

The background of the entire page is a photograph of a coastal landscape. It shows a wide, sandy beach in the foreground, leading to a calm body of water. In the distance, there is a small, dark, rocky island or headland. The sky is a pale, hazy blue. The overall tone is serene and natural.

Coastal Zone Management & Planning

Review of Central Coast Council's Lagoon and Lake Entrance Management, Policies and Practices

Report No 2021/3

April 2021

Entrance Management of the Central Coast Lagoons

Foreword

Central Coast Council (CCC) engaged Angus Gordon of Coastal Zone Management and Planning (CZM&P) to briefly review both the policies and practices of entrance management for the CCC open coast lagoons. This report is the written response to the request.

Executive Summary

There are five open-coast Intermittently Closed and Open Lagoons (ICOLS) in the CCC LGA. The smaller lagoons are, from south to north, Cockrone, Avoca, Terrigal, Wamberal. Tuggerah, is the fifth and is considerably larger and more complex than the other four. Tuggerah is actually made up of three water bodies, being the main Tuggerah “lake” and then Budgewoi and Munmorah to the north, both of which connect to the main waterbody and do not have separate ocean entrances; all effectively exit at “The Entrance”.

CCC is currently developing an Estuary Management Policy for the four smaller lagoons but in the meantime is continuing to utilise the former Gosford Council Entrance Management Policy; a policy that has been evolving over decades of application and operational experience. The basics of this policy can be considered good management practice when compared to similar policies elsewhere. In 2017 Gosford Council engaged Salients Environmental Consultants to review the Policy and suggest improvements. Salients produced a detailed report including a draft new Policy and Procedures that could be applied to the management of the four lagoon entrances however the initiative was overtaken by other events. The current development of an updated CCC Policy is building on the Gosford policy and taking into account the Salients recommendations. This review report also suggests some minor fine tuning to assist with communication of the new policy to both the staff operators, and importantly to the community. This review was impressed by the level of understanding staff had of the matter so, given the advanced form of the available information and understanding, the finalization of the new CCC (updated) Entrance Management Policy for the four smaller lagoons should be a relatively straight forward matter that doesn't require a great deal of effort. In addition to the Policy CCC, is currently looking to improve its on-line communications with the community so that members of the community can not only access real time lagoon levels, as is currently possible, but also can monitor and be advised of the status of proposed management actions such as when the Lagoon breakout is planned to occur.

In regard to entrance management of Tuggerah, a far more complex system, it is not apparent that a formal entrance management policy currently exists. Over the past few decades, a heuristically based dredging program, triggered by any one of three criteria being exceeded, has been used in an attempt to maintain the northern ebb tide channel so it can function as a flood relief pathway. The dredging has been reportedly undertaken in what could be perceived as an ad hoc manner every 1 to 2 years. It has reportedly removed somewhere between 30,000 to 80,000 cum of sand each time, over a period of up to 4 months. The excavated sand was placed on North and South Entrance Beaches, as dictated by conditions at the time. There have been various “trials” with the location of the dredged channel, and in

particular the location of the actual entrance. This approach has produced varying results leading to some lack of confidence in the process by community members.

In 2020, in order to address this issue CCC engaged Manly Hydraulics Laboratory to undertake a detailed study, in a staged manner, that would lead, in part, to the development of a robust entrance management policy. The reason a staged approach was adopted was because of the level of detail required due to the complex interactions between rainfall runoff, lake levels, ocean conditions, shoaling in the entrance channel, channel widths and impacts on shore based development and usage. The complexity is due to the relatively low average water level of the lake system, hence the lack of adequate hydraulic head to drive floods through the system. This being compounded by the often elevated ocean water levels associated with East Coast Lows that in part add to the rainfall causing the flood. The first stage of the MHL project, which is in an advanced draft report form, summarises and reviews 23 of the studies/reports that already exist regarding the behaviour of the entrance to Tuggerah along with the various ideas on entrance management strategies. This is a particularly useful summary and analysis of the available information. The report also includes a credible conceptual model (including easy to understand diagrams) and an overview of how the entrance behaves both between and during floods and the natural sand interchange between the entrance channels and the beach under different conditions. As such this MHL first stage report is an important tool for Council but also as an aid to community understanding of the challenges facing entrance management options and policies. There is relevantly little additional work required to finalise this first stage report and it would not be out of context for it to be released as soon as practical as it would provide a soundly based background for future community consultation.

The second stage of the MHL project involves the development of numerical models that allow an understanding of the interactions of different rainfall runoff, oceanic conditions and the state of the channel system connecting the Lake to the ocean. That is, the entrance behaviour and water level variability in Tuggerah Lake due to the various mechanisms in play. This stage is aimed at providing the ability to examine the effectiveness and optimization of various possible entrance management options. The report is currently in draft form but is a work-in-progress. Whereas the first stage report is likely to be of interest to the overall community the second stage report is more aimed at those with a more technical interest. One of the overall aims of the project is, through future stages, to not only detail how the Lake and entrance work but also the impacts on the ecology and flood risk management and as a result determination of an entrance management policy.

In addition to the many reports that already exist regarding the entrance to Tuggerah Lake the State Government established an “Expert panel” to examine the overall behaviour of NSW Lagoons and Lakes that close from time to time (referred to as ICOLs). The yet to be released report contains extensive information on the behaviour of the different types of NSW ICOLs and their entrances. While this information is helpful in providing an understanding of ICOLs its relevance to Tuggerah is that it provides the information necessary to put the Tuggerah issues into the overall context of other NSW ICOLs and so is a useful background document.

Australia is indeed a land of droughts and flooding rains. Given that droughts, like the recent one, can last for several years, estuary entrances such as that at Tuggerah become choked

with sand. Memories fade and people and organizations can become complacent. New people move in who don't realise their house was elevated to overcome flooding and so fill in the "conveniently" available space under the house to create more habitable space. Then when floods come understandably community concern grows. Unfortunately, like the conditions that create droughts, the weather systems that cause floods tend to come in groups. But the way places like Tuggerah Lake responds to heavy rainfall and runoff depends very much on the conditions of the catchment at the time, the hydraulic head difference between the Lake water level and that of the ocean, and to a lesser degree the existing state of the interconnecting channel, provided it is open. That is not to say the state of the channel has no influence rather that as so long as the entrance is open there can be very different responses depending on the hydraulic head difference between the Lake and the ocean at the time. This is born out by several of the available studies and by the recent flood events (2020 and 2021).

In 2020 the Lake level was very low before the event and the catchment dry. Evidence shows the entrance was open (despite community comment that it was closed) but the channel was very narrow and choked with sand. The rainfall event was reportedly some 25% larger than the 2021 event. However, with a dry catchment and low initial lake levels a considerable volume of the rainfall was absorbed by the catchment and by filling the Lake(s). The choked channel and adverse oceanic conditions caused the Council to act to excavate a channel in the central section of the spit in order to realign the flood flow and reduce the flood peak.

In 2021 the catchment was wet resulting in greater runoff even though the actual rainfall was less. Further, the lake level was initially higher. The entrance was open but somewhat tortuous (doubling back to the north) and oceanic conditions more favorable however the resulting combination of factors meant that the peak lake level was similar. For the 2021 event CCC had equipment ready to assist in widening the channel and did in fact operate to help straighten the channel through the spit thereby reducing the head loss associated with more tortuous route. What both the 2020 and the 2021 events demonstrate is that flood levels in the lake are dependent on a number of factors the combination of which can differ each time. The entrance channel is but one important component however not a great deal can be achieved unless proactive action is taken well before flood events and hence the need for a well-considered on-going entrance management policy that ensures timely responses in order to minimize adverse flooding. It is just not practical to have a dredging procedure that takes months to implement when flood prediction is limited to a few days and at best perhaps a week. Finally, there is an on-going need to recognise that the elevation of the Lake and its immediate surrounds is unfavorably low compared to the potential oceanic conditions that can occur from time to time so planning controls and flood risk management are key matters in minimizing flood impacts.

Given the realities of the situation it is clear there is little else the CCC could do during both the 2020 and 2021 events to alleviate flooding of properties. The fundamental problem with the overall system is that the Lake(s) level is too low. The average water level is 0.2m to 0.3m AHD that is approximately 0.3m above mean sea level. If the entrance and channel conditions are made hydraulically more efficient the tidal range of the Lake(s) would increase resulting in more regular flooding at high tides and, at low tide, shallower Lake depths with the resulting adverse impacts on seagrasses.

Drivers of the need for lagoon entrance Management

The two principal drivers for lagoon management and intervention in natural processes are flooding of properties and water quality in the lagoons. In their natural state the type of lagoons/lakes on the NSW coast trend to closure because of the imbalance between flood tide transport of sand in through the entrance and the lesser scouring ability of the ebb tide flow to remove sand back out to the ocean. Not only are velocities greater on the flood tide than the ebb, albeit for a short duration, but wave stirring in the surf zone entrains sand that is then available for the flood tide flow to transport into the entrance, whereas on the ebb tide there is no matching entrainment mechanism within the estuary to enhance ebb tide transport.

Entrance closure generally follows a period of low rainfall runoff into the lagoon/lake and is usually finally caused by sand transport into the entrance during an ocean event that enhances sand movement on the beach and drives a sizable quantity of sand into the entrance in a short period of time. Once closed the sandbar across the entrance is built up by wave runup pushing sand up on top of the bar and by wind born sand transport onto the bar. Evidence from many of the Lagoon/lake entrances on the NSW coast indicate that sandbar crests can typically build up to +3m to +4m AHD given an extended period of closure. This means that for a natural lagoon/lake breakout to take place following an extended period of closure, flood levels in the lagoon/lake have to exceed +3m to +4m. Unfortunately, in the case of many NSW lagoons/lakes property subdivision historically took place on land below these levels and hence many properties are potentially liable to flooding. Initial development often took the form of “weekenders” or fibro and weatherboard housing and occasional flooding was an accepted outcome. However, as property values have increased, and higher value permanent residences replaced the earlier development, flooding has become a less acceptable outcome. Hence there is an increasing expectation for flood relief by opening or retaining entrances open. Interestingly few are aware that oceanic flooding through an open entrance, during a major storm event, can produce water levels in lagoons/lakes that approach the levels caused by major rainfall runoff events.

Once catchments become developed water quality in the associated lagoons/lakes deteriorates because of the introduction of pollutants including nutrients. This is most marked in areas that rely on on-site sewage disposal systems. As those areas become sewered there is generally an improvement in water quality however, broken pipes, non-connected housing and pumping station overflows can still result in fecal contamination. Run-off from gardens, nutrients from lawn clippings and stormwater flows into lagoons and lakes can also result in poor water quality and algal growths that can damage seagrass beds. This damage along with strong winds causing wind waves can result in seagrass shedding their leaves which form “wrack” that collects on lee shores and generate odour problems. Keeping entrances open and hence ocean water flushing is often seen as a solution. However, while such flushing can effectively take place in smaller lagoons studies have demonstrated that in larger water bodies the oceanic flushing effects only part of the water body and so the interchange is also dependent on wind induced currents that draw water past the “mixing zone” which is generally in the vicinity of the lake end of the entrance channel.

Background to CCC entrance management

CCC has a total of five open coast lagoons. The smaller lagoons are, from south to north, Cockrone, Avoca, Terrigal Wamberal and Tuggerah, although Tuggerah is actually made up of three water bodies, being the main Tuggerah “lake” and then Budgewoi and Munmorah to the north, both of which connect to the main waterbody and do not have separate ocean entrances; all effectively exit at “The Entrance”.

Although variously known as “lakes” or “lagoons” all of these waterbodies are technically classified as Intermittently Closed and Open Lagoons (ICOLs) and so for the remainder of this report are generally referred to as such. Hence for consistency and in keeping with the technical literature the name “lagoon” is used rather than “lake” even though it is recognised that some, such as Tuggerah are formally referred referring to, and known as “lakes”.

All five entrances display the characteristics of what is known as being in a long term shoaling regime with scour of the entrances only occurring after heavy rainfall and either overtopping of the beach berm by the water in the lagoon or breakout being induced by mechanical means. What this fundamentally implies is the entrances trend to closure under the natural coastal processes and remain closed if there is no significant runoff from their catchments, unless artificially opened.

While the four smaller lagoons tend to close rather rapidly after breakout because the beach sand movement and flood tide transport of sand into the entrance overwhelms the ebb tide scour processes, Tuggerah is somewhat different. Tuggerah displays the characteristics of an entrance trending to closure but that remains open for extended periods of time. This results in the development of a flood tide delta that slowly moves into the main channel and overwhelms the ebb tide scour channel. This process is classified as flood tide dominated tidal asymmetry; a phenomenon that features, and has been studied, in many locations both in Australia and overseas, particularly in the United States.

Interestingly there are significant similarities between the CCC lagoons and those of the Northern Beaches Council’s (NBC) open coast lagoons being Manly, Curl Curl, Dee Why and Narrabeen. All three of the smaller NBC lagoons have similar entrance management issues to the four smaller CCC lagoons, and Narrabeen also has very similar issues for entrance management as does Tuggerah. This means there are joint experiences and lessons to be shared by both Councils. It is understood that informal relations between both Councils exist at officer level and it is clearly in the best interests of both councils that these relations be encouraged.

This report firstly looks at the entrance management of the four smaller lagoons before focusing on the more complex situation at The Entrance.

Cockrone, Avoca, Terrigal and Wamberal Lagoons

CCC currently has an entrance management policy, “Opening of Coastal Lagoons” (reviewed in 2017), that covers all four lagoon entrances. It is a previous Gosford Council Policy that has been in existence for many years. It is currently being revised and updated to become a formal CCC policy. The current policy sensibly includes statements such as:

“OPENINGS

Terrigal, Wamberal, Avoca and Cockrone Lagoons have marked level heights at various points around the shores. These levels show the critical heights above which local residences and property may be flooded. Once the water reaches these levels, the lagoons **must** be opened. The let out levels are shown on the attached schedule (Table 1).”

“SANDBAR LOWERING

As heavy rain occurs, there is a possibility that lagoons can quickly fill and exceed the heights at which the lagoons are let out. In order to control this eventuality, the flood management plans for the lagoons have calculated levels at which the sandbars of lagoons should be retained in order to allow the lagoons to let themselves out should severe floods occur. The levels at which the sandbars should be kept are indicated in Table 1.”

The policy states that the sandbar levels (entrance beach berm levels) are to be regularly checked by survey, which it is understood occurs, however this process is somewhat resource hungry and so it is also understood that thought is being given to alternative methods to achieve the same result.

“SAFETY

Suitable signs and barriers are to be erected at the time of opening and maintained during the initial run out period.

There will be times when the sandbars need to be excavated but the sea conditions are so large that working on the sandbars would be dangerous and contravene occupational safety provisions. In these circumstances the work shall be delayed until the tide and sea state have moderated to a point at which the work can be safely carried out. However, due to the flooding that is likely to occur, any delay should be kept to a minimum.”

Elsewhere it is noted that, along with the caution regarding attempted mechanical breakouts during high seas, mechanical openings should be carried out during the daytime for occupational safety provisions and so that the safety of the public can be best managed. To this end it may be desirable that in the new policy consideration be given to having a suitably trained safety officer(s) on hand as experience indicates young people tend to enjoy the often “wild ride” down the breakout channel on body boards which can often be a rather dangerous pursuit.

The current policy makes reference to notifying lifeguards if they are on duty, but this provision should probably be reviewed and strengthened given the potentially dangerous

nature of the activities that some members of the public engage in while the breakout channel is in full flow.

The policy includes a simple but effective table which can be summarised as:

Lagoon	Let out level “Trigger level”	Sandbar height
Terrigal	1.23 m AHD	1.7 m AHD
Wamberal	2.40 m AHD	2.6 to 2.7 m AHD
Avoca	2.09 m AHD	2.7 to 2.8 m AHD
Cockrone	2.53 m AHD	3.3 to 3.5 m AHD

In addition to this ex-Gosford Policy and the new policy under development there is also a document entitled “Gosford Lagoon and Entrance Management Review: Phase 3 (including Revised Policy and Procedures)” prepared by Salients Environmental Consultants in 2017. The document contains a considerable amount of useful supportive information, including a more sophisticated table. It also covers lagoons other than the four open coast lagoons being currently considered, and helpful maps. The policies and procedures are in draft form and need some updating however do contain suggestions and procedure steps and directives that would be helpful in preparing the new CCC Policy.

Based on recent experience it is recommended that in preparing the new policy the levels in the above table be compared to the acknowledged tolerable flood levels. It is understood there may be some disconnect between the flood planning levels for development around the lagoons and the management of the entrance. The disconnect may include flood risk management assumptions regarding the ability to ensure levels in the lagoons can be controlled at all times whereas, even with best endeavours this may not be achievable. For example, if the berm is fully developed but conditions are such that it is considered unsafe for personal and plant to open a lagoon a natural breakout will eventuate at a level dictated by the berm crest level at the time, which may be considerably higher than the planned management level. As a rough guide, experience has shown that fully developed berms at lagoon entrances can have crest levels of 3m to 4m AHD.

It is noted that the NBC (Warringah Policy) trigger level for the two most similar lagoons is 1.8m AHD although significant differences in factors such as beach berm widths and heights, and flood planning levels determine the site specific trigger levels that should be applied.

The table, and the document contains Contact Numbers, Job Numbers and a “Who to Notify”, are out of date and clearly intended to be instructions to Council officers rather than information for interested community members. Importantly it isn’t clear who the officer ultimately in charge is, nor the chain of responsibility. Further, given that the policy was originally developed for Gosford Council there isn’t a current contact number for the public if they become concerned at developments in regard to water levels in the lagoons. It is however understood it is intended to deal with these matters in the new policy.

The lagoons have automatic water level gauges that can be accessed by the community online through the MHL website and Council is working with MHL to provide near real time

information on likely water level and flooding developments using the MHL “Fit Tool” which should facilitate community access to relevant information.

The current policy makes reference to ensuring that artificial openings be made at the centre of the “sandbar” in order to minimise meandering and hence threat to adjacent property. This is a sensible provision to which it could be added that a breakout at the centre location tends to produce the minimum length of channel and hence the steepest grade which therefore means the most effective and energetic breakout thereby lowering the lagoon levels in minimum time.

One matter that could be more clearly covered in the new policy is in relationship to experience dictating that an artificial breakout channel should be started at the lagoon side of the sandbar and carried across to be finally broken out on the ocean just after high tide, if possible.

This may seem counter intuitive however breakout channels generally take several hours to develop and so if the breakout takes place just after high tide the channel has the best opportunity to form as the tide drops, and the head difference between the lagoon level and the ocean progressively increases. Whereas if breakout occurs at low tide the rising ocean levels and waves tend to throttle the channel development and often end up with the channel being closed off at the next high tide.

The current policy however makes an exception for Avoca Lagoon where there are a couple of factors, such as the breeding of Green and Golden Bell Frogs and odour issues, that make it desirable to have the entrance close as soon as possible after a breakout. So, at Avoca it may be desirable to commence the breakout near low tide so that the breakout is less energetic, and the entrance closes as soon as possible.

The timing of breakouts should be reviewed from time to time in the light of the outcome desired. For smaller lagoons, even with an energetic breakout, the lagoon entrance generally closes in a couple of weeks, unless there is follow up rain. During the time they are open to ocean tides these smaller lagoons have the opportunity to experience near total oceanic flushing.

It is understood that as part of the CCC revision some of the approach currently in the NBC policy (Warringah Policy) is to be included, such as the use of a diagram for each lagoon entrance that simply summarises the desired location of the breakout channel and relevant information regarding artificial breakouts. This is also in keeping with the Salients report that includes a series of “Field Operations Maps” for each of the lagoons that are very similar to those included in the NBC (Warringah) Policy.

The Salients maps have some additional information that would assist both Council operators and the community to clearly understand issues regarding artificial openings. Although both contain important information, it is felt that the addition of trigger water levels and berm heights for each lagoon would also be helpful. A copy of one of the Warringah maps, along with one of the Salient maps is included to illustrate the value of this approach as community information.

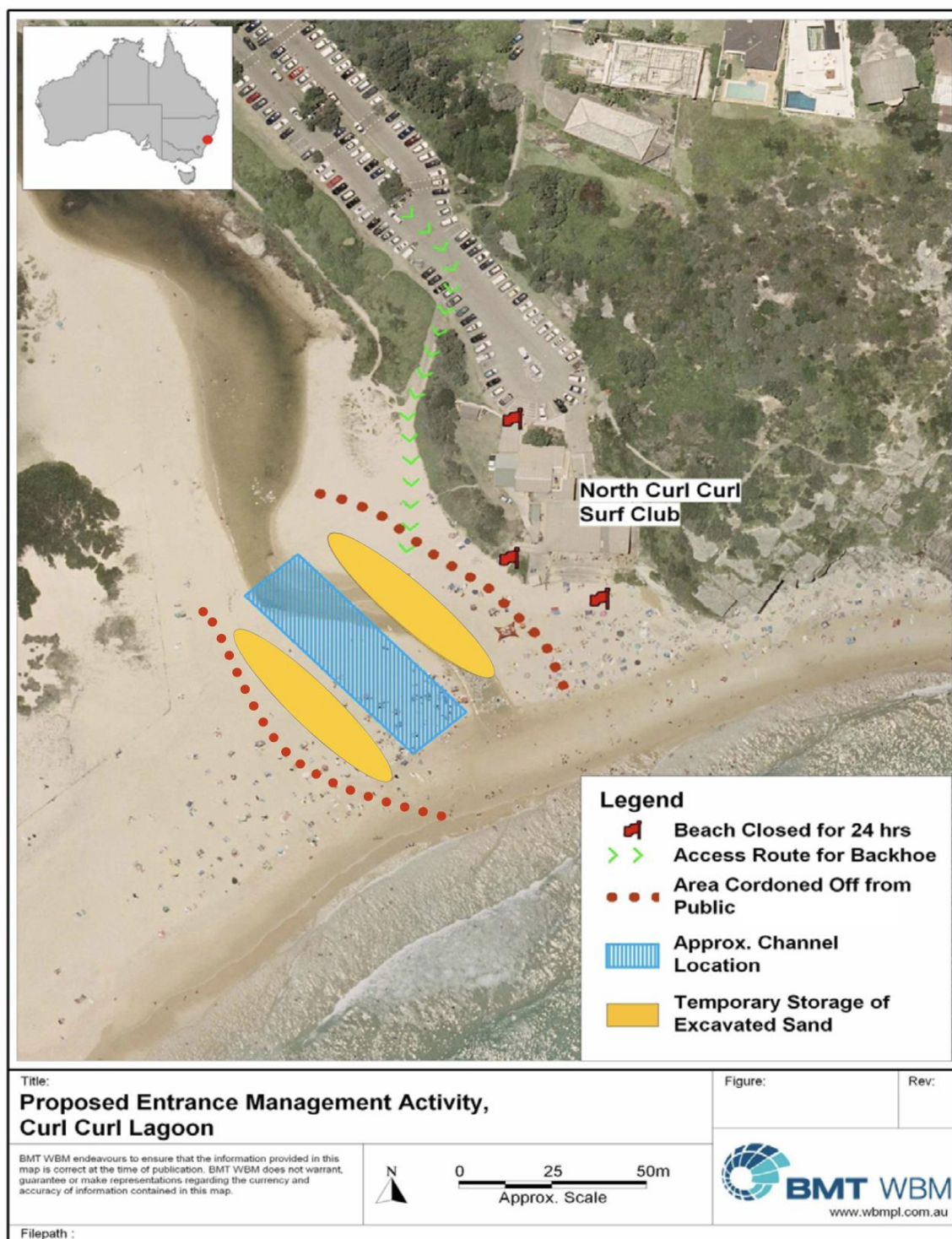
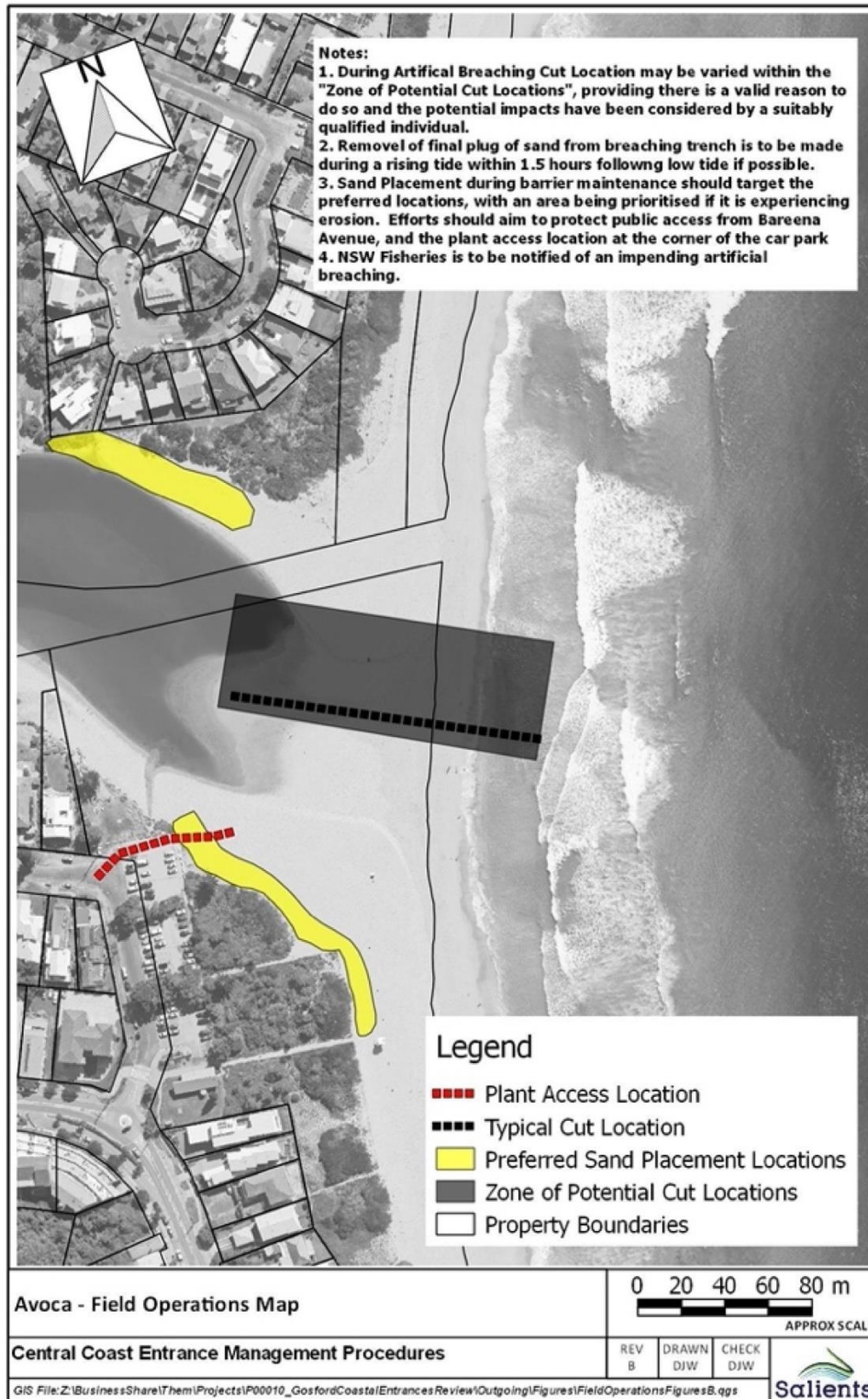


Figure 3: Map of Curl Curl Lagoon Entrance

From Warringah Council "Lagoon Entrance Management Policy" about to be reviewed to become the Northern Beaches Entrance Management Policy



From Salients Draft Policy as included in the Salients report "Gosford Lagoon and Entrance Management Review: Phase 3"
June 2017

Tuggerah Lagoon/Lake Entrance

There does not appear to be a formal CCC Policy for the management of the entrance to the Tuggerah system. Rather there has been an ad hoc arrangement in place since 1993 that has sought to manage flooding through the “entrance maintenance dredging works” initiative. According to the available information these ad hoc works have been undertaken every 1 to 2 years whenever the following indicators have been reached:

- The throat of the channel at the southern tip of the sand spit at the Entrance reduced to a width of 15 m at mid tide level.
- The flood tide sand shoals threaten to block the ebb tide dominant channel along the northern/eastern side of the Entrance area.
- The flood tide shoals threaten to block the main channel east of the bridge.

It is understood that for many years the then Wyong Council owned and operated a dredge that was used for the dredging program but, with the demise of the dredge a private contractor was engaged to deliver this service. The available information suggests that any one dredging campaign involved the removal of between 30,000 and 80,000 cum, usually over a period of up to 4 months, with the sand used to nourish South and North Entrance beaches.

The Tuggerah Lakes Flood Plain Risk Management Study indicated that:

“entrance management via periodic dredging would have no adverse effect on flooding except for potentially increasing the likelihood of ocean inundation compared with a non-dredged entrance. The study noted minor benefits of the maintenance dredging including possible prevention of minor flooding, small reduction in flood peak levels of up to 0.03 m and potentially 6h reduction in duration of inundation.”

Unfortunately this is contrary to experience, the information contained in Tuggerah studies and conventional wisdom. Oceanic flooding can occur and produce more frequent minor floods. However in some circumstances it can also cause more serious flooding as demonstrated at Narrabeen Lagoon during the May 1974 event.

The Tuggerah Lakes Estuary Management Study recommended that:

“maintaining open entrance conditions and ocean tidal exchange to assist managing water quality in the lake system”

Again, while notionally correct studies both at Tuggerah, but also at many other similar lagoons/lakes, indicate that while tidal flushing of smaller lagoons can significantly affect water quality, the benefits of tidal flushing of larger lagoons/lakes tends to be mainly confined to the interconnecting channel and part way into the lake. The extent to which it impacts on the main water body is dependent on wind driven circulation currents.

Manly Hydraulics Laboratory (MHL) is currently engaged by CCC to undertake the “Tuggerah Lakes Entrance Management Study”. To date the draft report is in two volumes with the first volume itemising and analysing the 23 previous entrance and lagoon management studies

undertaken since 1988. The list does not include some further Office of Environment and Heritage (OEH) studies nor the recent Expert Panel report which is yet to be released by the State Government; but was made available to this review on a confidential basis. The first volume of the MHL study report is nearly complete and is a very useful reference document summarising each of the 23 studies and providing an easy to understand conceptual model of sand movements associated with the entrance and nearby beaches. The report demonstrates the flood tide asymmetrical dominance of entrance processes and the role the ebb tide plays in attempting to maintain a channel, that doubles as the flood channel during flood events. The second volume is focussed on modelling entrance behaviour associated with various entrance conditions, rainfall runoff and oceanic conditions. This second volume is well advanced but still a work-in-progress. It contains a great deal of relevant information including a detailed analysis of the 2020 flood. In addition CCC staff has compiled a most useful, and inciteful document comparing the February 2020 flood to that of the March 2021 and the June 2007 events.

There is therefore a considerable body of information in regard to the entrance performance. Importantly, because of the relatively small grade between the main water body and the ocean, oceanic conditions play an important part in controlling flood levels. That is, if a terrestrial flood event occurs at a time at which there are large tides, storm surge and wave set up, water levels in the estuary can be controlled by the “tailwater” ocean conditions. If oceanic conditions are sufficiently severe there can even be oceanic flooding. Hence, as the various studies demonstrate so long as the entrance is open the actual width of the entrance is not as important as the relative ocean to lake water levels. In fact the larger the entrance the more impact oceanic conditions can have under adverse conditions. This is not unusual. As previously alluded to the second highest flood levels in Narrabeen Lagoon were recorded in May 1974 with very high ocean levels and wave set-up but only modest rainfall, the evidence demonstrated that the lagoon flooded from the ocean.

Hence while an open entrance will undoubtedly reduce a flood duration it will not necessarily significantly alter the peak water levels in the lake(s) system simply because there is insufficient water head difference between the lake and the ocean under adverse conditions. However, given favourable oceanic conditions the wider the entrance the greater the reduction in flood water levels, particularly for the larger floods. An important factor that needs to be recognised is that compared to other ICOLS the water level in the Tuggerah Lake system is naturally quite low and so there is, and will be, ongoing difficulties with the flooding of lake front properties.

The various studies and the MHL report all confirm the natural entrance behaviour which is in keeping with the behaviour of similar entrances. Sand moves into the entrance on the flood tide to progressively build a flood tide delta that expands in width from south to north and in length from east to west until it effectively blocks the ebb tide channel on the northern side of the estuary. The longer the entrance is open without significant flood water outflow, the larger the flood tide delta becomes and the shallower the water is as the sand chokes the lower estuary region. The available evidence shows that the flood tide delta can expand past the bridge and can throttle the channels upstream. Scour of the lower estuary can occur naturally during flood events however, without an ebb tide channel this can take some time to develop. Sand scoured out of the channel is initially discharged into the surf zone to form

an underwater bar off the entrance. That bar then progressively moves onshore to build up the beach, usually in the vicinity of the spit and North Entrance. The cycle then restarts with the beach sand making its way back into the entrance on the flood tide to rebuild the flood tide delta. Intervention in the form of dredging is attempted so as to open, or keep open, the ebb tide channel located on the northern side of the entrance.

In general entrance width is currently primarily driven by rainfall runoff from the catchment and to a lesser degree by the dredging activity.

Recent Flood events (2020, 2021)

For several years in the recent past Australia has experienced wide-spread drought conditions. Without floods estuary entrances become dominated by sand infill from the ocean because of the differentially larger sand transporting capabilities of flood tides against ebb tides. Floods act to scour out ICOL entrances thereby tending to keep them open for extended periods of time. The recent drought has meant that estuary entrances such as that at Tuggerah become choked with sand. Memories fade and people and organizations can become complacent. New people move in who don't realise their house was elevated to overcome flooding and so fill in the "conveniently" available space under the house to create more habitable space. Then when floods come, understandably community concern grows.

Unfortunately, like the conditions that create droughts, the weather systems that cause floods tend to come in cycles. But the way places like Tuggerah Lake responds to heavy rainfall and runoff depends very much on the conditions of the catchment at the time, the hydraulic head difference between the Lake water level and that of the ocean, and to a lesser degree the existing state of the interconnecting channel, provided it is open. That is not to say the state of the channel has no influence, rather that as so long as the entrance is open there can be very different responses depending on the hydraulic head difference between the Lake and the ocean at the time. This is borne out by several of the available studies and by the recent flood events (2020 and 2021).

In 2020 the Lake level was very low before the event and the catchment dry. Evidence shows the entrance was marginally open, despite community comment that it was closed. The photographic evidence indicates the channel was very narrow, shallow and choked with sand and so it is understandable that community members were of the view it was "closed". The rainfall event was reportedly some 25% larger than the 2021 events. However, with a dry catchment and a low initial lake level a considerable volume of the rainfall was absorbed by the catchment and by filling the lake(s). Although the channel scoured out rapidly once the flood waters built up in the lakes the Council decided to assist the situation by excavating a second channel in the central section of the spit in order to realign the flood flow and reduce the flood peak.

In 2021 the catchment was wet resulting in a greater runoff even though the actual rainfall was considerably less. Further, the lake level was initially higher. The entrance was open but somewhat tortuous (doubling back to the north) and oceanic conditions more favorable, however the resulting combination of factors meant that the peak lake level was similar to that of the 2020 event. For the 2021 event CCC had equipment ready to assist in widening the

channel and did in fact operate to help straighten the channel through the spit thereby reducing the head loss associated with more torturous route. The attached photograph is part of the report detailing the conditions in the 2020 flood and the 2021 flood and was supplied by Council. It demonstrates the channel straightening operation undertaken in 2021.



Figure 14: Channel Maintenance undertaken on Friday 19 March 2021 with approximate area of sand removal. The pre-existing general direction of 'ebb' channel flow is indicated with the blue line with sand removal works undertaken to allow for a more direct ebb flow channel as indicated by the pink line.

From Council file notes

As mentioned, both the 2020 and the 2021 events resulted in similar peak Lake levels which demonstrated that flood levels in the lake are dependent on a number of factors the combination of which can differ on each occasion. The entrance channel is but one, albeit important, component however not a great deal can be achieved unless proactive action is taken well before flood events and hence the need for a well-considered on-going entrance management policy that ensures timely responses in order to minimize adverse flooding. It is just not practical to have a dredging procedure that takes months to implement when flood prediction is limited to a few days and perhaps a week. The entrance needs to be maintained in a "ready" state. Finally, there is an on-going need to recognise that the elevation of the Lake and its immediate surrounds is unfavorably low compared to the potential oceanic conditions that can occur from time to time, so planning controls and flood risk management are key matters in minimizing flood impacts.

Conclusions and Recommendations

In regard to the four smaller open coast lagoons, Cockrone, Avoca, Terrigal and Wamberal CCC is currently using the previous Gosford Policy for entrance management. However, a draft CCC policy is well advanced. There is sufficient additional information, staff expertise and knowledge to finalise the updated Policy.

Recommendation 1: The proposed updated CCC Policy for entrance management of the four lagoons, Cockrone, Avoca, Terrigal and Wamberal, be completed, placed on public exhibition, finalised and adopted by Council.

The Tuggerah Lakes system (Tuggerah, Budgewoi and Munmorah) has what is termed a “wicked problem” which needs to be understood to enable an effective entrance policy to be developed. The basic problem is that the lakes have a normal water level of between 0.2m and 0.3m AHD which means they are only about 0.2 to 0.3m above mean sea level and therefore 0.7 below high spring tides and nearly 1m below “king tides”. It also means the lakes can be up to approximately 1.5m below the sea levels that are associated with East Coast Lows due to the addition of storm surge and wave set up. They also experience a small tidal range. Both their low elevation and small tidal range are to a large degree due to the frictional energy losses through the entrance and up the channel connecting the lakes to the ocean. If the entrance is made more efficient to pass floods, it will also increase the tidal range in the lakes and the ability of ocean waters to enter the system with both effects increasing the potential for more frequent flooding (oceanic flooding). In addition, the greater tidal range will mean low tides are lower exposing seagrass beds and sand/mud banks thereby exacerbating odour problems and wrack generation. CCC has engaged Manly Hydraulics Laboratory (MHL) to document the studies and reports that provide an insight into the vulnerable balance that rules the behaviour of the entrance and the lakes system and develop detailed options for an entrance management policy. MHL is an internationally recognised research and consulting agency with competent, experienced, staff and so is well positioned to undertake the project. The first stage of the MHL work is in draft report form which requires little additional work to finalise.

Recommendation 2: The first stage report by MHL that documents, reviews existing studies and provides a conceptual model of entrance behaviour and sand movements be finalised and made available for public discussion as it provides key background material leading to an understanding of the complex nature of the management issues at Tuggerah.

Clearly any sea level rise in the future will only exacerbate the flooding issues in all lagoons. Given that, and the fact that management improvements in the hydraulic efficiency of the entrance while providing improved flood management of larger floods will most likely increase the frequency of lesser floods, development controls on vulnerable properties is an important management tool. CCC currently provides flood advice on planning certificates.

Recommendation 3: CCC ensure that flood risk management awareness is routinely brought to the attention of those whose properties are considered to be in vulnerable areas and that

particular attention be given to ensuring people do not create habitable rooms under houses that have been elevated above the local flood planning levels.

The current management practice at Tuggerah involves intermittent dredging to encourage the continuation of the ebb tide channel that doubles as the flood relief pathway. The dredging is triggered by one of three criteria associated with substantial channel size reduction or blocking being exceeded. Unfortunately, by the time these criteria are exceeded, the necessary dredging required can take months including the time to obtain the necessary approvals. Warnings of potential flood producing conditions, apart from very general La Nina/El Nino postulations, are generally only days at best before the actual event so there is a major disconnect between the warnings of impending floods and the time it takes to actually prepare the channel(s) by dredging using the current criteria.

Recommendation 4: Any new Entrance Management Policy for Tuggerah Lake take into account the recognition that, given the relatively short time available after flood warning advice is available, the entrance be maintained in a flood ready condition; the condition that best optimizes the complex interaction of the various components and impacts. This flood ready condition should be a key outcome from the later stages of the MHL study. Further, that before an Entrance Management Policy is finalised it be placed on public exhibition for community input.

In regard to the recent floods and given the significant limitations of the historical entrance management technique of dredging when certain criteria are exceeded, it should not be a surprise that when flood events occur there are very limited actions the Council can practically take. Further there is a need for all to understand the very fine hydraulic balance that exists between the ocean and the Lake and hence the constraints on options to solve the problem of development that has historically taken place in vulnerable areas. This review was impressed by the quality and experience of the CCC staff who are wrestling with this “wicked” problem; to which there is no easy solution. For the time being experience elsewhere dictates that CCC has attempted to take reasonable actions to manage the recent floods given the significant limitations placed on Council by the complexity of the issues and the current dredging philosophy.

Recommendation 5: The community be encouraged to work with CCC staff in an atmosphere of mutual respect so that through a team effort the best result can be obtained albeit with the recognition that both Australian and overseas experience is that there is no “silver bullet” for this type of challenge.