APPENDIX A: SEDIMENT TRANSPORT WITHIN THE ENTRANCE AREA OF SMITHS LAKE

The following appendix is an investigation into the sediment transport within the entrance area of Smiths Lake, to determine whether the area is significantly infilling with sediment, due to human intervention.

A.1 Introduction

Coastal Lakes and lagoons are ephemeral features on a geological timescale as they develop within a short time-span (Cooper 1994). The present location of the sand barrier between the Lakes/lagoons and the ocean is a result of sea level rise since the last ice age and the consolidation of sandy and muddy sediments over the last 6,000 years (Short & Woodroffe 2009)

The different stages of infilling are shown in Figure A-1. Wave dominated estuaries, such as Smiths Lake, infill through the seaward progradation of the fluvial delta and the landward extension of the marine tide delta. Eventually the fluvial and marine sands bury the mud basin (Masselink and Hughes, 2003).

Smiths Lake is a large coastal Lake with no major river inflows. Therefore, there is no significant fluvial delta present. The largest source of sediment to the Lake is probably the landward extension of the flood tide (marine) delta (Figure A-1).

In the following sections the sedimentation of Smiths Lake's entrance is examined through the analysis of aerial photographs and water levels. The region of interest can be seen in Figure A-2.

The potential impacts of sedimentation on navigation, Lake ecology and water quality are subsequently discussed.

The report concludes with a discussion and some possible options to reduce sediment accumulation in the entrance region.

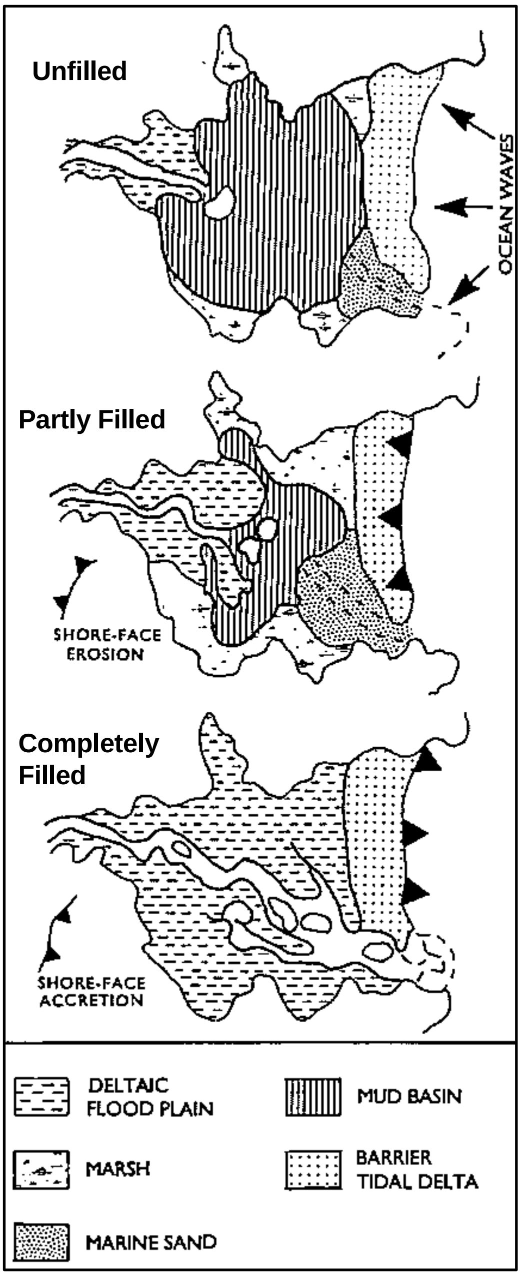
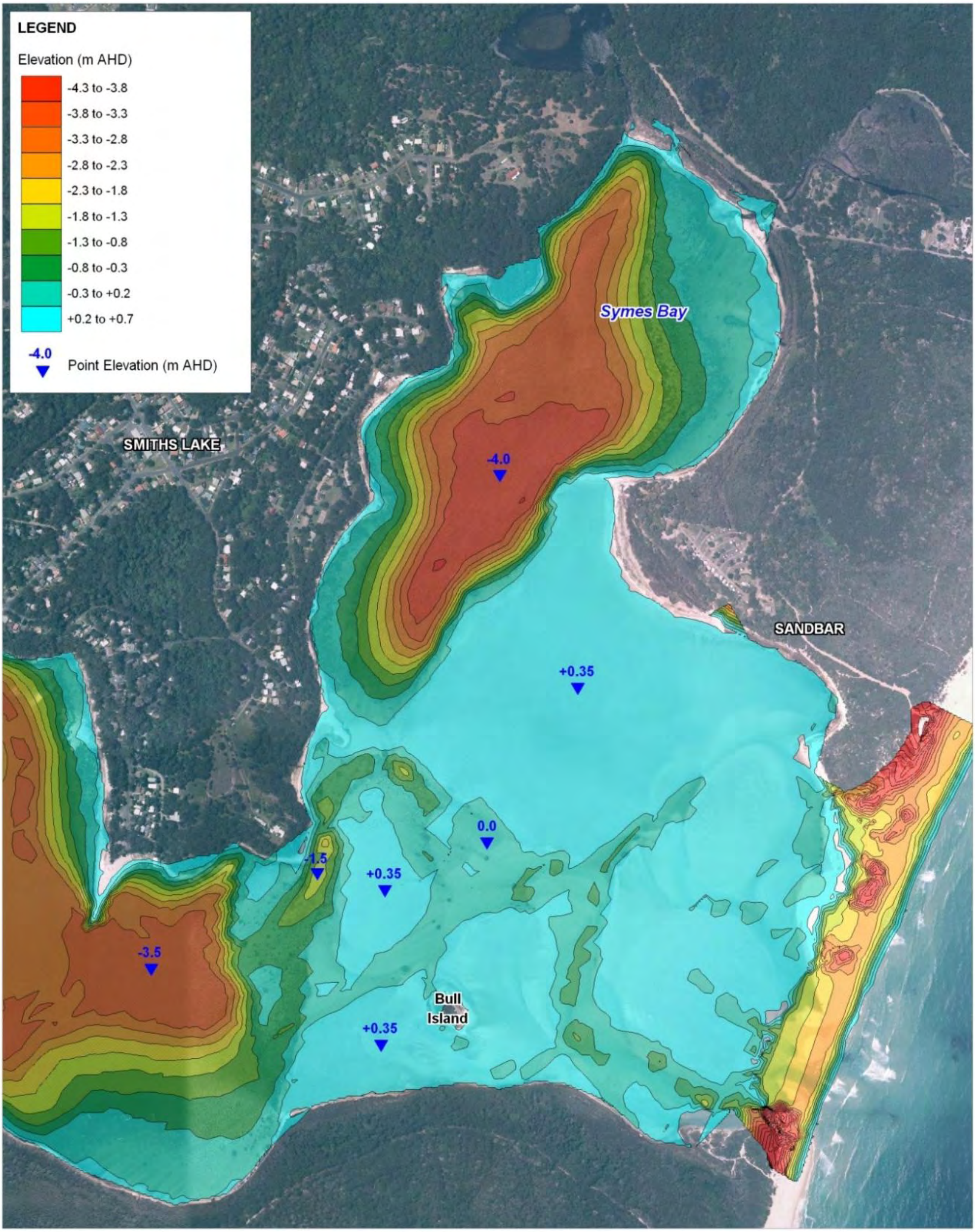


Figure A-1 Stages of infilling (Masselink and Hughes, 2003)



Title:

Entrance Region of Smiths Lake

Figure: **A-2**

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BMT WBM endeavours to ensure that the information provided in this map is correct at the time of publication. BMT WBM does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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A.2 Relationship between Lake Opening and Sediment Transport

During an opening or “breakout” a large volume of water leaves the Lake during a very short period of time, and a large amount of sand is removed from the beach barrier as the entrance channel forms. The potential energy associated with the opening strongly influences the amount of sediment that will be removed from the barrier, and the magnitude of that energy can be defined through the following processes.

Firstly, the difference in water level between the Lake and the ocean can be defined by an average hydraulic gradient or slope (s). As the Lake fills we can say:

- the slope becomes steeper;
- the amount of potential energy held within the Lake increases;
- The amount of kinetic energy generated as the Lake breaches increases; and
- The tractive force (shear stress), which moves sediment as the Lake breaches, is higher.

The slope can be calculated as follows:

$$s = \frac{h_1 - h_2}{length\ (x)}$$

Equation A-1

Where h_1 is the height of the Lake water level (mAHD), h_2 is the height of the ocean water level (mAHD) and x is the distance between the two locations (Figure A-1).

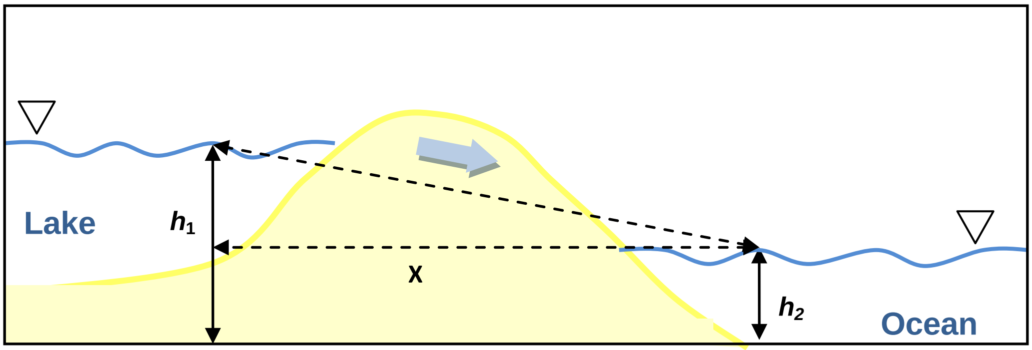

Figure A-1 Hydraulic gradient between the Lake and the Ocean

The slope can be related to the shear stress through the following relationship:

$$\tau = \rho g d s$$

Equation A-2

Where ρ = the density of the Lake water, g =gravity, d = depth of outward flowing water and s = the starting slope between the Lake water level and the ocean.

The following information has been summarised in Figure A-2.

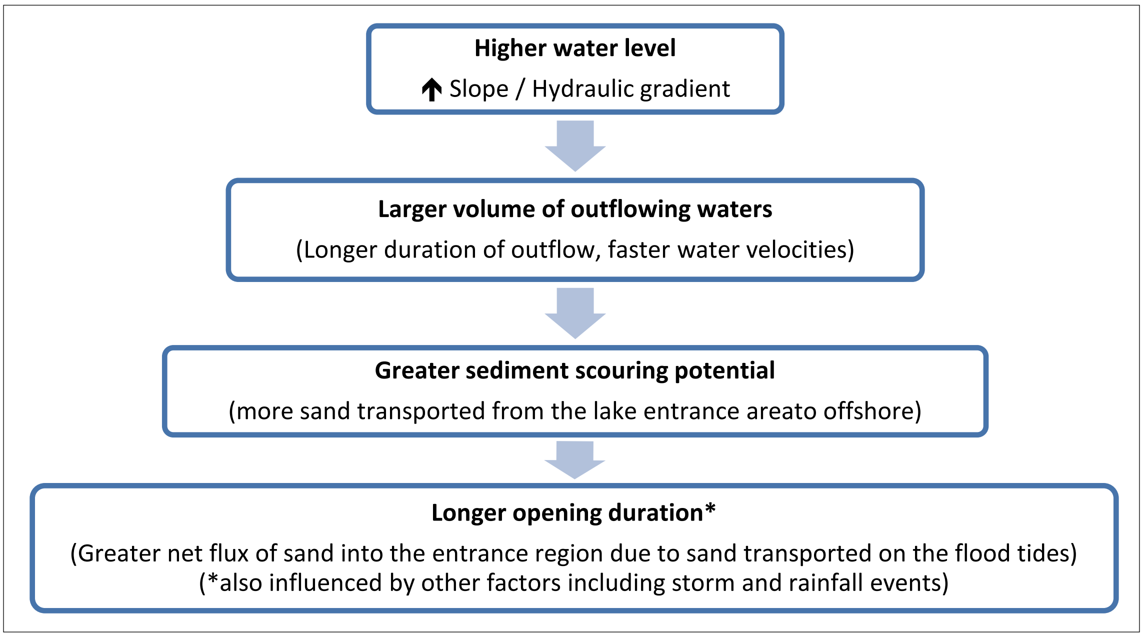

Figure A-2 Relationship between Lake water level and Ocean water level

A.3 Assessment of historical sediment transport within the entrance

A.3.1 Aerial Photograph Assessment

A desktop assessment was undertaken to examine potential sediment changes within the entrance region. Aerial photographs (Dates from 1953 to 2008) were sourced from the Department of Environment, Climate Change and Water.

A.3.2 Key Features

The following assessment involves the identification of key depositional features in each of the aerial photographs and how these features have changed over time. The absence or presence of depositional or erosional changes provides an indication of "morphological" activity (erosion and/or deposition of sediments).

The sediments comprise sands, most likely of marine origin. The clarity of the water and colour of the sands suggest good water quality, another indicator that the sands are clean and of marine origin.

Examination of the aerial photographs identified the following features associated with sediment transport:

- **Sand Barrier:** The sand barrier between the main channel and Symes Bay has been present since 1953 (Figure A-1). There appears to be a small amount of deposition on the western edge of the sand barrier (outlined as Point of Deposition, in Figure A-1) however more investigation would be required to confirm this, as Lake water levels associated with the timing of the aerial photography is unknown and in this case may provide bias towards deposition (i.e. deposition looks higher at low water levels). No significant encroachment of the sand barrier to either the north-east (into Symes Bay) or the south-west (into the main channel) has been observed. The barrier also appears to have remained immobile, due to restricted exchange of water between

Symes Bay and the rest of the Lake. This means that less energy would be expended by flow moving over this barrier (i.e. less sand mobilised).

- **Flood Tide Delta:** After breaching, when an entrance channel has formed, the channel is restricted by the presence of a flood tide delta, located landward of the entrance. Literature suggests that the flood tide delta, in some estuarine systems, can extend vertically to an elevation close to that of mean sea level and cover an area of several square kilometres inside the Lake especially during periods of drought (Rustomji 2007). In Smiths Lake the flood tide delta has shown lateral growth since 1953 (Figure A-2) and a structural change by splitting from one main lobe into two – three interconnected lobes. The lateral growth of the delta indicates an increase in sediment deposition within this region, and this may be due to an increase in openings since 1961, although limited data of openings exists earlier than 1990 and as such this is hard to confirm. The lateral growth of the delta is likely to continue increasing if opening duration increases, due to the tidal asymmetry promoting flood tide deposition (CZMP Section 2.3.1.3).

- **Entrance Locations:** Only a couple of the aerial photographs captured the Lake with an open entrance, and two of the photographs (1961 and 2006) were selected for a comparison (Figure A-3). Between 1961 and 2006, large washover fans that developed in the early 1970's appear to have blocked a more northerly entrance channel. The extra sand within this area of the Lake would have promoted southward migration of the preferred opening channel. The location of the entrance opening specified in the entrance opening policy, is located at the southern end of the beach (Figure A-2). This represents a migration of around 330m.

- **Washover Fan:** A comparison between 1953 and 1977 photographs (Figure A-3) identifies a location of sand deposition over the beach berm and into the northern entrance region. The structure of the depositional feature is consistent with a storm washover fan. These features typically occur during large storms and investigation into historical storm events along the NSW coast shows that a significant East Coast Low (ECL) storm occurred in May 1974. During the storm the coast was battered by strong winds and heavy seas with swells of more than 17m at some port locations e.g. Newcastle (Callaghan and Hellman 2008). By 2006 the washover fans have merged into the flood tide delta.

- **Main Channel:** The main channel, inland from the flood tide delta, has shown minimal lateral movement since 1953 (Figure A-3). The lack of movement indicates minimal change in the energy (i.e. water velocities) within this area to alter the existing morphology. As a consequence it is assumed that any changes to the sediment deposition and erosion within this region are likely to be minimal, under the current regime. During some of the years (1953, 1961, 2006) seagrass has been observed in the main channel, and in other years it appears absent (1977). This may be due to the salinity, water clarity or the sediment stability within the channel

- **Dunes:** From 1953 to 1961 the presence of pioneer plants on incipient foredunes at the northern and southern extents of the entrance berm indicate low erosion and accretion rates (<0.5m/yr) (Duran and Herrman 2006, Masselink and Hughes 2003) (Figure A-2 and Figure A-3). Between 1961 and 1977 the washover fan provided a large supply of sand to the northern section of the berm and Lake, aiding in the stabilisation of the northern dunes and promoting southward migration of entrance channel flows within the Lake. The resulting higher capacity flows close to the southern dunes are likely the cause of erosion and 130m of dune recession between 1977 and 2006.

Title:

Symes Bay Sand Barrier

Figure: **A-5**

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Approx. Scale

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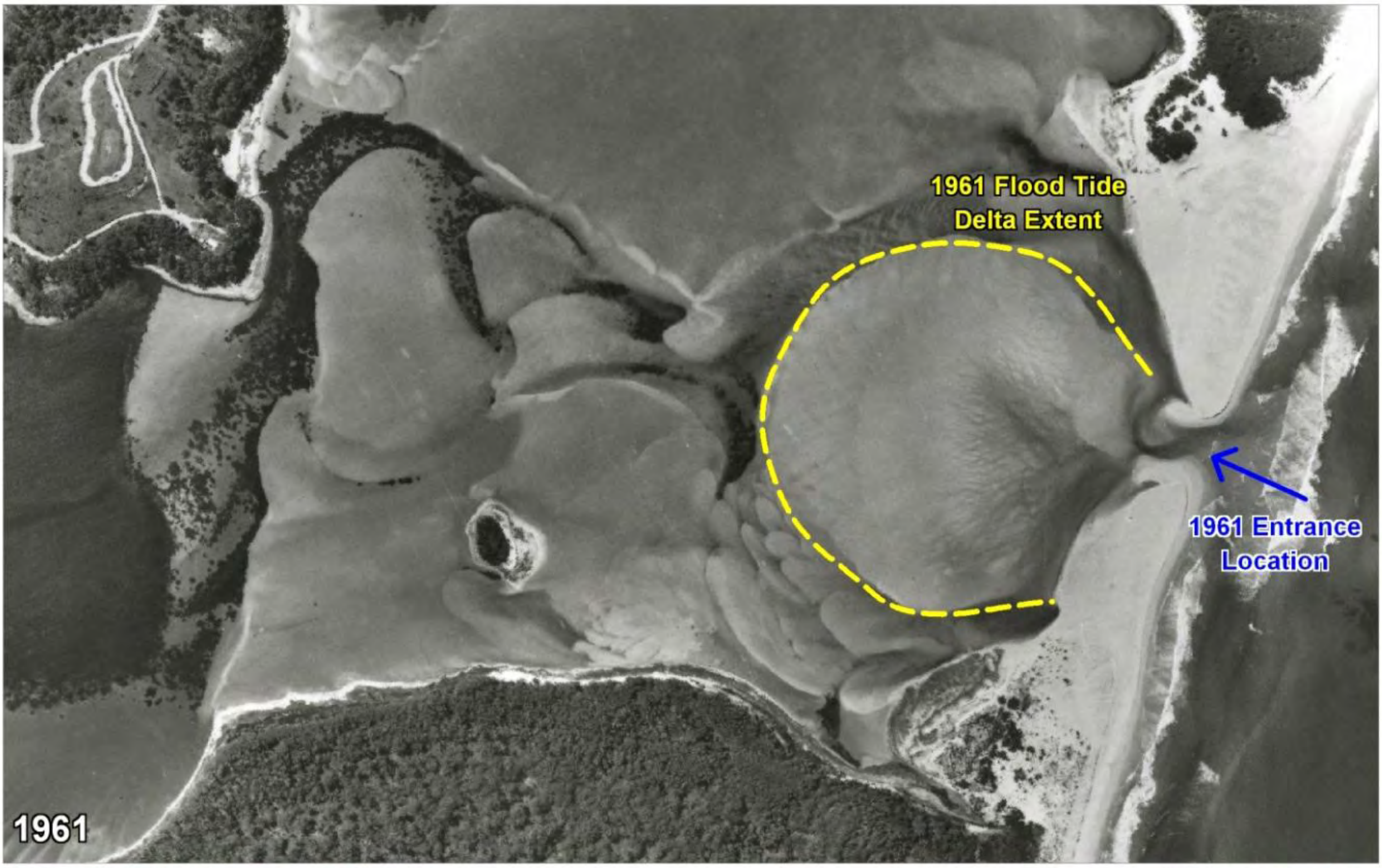

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Flood Tide Delta

Figure: **A-6**

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Title:

Washover Fans

Figure: A-7

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A.4 Tidal exchange as an indicator of sediment transport

While open, patterns of sediment deposition and erosion will affect the magnitude of tidal exchange between the Lake and the ocean. An approximate way of examining sediment changes involves examining the historical tidal fluctuations within the Lake.

The rise and fall of the tide in the Lake is forced by ocean tides, which are forced, largely, by the moon and the sun. An harmonic analysis of the tidal water level time series results in the derivation of "tidal constituents", which can be compared between periods. The analysis removes the interference of rainfall, storms or other phenomena that may also impact upon water levels. The results provide a comparative indication of the degree of tidal exchange occurring and therefore, whether deposition (reduced tidal exchange) or erosion (increased tidal exchange) has occurred within the inlet channel and entrance.

The analysis of tidal constituents for water levels in Smiths Lake (during the open state) over a number of years (Table A-1) found that the magnitude of the M_2 constituent (the largest constituent, related to gravitational pull of the Moon) has shown no appreciable trend since 1997. This indicates that there has been minimal change to the conveyance of the tidal water levels from the ocean through to Tarbuck Bay in Western Smiths Lake (location of water level recorder) over the 12 year period, and therefore minimal impact of sedimentation in the entrance on overall tidal exchange between the Ocean and Lake.

Table A-1 M_2 tidal constituent in Smiths Lake and the ocean

Location	Year	M_2 amplitude (metres)*	(*error*)
Smiths Lake	1997	0.023	(0.006)
	1998	0.022	(0.004)
	1999	0.029	(0.004)
	2001	0.023	(0.003)
	2003	0.034	(0.005)
	2009	0.023	(0.002)
Ocean	2009	0.488	(0.005)

*All results were based on water level records >32days

Results were not shown where the data set was too short, or the Lake did not open, or data was not available

A.5 Impacts of Sedimentation

A.5.1 Introduction

The extent and impact of sedimentation has been assessed by examining aerial photographs. The most significant erosion or depositional changes identified were immediately landward of the dune systems, and do not appear to have influenced the tidal exchange in recent times (refer A.4, although water level data was not available prior to the 1974 storms).

Gradual changes to the flood tide delta have occurred due to the re-working of sands by wind and tidal exchange, but these processes have not significantly altered the main channel location to the west of the delta. On a short timescale, large storm events can promote significant changes e.g. washover fans to the north of the entrance region in the 1970's. The appearance of these washover fans coincided with the closure of the northern entrance channel and southward migration of the preferred entrance location.

The rate of sedimentation within the entrance region and Symes Bay can only be qualitatively assumed from the changes to the morphological features, i.e. higher sedimentation rates may have occurred during the 1974 storms.

To clarify if there is an ongoing trend, it would be necessary to undertake bathymetric survey, and to compare this with the survey undertaken in 1995. The survey comparison could be supplemented by photogrammetric analysis of the barrier, sediment coring or ground penetrating radar survey or morphological (computer) modelling.

A.5.2 Navigation

In 1953 there were two channels either side of the flood tide delta (hereafter known as the northern and southern channel), connecting the main channel to the entrance opening (Figure A-3). The aerial photos indicate slightly greater depths within the northern channel, as opposed to the southern channel, however exact depths and potential navigability of these channels is unknown. Between 1961 and 1977 the northern channel was partially infilled with sediment due to a washover fan, restricting access directly from the north to the entrance. The southern channel became the preferred flow pathway for exchange of waters with the ocean, resulting in increased flow magnitudes, and localised sections of the channel becoming faster, wider and deeper. Obvious variations in depth suggest that any navigable channel would still be very problematic. The flood tide delta region can be highly dynamic, as indicated, and regular navigable waterways are unlikely, especially when combined with large water levels ranges as experienced within the Lake.

The remainder of the channel to the west of the flood tide delta has changed very little over the past 50 years; suggesting sedimentation at this location has likely not had a significant impact on the navigable waterway leading further into the Lake.

The sand barrier between the main channel and Symes Bay is present in all of the examined aerial photographs (Figure A-1) and analysis suggests that it has also changed very little in extent over the last 53 years. There was no observed encroachment of sands into *Symes Bay* (Figure A-1) with the edge of the delta readily identifiable in the aerial photographs. The main channel curves south west at this location and directs the majority of water into the western basin of Smiths Lake. The resulting water velocities occurring over the sand barrier and into Symes Bay are likely to be small and not large enough to mobilise significant amounts of sand. It is expected that the changing water level associated with opening events is likely to produce a greater impact upon the navigable waterways within Smiths Lake than sedimentation.

The desktop assessment, however, has not been able to assess any vertical changes across the tidal marine delta i.e. whether the shoals and channels have become deeper or shallower, and as a consequence it is not possible to categorically determine whether there has been a vertical change in this location which may hinder navigation. On the basis of other evidence however, it seems unlikely that changes have been significant. Incidentally it has been suggested that the shallow depth of the sand delta may act towards preserving the habitat in the bay through the restriction of powered water craft being able to enter the area at low water levels (NSWMA 2005).

Community feedback regarding the possible depth changes of the sand barrier have been inconclusive with different individuals suggesting there have been depth decreases or no changes, at the same location. The perception by community members may also be influenced by the status of the entrance e.g. closed or open entrance and the coinciding water level, e.g. high Lake water level, low Lake water level, high tide, low tide. See also Figure A-1

A.5.3 Water Quality

Symes Bay is a deep basin with likely minimal ocean exchange due to the existing sand barrier. The exact dynamics of water exchange are unknown; however higher chlorophyll-*a* values have been recorded in Symes Bay during times when the Lake has been open to the ocean and immediately after the Lake is closed (Everett 2007). This may be due to a reduction in flushing between Symes Bay and the remainder of the Lake due to smaller depths, or it could be a response to higher nutrient availability (from sediments or inflows) in combination with increased light penetration due to the reduced depth of the water column (Everett 2007).

The bed sediments in Symes Bay comprise beach and near shore sands, mixed coastal and fluvial sediments and reworked coastal sands (WMA 1998). Any sediment infill (of marine sands from the entrance region and opening process) is therefore not anticipated to significantly alter the existing sediment composition or promote the release of nutrients from the sediments in Symes Bay. Sediment sampling investigations could be undertaken to assess any changes to the bed sediments within the deeper regions of Symes Bay.

During periods when the Lake is closed, the water depth increases across the sand barrier and the exchange of water between Symes Bay and the main body of the Lake would also increase, reducing any localised problems with water quality.

A.5.4 Lake Ecology

The entrance region of the Lake, according to aerial photography, has comprised marine sands since at least 1953. As a consequence it is expected that there would be little impact on the ecology within the entrance region with respect to the sedimentology. The continual wetting and drying of the sediments is a historical feature present in intermittently opening coastal Lakes, and while this may impact in the short term on benthic communities, the ecological dynamics are likely to have adapted over time to this process.

During some of the years (1953, 1961, 2006) seagrass has been observed in the main channel, and in other years it appears absent (1977). This may be due to the salinity, water clarity or the sediment stability within the channel. For example, large storms in the early 1970's may have resulted in the movement of surface sediments, effectively ripping out seagrass from some areas, and smothering others resulting in absence in the 1977 aerial photograph. The species of seagrass also changes according to salinity, and is a natural feature of intermittently opening Lakes.

Slow sedimentation favors the growth of dune complexes and this has been observed by the expansion of incipient foredunes at the north and south extents of the entrance berm. This process was disrupted by the changing location and dimensions of the entrance channel, which resulted in a gradual erosion of the southern dune complex and a recession of approximately 130m between 1977 and 2006.

A.6 Discussion

The analysis of aerial photographs suggests there has been a gradual increase in the lateral deposition of sand into the flood tide delta, which is a common feature for most coastal lagoons. Specific events have also shown to promote large influxes of sand which can dominate the morphological features e.g. washover fan during a large storm event. Due to the analysis techniques it is still unknown the rate of vertical deposition due to these processes.

Further into the Lake there has been little change in the morphological features, e.g. the main channel (west of the flood tide delta) has shown little movement.

Overall there appears to be minimal impact on the navigation, ecology or water quality since 1953, due to sand infilling, although the southward shift of the entrance opening has resulted in dune erosion and recession south of the entrance.

A.6.1 Management Options

The entrance of the Lake is a natural deposition zone and over time, it will become infilled with sediments due to both natural processes and anthropogenic interventions. Two possible management options for consideration to reduce the sedimentation rates within the entrance region include:

Option 1 - Initiate changes to the opening regime, where:

- Higher trigger water levels may promote greater scouring during initial outflow, or
- Artificial closures may limit the transport of sands back into the entrance region, or

Option 2 - Site specific dredging

A.6.1.1 Option 1 - Opening Regime Changes

When a natural breakout occurs the Lake water levels reach the top of the beach berm, the barrier is breached and a channel is scoured. Generally this promotes the largest hydraulic gradient and most effective breach.

During an artificial breach the Lake is opened at a lower than naturally occurring water level, usually for flood mitigation and consequently the water level never reaches the top of the beach berm. The resulting hydraulic gradient and scouring potential of an artificial breakout is therefore less than what would typically occur under a natural breakout, and while the out flowing water will still have the capacity to scour an inlet channel, it is likely not strong enough to scour away the flood tide delta (Rustomji 2007). After repeated artificial breakouts there is likely to be a build up of sediments within the entrance region of the Lake.

The present managed water level for artificial opening is set at 2.1m AHD, and is limited by the requirement for flood mitigation. The proactive management of the specific locations requiring flood mitigation may allow an increase in the trigger water level. As the difference in water level between the Lake and the ocean becomes larger the scouring potential of the waters increases, and the opening duration is also likely to be longer (O'Connell and Wiltshire 2005). However the projected rise in sea level due to climate change will likely promote a higher beach berm, and higher Lake water levels will be required to achieve the same amount of scouring.

A.6.1.2 Legislative Requirements

Any significant changes to the existing opening regime would require an assessment of the potential implications of that change upon Lake ecology, under the *Marine Parks Act 1997*. Furthermore approval would be required from the Department of Lands for works carried out on Crown Lands (entrance and bed of the Lake).

A.6.1.3 Option 2 - Dredging

Within the Lake that key area that may benefit from the removal of sediment is the sand barrier located between Symes Bay and the main entrance channel. This would allow greater connectivity between the two water bodies especially during periods when the Lake is open and water levels are low. Furthermore this may also improve navigation opportunities within the Lake.

From an ecological perspective, dredging may have the following impacts, as described below:

- *Loss of benthic fauna*: Invertebrate benthic communities living within the sediments to be dredged would be lost, as they would not survive the transfer and burial process. Newly exposed sandy habitats would slowly colonise with benthic fauna, but probably with a different assemblage and lower biodiversity (at least in the short term).

- *Reduction in water quality:* During the dredging operations, increased suspended sediment would occur within the water column, and would have associated follow-on effects on mobile aquatic fauna.

Within the entrance channel future maintenance dredging may also be required to maintain efficient tidal flows and/or to optimise entrance breakout conditions for a predetermined location.

Further investigation would be required to rationalise any required dredging and to quantify the full impact that these works may have on navigation, water quality and ecology.

A.6.1.4 Legislative requirements

The activity of dredging bed material from Smiths Lake would require a permit from the Department of Primary Industries (Crown Land Division), as the bed is classified as Crown Land. The activity would also trigger the requirement for an environmental assessment under the *EP&A Act 1979* to ensure that biodiversity of the Lake was not adversely affected. For further information see section 10 within the CZMP.

A.7 References

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