6 Long term entrance management strategy options

6.1 Need for a long term management strategy

Council's management of the lagoon entrance has remained fairly consistent over the last 40+ years, with mechanical openings or emergency breakouts implemented as a short term management option, primarily for flood mitigation purposes, and entrance clearance operations implemented as a medium term management option every 3-5 years to remove the bulk of sand which has accumulated in the entrance since the previous entrance clearance operation.

During the last 5 years North Narrabeen Beach has been very wide due to the larger scale process of beach rotation over the entire Collaroy-Narrabeen embayment. This widening has increased local sand volumes adjacent to the entrance, which in turn has increased the potential for sand transport into the entrance of the lagoon. In addition, the wider beach has effectively increased the length of the entrance channel, which also increases the risk of closure. As a consequence of these factors, entrance clearance operations and mechanical breakouts have needed to be completed more frequently.

In the longer term, climate change will also impact on the effectiveness of entrance management. Previous studies by Morris (2010) have concluded that climate change impacts such as sea level rise would increase the rate of sand infilling at the lagoon entrance and decrease the duration of open entrance conditions. This may be offset to a small degree by increased rainfall intensity and enhanced ability of flood events to scour the entrance, however it was anticipated that increased sand infilling due to sea level rise would remain the dominant forcing mechanism for entrance conditions. As such, it is anticipated that entrance clearance will be required more frequently to keep the entrance in an open condition for a greater percentage of the time.

A closed entrance and subsequent elevated lagoon water levels can cause community concern and increases Council's reliance on emergency breakout procedures. In response to this growing concern, Council has investigated a range of options including options requiring high upfront costs for permanent infrastructure, to determine whether there is a better way to reduce flood risk in the longer term. These options could be implemented either in conjunction with or as alternatives to the current entrance clearance practices described in the medium term entrance management section of this report. The investigation has included consultation with a technical expert panel as well as the community, and the options have been assessed from a technical feasibility, economic, environmental and social impact perspective.

6.2 Objectives and prioritised options

The objective of the development of a long term management strategy for Narrabeen Lagoon entrance is to determine if there is a feasible permanent infrastructure option that could be implemented to reduce the frequency or eliminate current short term and medium term management interventions.

An Entrance Management Workshop was convened by Council in December 2019, and involved technical stakeholders and industry experts. The purpose of the workshop was to discuss a range of potential options including options considered in previous studies and ideas provided by community members, with a view to narrowing down the range for detailed investigation. The outcome of this workshop was the identification of the following four potential long term entrance management options:

1. Ebb tide channel;
2. Mobile sand pumping;
3. Rock training wall; and,

4. Low flow pipes.

Council commonly receives requests to consider a permanent opening at Narrabeen Lagoon entrance. The only method to permanently open the lagoon entrance is to build a training wall (or breakwater) with consideration given to removal of the bedrock platform and/or rock sill that act to control natural scour levels and form a hydraulic control for lagoon water levels. Training walls have been built at a small number of coastal lagoons in NSW including Lake Illawarra, Lake Macquarie, and Wallis Lakes. An example rock training wall at Tallebudgera Creek in QLD is shown in **Figure 6-1** below.

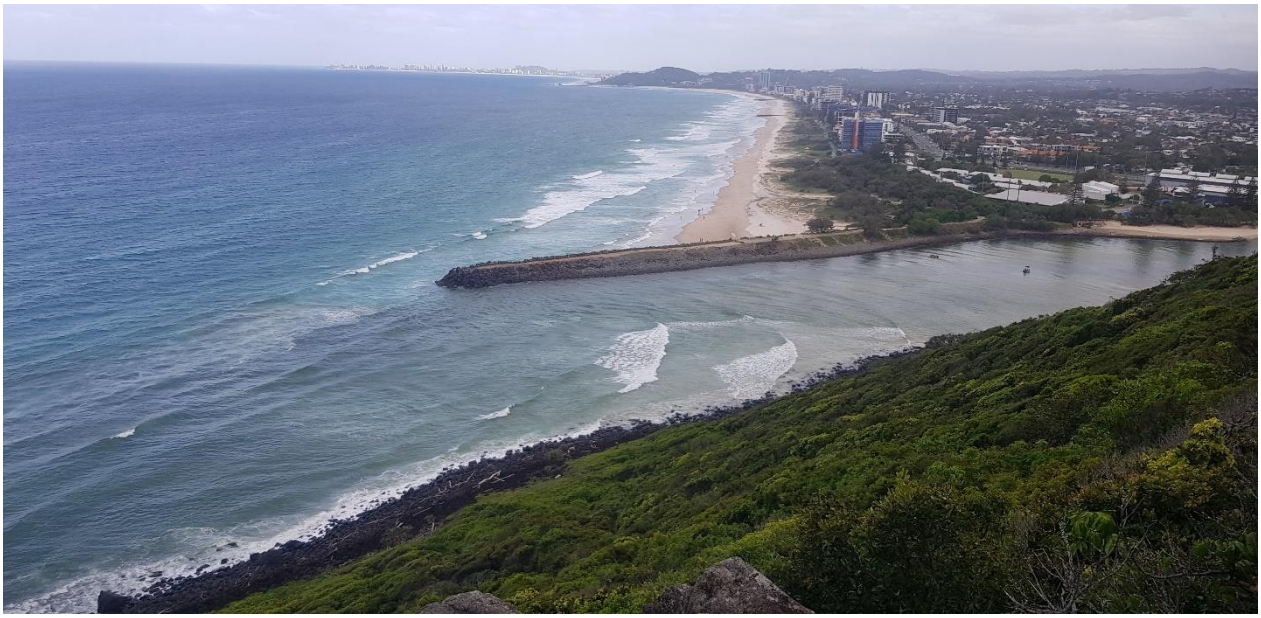

Figure 6-1: Example rock training wall at Tallebudgera Creek entrance

The option of constructing a training wall at the lagoon entrance was discussed in detail by the expert technical panel. Preliminary investigation of a training wall identified a range of significant environmental, recreational, public safety and aesthetic impacts associated with this option which would need justification by an extensive environmental assessment process, and would be unlikely to be supported by the community. These impacts included:

- increased tidal range and lowering of the mean water level and low tide level within the lagoon, resulting in alteration of the frequency of exposure of shallow water areas, and:
    - impacting on the movement of water craft such as kayaks, sailing boats and powered boats within the lagoon; and,
    - having the potential to cause die-off of the seagrass beds in the lagoon, which cover extensive areas within the lagoon and provide habitat for fish sheltering, spawning and foraging. The increased exposure of large areas of tidal flats would also adversely impact benthic species. The die-off of seagrass and increased exposure of tidal flats may also result in generation of odour from rotting vegetation and organic matter in muds, which would impact nearby receptors including foreshore residents and local businesses.
- removal of entrance bedrock would also have an impact on rocky shore ecosystems that may exist on areas of bedrock that are currently exposed either above or below water.

- broader morphological changes (erosion and accretion) within the lagoon may also occur due to adjustment of the system to the new entrance condition. This would modify the habitat for flora and fauna species, and in some cases may result in loss of foreshore land.
- Birdwood Park is currently used as a relatively sheltered wading and swimming area for children and their families. The increased hydraulic conveyance provided by training walls would likely increase the tidal velocities and water depths in this area, reducing its recreational amenity for young families.
- the surfing break at North Narrabeen was declared a National Surfing Reserve in 2009 and is highly valued by the local community. The implementation of an entrance training wall is likely to materially alter the characteristics of the surfing break due to several effects including:
    - the physical presence of the training wall, limiting access to previously available surfing positions and potentially causing rip currents;
    - modification of shoaling patterns formed near the entrance at times of flooding that are understood to influence surfing conditions; and,
    - accumulation of sand on the southern side of the training wall over time due to northerly littoral drift, and associated impacts on wave breaking patterns.
- an entrance training wall would limit public access to the northern end of the beach and the rock pool.
- several public safety issues that would be created by an entrance training wall, including:
    - public access on to the rock structure crest during hazardous surf conditions;
    - injury caused by surfers impacting the rock structure;
    - strong rip currents along the southern side of the rock structure;
    - strong currents through the entrance channel; and,
    - increase in current velocities and water depths within the lagoon.
- installation of a training wall would result in significant alteration to the visual character and scenic quality of the entrance, which is currently in a relatively natural state. The training wall would be a prominent structure that would be visible from most areas of Collaroy-Narrabeen Beach.

The investigation also identified that even a moderate training wall (reduced length, no entrance bedrock removal) would be twice as expensive as current management practices over a 30 year planning period with a full permanent entrance (including entrance bedrock removal) likely to be over five times more expensive.

It should also be noted that a permanently open estuary would have greater flood impacts in some circumstances, such as when ocean levels are very elevated. If during a flood event the ocean level is higher than the lagoon water level (which can occur due to the combination of astronomical tide, storm surge, and wave setup), then having the ICOLL entrance closed may in fact lessen the flood impact. A permanently open estuary would also likely have greater flood impacts in the long term due to sea level rise as a result of climate change (Coffs Harbour City Council, 2018).

As a result, the training wall option was not considered any further.

6.3 Description of long term management strategy options

The long term management options considered are described below to a conceptual level of detail that is sufficient for initial assessment. Schematic figures showing the proposed arrangements for the potential management options described below are also provided for reference.

6.3.1 Base case

The 'base case' represents the continuation of the current practice of entrance management undertaken by Council and will be used for comparison against other potential management options. The base case comprises the periodic removal of sand shoals accumulating immediately upstream (west) and downstream (east) of the Ocean Street bridge. This operation is referred to as 'entrance clearance works' and is completed every 3-5 years and involves the removal of approximately 30,000-50,000 m^3 of sand.

In recent times, entrance clearance operations have been completed more frequently (every 3 years) due to the relatively high volume of sand available at the northern end of Collaroy-Narrabeen Beach. This is due to the process of beach rotation, which is a decadal process related to the El Nino / La Nina cycle and its influence on wave approach direction and consequently alongshore sand transport.

The base case adopted to represent the average long term excavated volume and frequency for entrance clearance campaigns is 40,000 m^3 every 4 years. In practice, the future entrance management regime would need to provide flexibility to allow for a variable frequency of entrance clearance campaigns in response to different stages of the beach rotation cycle (as discussed in **Section 5.6**).

The works are normally completed by excavators that load the sand into dump trucks for road transport to the south for replenishment of Collaroy-Narrabeen Beach (refer **Figure 5-1**). The lagoon entrance is artificially closed during the entrance clearance operations. Accessible road heads of the side streets along Pittwater Road (e.g. Mactier Street, Wetherill Street, Ramsay Street) and the northern end of the Collaroy beachfront carpark (opposite Jenkins Street) can be used to access the beach for back dumping of sand, which is subsequently regraded with earthmoving equipment operating on the beach.

6.3.2 Ebb tide channel option

When the Narrabeen Lagoon entrance is open, it is subject to tidal influences. The ebb tide is the tidal phase during which the tidal current is flowing seaward out of the lagoon, and the flood tide is the tidal phase during which the tidal current is flowing inland into the lagoon.

An ebb tide channel is the naturally formed underwater channel which forms as the tide flows out of the lagoon. Depending on various factors such as water velocity, direction and sand grain size, a submerged wall structure may be able to deflect and focus the energy of the ebb tide to enhance natural channel scour and potentially keep the entrance open longer if ebb tide currents are able to transport sand out of the lagoon and into the ocean.

The ebb tide channel option involves the enhancement of an ebb tide dominant channel by installing submerged control structures downstream of Ocean Street perpendicular to the left hand bank (looking downstream) (refer to **Figure 6-2** for conceptual arrangement).

This option could potentially be achieved with a series of half-tide (i.e. height set at average water level between high and low tides in the lagoon) training walls formed by low-level rock structures, that would consistently direct ebb tide flows along a channel through the main area of entrance sand accumulation (flood tide delta). This option may need to be supported by periodic sand removal with earthmoving

equipment, but would aim to harness the natural power of the ebb tide to maintain an ebb tide dominant channel in a 'working with nature' approach.

This option could be implemented by installation of two rubble mound structures located:

- on the northern side of Ocean Street Bridge, adjacent to the caravan park; and,
- on the bend in the existing tidal channel running along the sandstone block seawall.

The rubble mound structures would be constructed from durable sandstone rock that is suitable for the marine environment and would have a design life of over 40 years. The crest of the rock mound structures would be at the half tide level, which is approximately +0.4m AHD according to analysis of the water level record from the gauge at the Ocean Street Bridge. The rock mounds would be approximately 1 m high above the seabed level and have crest width of approximately 3.5 m, maximum sideslopes of 1V:1.5H, and would extend around 60 m at right angles across the existing tidal channel running against the sandstone block seawall. This would result in the rock mounds requiring around 1,000 tonnes of rock for their construction.

It would be possible to trial this option by forming temporary training walls with sand-filled geotextile tubes. Based on recent application of geotubes at Stockton Beach, these structures would be 20 m long (3 geotubes needed for training wall length of 60 m), 3.5 m wide and 1.4 m high, and have a volumetric capacity of around 98 m^3. The geotubes could be laid in position and then hydraulically pumped with slurrified sand sourced from the surrounding ebb tide shoals.

To give the ebb tide channel option the best chance of success, an entrance clearance operation would need to be conducted immediately prior to construction. This would include the initiation of the preferred ebb tide channel alignment by over excavation in the area off the ends of each training wall.

The effectiveness of the proposed half tide training walls to create an ebb tide channel was evaluated within the Delft3D numerical model used for the Narrabeen Lagoon Floodplain Risk Management Study (Cardno, 2019). The half tide training walls were incorporated into the model grid representing the open entrance bathymetry from the post entrance clearance survey completed in December 2018.

The modelling demonstrated that the flood tide current speed peaks at a greater value than the ebb tide. This indicates an upstream bias in the sand transport potential suggesting that under normal tidal conditions the entrance area is generally subject to infilling processes.

The modelling examined the difference between the existing open entrance conditions (i.e. without half-tide training walls) and with the half-tide walls installed. The modelling results indicated that the walls would not be effective in generating the desired increase in ebb tide currents to maintain an ebb tide dominated entrance channel thereby keeping the lagoon open. As such, the ebb tide channel option is not considered to be a technically feasible entrance management option and has been eliminated from further consideration. The results also suggested that in the event that some additional ebb tide scour did occur at the outer end of the half tide walls the eroded sand would have settled only a short distance downstream. Full details and results of the ebb tide channel option modelling are provided in **Appendix D**.

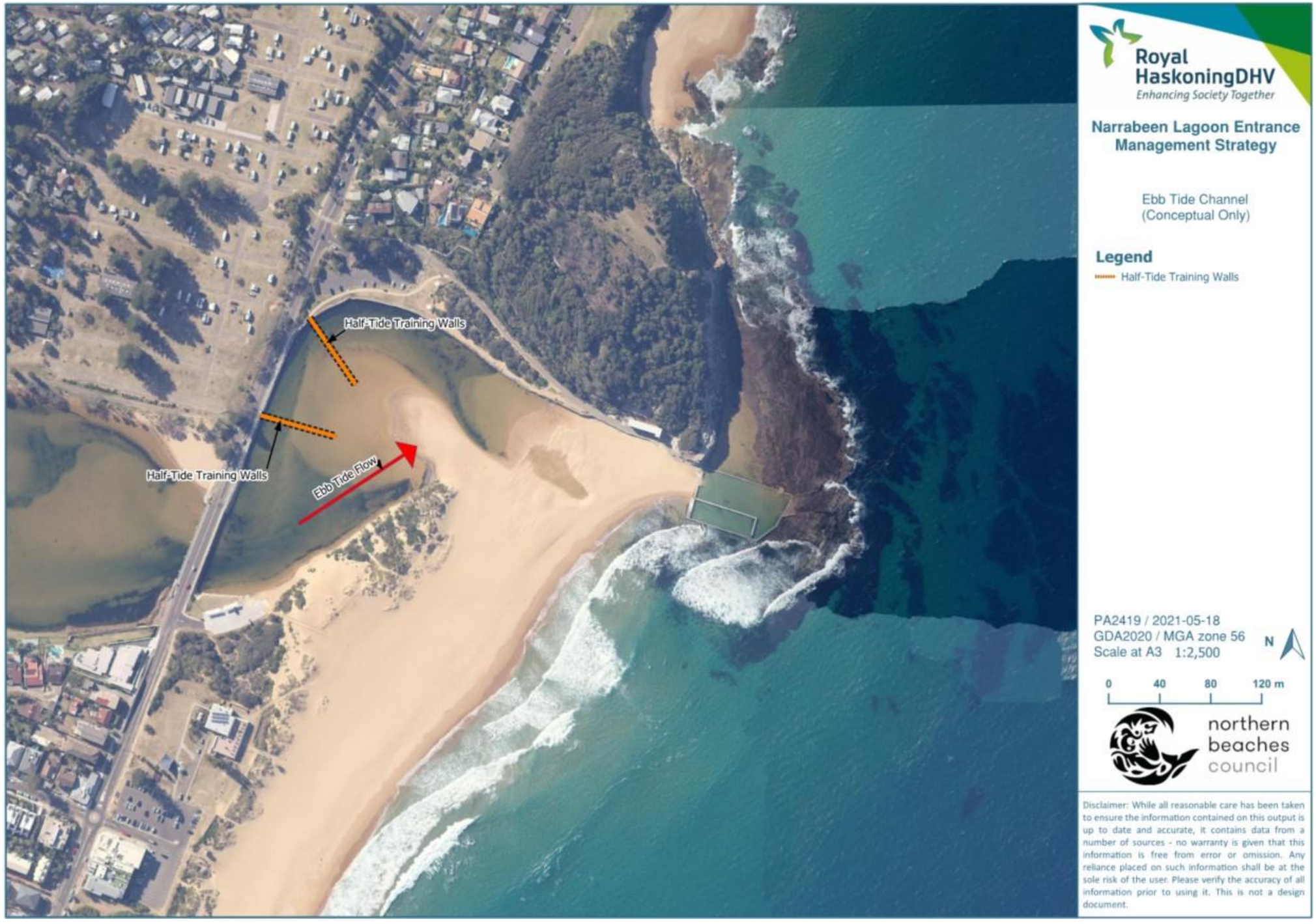

Figure 6-2: Ebb tide channel option conceptual arrangement

6.3.3 Mobile sand pumping option

An alternative to the historical practice of using dump trucks to transport excavated sand to beach access points at road heads at the southern end of Collaroy-Narrabeen Beach, is the establishment of a semi-permanent mobile sand pumping system (refer to **Figure 6-4** for conceptual arrangement). Such a system would facilitate pumping of excavated sand as a slurry within a pipeline along the beach to selected discharge points for subsequent redistribution and regrading by earthmoving equipment. The primary benefit of this system is the elimination of intensive truck traffic along local streets during entrance clearance operations, which would provide a reduction in associated impacts to local residents including traffic congestion and noise.

It is important to note that this option is not a different concept of permanently maintaining an open lagoon, but rather a different sand transport mechanism to remove and transport the sand during periodic entrance clearance operations.

The mobile sand pumping system would comprise a mobile hopper that is positioned on the beach berm adjacent to the lagoon entrance area. The mobile hopper could be mounted on a sled and pulled into different locations as required. Alternatively, proprietary tracked equipment exists, such as the Slurrytrak system (designed and built by CGC Group) which was implemented for sand bypassing at the Dawesville and Mandurah Inlets in Western Australia (refer **Figure 6-3**). The mobile hopper is fed with sand, placed into the hopper by several excavators, and with seawater pumped from the adjacent waterbody. The hopper is fitted with screens to filter out oversize material and a slurry pump at the base of the hopper is used to pump the sand slurry through a flexible connection pipeline to a primary pumping station.

Figure 6-3: Slurrytrak system operating at Dawesville and Mandurah Inlets, Western Australia

Figure 6-4: Mobile sand pumping option conceptual arrangement

The primary pumping station in the case of the Narrabeen Lagoon mobile sand pumping option would be located some 400m away within the reserve area adjacent to the North Narrabeen Beach carparking area and SLSC building. The temporary pumping station would comprise a portable unit that could be initially purchased by Council and then stored in a depot between clearance operation when it would be transported by truck float and lifted into position.

The primary pumping station would comprise a jet pump fitted inside a protective housing and would connect to the buried permanent delivery pipeline. The delivery pipeline would comprise a 200 mm diameter HDPE pipe that would be installed within public land at the rear of the dunes. Pipe segments would be supplied and welded together within a shallow trench (approximately 1 m deep) within the dunes and could be weighed down with concrete 'staples' if positioned within the coastal hazard zone. Once the pipework is laid, the trench would be backfilled and dune vegetation would be restored over the footprint of disturbance (approximately 5 m wide) along the pipeline alignment.

The buried permanent delivery pipeline would extend over a length of around 1,700 m from Birdwood Park to the foreshore reserve at Devitt Street where it would connect to a temporary booster station. The temporary booster station could be a similar portable unit to the primary pumping station and would be owned and maintained by Council.

A temporary pipeline would be installed from the booster station at Devitt Street to the particular replenishment site(s) on the beach, for the most efficient delivery of sand to the intended location. The maximum length of temporary pipeline required would be 1,100 m in the event replenishment was carried out as far south as the northern end of the Collaroy Beach carpark (opposite Jenkins Street). The temporary pipeline would comprise 12 m lengths of 200 mm diameter HDPE pipe that are hauled into position on the beach and bolted together with flanged connections. The pipe lengths could be dismantled and stored within a Council depot between clearance operations.

Alternatively, the sand could be deposited at Devitt Street by the pump and pipeline and then manually reworked to the southern end of the beach as required by excavators and trucks.

An inherent risk with placement of a pipeline along the active beach is the possible occurrence of coastal storms and associated wave action and beach erosion, which could result in dislodgement or damage to the pipeline. A recent example of this occurring is the damage to the Jimmys Beach (Port Stephens) sand transfer system (refer **Figure 6-5**) caused by large swell and beach erosion, although it should be noted that this is a permanent installation. The sand pumping contractor would need to continually monitor storm and swell forecasts and have the capability to rapidly disassemble and remove the temporary pipeline if required.

Figure 6-5: Damage to Jimmys Beach sand transfer system by large swell in 2019 (Source: Newcastle Herald, 5 June 2019)

To facilitate discharge of the sand slurry at discrete locations along the beach, offtake pipe outlets with isolation valves would need to be installed at key locations. To provide maximum flexibility for beach replenishment activities it is proposed that up to four (4) discharge points could be installed at accessible road heads at Mactier Street, Wetherill Street, Ramsay Street and at the northern end of the Collaroy Beach carpark (opposite Jenkins Street).

Discharge of sand slurry onto the beach would be managed by site supervision and operation of an excavator on the beach to rework the material over the beach profile and create sand bunds as necessary to facilitate water quality control from the slurry discharge (refer **Figure 6-6**). Sections of the beach would need to be closed to public access for the duration of pumping operations.

It is noted, that as with the 'base case' entrance clearance methodology, mobile sand pumping operations could also be undertaken at an increased frequency and involve a lower volume of sand excavation. That is, 15,000 m^3 removed every 2 years.

Figure 6-6: Management of sand slurry discharge within a bunded beach area at The Entrance, Central Coast

6.3.4 Low flow pipes option

The low flow pipe option involves the installation of a series of large underwater pipes at the lagoon entrance to provide some release of rainfall runoff into the lagoon (mitigation of build-up in lagoon water level and thus benefit to lagoon flooding), and to allow tidal exchange between the lagoon and the ocean when the entrance is otherwise closed for prolonged periods by sand ingress (refer to **Figure 6-7** for conceptual arrangement). A similar scheme has been implemented at the entrance to Manly Lagoon (refer **Figure 6-8**).

Figure 6-7: Low flow pipes option conceptual arrangement

The installation of low flow pipes at Narrabeen Lagoon could be achieved by directional drilling of conduits through the entrance bedrock platform. The inlet of the low flow pipes could be positioned at the bend in the tidal channel running adjacent to the northern seawall. At this location the bed levels within the entrance channel are relatively stable at around -0.6 m AHD, being a sufficient distance away from the more dynamic downstream areas opposite Birdwood Dune where extensive shoaling occurs. The adjacent foreshore reserve area beside the northern carpark is also accessible for plant and equipment.

Discussions with directional drilling contractors has determined that the maximum size of pipeline that can be installed has an 800mm diameter and that a clearance of at least 1 m is required below the top of bedrock to the top of the pipe. As such, for a proposed pipe inlet invert level of approximately -0.6 m AHD (the stable channel bed level referred to above) the pipe invert would need to grade down to -2.5 m AHD to provide sufficient clearance of the top of the pipe below the potential minimum top of bedrock level of -0.7 m AHD along the pipeline alignment. This top of bedrock level is indicative only as it is based on spot heights from an entrance rock shelf survey undertaken by NSW Public Works Department in 1976.

The technical feasibility of directional drilling would be subject to detailed field investigation of the top of rock levels and competency of the entrance bedrock material. Geological mapping indicates that North Narrabeen Headland and the surrounding rock platform is part of the Narrabeen Group of sedimentary rocks and comprises interbedded sandstones, claystones and shales.

Three 800 mm diameter pipelines spaced at a distance of 1-2 m apart could be installed and extend over a distance of around 400 m to a submerged outlet through the face of the rock outcrop drop-off beyond the ocean pool.

The inlets and outlets of the pipes would have a concrete headwall structure and be covered with stainless steel grating to reduce public safety risks for recreational activity (e.g. swimming) and the ingress of debris and vegetation (e.g. kelp). To further enhance public safety, the pipe inlets could be positioned through the face of the northern seawall (which may require localised seawall reconstruction) rather than being positioned within a headwall structure within the tidal channel. This would also improve constructability and reduce capital costs as the directional drilling could be completed from land rather than potentially requiring the expensive construction of a coffer dam structure for an in-channel installation.

The practicality of ongoing maintenance of the low flow pipes would require careful consideration and could be problematic if build-up of marine growth and/or ingress of large volumes of sand, debris and vegetation (e.g. kelp) significantly reduces the capacity of the pipes or results in complete blockage. Similar to the Manly Lagoon low flow pipes, vertical access chambers could be provided at intervals along the pipeline length to facilitate access for inspection and cleaning equipment. The access chambers would need to protrude above typical beach berm levels and would have a visual impact on the existing natural setting. Regular inspection of the pipelines would need to be undertaken by remote CCTV methods. It is assumed that routine pipe cleanout would need to be undertaken at least on an annual basis and potentially after significant coastal storm events. Maintenance of the proposed 400m length of low flow pipelines at Narrabeen Lagoon entrance represents significant cost and operational risk for the low flow pipes option.

The existing TUFLOW flood model was used to simulate the low flow pipe option (3 x 800 mm diameter pipes) under closed entrance conditions over a 20 day period of tides for initial water levels in the lagoon of 1.3 m AHD and 0.3 m AHD. The modelling showed that under tide only conditions with no catchment inflows the low flow pipes are able to reduce the lagoon water level from 1.3 m AHD to 0.4 m AHD in around 20 days. Over a further 20 days the lagoon water level reduces to 0.2-0.3 m AHD.

If the initial water level in the lagoon is 0.3m AHD, the water level reduces 0.1m to 0.2m AHD over the 20 day simulation period. It is noted that lowering of lagoon water levels to these levels for prolonged periods of time would have potential environmental impacts relating to reduced recreational amenity and drying of seagrass beds (refer **Section 6.4.3.2** and **Section 6.4.3.3**). Analysis of historical lagoon water level records from the Narrabeen Bridge (Pittwater Road) tide gauge has determined that water levels below 0.2m AHD and 0.1m AHD occur very rarely under the existing management regime. Furthermore, when these low water levels occur the duration of events is relatively short with an average duration of less than 6 hours.

As such, prolonged lowering of the lagoon water level to these levels has not occurred previously and the lower lagoon water levels, particularly during periods of minimal catchment inflow, is likely to have a significant impact on lagoon ecology and the overall recreational amenity of the lagoon.

From the modelling, it can be concluded that the installation of low flow pipes has the potential to lower lagoon water levels during periods of entrance closure. However, further assessment of their long term performance by modelled simulation of their performance using actual water level and flooding records is required.

It is also noted that the installation of low flow pipes would have no influence on lagoon entrance closure behaviour. As such, any installation of low flow pipes would be implemented independently of future periodic entrance clearance operations. Full details and results of the low flow pipes option modelling are provided in **Appendix D**.

Figure 6-8: Existing low flow pipes at Manly Lagoon beneath the beach berm at Queenscliff Beach

6.4 Evaluation and analysis of long term management options

The evaluation and analysis of management options for the longer term, whether they be in conjunction with or alternative to the current medium term entrance clearance practices, is described below for each option with regard to a variety of impacts including economic, flood risk, social and environmental. The option of increasing the frequency of entrance clearances with a reduced excavation volume, as discussed in the medium term entrance management section of this report, has also been evaluated.

As part of this process a Cost Benefit Analysis (CBA) was also undertaken by Marsden Jacob Associates to inform the economic evaluation of the various long term management options under consideration. The CBA is a complex process that identifies the economic benefits and costs of the investment options to all stakeholders, including Council, other agencies and businesses and community. The CBA is based on an assessment of market and non-market economic benefits and costs.

The following five (5) options were considered in the CBA:

- **Option 1 – Base Case:** continuation of the current periodic (4 yearly) entrance clearance by excavation and trucking, with a volume of 40,000 m^3 per campaign
- **Option 2 – Excavation and Trucking at reduced intervals:** periodic entrance clearance by excavation and trucking, with an increased frequency (2 yearly) and reduced volume of 15,000 m^3 per campaign, with focus on maintaining a regime tidal channel
- **Option 3 – Mobile Sand Pumping:** periodic (4 yearly) entrance clearance by mobile sand pumping system, with a volume of 40,000 m^3 per campaign
- **Option 4 – Mobile Sand Pumping:** periodic entrance clearance by mobile sand pumping system, with a 2 yearly frequency and reduced volume of 15,000 m^3 per campaign, with focus on maintaining a regime tidal channel
- **Option 5 – Installation of Low Flow Pipes:** installation of low flow pipes plus periodic entrance clearance by excavation and trucking, with a 2 yearly frequency and reduced volume of 15,000 m^3 per campaign, with focus on maintaining a regime tidal channel

The CBA considered infrastructure costs, project costs and flood damage costs. The CBA results identify the incremental difference between the costs and benefits of each option case compared with the base case to help identify a preferred option. The details of the CBA, including Whole of Life cost estimates prepared by Muller Partnership, are provided in **Appendix E**.

The results of the analysis show whether the incremental difference between continuing with current long term entrance management regime (i.e. Option 1 – Base Case) and implementing a new management option will generate a net benefit.

6.4.1 Base case

6.4.1.1 Economic

Capital and Operating Costs

Costs associated with the base case (CBA Option 1) comprise the ongoing costs of periodic entrance clearance operations using the existing methodology of excavating and trucking by a contractor, procured through a tender process undertaken for each campaign. Whole of Life cost estimates prepared by Muller Partnership (refer **Appendix E**) and additional cost estimates provided by Council for project management, contract administration and design indicate that the net present value of the base case over a 30 year analysis period is $7.8M[9]. If entrance clearance operations were completed at an increased frequency of 2 years and with a lower volume of sand removal (15,000 m^3 per campaign, refer **Section 5.5.3**) then the cost would marginally increase (for more detail refer to **Appendix E**).

Reduction of Flood Risk to Property

To allow comparative evaluation of flood risk between management options, flood modelling has been undertaken with the Delft3D morphodynamic model used for the Narrabeen Lagoon Floodplain Risk Management Study (Cardno, 2019). For the base case, the closed entrance and open entrance conditions represent the upper and lower bounds of flood risk within the lagoon foreshore areas. These were represented by the following two flood modelling scenarios:

[9] *Based on a discount rate of 7%.*

1. Closed and shoaled entrance condition, initial lagoon water level 1.3m AHD, beach berm level 1.3m AHD
2. Open entrance condition, post-entrance clearance campaign, initial lagoon water level 0.3m AHD[10]

Flood modelling results for various Average Recurrence Intervals (ARIs) for the above scenarios were compared against the ground levels and floor levels for the list of 2041 properties used for the flood damages analysis within the Narrabeen Lagoon Floodplain Risk Management Study. The number of properties subject to above ground and above floor flooding is summarised in **Table 6-1** and **Table 6-2** respectively. These results demonstrate that open entrance conditions significantly reduce the number of properties subjected to above ground level flooding for events up to the 100 year ARI, however this diminishes for larger events up to the Probable Maximum Flood (PMF). Open entrance conditions provide a significant reduction of properties subjected to above floor level flooding in all events other than the PMF.

Table 6-1: Above ground level flooding results summary for Base Case

Entrance Condition	No. Properties with Above Ground Level Flooding				
ARI	PMF	1000yr	100yr	20yr	5yr
Closed	1235	980	913	842	753
Open	1182	912	771	504	343

Table 6-2: Above floor level flooding results summary for Base Case

Entrance Condition	No. Properties with Above Floor Level Flooding				
ARI	PMF	1000yr	100yr	20yr	5yr
Closed	1171	862	673	531	318
Open	1057	694	377	102	61

It should be noted that under the current regime of entrance clearance operations the entrance is open approximately 75% of the time and closed for 25% of the time. In addition, the modelled open entrance condition represents the best possible time for flooding to occur, namely shortly after the entrance has been subjected to an entrance clearance campaign. In practice, although the entrance may be considered to be open, the degree of shoaling at the entrance would vary. As such, the flood risk to property would also vary between the modelled 'open' and 'closed' entrance conditions results during the period when the entrance shoals are building to the point of entrance closure. It is estimated based on recent experience that the entrance could be in a fully open state (i.e. post entrance clearance condition, before progressive shoaling occurs) for around 6-9 months within the 4 year period between entrance clearance campaigns. As such, under the base case, the entrance has been assumed to be fully open for 15% of the time, closed for 25% of the time, and in an intermediate state for the remaining 60% of the time.

The above percentages for entrance conditions under the base case were applied to the flood damage analysis undertaken by Marsden Jacob Associates (refer **Appendix E**). It was determined that the Annual Average Damage (AAD) cost for the base case was $4.3M.

[10] *Typical mean water level within lagoon under open entrance conditions when water levels are controlled by the natural rock weir at the lagoon entrance (BMT WBM, 2013).*

Flood modelling was also undertaken for CBA Option 2, which is for excavation and trucking at reduced intervals. This option is for an increased frequency (2 yearly) and lower volume entrance clearance scenario focused on excavation of a regime tidal channel through the lagoon entrance shoals, as described in **Section 5.5.3** of this report. The results for the entrance open condition are provided in **Table 6-3** and **Table 6-4**, and indicate that there is a slight increase in flood risk due to the increased constriction to flood flows caused by retaining the shoals adjacent to the regime tidal channel.

It was considered that increasing the frequency of entrance clearance campaign to a 2 yearly interval would keep the entrance in an open condition for a greater percentage of the time. For analysis purposes, it was assumed that under this entrance clearance regime the entrance could be fully open for 40% of the time, closed for 15% of the time, and in an intermediate state for the remaining 45% of the time. It was determined that the AAD for this scenario was $3.7M, providing a reduction in flood damages relative to the base case. A sensitivity analysis was also undertaken to test these assumptions (refer **Appendix E**).

Table 6-3: Above ground level flooding results summary for Increased Frequency / Lower Volume Entrance Clearance (regime tidal channel)

Entrance Condition	No. Properties with Above Ground Level Flooding				
ARI	PMF	1000yr	100yr	20yr	5yr
Closed	1235	980	913	842	753
Open	1206	935	821	574	371

Table 6-4: Above floor level flooding results summary for Increased Frequency / Lower Volume Entrance Clearance (regime tidal channel)

Entrance Condition	No. Properties with Above Floor Level Flooding				
ARI	PMF	1000yr	100yr	20yr	5yr
Closed	1171	862	673	531	318
Open	1105	723	488	128	64

The results of the CBA study identified CBA Option 2, for excavation and trucking at an increased frequency of two years with a reduced volume of 15,000m^3, as the preferred option based on net present value (NPV) outcome, compared with the other options. CBA Option 2 has the highest NPV of $6.38 million. A Benefit Cost Ratio cannot be calculated for this option because the Present Value of Costs is lower than the Base Case and thus cost savings are a benefit. This option reduces the flood damage costs by approximately $6.5 million compared with the Base Case (CBA Option 1).

6.4.1.2 Social

Recreational Amenity

Narrabeen Lagoon and its adjacent foreshore areas support a wide range of recreational activities including swimming, surfing (entrance area), wind surfing, sailing, stand-up paddle boarding, canoeing/kayaking, fishing, walking/jogging/cycling, golf (Cromer Golf Course) and passive recreation (e.g. picnicking, BBQs, cafés, restaurants). The condition of the lagoon entrance has an impact on most of these activities as outlined in **Table 6-5** and **Table 6-6**.

Table 6-5: Impact of open lagoon conditions on recreational amenity

Activity	Advantages	Disadvantages
Swimming	• Improved water quality and clarity	• Variable water depth due to tides • Unsafe swimming conditions at entrance due to tidal flow velocities • Less beach area available across the entrance berm area for passive recreation
Surfing	• Ebb tide current can assist with paddle out	• Dangerous to cross entrance during high flow conditions
Wind surfing, sailing, canoeing, kayaking, stand-up paddle boarding	• Improved water quality and clarity at the entrance for recreation	• Variable water depth due to tides • Lower water levels in general across the lagoon reducing area for sailing and windsurfing
Fishing	• Improved catches from ocean fish entering lagoon via the entrance channel	
Walking, jogging, cycling	• Narrabeen Lagoon Trail less likely to be subject to inundation	
Golf	• Cromer Golf Course less likely to be subject to inundation	
Passive recreation	• Visual amenity of entrance improved • Foreshore access to cafes/restaurants (e.g. The Boatshed and Limani Seafood) less likely to be subject to inundation	• Variable water depth due to tides • Exposed seagrass beds during periods of very low water levels, resulting in low visual amenity and unpleasant odour

Table 6-6: Impact of closed lagoon conditions on recreational amenity

Activity	Advantages	Disadvantages
Swimming	• Stable water level • Safe swimming area at entrance • Large area available for passive recreation across the entrance berm area • Dry access from the northern carpark and North Narrabeen ocean pool to patrolled area of North Narrabeen Beach	• Recreational water quality impacted by catchment runoff • Increased water depth following catchment runoff events • Visual amenity of lagoon water adversely impacted
Surfing	• Dry access to North Narrabeen Beach is available from northern carpark	
Wind surfing, sailing, canoeing, kayaking, stand-up paddle boarding	• Stable water level • Increased water depth	• Recreational water quality impacted by catchment runoff

Activity	Advantages	Disadvantages
	• Improved foreshore launching conditions	
Fishing		• Lagoon entrance closed to ocean fish passage
Walking, jogging, cycling		• Sections of Narrabeen Lagoon Trail are inundated and made inaccessible when lagoon water levels are elevated
Golf		• Areas of Cromer Golf Course susceptible to inundation when lagoon water levels are elevated
Passive recreation	• High water level improves visual amenity of the wider lagoon	• Water quality impacted by catchment runoff • Access to foreshore areas including cafes/restaurants can be limited by inundation

Based on the community consultation completed to date, it is understood that there is a general preference for the lagoon entrance to be in an open condition more often than the current average of 75% of the time. This sentiment is particularly strong in relation to the recreational amenity of the entrance area for swimming activities enjoyed in popular lagoon beach areas for families at Birdwood Park and adjacent to Narrabeen Caravan Park, where a preference was expressed for an open entrance providing regular tidal flushing with ocean water to maintain both water quality and clarity.

During entrance clearance operations, recreational amenity is temporarily adversely impacted by occupation of the lagoon entrance, Birdwood Park and sand replenishment locations along Collaroy-Narrabeen Beach by construction equipment and sand excavation and placement operations. These impacts extend for a period of 3-4 months every 4 years and can be minimised by scheduling entrance clearance operations outside of peak periods for lagoon and beach usage (e.g. outside of summer school holidays).

Public Safety

Public safety concerns associated with the base case are mainly related to the potential swimming hazards associated with an open entrance condition, particularly in the period after an entrance clearance operation. These hazards include deeper water within the excavated lagoon areas where shallow shoals used to exist and increases in flow velocity due to increased tidal exchange. Tidal velocities increase through downstream constrictions such as the Ocean Street Bridge and along the ebb tide channel adjacent to the northern seawall. However, as the entrance is open 75% of the time on average the local community has experienced these conditions before and is therefore familiar with the risks posed mainly to young children at the popular Birdwood Park swimming area.

The entrance clearance operation itself does pose some risk to public safety with public areas at the lagoon entrance and beach replenishment locations being occupied with construction plant and equipment and increased local road traffic. However, this can be adequately managed with worker supervised exclusion zones, traffic management measures, and scheduling of entrance clearance operations outside of peak periods for lagoon and beach usage (e.g. outside of summer school holidays).

Aesthetics
Periodic entrance clearance operations to re-establish or enhance open entrance conditions are considered to improve aesthetics of the entrance to the lagoon by facilitating exchange of clear ocean water into the lower portion of the lagoon to improve water clarity around the entrance area. The visual amenity of the entrance is also improved when it is open and tidal exchange with the ocean occurs, as opposed to an elevated beach berm blocking the continuity of the waterway. This management approach also maintains the natural aesthetic of the entrance, without the introduction of any additional hard structures.

Community Support
As noted previously, it is understood that the community is generally supportive of maintaining an open entrance for a greater proportion of the time. However, the increased road traffic generated by periodic entrance clearance campaigns is a common issue for local residents for the current methodology of excavation and trucking.

6.4.1.3 Environmental

Water Quality
As discussed in **Section 2.1.2**, monitoring of recreational water quality in Narrabeen Lagoon over the last 5 years indicates that the 'beach suitability grade' given through the State of the Beaches report to Bilarong Reserve is generally 'poor'. This is due to elevated levels of bacteria, particularly following low levels of rainfall. This site is located away from the lagoon entrance and is not well flushed by ocean water.

The 'beach suitability grade' given to Birdwood Park is generally 'good', although there have been periods of 'poor' grading (i.e. 2015-2016 and 2016-2017) that were noted to be associated with entrance closure for extended periods. DPIE advised that the site had generally good water quality during dry weather but elevated enterococci levels were measured following low levels of rainfall. It was recommended that swimming be avoided during and following rainfall, and when the lagoon is closed.

Beachwatch also monitors water quality at North Narrabeen Beach, which is generally 'good'. However, it was noted that the water may be susceptible to pollution after rain due to discharge from Narrabeen Lagoon causing elevated enterococci levels.

It is evident that water quality in the vicinity of the lagoon entrance is generally 'good' but can be adversely affected by periods of rain and closed entrance conditions. Periodic entrance clearance operations to re-establish or enhance open entrance conditions act to increase tidal exchange and flushing of areas around the lagoon entrance with ocean water. This generally improves water clarity and water quality after rainfall events at the popular swimming spots at Birdwood Park and along the foreshore adjacent to the caravan park (upstream of Ocean Street bridge). However, this effect diminishes over time as the entrance infills with sand and progressive shoaling limits tidal exchange to the point of entrance closure.

The water quality at poorly flushed areas in the upper reaches of the lagoon (i.e. Bilarong Reserve) is unlikely to improve significantly as a result of entrance clearance activities due to their considerable distance away from the entrance.

Ecology
Periodic entrance clearance operations to re-establish or enhance open entrance conditions result in tidal exchange of ocean water into the lagoon and maintenance of open entrance water levels. When the lagoon entrance is open and scoured to exposed bedrock, the natural rock weir (at approximately 0m AHD) at the entrance acts as a hydraulic control for water levels in the lagoon. Previous studies have

reported that under these conditions water levels in the lagoon are maintained at approximately 0.2-0.4m AHD (BMT WBM, 2013) and that mean water levels are of the order of 0.38m AHD during spring tide periods and 0.2m AHD during neap tide periods (MHL, 1989).

When the entrance is closed by build-up of the beach berm to natural levels of 2m AHD or higher, water levels in the lagoon can increase to above 1m AHD with inflows from catchment runoff events until the lagoon entrance is mechanically opened (i.e. excavated channel breakout) at trigger levels between 1m AHD and 1.3m AHD. As the entrance is closed approximately 25% of the time, the water level regime in the lagoon varies gradually between these two states and the ecology generally adapts to accommodate these changes in water depth, salinity, water temperature and water clarity.

Previous studies (WBM Oceanics, 2001) have determined that seagrass beds within the lagoon suffered a decline in the 1960s and 1970s. This was attributed to rapid urban development, unsewered areas, historical dredging practices, poor light conditions due to high water turbidity, nutrient enriched inflow water, and periodic low salinity levels causing seagrass beds to be restricted to shallower water depths.

If entrance clearance operations were completed at an increased frequency of two years, keeping the entrance in an open condition for a greater percentage of the time, this may have ecological effects on the lagoon as a whole. This would change the natural state of the lagoon from its historic condition of being a mainly closed body of water only open to the ocean for short periods of time due to flood, to being mainly open to the ocean and only being closed for short periods. Currently the lagoon is completely closed for approximately 25% of the time, and the ecology appears to have adapted to this situation. Further studies would be required to estimate the overall impact of having the lagoon open for a greater percentage of the time and its impact on water quality, vegetation communities and fish habitat.

The entrance of the lagoon is a dynamic area with progressive shoaling and active sand transport limiting the stability of seagrass beds, or benthic and rocky reef habitat. Nonetheless, there are procedures in place for periodic entrance clearance operations to minimise harm to local ecology by applying a 10 m buffer distance between these operations and mapped seagrass bed areas, installing floating booms and silt curtains around seagrass beds within the lagoon entrance channel, and limiting excavation to recently deposited marine sand to minimise turbidity generation.

6.4.2 Mobile sand pumping

6.4.2.1 Economic

Capital and Operating Costs

Costs associated with mobile sand pumping (CBA Options 3 and 4) comprise the ongoing costs of periodic entrance clearance operations using the alternate methodology of pumping the excavated sand as a slurry to beach replenishment locations along Collaroy-Narrabeen Beach and the dewatering and shaping of the sand. The permanent pipeline would be initially installed along the beach and the capital costs of purchase of the temporary pipeline, main pumping station and booster station would also be incurred. It is assumed that these assets would be stored in a Council depot between operations and that the pumping stations would need to be replaced every 15 years after their working life expires.

Whole of Life cost estimates for the mobile sand pumping option prepared by Muller Partnership (refer **Appendix E**) and additional cost estimates provided by Council for project management, contract administration and design indicate that the net present value of entrance clearance operations through sand pumping undertaken at a 4 year frequency (40,000 m^3 per campaign as per the base case) over a 30 year analysis period is $11.6M[11]. If pumping operations were completed at an increased frequency of 2

[11] *Based on a discount rate of 7%.*

years and with a lower volume of sand removal (15,000 m^3 per campaign, refer **Section 5.5.3**) then the cost would marginally increase (for more detail refer to **Appendix E**). Both of these cost estimates are considerably higher than for the base case.

Although a Council facilitated scheme has been adopted for the purposes of the cost benefit analysis, the economic ranking of mobile sand pumping should be reviewed if pricing is available from a 100% contractor delivered scheme (contractor supplies, installs and removes pumps and pipelines and associated equipment each operation and Council does not purchase pipelines and pumps) that may be considered for future entrance clearance operations. The outcomes of the current entrance clearance operation which partly involves sand pumping would be expected to also inform further consideration of the mobile sand pumping option.

Reduction of Flood Risk to Property
The reduction in flood risk to property provided by periodic entrance clearance campaigns using the mobile sand pumping method would be equivalent to that described for the base case method in **Section 6.4.1.1**, as it is simply just a different mechanism to remove and transport the sand during entrance clearance operations.

6.4.2.2 Social

Recreational Amenity
The benefits to recreational amenity of periodic entrance clearance and potentially increasing the percentage of the time that the entrance is open by undertaking more frequent operations would be similar to that described in **Section 6.4.1.2**.

The level of temporary disruption to recreational activities around the lagoon entrance during entrance clearance activities would also be similar to the base case. However, it would be expected that a greater footprint would be occupied on the beach by sand bunding and water management associated with discharge of the sand slurry at discrete locations along Collaroy-Narrabeen Beach. In addition, installation of the temporary pipeline for up to a kilometre length along the back of the beach berm would also result in occupation of a portion of the useable beach area for the duration of the works. The occupation of land by pump stations would result in visual disturbance to public recreation areas and their operation may cause noise impacts if appropriate sound dampening measures are not implemented.

Public Safety
The discussion of public safety matters for the base case (refer **Section 6.4.1.2**) is also relevant for periodic mobile sand pumping operations.

It is considered that the mobile sand pumping operations would pose higher public safety risks at the beach replenishment locations along Collaroy-Narrabeen Beach due to the nature of sand bunding and water management associated with discharge of the sand slurry. However, this could be managed by strict enforcement of worker supervised exclusion zones and scheduling of entrance clearance operations outside of peak periods for beach usage (e.g. outside of summer school holidays). The reduction of local road traffic associated with the mobile sand pumping operation in comparison to the base case (i.e. haulage truck movements) would provide a benefit to public safety for both vehicles and pedestrians.

Aesthetics
The mobile sand pumping methodology would result in similar aesthetic outcomes at the lagoon entrance and the beach replenishment sites to the base case (refer **Section 6.4.1.2**). However, the occupation of beachfront areas with pipework and pumping stations would have an increased visual impact.

Community Support
Community support for the mobile sand pumping methodology was evidenced during community consultation held in early 2021, due to the preference for maintenance of natural aesthetics at the lagoon entrance, open entrance conditions, and the benefit of significantly reducing construction traffic on local roads during entrance clearance operations in comparison to the base case.

6.4.2.3 Environmental

Entrance clearance operations undertaken with the alternate mobile sand pumping methodology would have similar water quality and ecology outcomes as the base case (refer **Section 6.4.1.3**). However, it is noted that there is potential for increased turbidity in the nearshore zone at beach replenishment locations if the discharge of sand slurry is not managed effectively. This potential impact is typically managed by establishment of a seaward sand bund to direct the sand slurry discharge along the beach over a sufficient length to facilitate settling of finer sediments to achieve acceptable water quality for discharge of return water into the ocean. In conjunction with adjustment of the slurry discharge location, earthmoving equipment is used to continually rework deposited sand and to maintain the sand bund (refer **Figure 6-6**).

6.4.3 Low flow pipes

6.4.3.1 Economic

Capital and Operating Costs
The objective of the low flow pipes (CBA Option 5) at the lagoon entrance is to mitigate the build-up in lagoon water level when the entrance is closed by letting it flow to the ocean through the pipes, and thus reduce potential lagoon flooding risks. It should be noted that as the low flow pipes themselves would have no influence on lagoon entrance closure behaviour, periodic entrance clearance operations would still be required as part of this management option.

Costs associated with low flow pipes comprise the initial capital costs of installation of the intake and outlet structures and the pipework itself, and the ongoing operational costs of annual pipe inspection and cleanout of obstructions (e.g. sand, kelp, debris etc.). It is noted that the inherent uncertainty associated with the ongoing costs of pipe inspection and cleanout and the potential for pipe blockage, represents a significant cost and operational risk for the low flow pipes option.

Whole of Life cost estimates prepared by Muller Partnership (refer **Appendix E**) for low flow pipes and periodic entrance clearance as well as additional cost estimates provided by Council for project management, contract administration and design indicate that the net present value of the installation and operation of the low flow pipes option over a 30 year analysis period is $15.9M[12] (for more detail refer to **Appendix E**).

Reduction of Flood Risk to Property
As discussed in **Section 6.3.4**, the benefit provided by installation of the low flow pipes is the maintenance of tidal exchange during closed entrance conditions and release of catchment inflows, resulting in a lowering of the lagoon water level, which may represent an improved initial water level condition prior to a design flood event. The lower initial water level in the lagoon provides a reduction in the peak flood level and associated flood damages.

For the low flow pipes, the closed entrance and open entrance conditions represent the upper and lower bounds of flood risk within the lagoon foreshore areas. These were represented by the following two flood modelling scenarios:

[12] *Based on a discount rate of 7%. Includes 50% contingency on capital cost and 20% contingency on operating costs.*

1. Closed and shoaled entrance condition, initial lagoon water level 0.6 m AHD[13], beach berm level 1.3m AHD
2. Open entrance condition, regime tidal channel, initial lagoon water level 0.3 m AHD[14]

Flood modelling results for various Average Recurrence Intervals (ARIs) for the above scenarios were compared against the ground levels and floor levels for the list of 2041 properties used for the flood damages analysis within the Narrabeen Lagoon Floodplain Risk Management Study (Cardno, 2019). The number of properties subject to above ground and above floor flooding is summarised in **Table 6-7** and **Table 6-8**, with the closed entrance modelling results for the base case also included for comparison. These results show that, based on the adopted initial water level condition, the low flow pipes provide significant reduction in properties experiencing above ground and above floor level flooding in flood events up to 20 year ARI and that this benefit diminishes for less frequent flood events.

Table 6-7: Above ground level flooding results summary for Low Flow Pipes

Entrance Condition	No. Properties with Above Ground Level Flooding				
ARI	PMF	1000yr	100yr	20yr	5yr
Closed (base case)	***1235***	***980***	***913***	***842***	***753***
Closed	1222	974	900	787	635
Open	1206	935	821	574	371

Table 6-8: Above floor level flooding results summary for Low Flow Pipes

Entrance Condition	No. Properties with Above Floor Level Flooding				
ARI	PMF	1000yr	100yr	20yr	5yr
Closed (base case)	***1171***	***862***	***673***	***531***	***318***
Closed	1151	833	647	410	165
Open	1105	723	488	128	64

Similar to the base case, the flood risk to property would vary between the modelled 'closed' and 'open' entrance conditions results in periods when the entrance shoals are building to the point of entrance closure. It was assumed that periodic entrance clearance operations would still be required as the installation of low flow pipes would have no influence on lagoon entrance closure behaviour. For analysis purposes, it was assumed that a more frequent 2 yearly entrance clearance regime would be applied and that the entrance could be fully open for 40% of the time, closed for 15% of the time, and in an intermediate state for the remaining 45% of the time. It was determined that the AAD for this scenario was $3.2M, providing a significant reduction in flood damages relative to the base case (where AAD = $4.3M). It should be noted that the reduction in flood damages was most significant for lower ARI events (e.g. 5 year and 20 year ARI), however these events would occur more often.

[13] *Lowered initial water level condition able to be achieved given sufficient time for tidal exchange without significant catchment runoff inflows into the lagoon.*
[14] *Typical mean water level within lagoon under open entrance conditions when water levels are controlled by the natural rock weir at the lagoon entrance (BMT WBM, 2013).*

6.4.3.2 Social

Recreational Amenity

The installation of a pipe intake structure at the lagoon entrance would impact on recreational amenity by introduction of a potential obstruction for passive recreational craft (e.g. stand-up paddle boards, canoes, kayak etc.) and swimming activities, depending on the final location of the intake. Localised currents around the intake structure under certain conditions may create a safety hazard for swimming activities and would need to be assessed. It is however noted that the potential location of the intake structure at the bend in the tidal channel running adjacent to the northern seawall is at a significant distance away from the popular swimming areas for families at Birdwood Park and along the foreshore adjacent to the caravan park.

The low flow pipes would allow tidal exchange between the lagoon and the ocean when the entrance is otherwise closed for prolonged periods. This would be expected to enhance the recreational amenity in the immediate vicinity of the lagoon entrance area during closed conditions by improving water clarity with inflow of ocean water and facilitating tidal flushing of rainfall runoff thereby improving any associated poor water quality.

There is potential for the low flow pipes to significantly lower lagoon water levels, particularly during prolonged periods of minimal catchment inflow. This would likely impact the recreational amenity within the lagoon for activities that rely on adequate water depth such as swimming and use of passive recreational craft (e.g. wind surfing, sailing, canoeing, kayaking, stand-up paddle boarding).

Public Safety

As noted above, the introduction of a pipe intake structure may create a potential safety hazard for passive recreation activities. This risk is partially mitigated by the distance of the pipe intake away from popular areas and the provision of stainless steel grating over the pipe intake and outlet points. However, the residual risk of the structure as an obstruction or area where localised currents may exist would still need to be addressed. The public would need to be adequately informed of the hazard with warning signage provided in the vicinity of the pipe intake and outlet locations (near the ocean pool) and also at popular nearby swimming locations.

Aesthetics

The low flow pipes themselves would be installed generally out of sight below the bedrock surface and beach berm, and the submerged outlet structure would be located offshore of the ocean pool. A noticeable feature of the scheme would be the pipe intake structure, although the visual impact of this could be minimised by incorporating the pipe intake into the face of the existing northern seawall structure. Vertical access chambers for maintenance access would need to be provided at intervals along the pipelines and would likely protrude above typical beach berm levels. This feature would have a visual impact on the existing natural setting.

Community Support

Community support for installation of low flow pipes was low relative to other options based on feedback received during community consultation held in early 2021.

6.4.3.3 Environmental

Water Quality

As noted previously, the installation of low flow pipes would be expected to improve water quality within the immediate lagoon entrance area, particularly during periods of prolonged entrance closure. During closed entrance conditions, the pipes would facilitate tidal flushing of rainfall runoff and improve any

associated poor water quality that may have otherwise impacted popular swimming areas in the immediate vicinity.

Ecology
The tidal exchange provided by low flow pipes during closed entrance conditions would be expected to improve water clarity, which is beneficial to the maintenance of seagrass beds within the lagoon entrance area.

The pipes may also maintain a route for fish passage and recruitment at times of entrance closure. The viability of the low flow pipes for these purposes would depend on further assessment and design. It is noted that shafts of natural light were incorporated in the design of the low flow pipes extension at Manly Lagoon to aid in fish passage and recruitment.

As noted in **Section 6.4.1.3**, the natural rock weir at the entrance acts as a hydraulic control for water levels in the lagoon. Installation of low flow pipes would alter this natural water level control and would potentially lower the water levels generally experienced in the lagoon during prolonged periods with no catchment inflow (refer **Section 6.3.4**). This could have detrimental impacts on the large areas of seagrass beds established on extensive shallow sand banks located mainly within the central and western areas of the lagoon (refer **Figure 6-9**). Significant areas of shallow seagrass beds include:

- the nearshore area on the eastern shoreline between Loftus Street and Malcom Street;
- the nearshore area adjacent to Mactier Street and Wheeler Park, and extending into the central area of the lagoon opposite Bilarong Reserve;
- the nearshore area adjacent to Jamieson Park and Pipeclay Point;
- the nearshore area between the western end of Bilarong Reserve and Deep Creek; and,
- in the south-western corner of the lagoon, in the nearshore area to the east of South Creek.

The above seagrass areas include shallow banks with bed levels of 0-0.2m AHD. These areas would be adversely impacted and subject to seagrass die-off if a general lowering of mean lagoon water levels resulted in more frequent or more extended exposure of seagrass beds at low tides.

If the water level of the lagoon was permanently lowered due to the low flow pipes, this may have significant ecological effects on the lagoon as a whole. Currently the lagoon is completely closed for approximately 25% of the time, which lends to higher water levels, and the ecology appears to have adapted to this situation. Further studies would be required to estimate the overall impact on the lagoon of having significantly lower lagoon water levels all of the time, including the impact on water quality, seagrass beds, riparian vegetation communities, fish and birds, and recreational amenity.

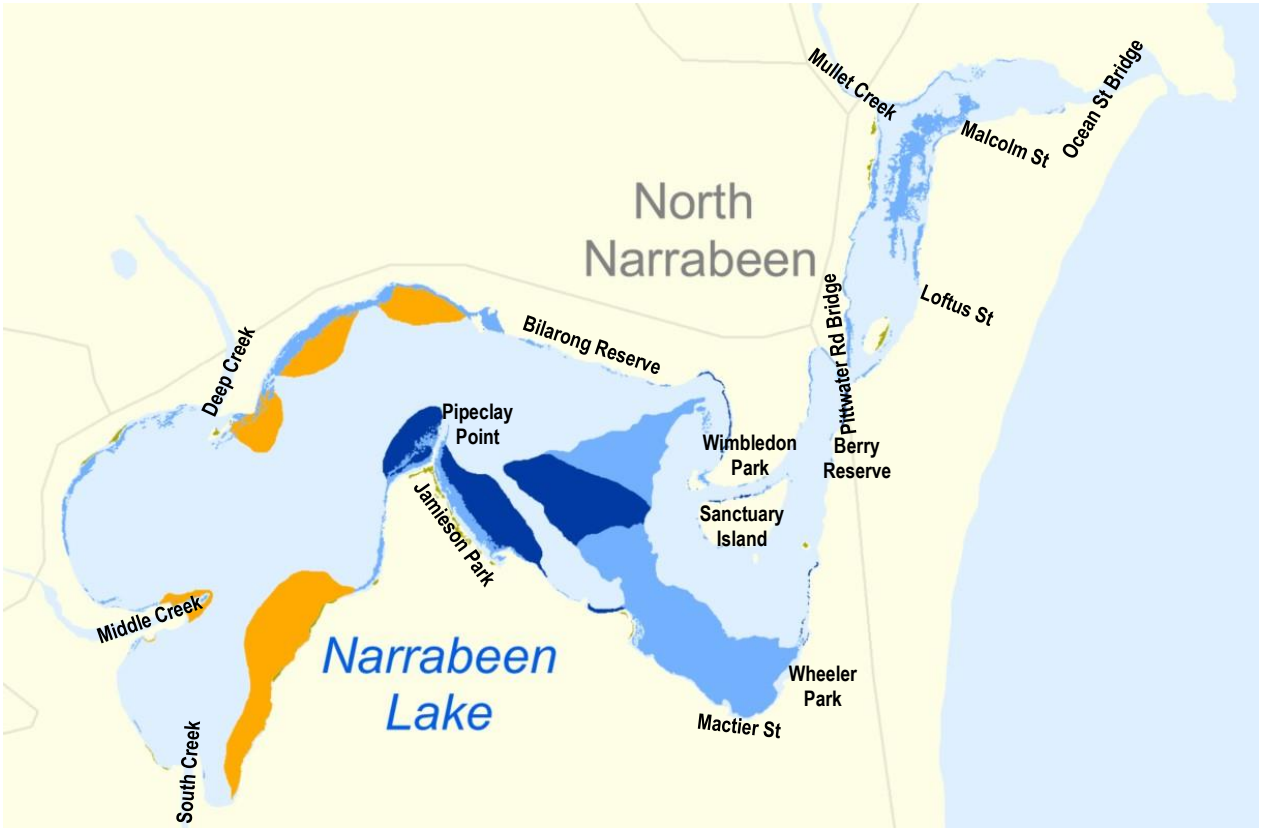

Figure 6-9: Seagrass beds within Narrabeen Lagoon, Light blue = Zostera, Dark blue = Zostera/Halophila, Orange = Halophila (NSW Government, 2005)

6.5 Summary assessment of long term management options

A summary of the assessment of long term management options against various economic, social, and environmental criteria discussed in **Section 6.4** is presented below in **Table 6-9**.

Table 6-9: Summary assessment of long term management options

CRITERIA	Option 1 – Base Case	Option 2 – Excavation and Trucking (2 yearly)	Option 3 – Mobile Sand Pumping (4 yearly)	Option 4 – Mobile Sand Pumping (2 yearly)	Option 5 – Installation of Low Flow Pipes + Excavation and Trucking (2 yearly)
ECONOMIC					
Feasibility	Yes	Yes	Yes	Yes	Feasibility subject to detailed investigation of rock levels and competency for directional drilling, and assessment of long term hydraulic performance in reducing lagoon water levels.
Capital and Operating Costs	As per existing.	Low Marginal increase if reduced sand removal volumes can be achieved.	High Could potentially be reduced with 100% contractor delivered scheme.	High Could potentially be reduced with 100% contractor delivered scheme.	High Significant cost risk associated with ongoing maintenance requirements.
Reduction in Flood Risk to Property	As per existing.	Moderate Subject to assumed increase in open entrance conditions.	As per existing.	Moderate Subject to assumed increase in open entrance conditions.	Significant Subject to confirmation of long term hydraulic performance
Net Present Value (NPV, $'000)	-	6,380	-3,450	790	5,523
Benefit Cost Ratio (BCR)	-	n/a	0.00	1.14	1.69

CRITERIA	Option 1 – Base Case	Option 2 – Excavation and Trucking (2 yearly)	Option 3 – Mobile Sand Pumping (4 yearly)	Option 4 – Mobile Sand Pumping (2 yearly)	Option 5 – Installation of Low Flow Pipes + Excavation and Trucking (2 yearly)
SOCIAL					
Recreational Amenity	As per existing. Impacts subject to open or closed entrance condition.	Positive impact if increase in open entrance conditions can be achieved. Increased temporary disruption during entrance clearance campaigns from occupation of lagoon entrance/Birdwood Park and sand trucking and placement operations at sand replenishment locations.	As per existing. Increased temporary disruption during entrance clearance campaigns from occupation of lagoon entrance/Birdwood Park, installation of pipeline along beach, and management of sand slurry discharge.	Positive impact if increase in open entrance conditions can be achieved. Increased temporary disruption during entrance clearance campaigns from occupation of lagoon entrance/Birdwood Park, installation of pipeline along beach, and management of sand slurry discharge.	Potential improvement in entrance area water clarity from tidal flushing during closed entrance conditions. Potential adverse impacts from lowered lagoon water levels. Increased temporary disruption during entrance clearance campaigns from occupation of lagoon entrance/Birdwood Park and sand trucking and placement operations at sand replenishment locations.
Public Safety	Minor impact, managed with existing worker supervised exclusion zones, traffic management measures, and scheduling outside of peak periods.	Minor impact, managed with existing worker supervised exclusion zones, traffic management measures, and scheduling outside of peak periods.	Minor impact, managed with existing worker supervised exclusion zones, traffic management measures, and scheduling outside of peak periods.	Minor impact, managed with existing worker supervised exclusion zones, traffic management measures, and scheduling outside of peak periods.	Moderate impact, subject to configuration of pipe alignment, intake structure, and access chambers.
Aesthetics	Positive impact, maintains existing natural open entrance condition.	Positive impact if increase in open entrance conditions can be achieved.	Positive impact, maintains existing natural open entrance condition.	Positive impact if increase in open entrance conditions can be achieved.	Moderate impact, subject to configuration of pipe alignment, intake structure, and access chambers.
Community Support	Supported, but increased local road traffic is main complaint.	Supported, but increased local road traffic is main complaint.	Supported, due to potential reduction of local road traffic.	Supported, due to potential reduction of local road traffic.	Low, relative to other options.

CRITERIA	Option 1 – Base Case	Option 2 – Excavation and Trucking (2 yearly)	Option 3 – Mobile Sand Pumping (4 yearly)	Option 4 – Mobile Sand Pumping (2 yearly)	Option 5 – Installation of Low Flow Pipes + Excavation and Trucking (2 yearly)
ENVIRONMENTAL					
Water Quality	Entrance clearance campaigns improve water clarity and quality locally around the lagoon entrance area due to increased tidal exchange and flushing associated with open entrance conditions.	Positive impact if increase in open entrance conditions can be achieved.	Entrance clearance campaigns improve water clarity and quality locally around the lagoon entrance area due to increased tidal exchange and flushing associated with open entrance conditions.	Positive impact if increase in open entrance conditions can be achieved.	Positive impact locally around the lagoon entrance from tidal flushing during closed entrance conditions, and if increase in open entrance conditions can be achieved.
Ecology	As per existing, ecology adapts to gradual changes in water level regime associated with open, intermediate and closed entrance conditions.	Positive impact at entrance if increase in open entrance conditions can be achieved. The lagoon being open for a greater percentage of the time may result in changes to the water quality and water level regime, requiring the ecology in the broader lagoon to adapt.	As per existing, ecology adapts to gradual changes in water level regime associated with open, intermediate and closed entrance conditions.	Positive impact at entrance if increase in open entrance conditions can be achieved. The lagoon being open for a greater percentage of the time may result in changes to the water quality and water level regime, requiring the ecology in the broader lagoon to adapt.	Potential lowering of lagoon water levels during prolonged periods with no catchment inflow could have detrimental impacts on large areas of seagrass beds established on extensive shallow sand banks.

6.6 Recommendations for long term entrance management

Council has investigated a range of options including options requiring high upfront costs for permanent infrastructure, to determine whether there is a better way to reduce flood risk in the longer term. These options could be implemented either in conjunction with or as alternative to the current entrance clearance practices described in the medium term entrance management section of this report. The investigation has included consultation with a technical expert panel as well as the community, and the options have been assessed from a technical feasibility, economic, environmental and social impact perspective.
These options have been compared with the Base Case option, which comprises the continuation of the current entrance clearance practices as described in the medium term entrance management section of this report.

The following conclusions and recommendations are made with respect to long term entrance management:

- Entrance clearance operations involving excavation and trucking (as per the base case current practice) is the more economically beneficial option in comparison to the mobile sand pumping option, based on current costing assumptions for installation of a permanent pipeline partially along the beach and Council purchase and maintenance of all assets (i.e. permanent and temporary pipeline and pumps).

- The economic ranking of mobile sand pumping should be reviewed if lower cost pricing is available from a contractor delivered scheme (Contractor supplies, installs and removes pumps and pipelines and associated equipment each operation and Council does not purchase pipelines and pumps).

- The installation of low flow pipes with excavation and trucking every two years has a positive cost benefit analysis, but less so than more frequent entrance clearance operations. However, given the potential environmental impacts of this option associated with lagoon water level lowering (both recreational amenity and ecological impacts) and the likely operational challenges associated with pipe access and maintenance, it is recommended that this option is not pursued any further.

- Hydrodynamic modelling identified that the installation of half-tide walls would not be effective in generating the desired sustained increase in ebb tide currents to maintain an ebb tide dominated entrance channel. Therefore, the ebb tide channel option is not considered to be a technically feasible entrance management option and has been eliminated from further consideration.