and WSUD features.
	Terrigal Lagoon	1.23		
	Avoca Lagoon	2.09		
	Cockrone Lagoon	2.53		
	Pearl Beach	2.75		
Wollongong City Council	Fairy Lagoon	1.3	1.6	• Artificial opening of lagoon entrance at predefined trigger water levels to prevent flooding of surrounding properties. • (TBC) Maintaining a 'dry notch' (i.e. a low or 'saddle' point in the beach adjacent to the entrance which the Lagoon can preferentially flow across).
	Towradgi Lagoon	1.4	1.6	
Shoalhaven City Council	Burrill Lake	1.1	1.2	• Decision tree based on water level for management decision(s) (refer **Figure 3-3**)
	Currarong Creek	n.a.		
	Lake Conjola	1.0	1.2	
	Shoalhaven River	2.5	3.0	
	Swan Lake	2.2	2.5	
	Tabourie Lake	1.17		
Coffs Harbour City Council	Woolgoolga Lake	1.6		• Scenario decision trees based on water level for management decision(s)
Port Macquarie-Hastings Council	Lake Cathie	1.2	1.6	• Decision tree based on water level for management decision(s) (refer **Figure 3-3**)

[3] *To Be Confirmed.*



* The decision for opening at lower levels is at the discretion of Council officers

Figure 2: Bega River Entrance Management Decision Flow Chart



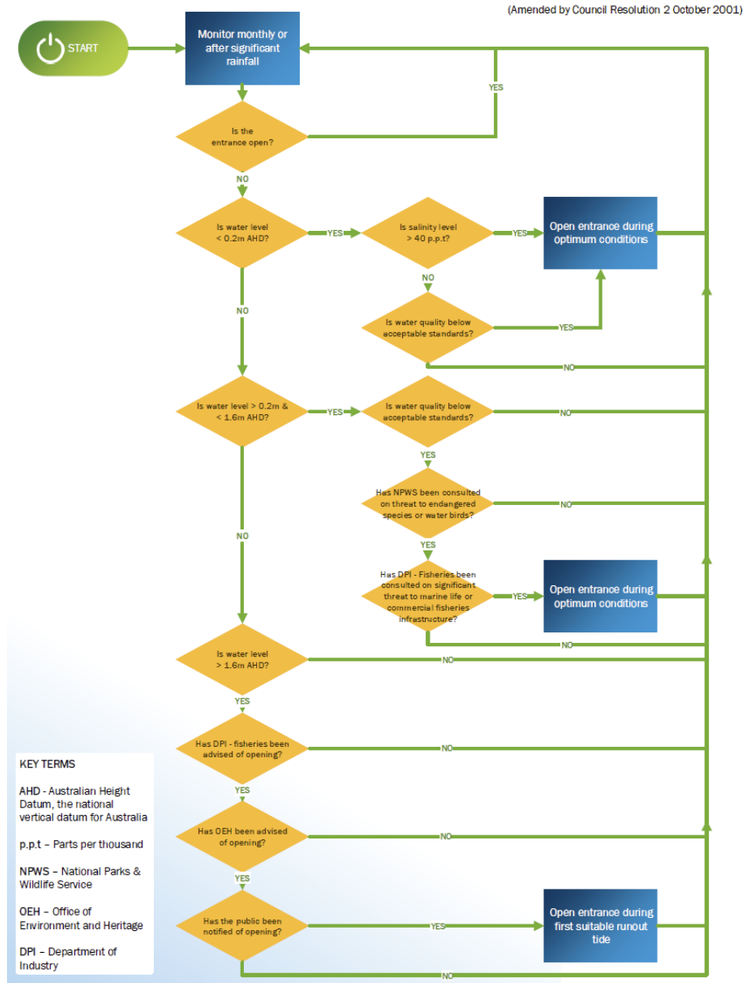


Figure 3-3: Example decision trees for entrance management; Right: Bega Valley Shire Council, Middle: Shoalhaven City Council, Left: Port Macquarie-Hastings Council

3.3 National ICOLL entrance management

With respect to entrance management, the National Committee on Coastal and Ocean Engineering (NCCOE) has the following guidelines and recommendations (refer **Table 3-2**).

Table 3-2: NCCOE guidelines for entrance management

Management Option	Advantage	Disadvantage	Applicability at Narrabeen Lagoon
Barrage(s) / Tidal Gate	• Protects inland areas from ocean inundation caused by elevated storm surge water levels. • Significantly reduces ingress of sediment.	• Very high capital cost. • High maintenance cost. • Potential major adverse impacts on the estuary entrance and adjacent coastline. • May require pumping to control flooding from upstream. • Altered ecology.	Ultimately does not address fundamental issues at Narrabeen Lagoon. Entrance would remain closed during elevated ocean levels. If this coincides with catchment flooding, properties along foreshore would likely be inundated.
Breakwater(s)	• Increased hydraulic conveyance of entrance successful in keeping entrances open and mitigating flooding. • Exposed to tidal flushing every cycle, likely leading to enhanced water quality.	• Breakwaters constructed on littoral drift coasts have the potential to cause “downdrift” erosion by reducing sediment input and by altering beach alignments through nearshore wave diffraction. • High capital costs. • Can potentially change tidal planes and increase tidal inundation within estuaries and flooding of fringing areas. • Can increase channel velocities and channel bank scour. • Increased sediment deposition within the estuary. • Interrupts alongshore littoral drift which may require installation of sand bypassing system. • Can impact of surf amenity of coastline.	Maintaining surf amenity is a particularly important consideration at North Narrabeen. The potential impacts of breakwaters on surf amenity, the high capital cost and likely ecological impacts within the lagoon from altered tidal exchange result in this option not being feasible.

Management Option	Advantage	Disadvantage	Applicability at Narrabeen Lagoon
Training Wall(s)	• Protect internal estuary channel banks from scour resulting from the increased velocities induced by entrance breakwater construction and/or migration of flood and ebb tide channels. • Can be a flexible solution that is adaptable to prevailing sea level and climate conditions.	• Limited success because the scale of the scour process is very much larger than that of the bank protection works. • Can create localised scour or high velocities. • Increase in the tidal prism (due to more efficient tidal exchange) may destabilise the entrance.	A training wall is already present along the northern bank of the lagoon entrance. The potential impacts of installing a training wall on the southern side of the lagoon entrance on surf amenity, the high capital cost, and likely ecological impacts within the lagoon from altered tidal exchange result in this option not being feasible.
Dredging	• Keep untrained entrances open. • Dredging can allow for maintenance of some exchange of ocean water with the lake and for flood conveyance. Placing sand onto the beaches, in the short term, maintains beach amenity and provides a greater sand buffer to mitigate storm erosion.	• Can become expensive and/or frequent during periods of drought or particular coastal conditions (swell directions, beach rotation). • High long term operation costs. • Potentially disruptive operation.	Dredging (i.e. entrance clearance operations) has been effectively employed as a primary entrance management procedure at Narrabeen Lagoon for over 50 years. Though recently it has been required, in its current form, more frequently due to the prevailing coastal conditions.
Entrance Bypassing Systems	• Can be developed where entrance breakwaters have interrupted the natural transport of littoral drift along the coast. • Flexible systems that can vary from fixed sand pumps located on trestles that extend across the surf zone to shoreline operations using excavators, bobcats and trucks.	• High capital, ongoing and maintenance costs. • Can prevent use of a section of beach.	Entrance bypassing would require prior construction of breakwaters. Given the location of the entrance of Narrabeen Lagoon to the immediate south of several pocket beaches defined by headlands with limited sand exchange (essentially closed systems), an entrance bypassing is not considered to be necessary.

Management Option	Advantage	Disadvantage	Applicability at Narrabeen Lagoon
Artificial Reefs	• Induce incoming waves to break, thus reducing the wave energy reaching the shore. • Alter currents and hence sediment transport and beach alignment. • Can enhance surf amenity and/or ecology. • Structure is not visible from the beach if always submerged.	• Only suitable for small tidal ranges with low wave variability. • Limited protection during coastal storms. • High capital costs.	May reduce localised wave energy reaching the shore, however littoral drift would still occur along Collaroy-Narrabeen Beach. May increase time for sand to build-up inside entrance. Coastal storm events would still likely result in large ingress of sand to the entrance.

3.4 International ICOLL entrance management

A review of management was undertaken for ICOLLS in South America, America, Africa and New Zealand which showed there are a range of management approaches used worldwide from very active management in New Zealand, cultural management in Africa and a comparative review of the impact of intervention/inaction between 2 ICOLLS in South Africa.

Australia has the highest proportion of ICOLLs in the world at 21%. Outside Australia, ICOLLs occur in larger numbers in New Zealand, South Africa, North Africa and the Mediterranean, the southernmost coasts of South America and the west coast of North America (refer **Figure 3-4**).

ICOLLs around the world are concentrated along microtidal to low mesotidal coastlines in the mid latitudes and predominantly in temperate climates. ICOLLs form at the mouth of rivers with generally low mean annual discharges and typically occur where marine processes dominate (i.e. wave dominated) over fluvial inputs. The distribution of ICOLLs internationally is related to greater wave heights, driven by high intensity winds and longer fetch distances, and is associated with a tidal range of <~3 m, smaller catchments < 2000 km^2 and tidal prisms < 30 x 106 m^3.

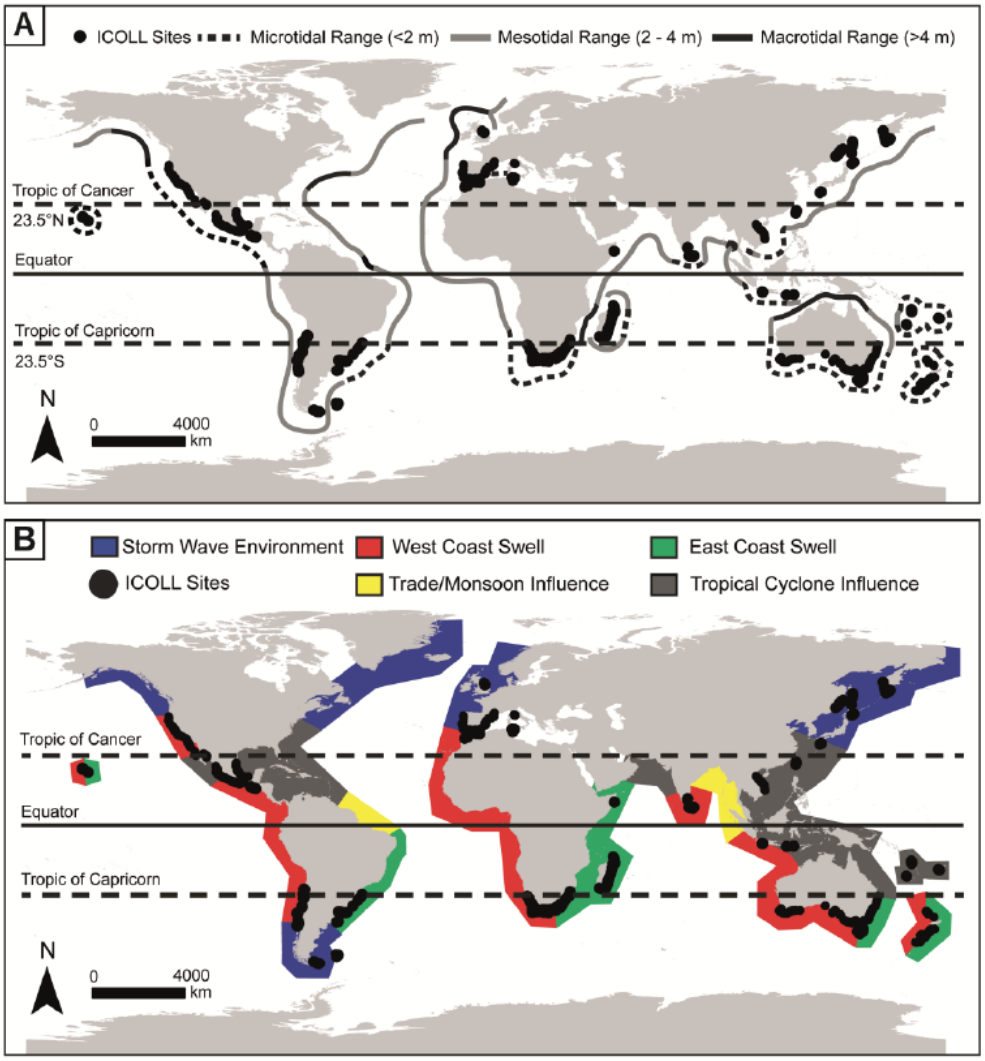


Figure 3-4: Global distribution of ICOLLs (Source: McSweeney et al., 2017)

3.4.1 Applicability at Narrabeen Lagoon

The entrance management of all ICOLLs requires a balance between environmental, social and economic factors. Each system should be carefully considered, and a policy developed that considers flood risk, the health of the ecosystem and public amenity. These factors need to be carefully considered in Narrabeen Lagoon due to the size of the catchment, the degree of development on the adjacent floodplain, and the engaged local community.

As discussed above, where possible, the best management strategy when dealing with ICOLLs is to leave these systems as close to natural and as undisturbed as possible. When ICOLLs are artificially altered there can often be adverse environmental impacts within the natural system. However, flood events within urbanised catchments are often considered to be a valid reason to intervene due to the risk to property, and in some cases risk to life. When managed correctly, the potential negative impacts of artificially altering the behaviour of an ICOLL can be reduced. While entrance management is important to ensure the reduction in flood impacts on properties, these strategies should be carefully managed to ensure minimal negative environmental impact.

In summary, a highly populated lagoon such as Narrabeen Lagoon, with large numbers of properties and assets on the surrounding floodplain, should have appropriate procedures for mechanical opening and entrance clearance which consider long term impacts.

3.5 Priority considerations for Narrabeen Lagoon entrance management

The reviews undertaken in this Section have confirmed that undertaking mechanical openings and entrance clearance operations at Narrabeen lagoon is appropriate as a means of flood mitigation. The entrance clearance operations also aim to maintain or enhance water quality in the Lagoon and to conserve or enhance the biological diversity of the Lagoon system. Key considerations for this assessment include:

- The Narrabeen Lagoon Floodplain Risk Management Plan lists entrance clearance operations, with the included result of facilitating mechanical openings to be done when the lagoon does close, as its highest priority flood mitigation action;
- Community expectations including those of property owners and recreational users;
- The short term mechanical openings are consistent with State, national and international management practices;
- As an ICOLL, the lagoon is a sensitive natural environment and therefore any management process or activity needs to carefully consider the environmental impacts; and,
- The conditions at the entrance are changing all the time, such as with the decadal beach rotations and state of Birdwood Park Dune, and a variety of approaches, or more flexible processes, may be needed to appropriately manage the entrance.

Sections 4, 5 and 6 of this report consider, analyse and evaluate the way that current entrance management activities are undertaken as well as identify alternative options.

The alternative options were developed through engagement with Council and identified industry experts who have a thorough understanding of Narrabeen Lagoon. This initial stage identified, considered and prioritised possible alternatives to ultimately develop a list of viable alternate options that should be evaluated in detail. These options were refined following community consultation via a draft options paper in 2021. Alternative options were considered to address the short and medium term entrance management works that are currently already undertaken, as well as to consider if there may be a suitable

longer term solution. It is important that financial, environmental and social aspects are considered when assessing all activities.

Short term management
Short term management needs to carefully consider the emergency response, reducing risk of damage to properties in low-lying areas surrounding the lagoon, as well as the efficiency of the opening to maximise the time the lagoon will stay open, thus minimising the return time for undertaking a new mechanical opening.

Council currently mechanically opens the entrance of Narrabeen Lagoon when the water level reaches 1.0-1.3m above mean sea level. While at this water level the minor flooding is considered to be nuisance flooding, water levels are noticeably high and can cause alarm in the community, especially if they remain elevated for long periods of time. As reported in the community engagement options report "A key outcome of this analysis will be a decision as to whether there is scope to mechanically open the lagoon at lower water levels and, if so, what conditions are required to ensure it is a successful opening." (RHDHV, 2021).

Medium term management
The review of medium term management considered potential improvements and refinements to the existing entrance clearance practices, including planning, design, work methods, and construction operations and management. As reported in the community engagement options report "A key outcome of this review will be to identify whether it is possible to shorten the time between the entrance being completely full of sand and the clearance works starting on site. It will also provide an assessment of the frequency, design and alternative clearance methodologies." (RHDHV, 2021). Dune management at Birdwood Park dune is also an important medium term consideration due to its impact on sand movement in the area.

Long Term Management
The objective of the development of a long term management strategy for Narrabeen Lagoon entrance is to determine if there is a feasible, alternative permanent management option that could be implemented to reduce the frequency, improve the effectiveness of, or eliminate, current short term and medium term management interventions referred to above. Several potential long term entrance management options have been investigated in **Section 6** of this report.

3.5.1 Climate change

Climate change and projected sea level rise pose an issue for the management of the Narrabeen Lagoon entrance. Projected sea level rise scenarios will result in worsening flood conditions due to higher ocean water levels, a higher entrance berm level and higher initial water levels in the lagoon.

The latest IPCC sea level rise predictions are documented within the IPCC Special Report on the Ocean and Cryosphere in a Changing Climate – Chapter 4 Sea Level Rise and Implications for Low-lying Islands, Coasts and Communities (IPCC, 2019). Predictions for the upper bound of the likely range (i.e. 13th to 87th percentile) of sea level rise for the worst case RCP8.5 climate change scenario are 0.08m in 2030 and 0.17m in 2040 relative to the present time. Equivalent predictions for the mid-range RCP4.5 climate change scenario are 0.07m in 2030 and 0.14m in 2040 relative to the present time.

Higher sea levels mean that Council's trigger levels (currently 1.0 to 1.3 m AHD) will require reconsideration in the future and likely will need to be significantly higher to be effective (BMT WBM, 2013), however consideration must be given to the lagoon water level at which inundation becomes problematic for Council and the community.

The 2013 Narrabeen Lagoon Flood Study identified that peak design flood water levels are expected to progressively increase as the impacts of climate change manifest resulting in a worsening of existing flood conditions through higher ocean water levels (tide and storm surge), higher entrance berm and higher initial water levels in the lagoon.

Morris' (2010) investigations into climate change suggested that the natural cycle at which the entrance opens and closes would accelerate leading to decreased periods in which the entrance was open to the ocean. This will impact the frequency and effectiveness of entrance clearance operations.

The report discusses the impacts of climate change in each section as appropriate.